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# *CLASSIFICATION OF ROCKS FOR ROCK MECHANICS*

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FUELS AND MINING PRACTICE DIVISION

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## *A Paper for Discussion*

**Editorial Note**

*The need for a generally acceptable classification of rocks, based on their functional properties relevant to the problems of rock mechanics, is universal. However, there must inevitably be much discussion before an acceptable classification will be evolved. Correspondence is therefore invited upon the content of this paper. Contributions should be sent to the Journal with a copy to the author for subsequent comment.*

# CLASSIFICATION OF ROCKS FOR ROCK MECHANICS

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## INTRODUCTION

IN THE field of rock mechanics efficient communication between the laboratory and the field engineers, operators and contractors is important. For example, a rock may be described as a Cretaceous shale with quartz and pyrite, etc. However, some of the principa factors of practical interest would be: (a) is it jointed, badly fractured, distinctly layered or massive; (b) does it fail in a brittle or plastic manner; (c) is it viscous before failure; (d) can the information be interpolated between boreholes, etc. ? Hence it is important that the significant properties of both the substance and the mass be recognized and the appropriate information obtained so that an initial appraisal can be made of any potential problems.

Classification can be on the basis of natural, inherent characteristics or on the basis of purpose. The classification of rocks for rock mechanics problems should be functional, and the words used for communication between groups should be defined, widely recognised and related to the use of the information.

A classification system would principally be of value to engineers or those concerned with applied problems. At the same time, it has always been the concern of scientists to group or systematise and thus explain knowledge. In this way, scientists can point out similarities or differences which are not otherwise apparent. For the engineer, the appropriate classification of a rock mass would greatly assist in making the initial appraisal of any problem and in pointing to the areas where additional engineering information must be obtained for the final resolution of the matter. A review of rock mechanics' applications, of important properties and of other classifications are presented below. A proposal is then made for a classification system to be used initially in this field.

## FIELDS OF APPLICATION OF ROCK MECHANICS

To provide perspective on the uses of rock mechanics, the following list describes most of the applications that can be made of this knowledge at the present time:

(1) Design of slopes for open pits and construction cuts.
(2) Design of tunnels, shafts, drifts, crosscuts, underground power houses and pressure tunnels.
(3) Design of mine workings (e.g. stopes, rooms and pillars, etc.).
(4) Design of tunnel and power house linings, rock bolting systems, drift and crosscut sets, stope supports and other systems of rock support.
(5) Design of caving operations (i.e. to achieve the initial cave, efficient drawing, and minimum subsidence effects).
(6) Design of underground defence installations to resist nuclear explosions (i.e. the stress and ground motion effects of the dynamic strain pulse together with the geometry and required linings).
(7) Design of dam foundations and abutments.
(8) Design of structural foundations and cantilever anchorages.
(9) Appraisal of rockburst dangers.
(10) Design of optimum drilling patterns and optimum explosive charges.
(11) Study of comminution processes.

## IMPORTANT AND DETERMINABLE ROCK CHARACTERISTICS FOR MINING AND CONSTRUCTION

From the review of the uses to be made in engineering work of rock mechanics the following properties are suggested as being the most important for these applications:

(1) *The uniaxial compression strength* of the rock substance. This property immediately indicates whether the rock substance is weak enough with respect to the application to be a source of trouble in itself. Also, from experience it is known that there is a rough correlation between the modulus of deformation of the substance, as well as its brittleness, with its compressive strength. Finally, the property has the virtue of being easily determined.

(2) *The pre-failure deformation characteristics* of the rock substance. This property would indicate whether creep of some nature could be expected in the material itself at stress levels less than those required to cause failure. In extreme cases it could also indicate the possibility of the ground swelling. The appropriate test for the determination of this property has not yet been established; however, it is visualised that one of several techniques could be used.

(3) *The failure characteristics* of the rock substance. The nature of failure of the material itself, i.e. either by rupture or flow, should influence the safety factor that is used or judged to be appropriate in design as well as the precautions to be taken during operations. It has been well established in structural work that lower safety factors against yield than against rupture are appropriate. Again, no test method has been established for determining this specific property, but it should be largely a matter of workers in the field agreeing on certain specifications to be applied to tests already in use.

(4) *The gross homogeneity* and isotropy of the formation. The origin of the rock formations govern to a large extent whether the rock mass will be generally isotropic

or anisotropic in nature. From a mechanics point of view it is essential to know which type of general mass exists in the zone of concern.

