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POINT-LOAD STRENGTH : AN INDEX FOR CLASSIFICATION OF ROCK MATERIAL

RÉSISTANCE AU FENDAGE SOUS CHARGE PONCTUELLE : UN CRITÈRE DE CLASSIFICATION POUR LES ROCHES

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Abstract

Point-load strength (Is) as a measure for the determination of rock strength and for estimating uniaxial (unconfined) compressive strength (UCS) are described and both put together and used for rock strength classification of brittle and hard rocks.
The estimated point-load strength values of specimens of varying sizes and also the values corrected to a standard thickness of 50 mm, and the resultant point-load strength values (Is-50) have been used to estimate the uniaxial (unconfined) compressive strength which correlates well with actual recorded uniaxial (unconfined) compression test results. Using graphical and mathematical relationships between the observed and estimated UCS and Is values, a conversion factor of 16 is obtained for estimating uniaxial (unconfined) compressive strength values from point load strength results A nomogram for computing point-load strength index and a system for the classification of rock material are presented.

Résumé

La résistance au fendage sous charge ponctuelle (Is) constitue une évaluation de la résistance de la roche et permet d'estimer la résistance en compression uniaxiale (UCS); les deux essais sont utilisés pour établir une classification des roches résistantes de type fragile.
Les valeurs de résistance au fendage sous charge ponctuelle réalisées sur des échantillons de différentes tailles, ainsi que les valeurs ramenées par corrections à une épaisseur standard de 50 mm fournissent une valeur résultante Is-50 qui a été utilisée pour estimer la résistance en compression uniaxiale avec une bonne corrélation.
En utilisant des comparaisons graphiques et mathématiques entre les valeurs UCS et Is, un facteur de conversion de 16 est obtenu pour avoir la valeur UCS à partir de la valeur Is. Un nomogramme pour calculer la valeur de résistance au fendage sous charge ponctuelle, et un système de classification des roches son présentés.

Introduction

In engineering practice, rock strength is considered an important property and a suitable strength-index for rock classification. Common methods for determining rock strength are the point-load strength test and the uniaxial (unconfined) compression test. The Schmidt Rebound test is another method for assessing hardness of rocks and an indirect method for rock strength analysis. The Schmidt. Rebound and point-load strength tests are quick methods and can easily be applied in the field. The Schmidt Rebound test is sensitive to strength variation influenced by rock anisotropy. Whereas the point-load strength test is comparatively more accurate and gives fair assessment of rock strength though sensitivity to rock anistropy remains in the test results. The uniaxial (unconfined) compression tests require costly machines and time consuming processes. Hence in searching for quick, practical and fairly reliable strength index tests, the point-load strength and Schmidt Rebound tests were carried out on irregular (prismatic type) specimens of Himalayan granitic rocks (Fig. 1) of Ravi Basin, Himachal Pradesh, India (collection by the first author – D.K. Ghosh) and Alaknanda Valley, Uttar Pradesh, India (collection by A.R. Bhattacharya) as a measure for rock strength and for estimating uniaxial (unconfined) compressive strength, and then correlating with actual uniaxial (unconfined) compression test results for assisting in rock strength classification.

It has long been known that point-load strength results can be used for rock strength classification and predicting uniaxial (unconfined) compressive strength with a conversion factor of 24 (Broch and Franklin, 1972). The Indian Standard (I.S. Code : 8764, 1978) gives a conversion factor of 22 for which no basis or justification is given. More recently (Turk and Dearman, 1985), improvements in the determination of point-load strength and a new procedure for increasing the prac-

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tical application of the test are provided. However, there is yet limited experience in using the tests with various limitations and interpreting the results for quick application. Hence the present study is an attempt to fill this gap in our knowledge and further to improve upon the evaluation methods for quick practical application.

