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Determination of Rock Mass Modulus

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SUMMARY In order to assess the behaviour of a rock mass when an engineering function is performed on the rock mass the deformational response must be assessed. To do this the rock mass and the associated defects in the form of joints and faults are classified and a geological model is built up. Quantification of this geological model is required if the behaviour of the rock mass to the imposed engineering function is to be predicted. Both laboratory and field tests are performed. A simple plate bearing jacking field test is described and its cross correlation with a numerical model representing the geological model of the rock mass is described. Results of the laboratory tests are used in the numerical model and the resultant deformational response is compared with the deformational response of the plate bearing jacking field test. Results of the deformational response are not presented as these are given elsewhere in another paper. Nevertheless, correlation of the rock mass rating with deformational modulus and the Poisson's ratio of the rock mass is proposed.

1 INTRODUCTION

Many investigators such as Schneider (1969) and Bieniawski (1978) have criticized the validity of insitu deformability field tests because, in the main, the variability of the measured and evaluated results. Variability, however, is a valid criticism because the very nature of geology and geomorphology is variability. The difficulty is to measure the geological factors and recognise the geomorpholigical influences. In field testing these aspects are most important and neglect of them will not only cause variability in results but confusion in thought.

One aspect of rock mass behaviour namely rock mass deformational response is considered here. The objectives of the field tests described in this paper are to retrieve deformational response moduli which are then compared with the deformational response of a numerical model which in turn represents a geological model, Chappell (1983a). This geological model is represented by an anisotropic rock mass, Chappell (1983b), on which the engineering function be it a slope, underground opening, or building, is imposed. Of the many insitu field tests such as the plate bearing tests, flat jack tests, radial pressure tests, pressure chamber tests, bore hole jacking and dilatometer tests, the plate bearing with bore hole jacking tests are considered here. Nearly all the other tests have very different boundary conditions and are found difficult to correlate with the geological model of the rock mass.

It is recognised that water is a basic parameter effecting the behaviour of a rock mass, however in this paper the rock mass is examined in terms of effective loads or stresses. Another important factor not considered in detail here but is as important as the rock mass defects is the insitu stresses. This aspect alone deserves careful consideration, Chappell et al (1983c) and though the flat jack test can give an idea of the magnitude of the insitu stresses, the measurement of insitu stresses requires much more consideration than can be determined by this test or given here. Consequently of the rock mass characteristics related to insitu stresses, deformability and strength only the measurements of deformability are considered in this paper.

A simple plate bearing jacking test is explained and its cross correlation with a numerical plate bearing jacking test using laboratory derived parameters is described. From experience using this test for rock mass deformational response and classifying these rock masses a table correlating the Geomechanics rock mass rating RMR and rock mass stiffness is given plus recommended values of Poisson's ratio related to the classified rock mass rating.

2 ROCK MASS STRUCTURE

It is generally recognised that the main mode of deformation in a rock mass is caused by its defects such as joints and faults. The importance of these defects on the deformational response is to some extent dependent on the ratio of the stiffness of the intact rock material to the stiffness of the defects or joints, Chappell (1983a). For example if the stiffness of the intact rock material such as soft shale is nearly equal to the stiffness of the joints then the deformation of the rock mass tends to be independent of the influence of the defects or joints. Fig. 1 shows that if the ratio of the stiffness of the joint material (E_j) to the stiffness of the intact material (E_i) is 0.5 or greater then the maximum difference between rock mass modulus and intact rock modulus is less than 10%. This shows that when the ratio of E_j to E_i exceeds 0.5 the magnitude of the rock mass modulus tends to the intact rock modulus.

A word of warning is stressed at this point. From experience, joints in many soft rocks though at times stiffer than the intact rock material are avenues for water, and of consequence the soft rock mass behaviour can be very different to what is measured if this factor is not included in the test results or numerical model. In addition for soft rock though the stiffnesses tend to one another and the deformational response of the rock mass tends to that of the intact rock material the strength of the rock mass is still very much anisotropic and dependent on the defect or joint system. In summary do not neglect the defect or joint systems of a soft rock mass. What is implied here is that bore hole pressure metres for measuring rock mass deformational responses are reasonable to good but not necessarily good for measuring rock mass strengths.

