HANDBOOK ON

MECHANICAL PROPERTIES OF ROCKS

VOLUME III

R. D. LAMA · V. S. VUTUKURI

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HANDBOOK ON MECHANICAL PROPERTIES OF ROCKS

– Testing Techniques and Results –

Volume III

by

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FOREWORD

Rock mechanics is an essentially applied science, directed towards the improved understanding and prediction of the behaviour of rock in a wide range of practical fields in mining, engineering, geology and seismology.

In major civil engineering works such as tunnels and underground power plants and dams, and in mining underground or in large open cuts, it is necessary to base designs for these works on reliable predictions of the subsequent behaviour of rocks during construction and in later operation.

Predictions are based on site observations of rock conditions, test results, analysis and calculation of rock behaviour, and also comparison with similar works constructed elsewhere in the world in related rock types.

Accumulated experience has long shown that prototype rock behaviour may be more closely predicted from tests on rocks in-situ rather than from laboratory tests—a wide range of in-situ tests have accordingly been developed and refined, but it has been found that the various techniques give somewhat differing results.

Nevertheless, it is only by the improved understanding of these in-situ tests that we can more confidently predict the behaviour of the rocks in prototype structures.

Rocks also exhibit time-dependent behaviour, such as can be seen in the slow deterioration and closure of coal mine workings, and the slow diminishing adjustment of a rockfill dam to water load. The understanding and prediction of time dependent behaviour is also necessary for engineering works in those rocks showing prospensity for continued deformation with time.

Rock tests, particularly in-situ tests, are rather expensive, and it is desirable that we develop our understanding of rock behaviour to such an extent that, as far as possible, our predictions can be based on a few carefully selected and less expensive tests.

With this objective in mind, there has long been a need for a critical review of all the various methods of testing the mechanical properties of rock, both in the laboratory and in-situ.

Dr. Lama and Mr. Vutukuri have taken on this task and succeeded admirably. Their volumes in this series are all exceedingly well done, and constitute a most thorough and comprehensive review of rock testing and rock mechanical properties.

The subject of rock mechanics has developed in an essentially observational pattern. It is now an appropriate time to move more strongly towards classification of rocks and rock masses, the classification of rock mechanical properties and the rationalisation of testing procedures.

This valuable book by Dr. Lama and Mr. Vutukuri provides an ideal base for such continuing work.

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January 1978

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CHAPTER 8

In Situ Testing of Rock

8.1. Introduction

In general, the mechanical behaviour of rock mass cannot be determined purely from laboratory tests. Large scale in situ tests form an extremely important part in design considerations of all major projects.

Major developments in in situ testing have been with their applications in civil engineering projects. The need to build higher and larger dams, the necessity of constructing dams at places having deficient foundation and surrounding rock characteristics, the driving of larger hydraulic pressure tunnels, large diameter multiple transportation tunnels and the belief that a great deficiency exists in the knowledge of the behaviour of rock masses, their heterogeneity and discontinuity have contributed to the development of the techniques.

Two parameters of great importance are the deformability of the rock mass and its shear characteristics. As such these are the two aspects which have been studied in great detail.

In mining engineering application, the strength of large pillars is an important mine design parameter and most of the work in the field of strength of rock, in situ, has been done from the point of view of design of mine pillars.

This chapter deals with the various methods used in the determination of deformability of rock masses. The commonly used methods such as plate bearing test, pressure tunnel test along with their modifications are discussed in detail. Large scale in situ shear tests are described. The results of a limited number of triaxial in situ tests on rocks are given. The mechanical behaviour of rocks in uniaxial compression obtained from in situ tests is discussed in detail along with limited in situ tension and torsion tests. The chapter should be read in conjunction with chapter 10 where more details about the shear behaviour of joints and jointed rock are given.