Test and computation of results

22 irregular (prismatic type) specimens of granitic rocks with longest-shortest axis ratio of 1.4 : 1 and 11 cubes of the same rocks were tested in the laboratory for determining point-load and uniaxial (unconfined) compressive strength values. The rocks are anistropic in their mechanical properties and contain visible planes of foliation. The strength of rock specimens vary by a factor of four or more depending upon the direction of loading relative to that of the foliation plane and it is recorded that the strength could be four times greater if the foliation plane is across the direction of applied load. Again the recorded strength could be nearly doubled or increased by at least 50 % if the specimen size is halved or if the long axis of the prismatic specimen is perpendicular rather than parallel to the applied load. Although it is misleading to classify the strength of these granitic rocks by a single factor which bears no relation to direction, yet the rocks can be described as fresh, brittle and hard in nature. They show elastic deformation under failure load. In case of loading along and or parallel to foliation, the failure was along and oblique to planes of weakness. When loading across foliation, the failure was irregular by and large. Hence natural variability of granitic rock material is portraid. The specimens for point-load strength tests varied from 30 mm to 56 mm in diameter. Subsequently 11 representative samples were selected and

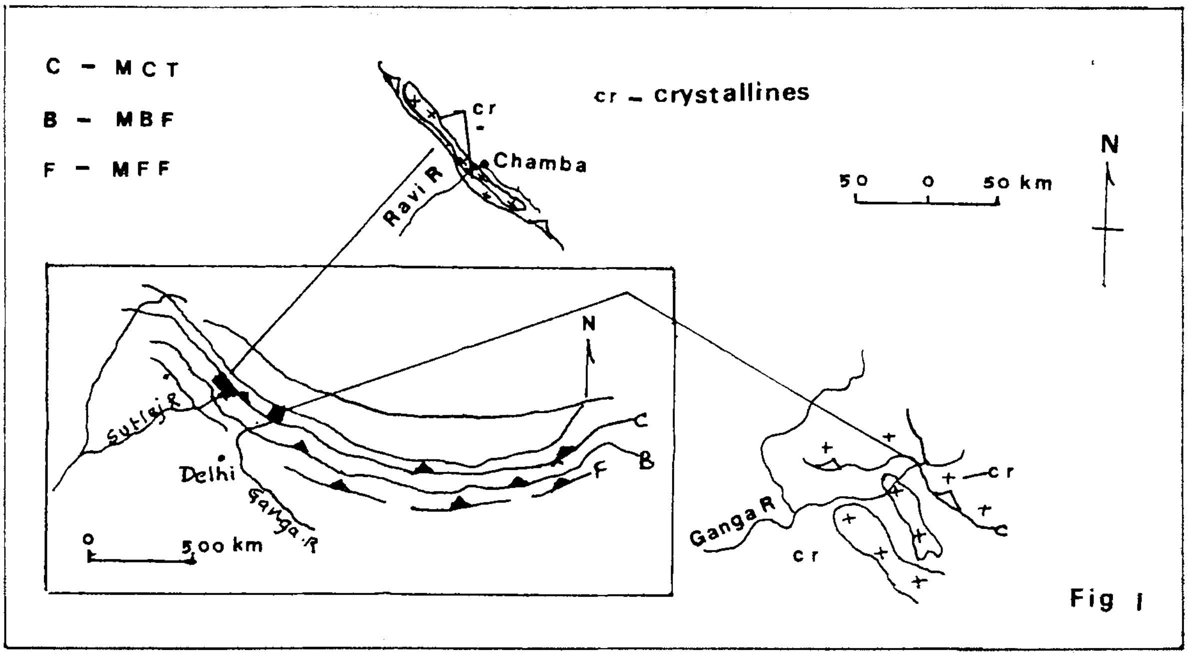

Fig. 1 : Showing location of area study under and generalised geologic setting.