(5) *The continuity of the rock substance* in the formation. As opposed to the properties of the rock substance which may or may not be a source of trouble, the properties of the rock mass are of great importance. Whether the rock is divided into large blocks or small pieces or not divided at all will often be more important than the properties of the rock substance itself.

Other properties will be important for specific projects. However, most problems will require additional tests and engineering data which would not be usefully included in a general classification. The above properties are selected as being not only those of the most general interest but also those which can be determined at modest expense.

## GEOLOGICAL CLASSIFICATION

Hitherto, the geological classification of rocks according to origin has been the most common method of describing a rock type. It is interesting to examine this classification method from a functional point of view with respect to rock mechanics. Briefly, the classification system is as follows:

(1) Sedimentary: (a) mechanical (b) chemical (c) organic.
(2) Igneous: (a) acid (b) intermediate (c) basic, and (i) plutonic (ii) hypabyssal and (iii) extrusive.
(3) Metamorphic.

It can be seen that the above geological classification contains little information on the rock properties that have been suggested above as being of most importance for rock mechanic purposes. The structural information that is often recorded when geological mapping is done, of course, would provide valuable information. In addition, it goes without saying that the work of the geologist in the determination of an appropriate classification is absolutely essential.

Even a more detailed description of the rock substance, which would include chemical, mineralogical and petrographic data, would not add a great deal of useful information for mechanics purposes. The chemical analysis would clearly have little use. The mineralogical data could be of some value in judging the likelihood of certain possibilities, e.g. the effect of exposure to the atmosphere, the effect of percolating water, the possibility of wet strength being different from dry strength, the possibility of swelling, etc.

Petrographic analysis, which would include information on texture and origin as well as on the minerals, could provide more pertinent information. For example in an indirect way the magnitude of strength and the nature of deformation properties can be deduced from such analyses, e.g. micro-fractures detected in quartz crystals in a granite would be significant with respect to the strength of the granite. However, this would be an expensive way to obtain indirectly such information when the direct testing of strength would give more cheaply better strength information.

Alternatively, a petrographic study could give such information as the reason for the deterioration of rocks. For example, the determination of whether alteration has resulted from surface weathering or from hydrothermal action would assist in judging whether the alteration products could be expected to extend in any one particular direction. The presence of weathering products adjacent to joints could be very significant with respect to the strength properties of the formation as opposed to those of unweathered rock cores.

However, such detailed information could never be included in a simple classification system; it would be determined, when warranted, by special testing.

## SOIL MECHANICS CLASSIFICATION

Soil is a geological material similar to rock that has been the subject of considerable study and used for mechanics purposes. Consequently, the classification used in the subject of soil mechanics is of some interest as both the material and the purpose of the system are very similar to those of rock mechanics. An outline of the system is given below: [1]

(1) Coarse-grained soils: (I) gravel, (II) sand;
(i) relative density;
(a) residual, (b) transported: water (river or beach), air, or ice.

(2) Fine-grained soils: (I) silt, (II) clay;
(i) consistency limits;
(a) unconfined compression strength;
(x) residual, (y) transported, (lake or sea deposited).

(3) Mixed-grained soils: (I) residual (II) transported (water or ice);
(i) relative density;
(a) consistency limits;
(x) unconfined compression strength.

(4) Organic soils.

As can be seen this classification system gives information both on the material and the formations in which it is found. Although it is based on composition, for soils this results in a functional classification. Thus it might be a system that could be used for other geological materials such as rocks. However, this system does not include some of the important detailed aspects of rock masses such as joint frequency, the nature of failure and the possibility of creep.

Economy of words and effort is obtained in the soil mechanics classification by only using the parts of the system that are pertinent to the soil being described and to the problem being considered (e.g. the properties of interest for a soil foundation are not the same as those for soil to be placed in a fill). In addition, the means of identification are easy, cheap and now standardized. A minimum amount of money is spent on classification as most of the properties can be determined visually with the help of some simple laboratory tests. Even these simple classification tests are not done unless the property is important for the particular use of the material.

This classification system has served to describe efficiently the general nature of foundations or fill. In many cases the information is sufficient to point to special problems that will arise from the typical nature of the soils in question. It has also served to extrapolate research data to other particular soils falling within the same classification. In this way it has stimulated testing for identification within the classification system and also stimulated research on the best identification tests to be used.

