A Technical Note on

Variability Analysis of Physico-Mechanical Properties of Some Indian Rocks

T.N. Singh
&
A. Suresh Naidu

Department of Mining Engineering
Institute of Technology
Banaras Hindu University
Varanasi - 221 005, India
E-mail: tnsingh@banaras.ernet.in

1. INTRODUCTION

The variability of rock test data can be used as an index of the anisotropy, heterogeneity and volume difference of the specimens tested. Variations in the value of a rock properties emerge in a few ways. They can originate mainly because the sample tested cannot represent the entire rock variability. They also occur in general because of the sample properties that can be changed or disturbed in the procedure of sampling and transportation to the laboratory (sample errors) or even due to the test in which procedure may not be conducted in accordance to the standardised test method (testing errors). Also, due to the anisotropy and heterogeneous nature of rock properties, scattering of rock test data cannot simply be attributed to experimental error.

In proposing a statistical model, Yegulalp and Mahatab (1983) explained that inherent variations in rock test data need to be represented in design relationship by the introduction of random variables instead of constants. Sun (1983) described that test data should not be taken as an absolute property, even in the case of large scale insitu tests because even the most reliable insitu test is still only an approximate method applied to a small part of the geological unit being studied. Ratigan (1981) and Peres - Rodrigues (1970 & 1983) suggested that physico-mechanical properties could be expressed in the form of mean, mode and deviation.

The present technical note deals with analysis of test results based on planned laboratory testing program to evaluate statistical correlations between various rock strength properties and their individual variations in test data.

2. TEST PROGRAMS

All the tests were performed on a close loop servo-controlled hydraulic loading system in which feed back control was used to load and specimen. Specimens were loaded between the platens, for applying a uniaxial compressive load along the longitudinal axis of the specimen. Load and deformation curves were plotted simultaneously by the machine. The uniaxial compressive strength was then calculated from these curves. The uniaxial tensile strength and shear strength was determined using respective size and shape of the sample as the case may be, recommended by ISRM (1981). In all 124 rock specimens were tested for 12 different types of rock of sedimentary and metamorphic origin.

The samples of sedimentary rocks were collected mostly from coal measures of Vindhyan supergroup; quartz-micas schist, rock-salt and biotite schist from lesser Himalayan region and marble samples from Makarana, Rajasthan. The test results (showing range of strength) for 12 different rocks are presented in Table1. Since the samples were collected from the same locations for a particular rock type and not from the same bedding planes, the strength properties of different rock types shows large variations. These variations are also due to presence of different discontinuities and defects within the rock samples. Variation of depth may also affect strength properties. Each result includes average of five specimens.

Table 1 - Physico-mechanical properties of 12 different rock types

S. No.	Rock Type	No. of Specimen	Range of Strength in MPa		
			Uniaxial Comp. strength	Tensile strength	Shear strength
1.	Sandstone	22	5.28 - 20.88	0.63 - 2.61	0.47 - 4.17
2.	Coal	14	4.74 - 23.91	0.59 - 2.99	0.95 - 4.79
3.	Carbonaceous shale	07	22.12 - 43.21	2.77 - 5.40	4.42 - 8.64
4.	Fine grained sandstone	09	9.60 - 22.49	1.20 - 2.81	1.92 - 4.49
5.	Medium grained sandstone	06	16.59 - 32.61	2.16 - 4.07	3.32 - 6.52
6.	Coarse grained sandstone	08	5.94 - 22.92	0.74 - 2.87	1.18 - 4.58
7.	Chunar sandstone	15	25.22 - 64.25	3.79 - 8.03	6.18 - 12.85
8.	Weathered sandstone	07	3.21 - 12.50	0.40 - 1.58	0.64 - 2.25
9.	Rock salt	09	20.42 - 40.41	2.55 - 6.05	2.56 - 8.08
10.	Quartz-mica-schist	09	2.89 - 64.82	5.22 - 8.12	8.58 - 12.96
11.	Marble (Makrana)	09	67.77 - 97.89	8.47 - 12.23	13.69 - 19.29
12.	Biotite-schist	09	40.28 - 63.44	5.04 - 7.93	8.06 - 12.36

3. ANALYSIS

The arithmetic mean (σ), standard deviation (SD), and the coefficient of variation (CV) of each of the three parameters (σ_c , σ_t ,τ) were determined for all rock types, where the CV was calculated from the following expression (Barry, 1978)

$$CV = (SD / \sigma) \times 100$$

Evaluations of the correlation coefficient (R) between σ_c, σ_t, τ , and their corresponding CV's & SD's provide that the results are upto satisfying accuracy (Fig. 1-6). Significant correlations exist between CVs and their corresponding strength parameters σ_c , σ_t and τ. Same is the case with SD.