Table 1 : Test results of granitic specimens from parts of western Himalaya

Sample No.	*Platen distance*	Load applied		Point-load strength		Direct uniaxial compressive Strength		*Rebound number*
	(*mm*)	*KN*	Kgf	Kgf/cm^2	*MN/m^2*	*Kg/cm^2*	*MN/m^2*	
1. MG-1	30	6.5	663	74	7.4	1190	119.0	40
2. PG-1	47	10.5	1071	48	4.8	790	79	52
3. HG	56	16	1632	52	5.2	750	75	53
4. BG-25	47	4.5	459	21	2.1	418	41.8	50
5. DG-1W	35	3.5	357	29	2.9	250	25	24
6. DG-1F	30	5	510	57	5.7	300	30	36
7. OM-13	37	5	510	37	3.7	705	70.5	38
8. MO-13	36	8	816	63	6.3	833	83.3	50
9. SS-37	47	4.5	459	21	2.1	270	27	42
10. SS-33	43	4	408	22	2.2	442	44.2	47
11. OM-15	43	4.5	459	25	2.5	455	45.5	–
Mean values	41	6.55	668	41	4.1	582	58.2	

1 KN = 102 Kgf   1 Kg = 1.02 Kgf   1 MN/m^2 = 10 Kg/cm^2

Note 1. Estimated values of point-load and uniaxial compressive strengths have been rounded off to nearest whole number.

2. For reference to areas under study see figure 1.

tested for Schmidt Rebound hardness. The results of the tests carried out for 11 samples are given in table 1. For the point-load strength test, the Point-Load Tester (HR. 72.25) of Hydraulic and Engineering Instruments, New Delhi was used. A 200 ton Compression Testing Machine – CCM-9A (SP) was used for uniaxial (unconfined) compressive strength tests while the Rock Classification Hammer (HC.46.20) was used for Schmidt Rebound hardness test.

A strength index was obtained by dividing the rupture or failure load (P) by an area perpendicular to the loading direction (D^2), where this was calculated as the ratio of the specimen mass to the product of specimen height and density. Computation and evaluation of test results include methods using slope of best fit line, regression analysis, applying mean test values for determination of relation and coefficient of correlation, empirical relationships and mathematical equations between various parameters, significance of size dependence, rock anisotropy and various other aspects of analysis procedures on strength results. Since the results from irregular (prismatic) samples, as would be expected, are more scattered, these have been plotted on log-log scale in respect of the relationships between point-load and specimen diameter or platen distance (P-D) (Fig. 2, 3), between point-load and failure load (P) (Fig. 4), between failure load and specimen diameter or platen distance (Fig. 5) between point-load and rebound number (R-N) (Fig. 6). Because of less scatter, the relationship between the point-load (P-L) and the uniaxial (unconfined) compressive strength (UCS) is plotted on a simple graph (Fig. 7). The experimental results directly plotted on log-log and simple graphs simplified the process of evaluation. In all the correlations a linear relation is obtained and the best fit line is determined using least squares regression analysis balancing the sum of left residuals with the sum of right residuals. The relationships between point-load (P-L) and failure load (P), between point-load and rebound number (R-N), and between point-load and uniaxial (unconfined) compressive strength (UCS) are direct linear whose slope of straight line correlation (m) is positive. The relationships between point-load and platen distance, and between failure load and platen distance are inverse linear with a negative slope.

Using mean values of various experimental determinations, the coefficients of correlation are obtained which establish that correlation exists between two variables (Table 2). Mathematical relations are obtained using

