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SOME IMPLICATIONS OF EMPIRICISM AND ASSUMPTIONS IN LABORATORY TESTING

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Abstract: The implications of approximations, introduced by empiricism and/or assumptions, in laboratory assessment of rock are brought out with the help of discussions on three topics – correlation between uniaxial compressive strength and point load strength index; triaxial compression test data's use for assessment of c, Φ, m and s parameters; and evaluation of dynamic elastic parameters (based on compression and shear waves' velocities). The objective is to highlight that in certain cases the theories, practices, and/or the empirical relationships, normally adopted, may not be applicable when the underlying assumptions do not hold good; and unacceptable distortions are introduced if these are used. The paper presents suggestions to deal with the discussed atypical situations. The submission is that ingenuity is called for to assess a rock; and the assessment must be holistic. Two things need to be made mandatory – one, to communicate the tests data to a centralised place, so that suggested relationships can be re-examined; and, two, to declare the data-base on which any relationship is based.

Keywords: rock, laboratory, assumptions, empiricism, static, dynamic.

1. INTRODUCTION

As rock engineers, involved in the task of assessment of rock for our clients so that they can build structures on/in rock, our primary concern vis-à-vis implications of empiricism and assumptions is of a practical nature. We are essentially interested in the answer to the query: How best we can use the generated data to assess the rock? Fortunately for us, often, we are able to satisfactorily employ the standard ways (available in the literature) of interpreting different data. However, at the same time, equally, if not more, fortunately for us, the available methods of interpretation do not satisfy us in certain other situations. In these situations, as we have shown through certain examples later in this paper, we make new introductions.

Therefore, from the view point of practicality, the implications of empiricism and assumptions are that in certain situations, the applications based on them are inapplicable, whereas in most others one can ignore the distortions introduced by these assumptions/ empiricism as of no practical significance. In other words, the implications of assumptions and/or relationships are highlighted through limitations, i.e. through cases where these theories are inapplicable.

It is crucially important to understand the implications of empiricism and assumptions, because their inapplicability can introduce unacceptable distortions in the assessed response. That is so because, in the ultimate, through assumptions and/ or empirical relationships, we introduce approximations, in order to deal with the complex reality, which is not amenable to our simplified understanding of nature. Thus, empiricism and assumptions play a dual role which, on the one hand, helps one grapple with the real world, but on the other hand, can also lead us astray, in case one is not alert, and applies them in situations where these are not applicable.

Empiricism, as the name itself suggests, somewhat lacks in theoretical underpinnings; and, therefore, it is all the more necessary that the data-base, on which an empirical relationship is based, is made explicit. Also, it would be desirable to detail the cases where the proposed empirical relationship is at variance with the observed response. In fact, in empiricism, we need to be more cautious as we are at one-extra step removed from reality, because the assessed response is being indirectly inferred.

Assumptions are inevitable if one wants to treat the rock as an engineering material, in a practical way – especially because the rock is formed as a consequence of geological processes spread over geological time-scale, whereas the mortal human is incompetent to grapple with the changes brought about over that time-scale. Rock, being a naturally occurring material, refuses to slavishly conform to different empirical relationships, theories and assumptions.

At times, these assumptions and/or empirical relationships introduce distortions leading to unacceptable results. In some other situations, the scatter in the test data is so high that ingenuity needs to be brought upon the data to realistically assess the rock. The three topics chosen for illustration of implications of empiricism and assumptions are – correlation between uniaxial compressive strength and point load strength index; triaxial compression test data's use for assessment of c, Φ, m and s parameters; and evaluation of dynamic elastic parameters (based on compression and shear waves' velocities).

1.1 The Discussed Empiricism

First, the implications of empiricism are highlighted with the help of discussion on correlation between uniaxial compressive strength and point load strength index. The point of discussion for this is the ISRM Suggested Method (1985), which proposes a relationship (a factor of 20-25) between uniaxial compressive strength and point load strength index. At the same time, ISRM also qualifies that relationship somewhat, by stating that this factor could vary from 15 to 50.

The stipulation of 20-25 correlation factor, in the light of attendant qualification – and, in the absence of any more information – implies that one could be greatly off-the-mark (25/15, i.e., 67% higher, or 50/25, i.e., 50% lower). The discussion on the involved issues in this empirical relationship is based on our investigations of this correlation.