8.2. Types of Large Scale In Situ Tests

The need for in situ testing arises when large-scale effects are anticipated which cannot be ascertained from small scale laboratory tests. It is not always essential to conduct a large scale test. The sensitivity of a structure to any particular parameter plays a dominant role in decision making. For example, in concrete dams, the ratio between moduli of deformation of rock mass (E_m) and concrete (E_c) becomes important only when $E_m/E_c < 1/4$. For $E_m/E_c \geq 1/4$, the modulus of deformation of foundations plays a very slight role. For $E_m/E_c < 1/16$, the behaviour of the dam is entirely governed by the modulus of deformation of the foundation. This is particularly important when the foundation rock is nonhomogeneous. For homogeneous rock, the structure is not much influenced even by values as low as $E_m/E_c < 1/16$ (ROCHA, 1974).

The sensitivity of the structure is very important in deciding upon the number of tests and the test locations. The greater the number of tests, the higher the reliability of the results will be. Because of the marked heterogeneity of the rock mass, and the need to test large volumes, it becomes essential to first establish three dimensional zoning of the rock mass based upon geological information available from initial borings. Dilatometers or other borehole devices can be used in the initial stage of zoning before any plate bearing or other large scale tests are planned. It is possible that the zoning from dilatometer test results may not coincide with the geological division of the rock mass. But zoning from *RQD* values (Chapter 11, Volume IV) may agree fairly well with dilatometer zoning.

The problem of arriving at a representative value in any test is fairly complex and there is no quick answer. Each case has got to be studied separately. The ratio of laboratory to in situ values of modulus of deformation may vary in wide limits; 10:1 or even more. In general, the ratio is lower for high modulus rocks.

The number of tests depends upon the sensitivity of the structure, the relative homogeneity of the various zones and within the zone and the modulus of deformation of the rock. When the anticipated modulus of deformation exceeds 10000 MPa (1450000 lbf/in^2), in situ tests can be dispensed with or their number reduced only to confirm the anticipated values (ROCHA, 1974). When modulus of deformation is lower, 2 to 6 tests may be performed in each zone..

Large scale in situ tests can be divided into 3 main categories.

(1) Deformability tests

(2) Shear tests

(3) Strength tests

Deformability tests are conducted to obtain deformation parameters of the foundation and surrounding rocks on which a heavy structure is to be placed (e.g. dam foundation) and give an important input parameter for design.

Shear tests are mainly conducted on existing planes of discontinuities such as bedding planes, joints, foliations etc. and have the purpose of obtaining information about the stability of the system when subjected to loads brought about by the structure.

Strength parameters such as compressive strength are important in case where rock mass is used as a supporting structure, for example pillars left in situ to support the surrounding rocks when mineral around them has been extracted.

Depending upon the type of information required, the test must be designed to provide the information which can be accepted and is reliable. Any in situ test must fulfil a number of conditions. Among others, the following seem to be most important.

(1) The test conditions must be as close as possible to the theory available for the interpretation of the results obtained from the test.
(2) The test must affect a rock-mass-volume large enough so that it represents the behaviour of the representative volume of the rock mass or a zone of the rock mass that is geologically and structurally differentiable. Consequently the method of testing and the dimensions of the surface to be loaded are conditioned by the type of rock mass.
(3) The cost of testing must be low. This involves both the preparation of the test site and the conduct of tests. Tests, when conducted during the periods when other excavation works are going on, should have least interference. It should have maximum speed in its preparation and conduct but it should not compromise the main features of the test (such as time in drained shear test).
(4) The loading system and other necessary equipment should be simple and easy to operate. The deformation measuring equipment must be able to operate under severe in situ conditions. Certain equipment may have to conform to special statutory regulations (e.g. flame safety law for underground coal mines).
(5) The measurement of deformation must be referred to fixed points i.e. these must not be affected by the test.

(6) The loading equipment must not be too heavy. These must allow easy transportation and installation (weight of each unit limited to 80 kgf (175 lbf) maximum).

(7) The test should reproduce as faithfully as possible the state of stress that shall be occurring during and after completion of the structure.

It is advisable to consider creep tests while planning deformability tests. It is also advantageous to obtain data about rock anisotropy by conducting tests in different directions.

The types of large-scale in situ tests required for different types of structures as suggested by the International Society for Rock Mechanics are given in Table 1.