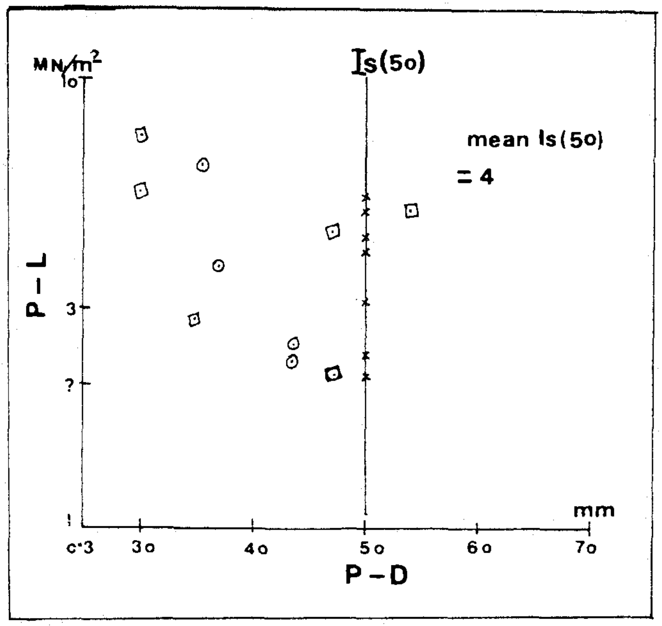

Fig. 3 : Relationship between point-load strength (P-L) and platen distance (P-D) with Is (50) values using correction chart.

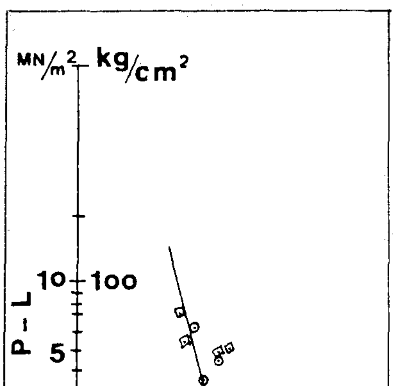

Fig. 2 : Relationship between point-load strength (P-L) and platen distance (P-D) of granitic specimens.

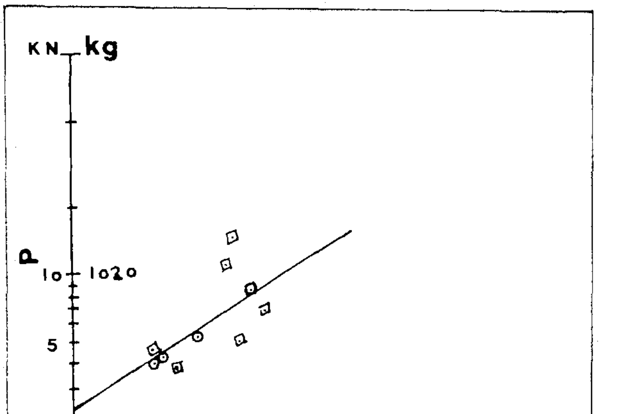

Fig. 4 : Relationship between failure load (P) and point-load strength (P-L) of granitic specimens.

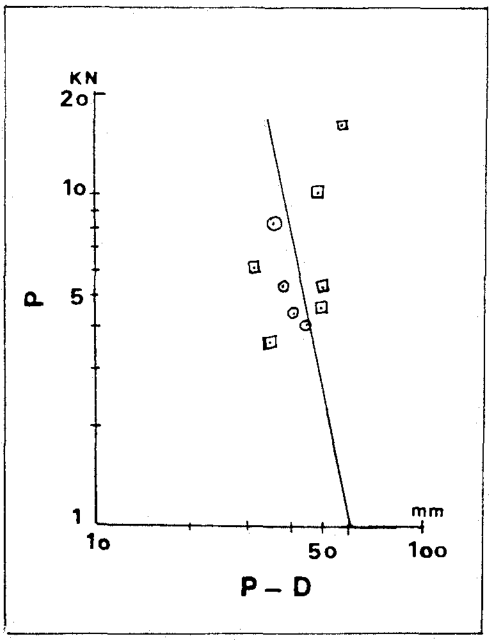

Fig. 5 : Relationship between failure load (P) and platen distance (P-D) of granitic samples.

