ESTIMATING THE INTACT ROCK STRENGTH OF A ROCK MASS BY SIMPLE MEANS

Robert Hack[1] and Marco Huisman[1]

ABSTRACT The intact rock strength of a rock mass has been determined by several different means in the context of research for slope stability assessment. The intact rock strength was determined with unconfined compressive strength testing, Schmidt hammer, Equotip, and estimation by so-called 'simple means'. Estimation by 'simple means' denotes estimating the intact rock strength by hammer blows, crumbling by hand, etc. Many different people to avoid observer bias have done hundreds of assessments of intact rock strength by different means on the same rock masses. The results show that in many cases an estimation of intact rock strength by 'simple means' is more representative for establishing the intact rock strength of a rock mass than establishing the intact rock strength by more elaborate testing.

RÉSUMÉ: La force de la roche intacte d'un massif rocheux est déterminée par méthodes différentes d'un contexte d'une recherche pour la stabilité des pentes. La résistance de la roche intacte est obtenue par tests de UCS, 'Schmidt hammer', Equotip, et de 'méthodes simples'. Le 'méthodes simples' sont méthodes que coups de marteau, émietter par main, etc. Un grand nombre de déterminants est fait en un massif rocheux par personnes différentes. Le résulte est que la détermination d'une force de la roche intacte par 'méthodes simples' est plus de représentative par un massif rocheux que les méthodes plus sophistiquées.

INTACT ROCK STRENGTH (IRS)

Intact rock strength (IRS) is a major rock property. Intact rock strength determines the strength of the intact rock block material and as such governs partially the strength of a rock mass. Standard determination of the IRS is by means of a unconfined compressive strength (UCS) test. In, for example, most rock mass classification systems and analytical and numerical calculations intact rock strength is a parameter and is it necessary to obtain the characteristic or mean value of the intact rock strength.

DATA

The research for this article is executed in the context of developing methodologies for slope stability in the area around Falset in Northeast Spain, in the province of Tarragona. Rocks in the Falset area vary from Tertiary conglomerates to Carboniferous slates and include rocks containing gypsum, shales, granodiorite, limestone, and sandstone. Thus, giving the opportunity to assess the determination of intact rock strength of rock masses in different lithologies. Many hundreds of assessments have been done to estimate the intact rock strength of a rock mass together with a detailed description of the rock mass and the variation of intact rock strength over the exposures. Also many hundreds of tests have been done by unconfined compressive strength testing (941 tests), Schmidt hammer, and Equotip. Estimating the strength by 'simple means' is to a certain degree subjective. Therefore, estimates have been made over a period of four years using at least sixty observers from staff and students of ITC and Delft University of Technology. It is therefore reasonable to assume that observer bias is absent.

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1. Section Engineering Geology, Centre for Technical Geosciences, International Institute for Aerospace Survey and Earth Sciences (ITC), Kanaalweg 3, 2628 EB Delft, The Netherlands

Engineering Geology for Developing Countries - Proceedings of 9th Congress of the International Association for Engineering Geology and the Environment. Durban, South Africa, 16 - 20 September 2002 - J. L. van Rooy and C. A. Jermy, editors

Géologie de l'Ingénieur dans les Pays en voie de Développement - Comptes-rendus du 9ème Congrès de L'Association Internationale de Géologie de l'Ingénieur et de l'Environnement. Durban, Afrique du Sud, 16 - 20 septembre 2002 - J. L. van Rooy and C. A. Jermy, éditeurs

ISBN No. 0-620-28559-1

UNCONFINED COMPRESSIVE STRENGTH TEST (UCS)

Intact rock strength is mostly defined as the strength of the rock material between the discontinuities. Strength values used are often from laboratory unconfined compressive strength (UCS) tests. Problems caused by the definition of intact rock strength and using strength values based on UCS laboratory tests are:

- The UCS includes discontinuity strength for rock masses with small discontinuity spacing. The UCS test sample is most often about 10 cm long and if the discontinuity spacing is less than 10 cm the core may include discontinuities.
- Samples tested in the laboratory tend to be of better quality than the average rock because poor rock is often disregarded when drill cores or samples break (Laubscher, 1990), and cannot be tested.
- The intact rock strength measured depends on the sample orientation if the intact rock exhibits anisotropy.