In addition, it is interesting to look back and see several elements of the classification system that have fallen into disuse. For example, at one time chemical analyses were performed; however, it was quickly realized that this information was actually of little or no use with the consequence that this type of testing is now very seldom done. Similarly, at one stage it was thought that textural composition (i.e. the combination of various size fractions in certain specified proportions) would provide the key to many common properties

Again, this type of description has fallen into disuse as practice showed it not to be particularly functional. More recently the composition of the individual grains or micelles has been studied. In some problems this information has been of practical value; however, it is questionable whether such mineralogy should be considered as part of the classification system owing to its expense and the specialized nature of its usefulness.

## ROCK CLASSIFICATION FOR TUNNELS

A classification system to be used for determining the appropriate kind and amount of support in tunnels has been proposed [2]. Rocks were placed in the following groups:

(1) Intact rock: rocks containing no joints.
(2) Stratified rock: rock that has little strength between the beds.
(3) Moderately jointed rock: a rock mass that is jointed but cemented or strongly interlocked so that a vertical wall requires no support.
(4) Blocky and seamy rock: a jointed rock mass without any cementing action in the joints and weakly interlocked so that a vertical wall requires support.
(5) Crushed rock: rock that has been reduced to sand-like particles without having undergone any chemical change.
(6) Squeezing rock: rock containing minerals with low swelling capacity.
(7) Swelling rock: rock containing minerals with high swelling capacity.

Although it is unfair to criticize this system with respect to its value for a general rock mechanics classification, it is useful to examine it from this point of view. It can be seen that this system gives no information on the strength of the rock substance, gives some information on the pre-failure deformation characteristics but none on the type of failure to be expected. On the other hand, the information that it gives on the properties of the rock mass is good.

However, the main criticism of the system is that the classification is related to use so that the same rock could be classified differently when it appeared in the walls of a 10-ft tunnel as opposed to those in a 50-ft tunnel if in the first case, quite conceivably, a rock would require no support whereas in the 50-ft tunnel support would be required. It is suggested that the same rock should have the same classification regardless of how it is being used. The other weakness in the system is that no definition has been provided for distinguishing between 'low swelling capacity' and 'high swelling capacity'. This, of course, is not a serious criticism as the deficiency could be easily rectified, if warranted.

## CLASSIFICATION FOR UNDERGROUND OPENINGS IN COMPETENT ROCK

A classification system for underground openings in competent rock has been included in a recent report [3]. A summary of the system is as follows:

(1) Competent rock: rock that will sustain an opening without artificial support:
  (a) massive-elastic (i.e. homogeneous and isotropic),
  (b) bedded-elastic (i.e. homogeneous, isotropic beds with the bed thickness less than the span of the opening and little cohesion between the beds),
  (c) massive-plastic (i.e. rock that will flow under low stress).
(2) Incompetent rock: rock which requires artificial supports to sustain an opening.

In considering this classification system for general rock mechanics use, the main limitation is that it is, as stated, only for competent rocks. It does distinguish between stable, elastic rocks and those which creep; however, it gives no indication of the type of failure to expect. Also, whereas it gives information on the type of formation that is present, no indication of the continuity of the rock substance, i.e. joints, is included.

The main criticism of this system, as for the previous one, is that the classification is related to the use. In other words, the same bedded rock would be classified differently for different size openings, which, it is suggested, is unacceptable for a general classification system. The other minor deficiency is the lack of definitions for 'flow' to distinguish between elastic and plastic rocks and 'little cohesion' to distinguish between massive and bedded rocks. Furthermore, it is somewhat anomalous to include a 'rock that will flow under low stress' under the general grouping of competent rocks.

## DEFORMATION MODELS

A series of deformation models has been postulated for analysing the response of various types of ground to air blast pressures generated by an explosion [4]. Some of the models being used in this study are as follows:

(1) Linear elastic: a body with a straight line, reversible stress–strain curve.
(2) Curvilinear elastic: a body with a curved, reversible stress–strain curve.
(3) Bi-linear elastic: a body with a reversible stress–strain curve comprising two straight lines.
(4) Elasto-plastic: a body with a stress–strain curve composed of a straight, inclined line connected to a horizontal line.
(5) Plasto-elastic: a body with a stress–strain curve composed of an initial, horizontal line connected to an inclined straight line.
(6) Visco-elastic: a body whose deformation varies both with the level of stress and the duration of stress but with the deformation being fully recoverable.
(7) Visco-plastic: a body whose deformation varies with stress level and duration and is not fully recoverable.
(8) Locking medium: a body with a stress–strain curve composed of an initial, horizontal straight line connected to a vertical straight line.