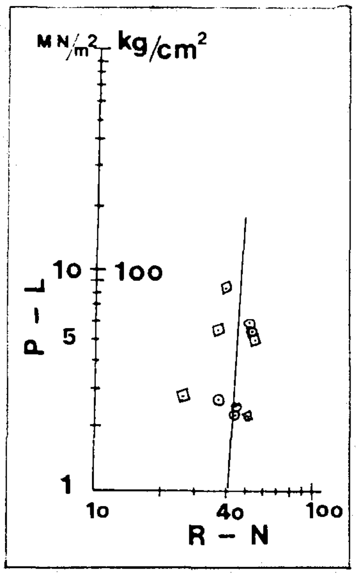

Fig. 6 : Relationship between point-load strength (P-L) and rebound number (R-N) of granitic samples.

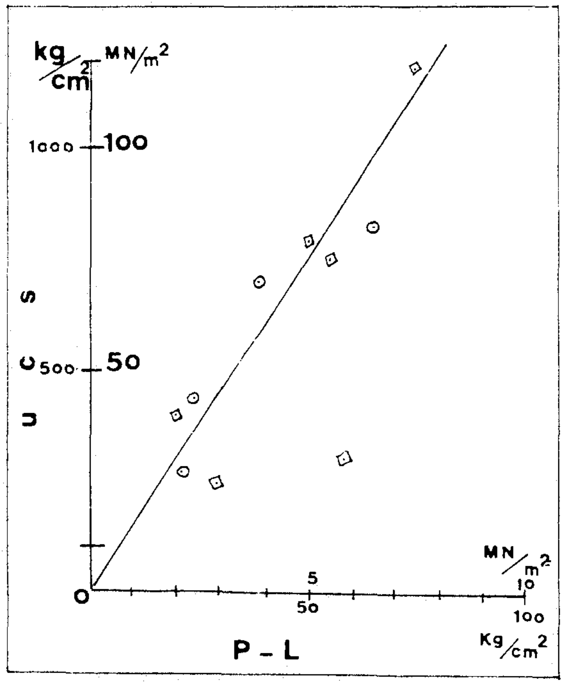

Fig. 7 : Relationship between uniaxial (unconfined) compressive strength (UCS) and point-load strength (P-L) of granitic samples.

Table 2 : Determination of empirical relationship between point-load (P-L) and uniaxial (unconfined) compressive strengths (UCS)

1. Mean point-load strength (x)	41 Kgf/cm^2	4.1 MN/m^2
2. Mean uniaxial compressive strength (y)	582 Kg/cm^2	58.2 MN/m^2
3. Mean deviation of point-load strength	4.40	
4. Mean deviation of uniaxial compressive strength	4.66	
5. Co-variance = mean of products of deviations	3826	38.26
6. Standard deviation of 11 values of point-load strength	≅ 18	≅ 1.8
7. Standard deviation of 11 values of uniaxial compressive strength	≅ 281	≅ 28.1
8. Ratio between point-load strength (x) and uniaxial compressive strength (y)	18/281 y = 16 x	1.8/28.1
9. Coefficient of correlation	0.75	
10. Slope of straight line correlation (m)	16	

equations y = mx + c for positive relation and x/a + y/b = 1 for negative slope (Table 2-4). These studies have further confirmed the validity and usability of the above graphical representations. In evaluating the test results of point-load and uniaxial (unconfined) compressive strength values where a straight line correlation is obtained (Fig. 7), a conversion factor of 16 corresponds to the ratio of uniaxial (unconfined) compressive strength to point-load strength. The correlation coefficient of 0.75 is fairly high (Table 2) to warrant use of point-load strength test for predicting uniaxial compressive strength when it is required.

Discussion

Evaluation of the results of experimental determinations indicates that close correlation exists between various test variables namely point-load strength, uniaxial (unconfined) compressive strength, specimen thickness or platen distance, failure load and rebound number. However, effects of size and shape of specimens and the variation in the nature of rock material related to strength and weathering or alteration are reflected in the test results (Table 1).