Many alternatives have been invented for UCS testing. Notable: the Point Load Test or hammer tests. The same problems as listed above also apply to the PLS test. The inclusion of discontinuities in the rock will cause a PLS value tested parallel to this discontinuity to be considerably lower than if tested perpendicular. This effect is stronger for the PLS test than for a UCS test, as the PLS test is basically a splitting test.

IMPACT METHODS

Often intact rock strength is not very important. The limited importance of intact rock strength does not require that sophisticated tests are done to establish the intact rock strength. Relatively easy to execute field tests with an impact method or with a 'simple means' field test (hammer, scratching, molding, breaking by hand, etc.) lead to intact rock strength values assessment. The Schmidt hammer determines the rebound of a piston activated by a spring. The rebound values measured on rock surfaces have been correlated to intact rock strength. Schmidt hammer values are, however, influenced by the material to a fairly large depth behind the surface. If a discontinuity lies within the influence sphere the Schmidt hammer values will be affected. The Schmidt hammer is thus not considered suitable to measure rock material strength in the field. The same applies to any other impact/rebound devices whose released energy per surface unit area is of the same order of magnitude as the Schmidt hammer. Equotip or other rebound impact devices might be suitable, but as these devices are only recently applied to rock mechanics it is not yet certain whether the relationships between rebound values and intact rock strength are correct.

'SIMPLE MEANS' INTACT ROCK STRENGTH FIELD ESTIMATES

'Simple means' field tests that make use of hand pressure, geological hammer, etc. (Burnett, 1975), are used to determine intact rock strength classes in the British Standard (BS 5930, 1981) (the test classes are listed in table 1). The 'simple means' field tests to estimate intact rock strength following table 1 have been extensively used in the field and compared to UCS test values. At many exposures multiple estimates of the intact rock strength, often more than ten, have been made per geotechnical unit and per exposure. The values obtained were averaged. Additional to these estimates also large amounts of unconfined compressive strength (UCS) tests have been done in the same geotechnical units and in the same exposures to establish the reliability of the strength estimates. If possible, estimates and

Table 1. Estimation of intact rock strength.

intact rock strength	‘simple means’ test (standard geological hammer of about 1 kg)
< 1.25 MPa	Crumbles in hand
1.25 – 5 MPa	Thin slabs break easily in hand
5 - 12.5 MPa	Thin slabs break by heavy hand pressure
12.5 - 50 MPa	Lumps broken by light hammer blows
50 – 100 MPa	Lumps broken by heavy hammer blows
100 - 200 MPa	Lumps only chip by heavy hammer blows
> 200 MPa	Rocks ring on hammer blows. Sparks fly.

UCS tests were done both perpendicular and parallel to the bedding or cleavage. The extensive quantity of tests allowed a thorough analysis of the accuracy and reliability of the 'simple means' field tests for estimating the intact rock strength. This analysis is presented in this paper. The estimated strength values in the graphs in this chapter are plotted as the mid values of the ranges of table 1. If the strength was estimated to be on the boundary between two classes the boundary value is used.

INTACT ROCK STRENGTH FIELD ESTIMATES VERSUS UCS TESTS

In figure 1a the estimated values of intact rock strength by 'simple means' field tests are plotted versus UCS test values for all locations for which both were available. In figure 1b the differences between the UCS test values and the estimated values as percentage of the estimated values are plotted. The averages of UCS values are the averages of all UCS values belonging to the range of estimated strength. A grouping of the UCS values in the same classes as used for the estimate, before averaging leads to about the same values.