8.3. Selection of Test Site

Selection of test site is extremely important. Prior to selecting a site, it is essential that all available surface and sub-surface geological data is compiled and analysed. In general, tests are conducted in exploratory headings, adits or pits. It is essential that in tests loads are applied to the rock surface in the same direction as loads from the proposed structure. If possible, loads may also be applied parallel and at right angle to the geologic structure. The test site should be so located that it is a representative of the conditions to be found in the significant portion of the rock mass. In this case, significance of a portion of the rock mass is determined by its relative influence on the deformability of the rock mass and its effect on the structure stability. A small volume of highly deformable material may be as important as a large mass of relatively competent rock mass. In other cases e.g. shear testing, certain weaker joints or thin layers lying in between competent rock mass may determine overwhelmingly the overall stability of the structure. A certain joint set may be more important than the other, not merely because it is more developed, but just because it is more unfavourably placed.

In test site evaluation, the following points should be carefully considered.

(1) Spatial orientation and intensity of loads to be transmitted to the rock mass by the proposed structure.

(2) Types of rock materials and their relative volume.

(3) Spatial orientation of rock structures i.e. bedding planes, foliation, joints, etc. and their relationship to the load applied by the structure.

(4) Joint continuity and joint density.

TABLE 1

Rock Mechanics In Situ Tests

(after Int. Soc. Rock. Mech., 1975)

Legend:

Test importance
n – necessary
a – advisable
oi – of interest
( ) – alternative

Stage of the work
F – Feasibility
DD – Detailed design
DC – During construction
AC – After completion

TYPE OF WORK / IN SITU MECHANICAL TESTS	FOUNDATIONS		NATURAL AND ARTIFICIAL ROCK SLOPES			UNDERGROUND WORK		ROCK EXCAVATION	HARBOURS & OTHER SUBMARINE WORKS
	gravity dams	arch dams	large structures	involving reservoirs	involving other works	large underground works	tunnels, shafts, underground mining	open air mining, quarries, large surface excavations	
1. Deformability Tests									
1.1 Static method	nDD	aF:nDD; nAC	aDD			nDC			oiF
1.1.1 Plate bearing (hydraulic jack; flat jack; cable jacking)		(n)DD; (n)AC				(n)DD	nDC		
1.1.2 Pressure tunnel (water loading; radial jacks)		(n)DD; (n)AC				(n)DD			
1.1.3 Pressure borehole (dilatometer)	aF	(n)DD; (n)AC	oiF			aF; (n)DD	oiDC		
1.2 Dynamic method	nDD	nF;nDD; nAC	oiF			aF;nDC	nDC		aF
1.2.1 Measurement of longitudinal waves velocity (geophones)	nDD	nF; (n)AC				aF	nDC		
1.2.2 Measurement of the velocity of longitudinal and transversal waves; Love's waves, Raleigh's (vibrograph)		nDD; (n)AC				nDD			

TABLE 1 (continued)

TYPE OF WORK / IN SITU MECHANICAL TESTS	FOUNDATIONS		NATURAL AND ARTIFICIAL ROCK SLOPES			UNDERGROUND WORK		ROCK EXCAVATION	HARBOURS & OTHER SUBMARINE WORKS
	gravity dams	arch dams	large structures	involving reservoirs	involving other works	large underground works	tunnels, shafts, underground mining	open air mining, quarries, large surface excavations	
1.2.3 Measurement of direct longitudinal waves velocity in borehole (sonic-coring)		aDD; (n)AC				aDC			
1.2.4 Detailed stratigraphic surveys							nDC		
2. Natural Rock Mass Stress Tests									
2.1 Rock surfaces tests						aF;nDD			
2.1.1 Measurement of deformation after over-coring or bond removal (by strain rosette)						(n)F			
2.1.2 Measurement of pressure to balance natural stresses (by flat jack)						a(F)			
2.2 Test inside borehole	oiDD	oiDD	oiDD	oiF		nDD			
2.2.1 Measurement of core deformation after over-coring						nDD			
2.2.2 Measurement of borehole wall deformation after over-coring						nDD			