Table 3 : Determination of empirical relationship between point-load (P-L) and load applied (P)

1. Mean of point-load strength (x)	41 Kgf/cm^2	4.1 MN/m^2
2. Mean of load applied (y)	668 Kgf/cm^2	6.6 MN/m^2
3. Mean deviation of point-load strength	4.40	
4. Mean deviation of load applied	4.5	
5. Covariance	3181	3.118
6. Standard deviation of 11 values of point-load strength	≅ 18	≅ 1.8
7. Standard deviation of 11 values of load applied	≅ 364	≅ 36.4
8. Coefficient of correlation	0.48	
9. Slope of linear correlation (m)	0.67	
10. Equation between point-load and load applied	y = mx + c y + mx + 2.5	

Table 4 : Determination of empirical relationship between point-load and platen distance

1. Mean platen distance (x)	41 mm	4 .1 cm
2. Mean of point-load strength (y)	41 Kgf/cm^2	4.1 MN/m^2
3. Mean deviation of platen distance	1.80	
4. Mean deviation of point-load strength	4.40	
5. Covariance = mean of products of deviations	- 1.176	
6. Standard deviation of 11 values of platen distance	0.774	
7. Standard deviation of 11 values of point-load strength	1.8	
8. Coefficient of correlation	- 0.84	
9. Slope of linear correlation (m)	0.2	

The vertical concentrated load (P) applied at the centre of prismatic specimens induces a near horizontal tensile stress and, eventually, failure occurs either along foliation planes or along a plane parallel to loading direction. Fractures oblique to loading direction or foliation planes are also seen but they are less prominent. Since existence of a compressive component during point-load testing is invariably greater than the induced tensile stress, the influence of specimen thickness or platen distance (D) cannot be ignored. Testing of various sizes of prismatic specimens do confirm this affirmation. The specimen size or platen distance of 40 mm – 50 mm is ideal for point-load testing. Away from this range there is wide scatter in the results. Although scatter in the results could be reduced appreciably by taking mean values, however, this does not overcome the influence of size and shape effects and therefore, standardisation or correction of these effects are needed by conducting point-load testing on a wide ranging thickness of variety of specimens. The present study has shown that point-load strength increases with increase in failure load and decrease in the platen distance (Fig. 8). This nomogram is considered very useful for computing point-load strength index ($Is = P/D^2$). The point-load strength changed more rapidly at shorter platen distance of less than 40 mm and of platen distance greater than 55 mm. The authors mention here that the specimen thickness of platen distance of 50 mm should be considered a reference diameter. For size correction the chart proposed by Broch and Franklin (1972) is considered useful. As discussed earlier the shape factor closer to 1.4 : 1 is ideal for testing irregular (prismatic)