Linear regression analysis was performed for these cases : σ_t - CV (σ_t), σ_c - CV (σ_c), τ - CV (τ). All regression equations tend to show the form

$$CV_i = m (X_i) + b$$

Where X_i represents the mean value of σ_c , σ_t or τ . CV_i is the corresponding coefficient of variation. The original data points are plotted in Fig. 1-3.

Here 'm' which is the slope of the linear correlation curve, always tends to show a negative value. This indicates a negative correlation between CV, and its corresponding strength of the rock i.e., with increase in the strength (Compressive, Tensile, and Shear) coefficient of variability decreases.

Similarly, linear regression analysis was performed for the cases; σ_c - SD (σ_c), σ_t - SD (σ_t); τ - SD (τ). All regression equations tend to show the form,

$$SD_i = m (X_i) + b$$

where SD_i is the standard deviation of the corresponding strength (X_i) of the rock. X_i represents the average value of σ_c , σ_t or τ . Here 'm' which is the slope of the linear regression curve, always tends to show a positive value. This indicates a positive regression curve, always tends to show a positive value. This indicates a positive correlation between the strength of rock and its corresponding SD. i.e., with increase in strength standard deviation increases. The original data points are plotted in Fig. 3-6. Rohde and Feng (1990) also reported the similar relation between unconfined compressive strength, with elastic Modulus and modulus ratio. They used 15 rock types of igneous and sedimentary origin having wide range of strength variation (between 290 to 329 MPa). Arigohe and Tokgoz (1991) found no definite correlation between variability coefficient with uniaxial compressive and tensile strength. The results were based on linear regression analyses, i.e. coefficient of correlation values but correlation found among various rocks based on standard derivation. Various equations, thus obtained, in Figs. 1-6 with the correlation coefficient (R^2) value have been tabulated in Table 2.

Table 2 - Correlations of coefficient of variation and standard deviation with various rock properties

S.No.	X-Variable	Y-Variable	Equation of Best fit Line	Correlation Coefficient (R^2)	Remarks
1.	Mean compressive strength (MPa)	Coefficient of variation (MPa/MPa)	Y = -0.468X+45.36	0.80	Fig. 1
2.	Mean tensile strength (MPa	Coefficient of variation (MPa/MPa)	Y = -3.688X+44.73	0.77	Fig. 2
3.	Mean shear strength (MPa)	Coefficient of variation (MPa/MPa)	Y = -2.40X+46.16	0.76	Fig. 3
4.	Mean compressive strength (MPa)	Standard deviation (MPa)	Y = 0.108X+4.08	0.87	Fig. 4
5.	Mean tensile strength (MPa)	Standard deviation (MPa)	Y = 0.107X+0.50	0.88	Fig. 5
6.	Mean shear strength (MPa)	Standard deviation (MPa)	Y = 0.106X+0.837	0.84	Fig. 6

4. CONCLUDING REMARKS

From the analysis of test results, following conclusions may be drawn :

- The coefficient of variation may be considered as a satisfactory basis for determining variations resulted from type of rock, sampling and testing procedures.
- The coefficient of variation may help significantly in defining the dispersion (variation) of test results.
- The negative correlation between the strength properties (compressive, tensile, shear) of rock and their respective CV's indicate that scattering of test data tend to decrease with increase in strengths. This is somewhat intuitive, but logical, if one considers that physically stronger rocks have fewer imperfections.
- The results also show that there is a remarkable increase in the standard deviation with increasing strength value, indicating a positive correlation between strength and Standard Deviation (SD).
- The lowest coefficient of variation was found in case of Makarana marble (14.62) whereas the sandstone shows maximum variation (50.89). This is because the Makarana marble is made of fine grained particles having homogenous and isotropic nature while sandstone appears to have number of impurities.

References

Barry, B.A. (1978). Errors in Science, Engineering and Technology, New York, Wiley, p.183.

Ergin Arioglu, Nuray Tokgoz (1991). Statistical analysis of the variability of uniaxial compressive and tensile strength tests of rock, Dept. of Mining Engg., Istanbul Technical University, Istanbul, Turkey.