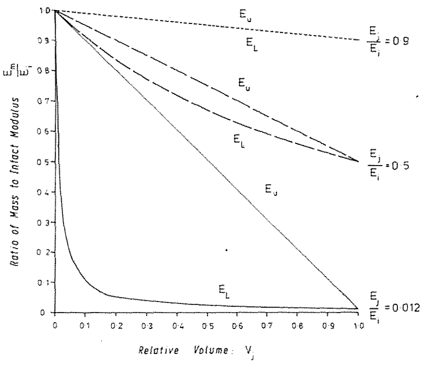


Figure 1

The first requirement in rock mass testing is to determine the rock mass structure and from this define rock mass zones which possibly have different deformational responses. From surface mapping and orientated drill core the joint and fault sets are demarcated and their frequency and orientation statistically defined, Goodman (1980). An assessment of joint, continuity, which is perhaps the most difficult parameter to define, is also made. From this, structural zones representing the rock mass are determined. These structural zones are the bases on which the geological model is built. Once this has been done it is necessary to quantify the various aspects of this geological model by laboratory and field testing. From this quantified geological model of the rock mass the engineering function is superimposed and the deformational response of the rock mass predicted, Chappell (1983a).

3 PLATE BEARING AND FLAT JACK TESTS

Besides the orientation, continuity and roughness of the joints affecting the rock mass deformational response, the stress environment of the rock mass is also very important, Alexander (1981), Chappell (1984). One of the main criticisms of the plate bearing tests is that generally in rock masses the load on the plate is a re-application of a relieved stress, Fig. 2, and in a rock blasted material one is reloading a blast shattered and/or a stress induced slabbing material. This criticism is also carried over to the flat jack test where it is said that the flat jack is installed in the blast shattered or effected zone but not relieved of stresses, Fig. 2. The main difference between the plate bearing and flat jack test, besides the orientation of the defects, is that in the flat jack test the rock mass is partly constrained in the direction of the applied load. Another important difference between the two field tests is the boundary conditions and constraints Van Heerdon (1976).

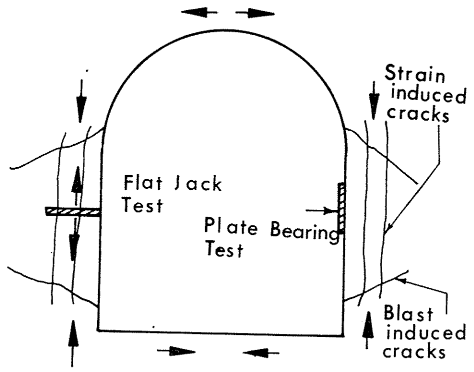


Figure 2

Alexander (1981) considering soft rock and recognising two different mechanisms of deformation in the soft rock shows that the flat jack tests give higher deformational moduli than that obtained for the plate bearing tests. For the reasons given previously namely that the rock mass joints have little effect on the deformational response of a soft rock mass it is reasonable to conclude that the difference in moduli is because of the insitu stress environment. It should nevertheless be recognised that for the flat jack a concentration factor pertaining to stress redistribution caused by the presence of the adit or excavation is required. Because the rock mass is soft and shear strength minimal Alexander (1981) assumes the concentration factor equal to one. However, as previously noted that even though joints in soft rock do not affect the deformability they certainly affect strength. That is the rock mass has a strength anisotropy and if redistribution of stress is caused by joint shear with consequent geometry change then the redistribution of stress at post failure is therefore also anisotropic.

Bieniaswki (1978) considers a number of field testing methods but reports mainly on the plate bearing test. Surprise is expressed because of the variation in the adit between the left and right side and the top and bottom side moduli at the same site location. Fig. 3. Three important factors which affect the moduli tests are insitu stresses, orientation with frequency of joints, and boundary conditions. Of these three factors Bieniaswki (1978) considers the boundary conditions as foremost. If the geological structure and insitu stresses are considered in the tests, Fig. 2, it would be surprising if the left and right side or top and bottom moduli were equal.