1.2 The Discussed Theories

Next, the use of triaxial compression test data for determination of different parameters – namely, cohesion and angle of internal friction (to estimate shear strength) and "m and s" parameters – has been discussed. This discussion is to highlight the implications of theories – which are after all based on some sort of assumptions.

The two theories that employ triaxial compression test data, and have been discussed here, are: i) Mohr's strength envelop, used for assessment of cohesion and angle of internal friction, and ii) the relationship between the axial failure stress, σ_1, and the confining pressure, σ_3, in a triaxial test (proposed by Hoek, E. and Brown, E. T.) which helps estimate m and s parameters.

Three data-sets have been presented herein, to highlight that i) two different theories may work equally well for a given data-set, ii) one of the two theories may not work for another data-set, and iii) the scatter may be too high, and the situation may not be tailor-made for the application of any of the two theories.

1.3 The Discussed Assumptions

The third topic of using compression and shear waves' velocities data for the assessment of dynamic elastic parameters (modulus of elasticity and Poisson's ratio) highlights the importance of assumptions. The data presented shows that the application of the standard equations can lead to unacceptable results – especially in the case of Poisson's ratio. And, therefore, it becomes questionable to use those equations for the assessment of modulus of elasticity, even if apparently acceptable results are obtained. The use of waves' velocities data for assessment of samples' selection is suggested.

2. CORRELATION OF UCS AND $I_{S(50)}$

2.1 The Issues Involved

The most important issue is that the detailed description of the data-base – rock types, number of samples, and attendant details on testing – on which the recommended correlation factor of 20-25 is based, needs to be provided. Because, once there is a recommendation by the ISRM, there is a tendency amongst the practicing engineers to use it – quite often oblivious of the circumstances under which the relevant correlation factor is valid. And, that is why it is important that the complete basis regarding the relationship is provided, so that the correlation is not misapplied.

The attendant details on testing, which have crucial bearing on the tests' results, are important because of two reasons. One, even for a given rock type, from a given area, the point load strength index and uniaxial compressive strength are not unique values. These are spread over a range. In our experience, 70% variation is a very common occurrence. Secondly, in the case of anisotropic rocks, large variation is observed in the case of point load strength index, with respect to the inclination of the core from the foliation.

In our perception, the mechanism of failure is entirely different in the case of uniaxial compressive strength and point load strength index, which makes it all the more crucial that as much attendant details as possible are provided. Especially for anisotropic rock, the position of the weakness plane would have to be 'similar' with respect to the 'normal' plane of failure, for the two to be comparable.

For an anisotropic rock, in case of diametral loading, the loading has only to initiate the failure, and the sample, almost irrespective of the failure area, fails; whereas in case of axial loading, it is the material that is to be failed through punching. Leave anisotropic rocks, even for largely isotropic rocks, the point load strength index values in cases of axial and diametral loading need not be same.

Along with the recommendation of the correlation factor, complete range of the two parameters for the given data-base should be provided – so that the user knows the variability that is involved, even in case the rock type is same as that is included in the data-base of the proposed relationship.

2.2 The Study

To investigate the applicability of ISRM suggested correlation factor between Point load strength index and uniaxial compressive strength, we have already conducted, for some rock types, over 500 point load strength index tests, and over 200 uniaxial compressive strength tests in different states (dry and saturated). Some aspects of the work have been presented by Abdullah et al. (1999), in "Point load strength index and uniaxial compressive strength"; a small portion of the summary of correlation factors (Table 1), and the important conclusions presented therein, follows:

Table 1. Summary of the data and recommended parameters for s_c and $I_{s(50)}$.

Rock/ Place	$s_c / I_{s(50)}$ (MPa)			Corr. Factor
	Minm.	Max.	Rec.	
*QMS_{dry} Ganwi	20/1.8	54/4.1	40/3.4	12
QMS_{sat} Ganwi	7/0.6	26/3.0	12/2.0	6
QMS_{sat} Tr. NJ	11/0.7	24/3.4	17/1.6	11
Schist_{sat} Sh., NJ	30/1.2	154/4.7	85/2.8	30

*QMS – quartz mica schist

- The variation of correlation factor, even for a rather small range of rock types, drawn from a limited geographical region, was rather large – 6 to 30. The ratio of 5 between the two extremes demands that more information is provided on these for a meaningful and reliable use of point load strength index data to assess uniaxial compressive strength.
- The same rock type tested in different states, i.e. dry and saturated states, in certain instances, resulted in different correlation factors. Generally, the correlation factor reduced on saturation.
- The same rock type from two different locations (although from the same region) resulted in different correlation factors.
- The scatter of the point load strength index test data and uniaxial compressive strength test data was observed to be dissimilar in most cases.
- Given the above observations, based on investigations of limited rocks, a general and universal correlation coefficient between the two parameters is unlikely.