ISRM, (1981), Rock characterisation testing and monitoring - ISRM suggested methods. Ed. E.T. Brown, Pergamon Press Oxford, p. 211

Press-Rodrigues, F. (1970). anisotropy of rocks - Most probable surfaces of the ultimate stresses and the module of elasticity, Proceedings of 2nd congress ISRM, Belgrade, pp.133-142.

Press-Rodrigues, F. (1983). simultaneous influence of several parameters over rock and rockmass properties, Proceedings of 5th congress ISRM, Melbourne, pp.37-41.

Ratigan, J. (1981). Statistical fracture mechanics approach. Ph.D. Thesis, University of California, at Berkeley, p. 63.

Rohde, J., Feng, H. (1990). Analysis of the variability of unconfined compression tests of rock, Rock Mechanics and rock Engineering 23, pp. 231-236.

Sun, G. (1983). Fundamentals of rock mechanics, China Science Publisher, Beijing, p. 241.

Yegulalp, T.M., Mahtab, M.A. (1983). A proposed model for statistical representation of mechanical properties of rock. Proceedings of 24th Rock Mechanics symposium, Texas A&M University, AEG, pp. 61-69.

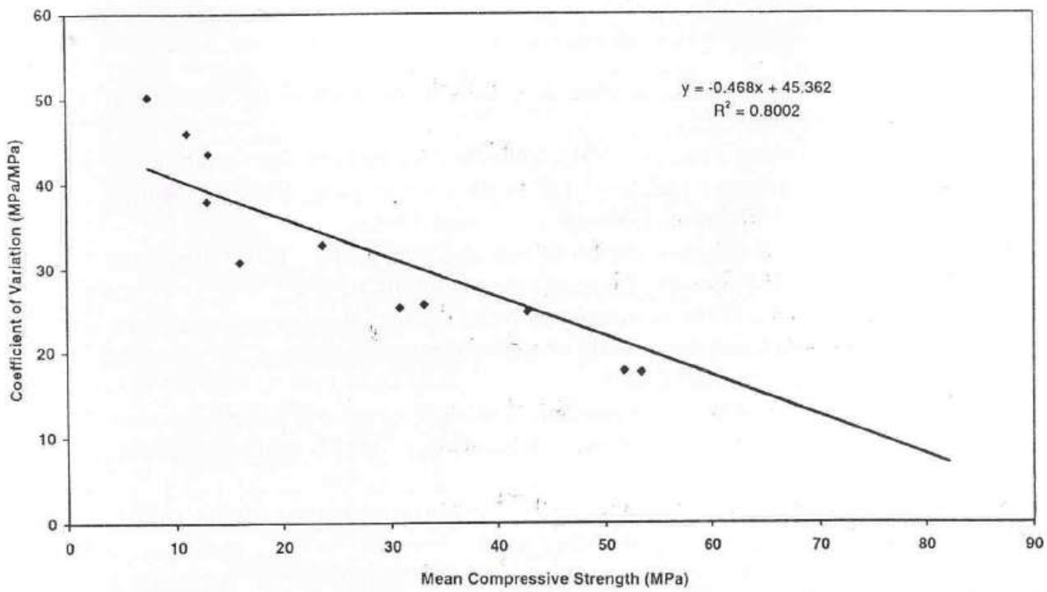

Fig. 1: Coefficient of variation versus mean compressive strength of 12 different rock samples