A very useful suggestion is propounded, however, and that is, that the rock mass at the site location be classified. The Geomechanics rock mass rating developed by Bieniawski (1978) is a very useful tool and when used in conjunction with rock mass deformation lends much experience and good assessment into interpreting rock mass behaviour.

Caution must however be expressed because as in any general description of a physical body there are specific factors which are required when that physical body is put to a specific use. For example there are similar yet different requirements for rock mass assessment in underground excavations, slopes and foundations. It is felt however that because rock mass deformation is common to all these problems and of consequence it is a prime factor that rock mass stiffness be included in rock mass classification. Chappell (1983a). Criteria such as insitu stresses, orientation, and boundary constraints are all a part of this rock mass stiffness but if the rock mass is measured by the simple plate bearing jacking test they are all incorporated into one parameter. Muller (1974) suggested that deformation rather than stress is a better basis for defining or assessing rock mass stability. An indirect way of assessing stability is to incorporate rock mass stiffness which is a measure of deformability.

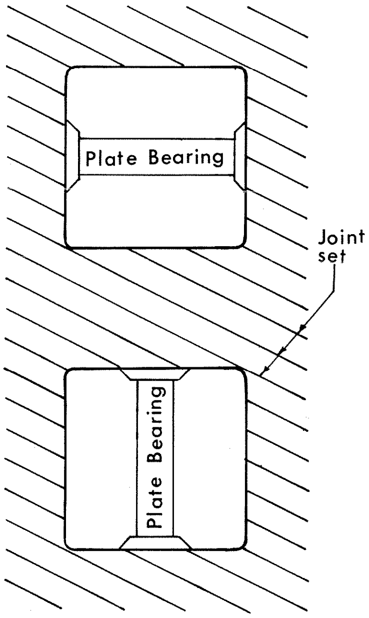


Figure 3

3 ROCK MASS MODEL

Now that the rock mass structural zones have been defined the problem is to quantify aspects of the rock mass zones so that the numerical model of the geological model can be analysed and the deformations caused by the engineering function predicted.

If one considers the basic deformational modes and associated parameters, Chappell (1984), it is well known when determining these parameters to model as closely as possible the geometry of the joints and the load path. If the geometry of the rock mass and engineering function hence load path are known the field test is designed to retrieve those parameters which in this case determine the deformational response of the rock mass.

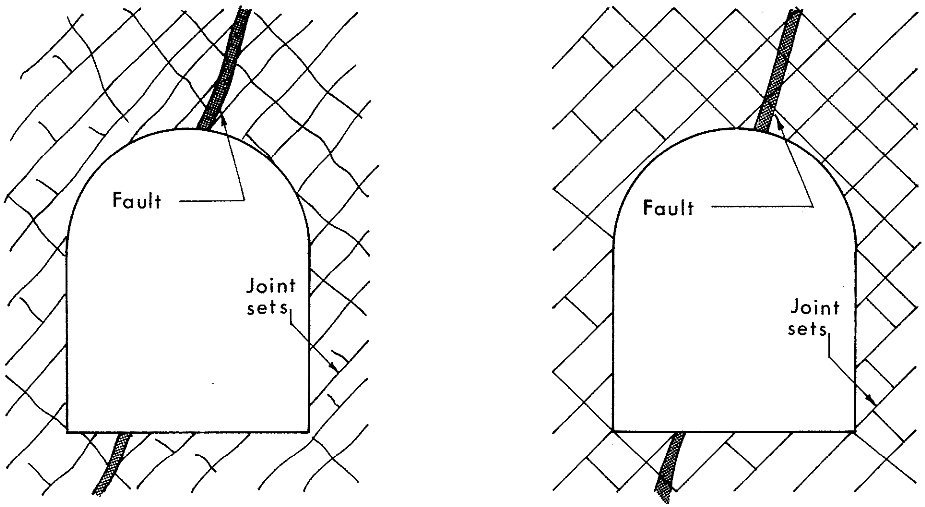
Excellent predictions of deformational response are possible, Chappell (1983a), if the rock mass structural zones and relevant rock mass deformational parameters are determined from both field and laboratory tests. The field test is the plate bearing jacking test, Chappell (1980) and the laboratory tests are standard strength shear and moduli tests where all aspects of stiffness are measured. By all aspects of stiffness is meant that besides the measurement of intact rock moduli such as Young's modulus, and Poisson's ratio, parameters such as shear joint and normal joint stiffnesses are also determined. This approach permits cross correlation of the field plate bearing jacking test and the numerical model in which are incorporated all the laboratory tests defining the intact and joint material characteristics, Fig. 4.