This system, of course, could not be used for rock mechanics classification. However, it gives information on the pre-failure deformation characteristics in a way that is usefully brief. No specifications, however, have been suggested by these workers for distinguishing between bodies (1), (6) or (7).

## PROPOSED CLASSIFICATION

As has been implied by some of the remarks above, the classes or characteristics used in a classification system should reflect the situation that some information is cheap and some is expensive. For example, experimentally determined characteristics can be expensive and should, if possible, be avoided. In addition, much information should only be determined if necessary, e.g. mineralogical or petrofabric data.

Economy of words is also necessary. To be a useful means of communication the minimum number of words should describe the optimum group of properties. The selection of the appropriate properties will give rise to the requirement of means of identification of the various classes and, for this reason as well, should not be done indiscriminately.

The following proposed classification is presented for criticism. It is thought to have some value and thus might serve as a basis from which a system can be evolved that will both be practical and have general acceptance. It has been recognized that the rock substance has certain properties that can be identified but that the condition of that rock substance in the rock mass in the field is of great importance. The proposed system is as follows:

(1) Uniaxial compression strength of the rock substance:
  (a) **Weak** (less than 5000 psi),
  (b) **Strong** (between 5000 psi and 25,000 psi),
  (c) **Very strong** (greater than 25,000 psi).
(2) Pre-failure deformation of rock substance:
  (a) **Elastic,**
  (b) **Viscous** (at a stress of 50 per cent of uniaxial compressive strength the strain rate is greater than 2 microstrain per hour).
(3) Failure characteristics of the rock substance:
  (a) **Brittle,**
  (b) **Plastic** (more than 25 per cent of the total strain before failure is permanent).
(4) Gross homogeneity:
  (a) **Massive,**
  (b) **Layered** (i.e. generally including sedimentary and schistose, as well as any other, layering effects which would produce parallel lines of weakness).
(5) Continuity of the rock substance in the formation:
  (a) **Solid** (joint spacing greater than 6 ft),
  (b) **Blocky** (joint spacing between 3 in. and 6 ft),
  (c) **Broken** (in fragments that would pass through a 3-in. sieve).

The terms used to describe strength could be 'hard' and 'soft' or 'competent' and 'incompetent'. These other terms are in more common use; however, the terms selected are more specific in their meaning. For example, does 'hard' just mean high strength or does it also imply something about the nature of the minerals which makes the rock either very durable or very abrasive? Similarly, does 'competent' just mean high strength or does it also imply a high modulus of elasticity, brittleness or absence of jointing. Actually, by definition the term competent means 'to lift not only their own weight but that of the overlying beds without appreciable internal flowage' [5].

Alternatively, the classification of strength might be in terms of basic strength parameters such as cohesion and angle of internal friction if Mohr's strength theory is accepted. Such a classification system would have to be based on the results of triaxial testing, which would probably be too expensive simply for the purposes of classification. Also, many practical cases of rock mechanics problems that are concerned with strength involve a configuration where the rock is in an unconfined condition; consequently uniaxial compression strength is possibly of most concern. Furthermore, for triaxial stress conditions, uniaxial compressive strength probably gives a good indication of the cohesion of the substance assuming the angle of internal friction to be quite high.

The main reason for using the strength of the rock substance in the classification system is to provide information on whether the strength of the substance itself is likely to be a source of trouble. Most cases of rock instability result from the structural conditions of the rock mass; however, the rock substance itself can be a source of trouble if its strength with respect to the applied stress is low enough. In addition, the uniaxial compressive strength of the rock substance provides some indication of the modulus of deformation and the brittleness of the material.

In view of the few situations that arise where the compressive strength of the rock substance is a significant quantity, it has been considered that this property might be divided simply into two groups: **weak** and **strong**. By only having two classifications the possibility of putting a borderline case in the wrong category is reduced by 50 per cent. In addition, it is quite possible that any rock substance with a compressive strength over 5000 psi would be stable under gravity stresses in any workings down to about a depth of 2000 ft, which probably covers the majority of construction and mine workings.