TABLE 1 (continued)

TYPE OF WORK / IN SITU MECHANICAL TESTS	FOUNDATIONS		NATURAL AND ARTIFICIAL ROCK SLOPES			UNDERGROUND WORK		ROCK EXCAVATION	HARBOURS & OTHER SUBMARINE WORKS
	gravity dams	arch dams	large structures	involving reservoirs	involving other works	large underground works	tunnels, shafts, underground mining	open air mining, quarries, large surface excavations	
3. Strength Tests									
3.1 Compression		aDD							oiDD
3.1.1 Triaxial tests		oiDD				aDD			
3.2 Shear	nDD	nDD	nDD	nDD	nDD	nDD	aDD	aDD	
3.2.1 Rock block test along discontinuity surface	nDD	nDD	nDD	nDD	nDD	nDD	aDD	aDD	
3.2.2 Concrete block test along interface	aDD	aDD	aDD					oiF	
4. Permeability									
4.1 Inside borehole (Lugeon)	nF;nAC	nF;nAC	aF	nF		nF			
4.2 In a joint pumping test	nF;nAC	nF;nAC							
4.3 Piezometric levels & ground-water flow				nAC		nF	nF	oiF	nF
5. Rock Anchor Tests				nF;aDC; oiAC	nF;aDC; oiAC	aDD	aDD	aDC	oiDC
6. Rock Movement Monitoring									
6.1 Long base extensometer	nAC	nAC		nAC	nAC	nAC			
6.2 Inverted pendulum	aAC	aAC	aAC	oiAC					
6.3 Slope indicator				nAC				aAC	
6.4 Blast & ground motion monitoring	oiDD	oiDD		nDC	nDC	nF;nDC	nF;nDC		oiDC
6.5 Rock noise monitoring				aAC				oiAC	oiAC

(5) Presence of major or minor faults in the area and their orientation with respect to the loads imposed by the structure.

(6) State of alteration and moisture content.

The geologic structure at each test site should be thoroughly evaluated. Invariably boreholes drilled for instrumentation purposes should be cored with care to ensure maximum recovery of oriented core. The cores from these boreholes should be logged to determine rock type, strike and dip of foliations, bedding planes and joints, weathering and alteration, etc. A geologic cross-section through the test site should be prepared. Boreholes, if possible, should be inspected using borehole cameras or boroscope devices. The cores should be properly stored for future laboratory tests etc.

In selecting the position of test site, maximum use should be made of the galleries, trenches, etc. excavated for geological investigations.

The division of the whole area into zones of same or similar mechanical state is important. In determining the mechanical state of rock mass, the internal state of stress, alteration of the rock mass, presence of microfissures and joint density, degree of decompression (expansion) and moisture content must be considered. Geophysical investigations can be of extreme value in this case.

8.4. Uniaxial Compressive Strength of Rock In Situ

The uniaxial compressive strength of rocks in situ is important in the design of pillars in mines. In situ test for its determination is an extension of the laboratory test conducted on smaller specimens. Because of the high costs involved, uniaxial compressive strength tests in situ have been conducted only to a limited extent. Most of the studies have been done on coal (GREENWALD, HOWARTH and HARTMANN, 1939, 1941; LAMA, 1966a and b, 1970; BIENIAWSKI, 1968, 1969; COOK, 1967), iron ore (JAHNS, 1966; GIMM et al, 1966; RICHTER, 1968) and granite (GEORGI et al, 1970; PRATT et al, 1970, 1972).

Extensive work has been done in the laboratory for compressive strength of rocks on specimens varying from a few centimeters (an inch) to several centimeters (a foot) or so (Chapter 2, Vol. I) but it is still not possible to predict the failure behaviour of rocks in situ. The main reason behind this is that the strength of rocks depends upon the visible and invisible planes of weakness present, the severest of which determines the strength. Because of the disorderly nature of these planes of weakness, their effect is difficult to interpret by extrapolation of results obtained from the testing of small specimens in the laboratory. These results could possibly be relied upon if it is assumed that the strength of rocks is governed only by the number of planes of weakness present in them.