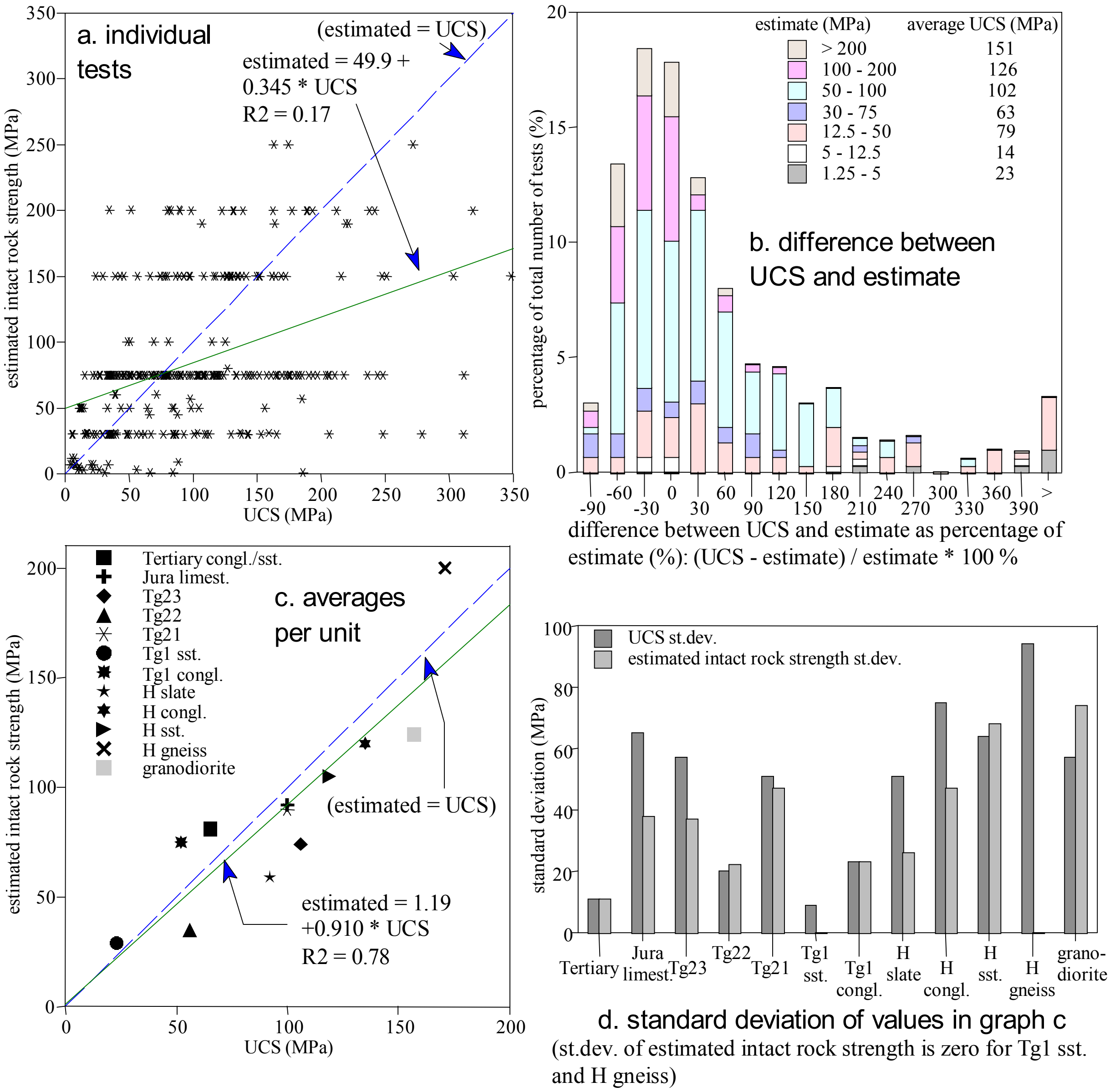

Figure 1. Estimated intact rock strength vs. strength values determined by UCS tests. (The dashed lines in A and C indicate the relation if estimated strength equals UCS strength.) (Number of UCS tests: 941)