In view of the large scatter in the correlation coefficient, it is suggested that the correlation factor and the data base for each rock type, in each state (dry/ saturated), is separately given (as in Table 1). The graphical presentation of the tests' data (as has been done by Abdullah et. al in the above-referred work) can be a rational way of treating the correlation issue.

3. TRIAXIAL COMPRESSION TEST

3.1 The Discussed Issues

At the most fundamental level, we presume certain behaviour; and on that basis proffer a theory. However, under all circumstances, the naturally occurring material such as rock may not conform to any theory. The rather high inherent variability of rock in certain instances, can also present peculiar situations requiring unorthodox treatment of the data.

To plot the triaxial compression test data as axial failure stress versus confining pressure, and then draw the Mohr's strength envelop as the best-fit to the data, in order to evaluate shear strength parameters (cohesion and angle of internal friction) is a normal practice. However, if the data does not lend itself to "best-fit", then how does one estimate the shear strength parameters? A case presented here, in a subsequent section (3.2.3), deals with such a scenario.

Another usage of triaxial compression test data is in the assessment of "m" and "s" parameters. However, as we shall show in subsequent sections (3.3.1 and 3.3.2), it may, or may not, be possible to determine these parameters, while one may be able to find cohesion and angle of internal friction employing Mohr's failure envelop, using the same data-base.

3.2 Assessment of c and Φ

3.2.1 Case I

Quartz Chlorite Mica Schist from Larji H. E. Project, was tested under triaxial compression for the confining pressure range of 4 to 13MPa. The data of 8 samples that are considered for the best-fit (Mohr's strength envelop) is plotted in Figure 1. In this, the correlation coefficient is over 0.96; and the cohesion and angle of internal friction computed are 7.33MPa and 38^{o}.5 respectively.

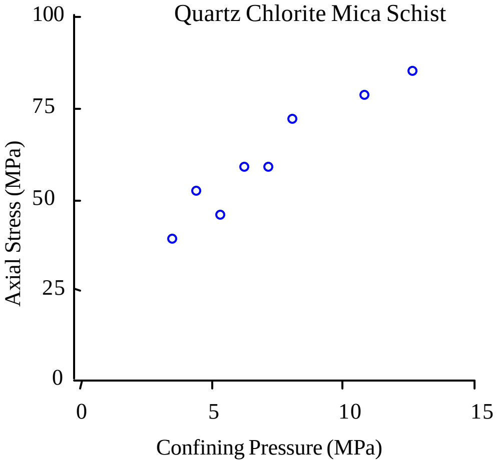

Figure 1. Strength envelop.

3.2.2 Case II

The quartzite rock from Powerhouse site of Chamera H. E. Project, H. P., India, was tested under triaxial compression; and the data has been plotted in Figure 2. The Mohr's strength envelop, i.e., the best-fit, for the above data gave a correlation coefficient of 0.99. (Incidentally, here, the computed cohesion and angle of internal friction are 1.7MPa and 73^{o} respectively). That means Mohr's failure criterion is equally valid for both, case I and case II.

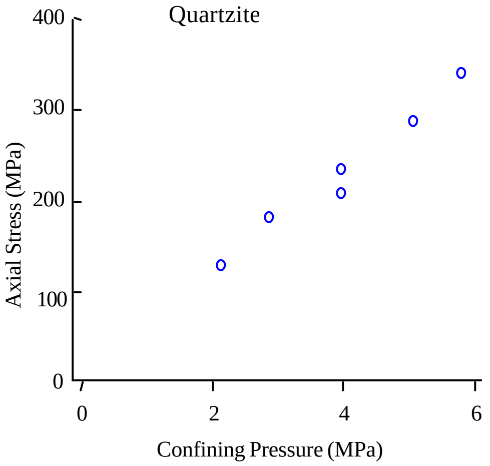

Figure 2. Strength envelop.