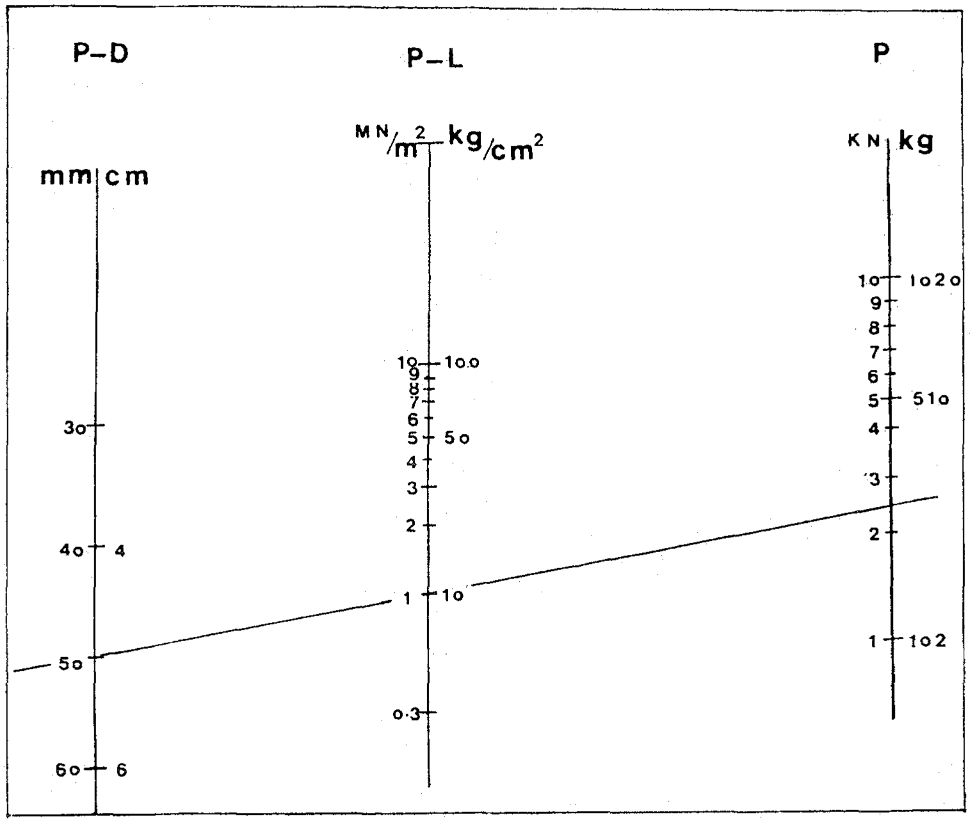

Fig. 8 : Nomogram for computing point-load strength (P-L) using data of platen distance (P-D) and failure load (P).

specimens. Any shape other than this ratio may not be suitable for point-loading unless the irregular lumps are easily broken or thinly bedded. For better accuracy of test results there should be an adequate number of varying nature of specimens so that the mean values can be closer to reasonably correct results. In achieving this the number of samples and the tests cannot be specified as it would depend more on the author's judgement of the accuracy of results. It has been known for long that the extent of improvement in the accuracy of results is marginal by testing large number of samples say more than 15-20 for each variety of rock material. In the present study point-load testing of 22 fresh and 22 weathered granitic rocks has shown that the point-load strength results vary according to nature, or variation in composition and rock alteration. The fresh rock materials show 40-50 % higher values of point-load strength than the weathered rock materials. Similar results were obtained while testing for uniaxial (unconfined) compressive strengths. Again if the results of uniaxial (unconfined) compressive strength are compared with those of granitic and other rock materials of the Indian peninsula (Gosh, 1980; Vaidyanath and Ghosh, 1980, 1981; Ghosh and Ahmed, 1981; Ghosh, 1982), it is found that the nature of variation in the results of fresh and weathered samples is almost similar. However, the strength results of UCS across the planes of discontinuities are nearly double that of the values along the planes of discontinuities.

The point-load testing is very quick and fairly reliable, and gives a high degree of correlation with uniaxial (unconfined) compression test results. The point-load strength results can, therefore, be used for predicting uniaxial (unconfined) strength values (Fig. 7). Hence the point-load strength test has important practical advantage for strengthy classification and both put together can be used for deciding the choice of measurement and designation to each class. In predicting uniaxial (unconfined) compressive strength, a conversion factor of 16 corresponds to the ratio of uniaxial compressive strength to point-load strength. This result relates to tests on specimens of thickness 30 mm – 56 mm. D'Andrea et al. (1965) reported a value of 16 for the strength ratio with the help of tests ond 25 mm diameter specimens, and Broch and Franklin (1972) reported a value of 24 for the strength ratio with the help of tests on 38 mm diameter specimens. The Indian Standards (I.S. Code : 8764, 1978) gives a value of 22 for the strength ratio for which no basis is given. On the basis of actual uniaxial compression tests on variety of rock material conducted by the first author earlier and also the present tests, it is argued here that conversion factor of 24 (Broch and Franklin, 1972) and 22 (I.S. Code, 1978) are much higher for the Indian rocks. The authors propose here that a conversion factor of 16 should be used for predicting uniaxial compressive strength from point-load strength results. This may be confirmed by conducting tests for uniaxial compressive strength on variety of rocks and then correlating with actual point-load strength results for the same rock material, as has been attempted by the authors. This study would assist in working out a fair degree of standardisation for the strength ratio. It is possible that the use of point-load strength test on irregular (prismatic) specimens, when cores are not available, would provide a basis for strength classification of rock material and mapping of outcrops on sound footing.