In figure 1c the averages of estimated and UCS values are shown per unit. In figure 1 no differentiation is made for the direction of the measurements. Figure 1a shows that the scatter is wide and consequently only low or no correlation can be seen. In figure 1b is clearly visible that the differences between UCS and estimated values do not show a normal distribution for lower strength values. The distribution is skewed to higher values, e.g. the UCS values are higher than the estimated values. For high strength values the distribution of the differences is more normal but the average values of the UCS tests per estimated strength class are lower than the averages of the estimated values. A quite good correlation is found for the averages per unit (figure 1c). The standard deviation of the UCS values per unit is for most units considerably higher than the standard deviation for the estimated strength value per unit (figure 1d).

If is assumed that a unit has a characteristic strength distribution with a characteristic mean strength value, which is very likely for the units assessed in the research area, then the estimated value will be nearer the mean value of the distribution because it is an average of more tests. The UCS test value is, however, only a single value or the average of few test values (normally less than three or four) and is likely to differ more from the mean value. This leads to the conclusion, as expected, that the characteristic mean strength value of a unit is better determined by a large quantity of estimated values than by few UCS tests. The skew of the distribution of the differences between UCS and estimated values for low strength (figure 1b) is probably caused by the fact that samples are not taken randomly. Samples are very seldom taken from the worst parts of a rock exposure. This is also confirmed by an analysis of the results of intact rock strength estimation and UCS tests for granodiorite with various degrees of rock mass weathering in the same exposure.

WEATHERING

In figure 2, UCS values are considerably higher than the estimates of intact rock strength for the higher degrees of weathering of the rock mass. The granodiorite has weathered starting from the discontinuities and often a complete sequence of weathering is found. The weathered material and certainly the highly weathered parts will break from the sample during transport and sawing of the sample. The UCS test is thus done on pieces of rock material less weathered than the average degree of weathering in the unit and therefore leads to a too high strength value when compared to the strength estimated in the field by lump hammering.

A better estimate of a representative material strength might be made with an in-situ test rather than a UCS laboratory test. In figure 3 a set of measurements is presented for different weathering degrees (BS5930) in granodiorite, for the UCS strength estimates based on Schmidt hammer and Equotip (Equotip, 1977, Hack, Hingera and Verwaal, 1993, Verwaal and Mulder, 1993) testing. As one of the limitations of rebound tests in general (as was mentioned before), a disadvantage of both field tests is that they have a certain depth of influence; discontinuities and weakened material around this depth (and this depth only) influence the measurement and the resulting estimate. The depth of influence for the Schmidt hammer is larger than for the Equotip, and therefore in rocks where weathering is limited to a relatively shallow zone close to the surface of discontinuities, the Equotip will tend to underestimate the strength (over-influenced by weathering) whereas the Schmidt hammer will overestimate the strength (under-influenced by weathering). In rocks where weathering manifests itself by opening of discontinuities within the rock mass, rather than weakening of the material itself, the situation will be reversed.