3.2.3 Case III

Figure 3 presents 47 data of granitic gneiss from one project wherein, often, the axial stress at failure did not increase with the increase in confining pressure (Different symbols denote samples from different drillholes). As the conventional treatment of the data was not possible, the method, given below, was adopted.

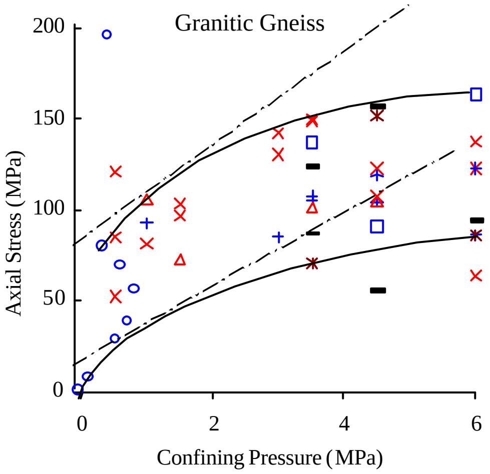

Figure 3. Strength envelop.

The lower-bound and upper-bound curves were drawn, ignoring 4 samples, which have lower/

higher failure stress at higher/ lower confining pressures respectively.

The tangents were then drawn at 1.5MPa confining pressure; and these were treated as the strength envelops (lower and upper-bounds), giving two sets of shear strength parameters. For detailed discussion, see Abdullah and Dhawan (2003).

3.3 Assessment of m and s Parameters

The basic empirical equation relating the axial failure stress, s_1, to the confining pressure, s_3, in a triaxial test, proposed by Hoek. E. and Brown, E. T. (referred from Hoek, E. and Bray, J. W.) is:

$$s_1 = s_3 + \left(m s_c s_3 + s s_c^2 \right)^{1/2} \qquad (1)$$

where, m and s are dimensionless constants.

The s_c in the above equation is uniaxial compressive strength of the intact rock pieces; and, m and s are dimensionless constants, which depend upon the shape and degree of interlocking of the individual pieces of rock within the mass. The triaxial compression test data of the first two cases has been used below to determine “m” and “s” parameters. The above equation is reduced to a “linear” equation form of $(s_1 - s_3)^2$ versus s_3, so as to find the best-fit solution of the equation.

3.3.1 Case I

Figure 4 shows $(s_1 - s_3)^2$ versus s_3 plot for the data of section 3.2.1. The correlation coefficient for the best-fit of this data is 0.95, which is as good as 0.96 of Mohr’s strength envelop for the same data. The computed m and s parameters on the basis of above data, for the confining pressure range of 4 to 13MPa, are 13.92 and 0.42 respectively. Hence, sections 3.2.1 and 3.3.1 together show that c, f, m and s, all four parameters can be satisfactorily assessed for the given data-base.

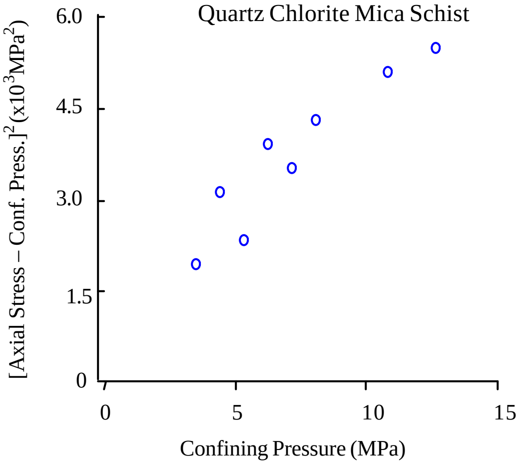

Figure 4. $(s_1 - s_3)^2$ *v/s* s_3.

3.3.2 Case II

Figure 5 shows the data of case II. Here the correlation coefficient is 0.97, but the computed s parameter is substantially negative, which is unacceptable, as it has to be between 0 and 1. Hence, we conclude that a data-set compatible to one theory, need not necessarily be compatible to the other theory also.