Strength classification

The present study, relating to the determination of point-load strength and uniaxial compressive strength of granitic rock material and the fairly high degree of correlation between them, provides us with a basis for proposing a strength classification of rock material by putting together both the results (Fig. 9). It possibly improves upon the classification proposed by Broch and Franklin (1972) based on a simpler point-load testing method. In this system of classification the terms low, medium and high have been maintained. The authors, however, agree with Broch and Franklin (1972) that the use of terms such as strong and weak rocks be dispensed with as they sometimes mean ambiguous equivalence in terms of nature of material. The present

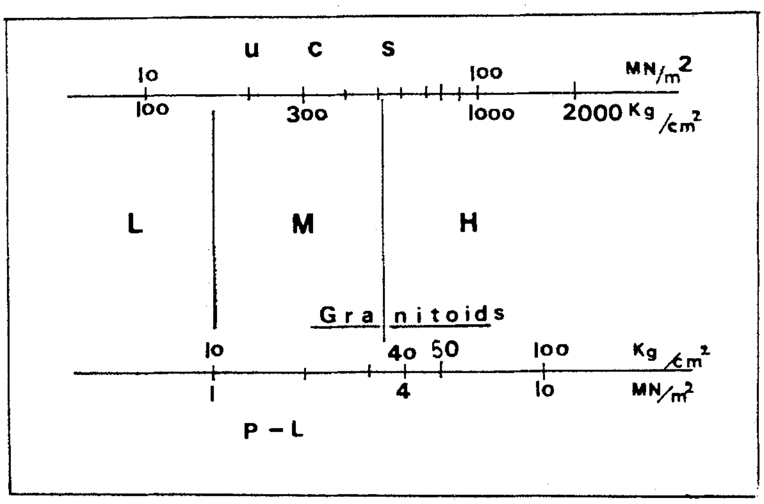

Fig. 9 : Strength classification using data of point-load strength (P-L) and uniaxial (unconfined) compressive strength (UCS) of granitic samples.

classification is based on limited data and needs to be improved upon by including strength ranges of a variety of rock material (fresh and altered).

Because of the wide range of strength values of point-load and uniaxial compressive strengths, a log scale has been used. Theoretical justification of the log-log plot has been given by Turk and Dearman (1985) in respect of the data relating to various test variables and regardless of this basis the existance of wide range of data also suggests the need of adopting a log scale. In the proposed classification (Fig. 9) the data of point-load and uniaxial compressive strengths as shown in Fig. 7 have been used on the same diagram by juxtaposing the two scales given in Fig. 9.

Conclusions

1) The results of point-load and uniaxial compression testing emphasize the importance of providing a system for strength classification and mapping of rock outcrops.

2) The results of point-load testing signifies their importance in predicting uniaxial compressive strength values.

3) Because of the wide scatter of results obtained from irregular (prismatic) type specimens of different thickness, these have been plotted on log-log scale directly on the graph paper. The relation is linear.

4) The determination of standard point-load strength - Is (50) from point-load strengths of varying types and sizes of specimens needs a cautious approach.

5) Irregular (prismatic type) specimens with thicknesses or platen distances of 40-50 mm are suitable for point-load testing.

6) In predicting uniaxial (unconfined) compressive strength, the straight line correlation with a slope of 16 corresponds to the ratio of uniaxial compressive strength to point-load strength.

7) A nomogram for computing point-load strength index ($Is = P/D^2$) is presented. For direct reading, the failure load scale may be vertically adjusted.

8) A wide variety of rocks with different specimen thickness may be tested for point-load and uniaxial compressive strength to standardise the nomogram, classification system and the strength ratio between point-load and uniaxial compressive strengths.

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