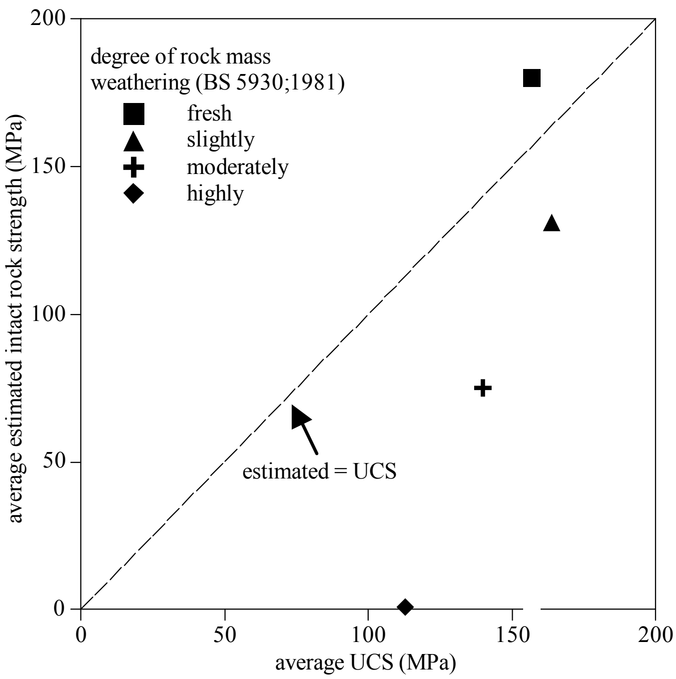

Figure 2. Average estimated intact rock strength vs. average UCS for granodiorite units with various degrees of rock mass weathering.

BIAS IN SAMPLE TAKING FOR TESTING

The difference between UCS test values and estimated values for high intact rock strength might be due to a similar, but reversed effect. For high intact rock strength (> 100 MPa) it is often difficult to get sample blocks out of an exposure without equipment (saw, blasting, etc.) and a tendency exists to do tests on loose blocks that are more easily obtained. These may, however, have a lower strength. This effect is also observed in the granodiorite for which the estimated strength of the fresh exposures is higher than the UCS strength values (figure 2). The same effects, but for all rock units, are obvious in figure 4, which shows the percentages of UCS tests falling in the ranges for the estimate of intact rock strength different from the estimated range value. For lower intact rock strength values the UCS values are higher than the estimated values while for the higher intact rock strength values the UCS value is lower than the estimated value.

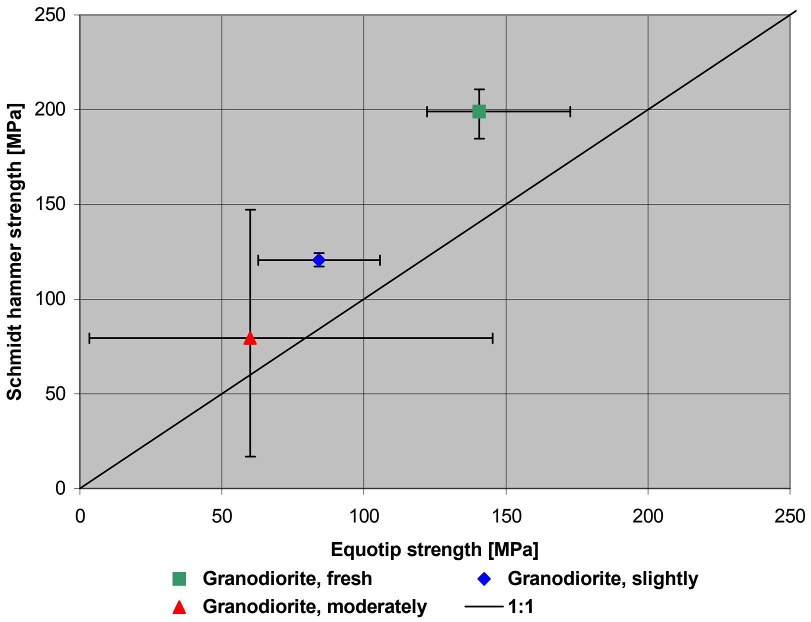

Figure 3. UCS strength estimated with in-situ field tests Equotip and Schmidt hammer; crosses indicate spread in measurements.