It is possible that a simple test could be devised for the classification purpose of distinguishing between strong and weak rocks. One of the hardness tests would probably give a sufficiently close measure of this property and with experience could probably replace most of the routine uniaxial compression testing. In addition, some such simple device might ultimately be used for determining the entire classification in the field.

The purpose of the pre-failure deformation classification is to indicate whether the rock can be expected to creep. A quantitative definition of failure is actually required at this stage for it generally means either fracture or flow. In the case where failure is by flow then it becomes necessary to have a quantitative definition of either the rate of flow or the amount of flow that will be considered failure. Then any creep deformation that occurs at lower rates would be described as pre-failure deformation.

The classification system proposed above does not indicate whether pre-failure strain that is time dependent, i.e. viscous rock, is recoverable or not. It is suggested that for most rock mechanics problems the reversibility of strain is not an important property. Furthermore, if it is argued that it can be important then it may be reasonable to consider this aspect to be a subject requiring special testing and not to be included in the simple appraisal required for routine classification. The same comments would apply with respect to the determination of whether an elastic rock substance would produce a stress–strain curve that was linear, bi-linear or curvilinear: if important, these would be determined by special testing.

As for strength, the behaviour of the rock substance with respect to pre-failure deformation is not necessarily a measure of the behaviour of the formation. However, if the substance is classified as **elastic** then the nature of the rock substance is eliminated as a source of creep; on the other hand, if the substance creeps then the formation can be expected to creep and any openings in the formation would be subjected to closure.

The term **viscous** is used in opposition to 'elastic' as any creep that occurs would likely be time dependent and hence could, theoretically, be characterized by a coefficient of viscosity. There would be a natural inclination to use the term 'plastic' for these rocks; however, among the various meanings of this much used word the aspect of irrecoverable strain should be included. This aspect is not necessarily part of the phenomenon of creep. Also, it is helpful to reserve the word **plastic** as there seems to be no other, to be used in opposition to **brittle**, for describing the type of failure.

The property of 'failure characteristics' may not ultimately be included in an acceptable rock mechanics classification. One reason is that most rocks fail by rupture. Another reason is that the properties of a rock after failure can be different in uniaxial compression from that occurring under triaxial compression. Also, a brittle rock substance *in situ*, can under certain circumstances, give a plastic reaction, e.g., the relaxed zone around an opening in a strong, brittle quartzite can, it would seem, actually give back pressure and form a plastic ring of ground inside the highly stressed elastic zone.

For the moment 'failure characteristics' is included in the classification system as the violence of rupture of different rock masses does vary, and this should be related to some fundamental property. The violence of failure of laboratory samples may be a measure of this property. As this violence presumably varies with the amount of stored strain energy before failure in the rock substance, it could be measured relatively by determining the amount of plastic strain in the total strain in a compression test. The difference would then be elastic or stored strain available for release on failure. The relative amount is the important property as even for weak rocks the appropriate safety factor should be based on this division of failure types. For example, the size of pillars or stopes will be adjusted to the strength of the rock regardless of whether it is weak or strong, but the margin of safety should be influenced by the consequences of failure.

Dividing the nature of the formations into **massive** and **layered** rather than using genetic terms permits rocks with compositional differences, such as occur in igneous and metamorphic rocks, to be included in the layered material. It is recognized that thick sedimentary layers that are isotropic within the beds might produce isotropic ground for small openings. However, the reaction of the ground around openings is a matter to be appraised in an engineering study. Also, whereas it is tempting to include the relative effects for different openings in the classification system, it is suggested that one type of rock ought to have the same classification regardless of the location or nature of the project.

The continuity of the rock substance in the rock mass is obviously of prime importance. The above division of this property into three groups will probably not stir any great criticism. However, the actual determination of joint spacing is not a simple matter.

In many types of ground it is not too difficult to make an appraisal of joint spacing from either diamond drill core or from the general appearance of a face. However, when a detailed study is made, the variation of orientation of strike and dip makes it difficult to determine which joints should be used for the measurement of the spacing. Also, a detailed examination reveals, in many rocks, a large number of faces of preferred breakage. The question arises—are they all joints? Some study is required on this subject.

It is suggested that the difficulties on this matter should not be over emphasized and that some discussion and exercise of good judgment should resolve the problem for the purpose of an applied rock mechanics classification system.

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