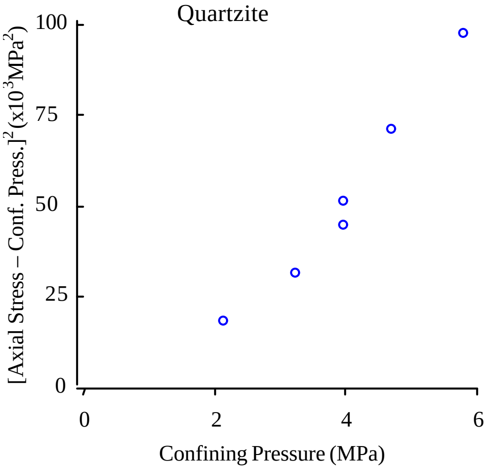

Figure 5. $(s_1 - s_3)^2$ *v/s* s_3.

4. DYNAMIC ELASTIC PARAMETERS

The dynamic elastic parameters, i.e. modulus of elasticity (E_{dyn}) and Poisson’s ratio (m_{dyn}), computed on the basis of compression wave velocity (V_p) and shear wave velocity (V_s) are based on the following equations:

$$E_{dyn} = \rho V_s^2 \left(3V_p^2 - 4V_s^2\right) / \left(V_p^2 - V_s^2\right) \quad (2)$$

$$\mu_{dyn} = \left(V_p^2 - 2V_s^2\right) / 2\left(V_p^2 - V_s^2\right) \quad (3)$$

where ρ is bulk density.

The waves velocities data for some of the samples of Mica schist with quartzite from a single drillhole of Rupaligad site of Pancheshwar Multipurpose Project, Uttranchal (India), in dry and saturated, both states, is presented in Table 2. These were Nx size samples with length to diameter ratio of 2 or 2.5. (These samples were later tested under triaxial compression or uniaxial compression, and the tests' data was found to be normal.

Table 2. The waves' velocities and dynamic elastic parameters of mica schist with quartzite.

Sample No.	V_p (km/sec)	V_s (km/sec)	E_{dyn} (GPa)	μ_{dyn}
$35A_{dry}$	2.73	2.23	13.4	-0.50
$35A_{sat}$	2.86	2.26	18.4	-0.33
$35B_{dry}$	2.56	2.01	15.2	-0.30
$35B_{sat}$	2.72	2.08	18.6	-0.20
$44A_{dry}$	2.87	2.11	21.9	-0.09
$44A_{sat}$	3.37	2.17	29.1	+0.15
42_{dry}	3.26	2.46	27.4	-0.16
42_{sat}	4.21	2.61	43.7	+0.19

In Table 2, the dynamic modulus of elasticity values are increasing on saturation – which is contrary to what one expects, because the sample gets weaker on saturation. And therefore strain should logically increase for the same stress-level. Also, that is what one observes in case of static modulus of elasticity values. And, theoretically, the dynamic modulus of elasticity is directly proportional to static modulus of elasticity.

One also observes that for some samples, in dry state, the Poisson's ratio is negative, whereas it becomes positive on saturating the sample, thereby suggesting high sensitivity of Poisson's ratio to the assumptions of elasticity, homogeneity and isotropy etc.

The above two simple observations, one each pertaining to modulus of elasticity and Poisson's ratio, put a big question mark on the applicability of waves' velocities data for assessment of dynamic elastic parameters.

In view of the foregoing, our submission is that the dynamic elastic parameters should not be computed using waves' velocities data, because involved assumptions are fundamentally wrong in case of most rocks. And, it cannot be argued that the samples that result in unacceptable values for the Poisson's ratio are qualitatively different from those that give apparently realistic values.

In "Use of waves' velocities in laboratory investigation of rock", Abdullah et al. (1999) have, however, presented a methodology of using the waves' velocities data to understand the scatter in the data of other engineering parameters. The methodology helps one arrive at a representative value of the involved parameters. The potential of the application of the waves' velocities data clearly emerges, but the technique does not explain every data, and the need for a holistic analysis and engineering judgment remains.

5. CONCLUSIONS

The conclusion of this paper is that the assumptions are necessary, if the rock is to be assessed as an engineering material; however, assumptions introduce approximations. And, in certain situations, these assumptions introduce such approximations so as to distort the reality to an extent that application of certain theories, inapplicable in those cases, may produce unacceptable results.

In certain other situations, the scatter in the test data may be so high so as to warrant unorthodox treatment of the data to assess the desired parameters of the rock.

The use of waves' velocities for assessment of dynamic elastic parameters, in general, is inadvisable. And, details of the data-base on which the correlation factor between point load strength index and uniaxial compressive strength is based, need to be made available, for its confident use.

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