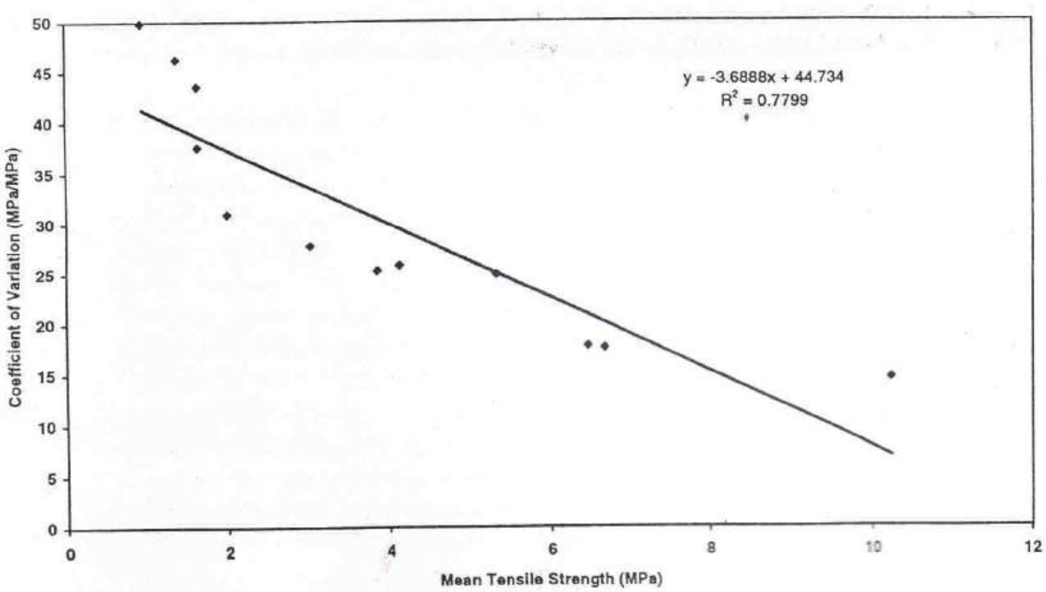

Fig. 2: Coefficient of variation versus mean tensile strength of 12 different rock samples

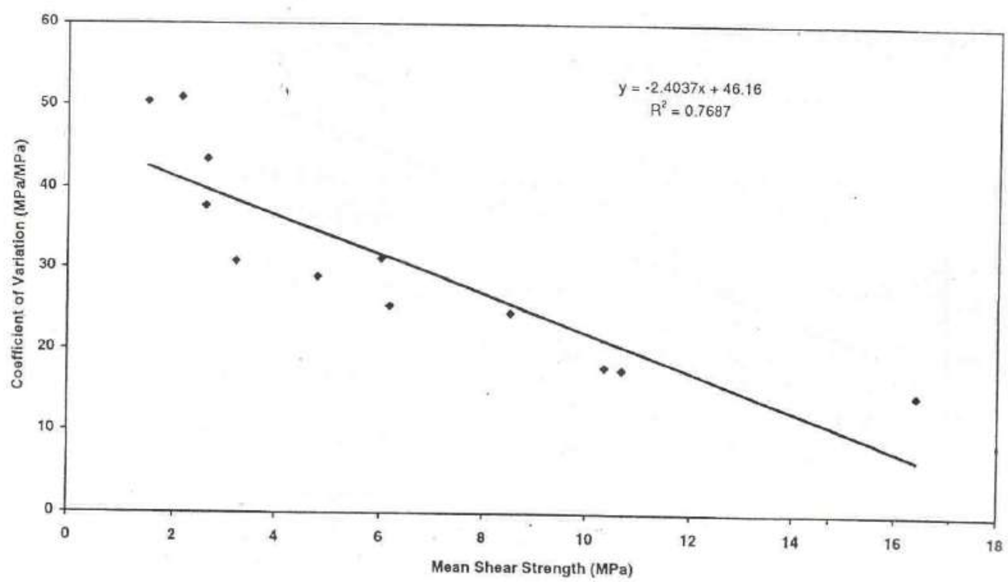

Fig. 3: Coefficient of variation versus mean shear strength of 12 different rock samples

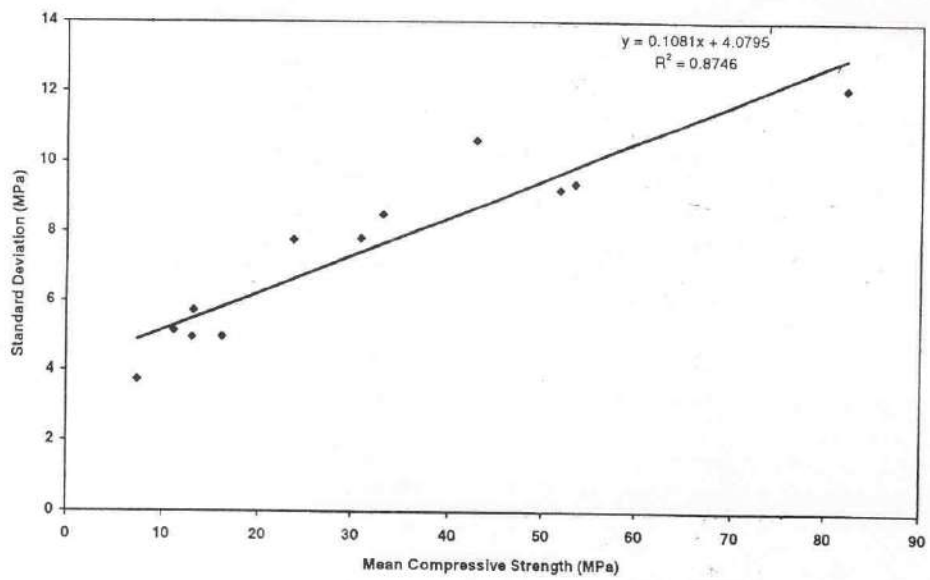

Fig. 4: Standard deviation versus mean compressive strength of 12 different rock samples