REPEATABILITY OF INTACT ROCK STRENGTH ESTIMATES

The repeatability of estimating the intact rock strength is fairly good. In the field intact rock strength has been estimated by different students and staff members in the same exposure and in the same geotechnical unit. The results show that the majority estimate the strength to be in the same class and a minority estimate the strength to be in a one class lower or higher. Strength estimates more than one class different from the class estimated by the majority were rare and could often be attributed to real variability in intact rock strength within a unit. An argument against estimating intact rock strength by classifying following table 1, is that it would be dependent on the person who does the estimation, e.g. a large or physically strong person estimates the strength lower than a small or fragile person. This has not or only rarely been observed. The class ranges are obviously large enough to accommodate for most physical strength differences.

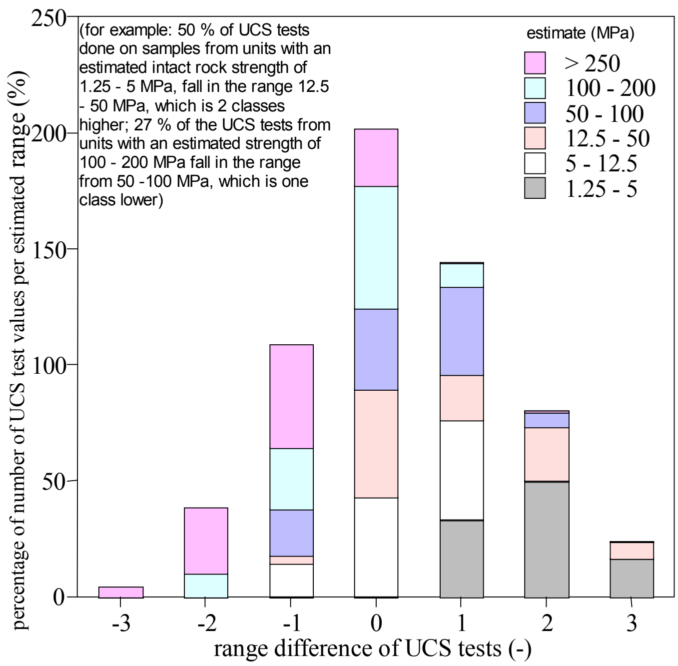

Figure 4. Percentage of UCS test values falling in a range different from the estimated value.

INFLUENCE OF DEGREE OF WATER SATURATION ON INTACT ROCK STRENGTH

Some porous rocks exhibit a difference in intact rock strength depending on the degree of water saturation when tested by UCS tests (Bekendam and Price, 1993). The permeability and porosity of the intact rocks in the research area is generally low (the porosity is generally less than a few percent) and the differences in UCS strength due to the degree of water saturation are therefore likely also very small and less than the scatter of the test results for most units. Only the Tg1 sandstone unit (Tg1 sst.) exhibits a larger porosity, is permeable, and could have shown a strength difference similar to that found in the literature. However, the quantity of tests done on this single unit does not allow for conclusive statements. Therefore it is not known whether a strength estimate is influenced in the same way by the degree of water saturation as the strength value obtained by a UCS test.

STRENGTH ANISOTROPY

The correlation of the estimated value of intact rock strength with the UCS tested in a particular direction could not be proven. Only in strongly anisotropic rocks (e.g. slate) the estimate is in agreement with the results from UCS tests. The highest strength is expected perpendicular to the cleavage direction. For the other rocks the estimation of intact rock strength results in higher values parallel to the bedding direction. In figure 3 are shown, per unit, the ratios of the strength perpendicular over the strength parallel for average UCS test values and for average field estimated values. Although this effect has not been studied in detail a possible (and tentative) explanation could be as follows. All rocks included in figure 5 have intact rock strengths that are in 'intact rock strength estimate' classes established by hammer blows (> 12.5 MPa). The field estimate by hammer blows is a form of impact (dynamic) testing by which the rock breaks due to the impact energy (e.g. hammer blow). The impact energy is a limited quantity of energy induced into the rock in a small amount of time. Energy induced per time unit is thus high. The UCS test is a static test by which an unlimited amount of energy is induced into the rock until failure in a relatively large time span. The energy induced per time unit is low.

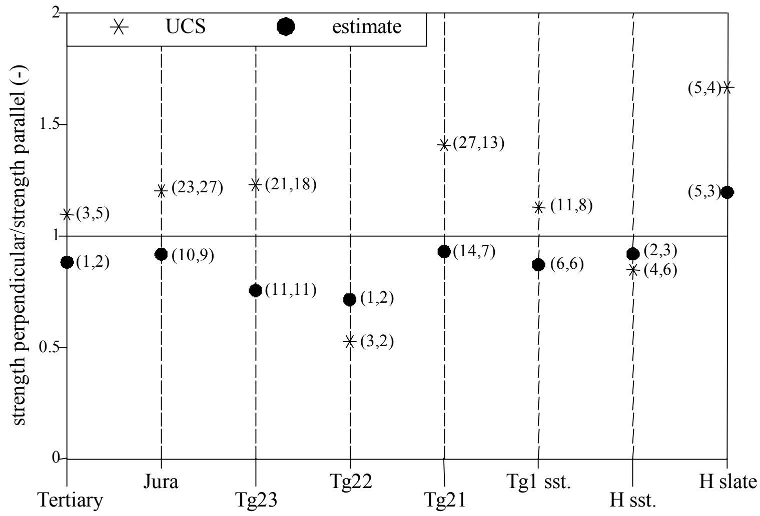

Figure 5. Ratio of average intact rock strength perpendicular over average intact rock strength parallel for UCS and field intact rock strength estimate per unit (values in brackets are the number of UCS tests respectively estimate)

Deformation of rock is a time dependent phenomenon. It requires a certain amount of time before a stress is converted into a deformation and vice versa. Stress and deformation are linked and it requires time to transfer stress and deformation throughout a test specimen. In an impact test part of the energy dissipates due to crack forming directly at the impact point. The remaining energy travels through the rock as a stress/deformation wave (e.g. shock or seismic wave). This wave is reflected at layer boundaries and at the end of the sample. When the incident and reflected waves are at the same location and have the same phase, the stresses (and deformations) are added and may cause the rock layer to break. In a layered sample the distance between layers is smaller than the length of the sample. The wave will loose energy (due to spherical dispersion, non-elastic deformation, absorption, etc.) during traveling through the rock. A wave reflected against the end of the sample with a longer travel distance, has thus less energy than a wave reflected against a layer boundary. The concentration of energy at a certain point due to the coincidence of direct and reflected waves will also be less.

This may be the explanation why a rock sample when tested (by hammer blows) breaks more easily perpendicular than parallel to the layering and thus that the strength estimate for a sample tested perpendicular is lower than tested parallel. It is likely that this mechanism is less (or does not occur) in very thin spaced layered material (e.g. slate) because the rock at the impact point is easily fractured and broken whatever the orientation.

In a UCS test the induction of energy in the sample is so slow that a stress/deformation wave will not occur. The whole sample will be stressed and deformed. The tensile strength perpendicular to the layer boundary planes in a layered material is normally less than the tensile strength of the material. In a UCS test of layered material tested parallel to the layering, failure will occur due to bending and separation of the individual layers, resulting in breaking of layers (starting with the layers at the rim of the sample). Perpendicular to the layering failure occurs due to stress concentrations in the intact rock of individual layers. Bending of the layers and consequent cracking/failure requires mostly less stress/deformation than breaking the rock due to stress concentrations and thus is the measured strength perpendicular larger than parallel to the layering.

CONCLUSIONS

The estimate of the characteristic strength of intact rock in a geotechnical unit with a 'simple means' test, following table 1, is equally good as executing a limited number of UCS tests. The higher accuracy that might be obtained by using UCS tests exists often only in theory. In practice the number of strength tests is so limited in comparison to the variations in strength in the rock mass that a large amount of simple field tests will give a better estimate of the intact rock strength at various locations in the rock mass than a limited number of more complex tests.

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