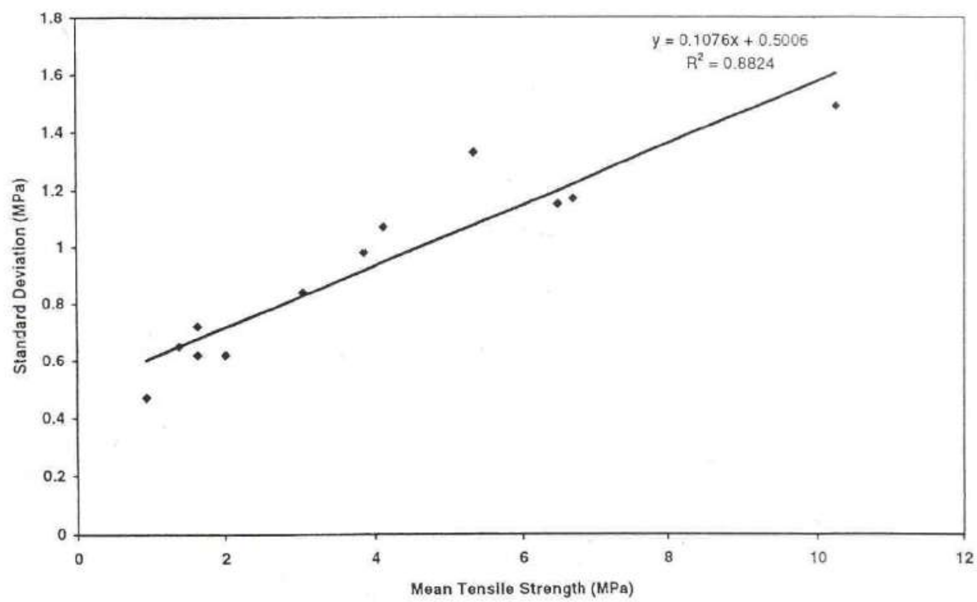

Fig. 5: Standard deviation versus mean tensile strength of 12 different rock samples

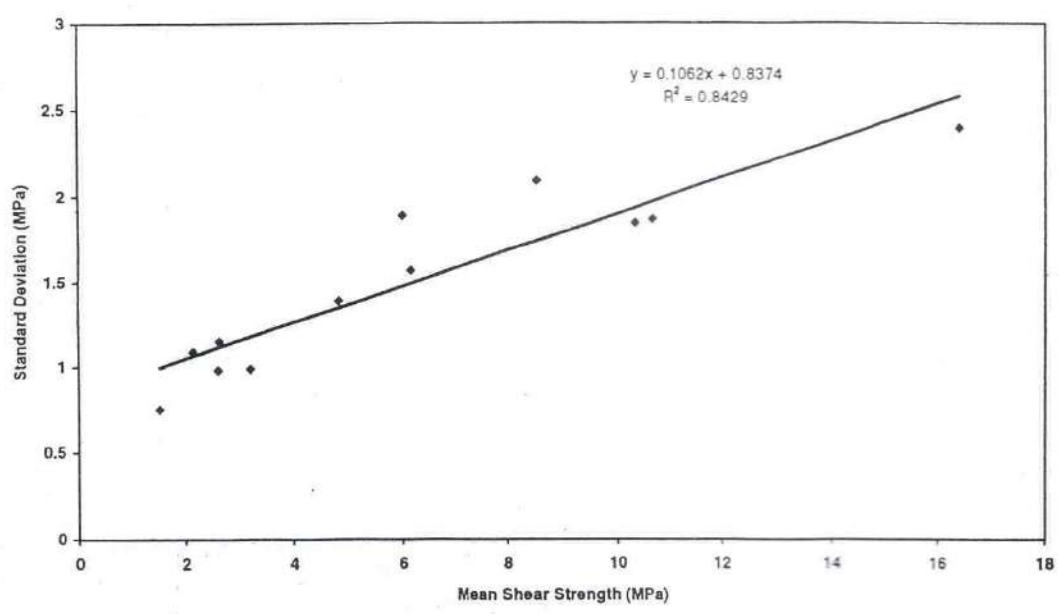

Fig. 6: Standard deviation versus mean shear strength of 12 different rock samples