4 PLATE BEARING JACKING TEST

Once the selection of a test site is determined, a cored drill hole is orientated relative to the joint sets, Fig. 5, so that the salient deformational parameters of the rock mass predominate the deformational response of the rock mass. For example one would endeavour to measure the so called lower and upper bound moduli of the rock mass. Chappell (1984). The lower bound modulus is the rock mass modulus which is perpendicular to a joint set. From the laboratory tests on the intact rock and joint material lower and upper bound moduli are evaluated. These values plus the joint set orientations define and quantify the anisotropic deformational characteristic of the rock mass Chappell (1980). To retrieve from field measurements the full range of anisotropic deformational parameters at least five tests are required. If all the joint orientations and frequencies are known from surface mapping and drill core this will reduce the number of tests to four. It should be noted however, that all the deformational parameters required to define the deformational response of the rock mass are obtainable from the laboratory results. From this the field tests are used to correlate and validate the anisotropic parameters and ensure that no hidden factors such as unusual material or pore water conditions occur.

Cross correlation of the field and laboratory tests is facilitated by using a numerical model of the test site, Fig. 4, in which the laboratory test results are incorporated. On the numerical model the same load path as was used in the field test is imposed. The resulting deformational response of the numerical model is then compared with the deformational response of the field test. If the results agree to within 10% to 20% the parameter evaluation is reasonable if not the reason why must be determined. From the numerical model and the field tests the deformational parameters are optimized so that the deformational responses of the field and laboratory tests are the same.

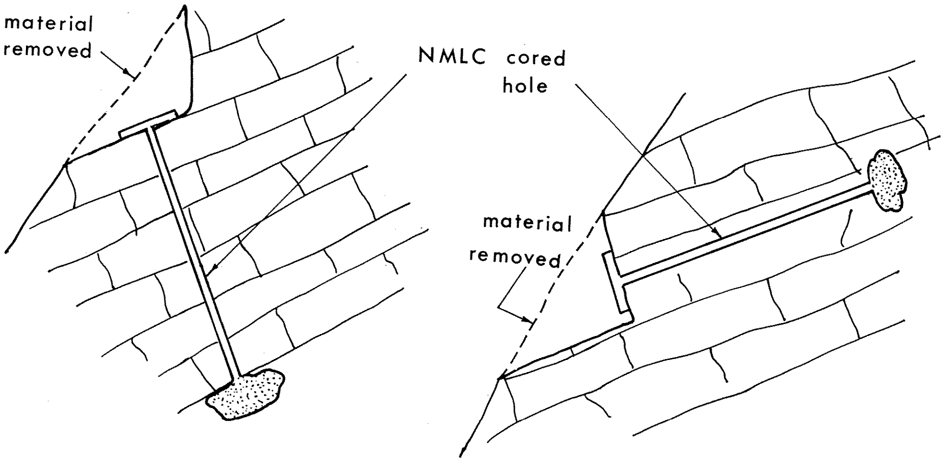
Fig. 6 depicts the essential features of the plate bearing jacking test. What is perhaps the main feature of this test is the shape of the anchor bulb. This is important because the mode of transferring the load from the hollow rock bolt to the rock mass controls the deformational modes hence response of the rock mass. For example if shear is relied on to transfer the load onto a discontinuous rock mass the deformational mechanisms caused by normal or direct load transfer, Fig. 7. In soft to medium rock this anchor bulb is formed by under-reaming, whereas in hard rock the bulb is formed by explosives varying from just a detonator to half a stick of ANFO dynamite. With the anchor formed from dynamite the resulting bulb and surrounding cracks produce a good load transfer mode, Fig. 7.



Prototype Tunnel

Numerical Model Tunnel

Figure 4



Lower Bound Rock Mass Modulus

Upper Bound Rock Mass Modulus

Figure 5

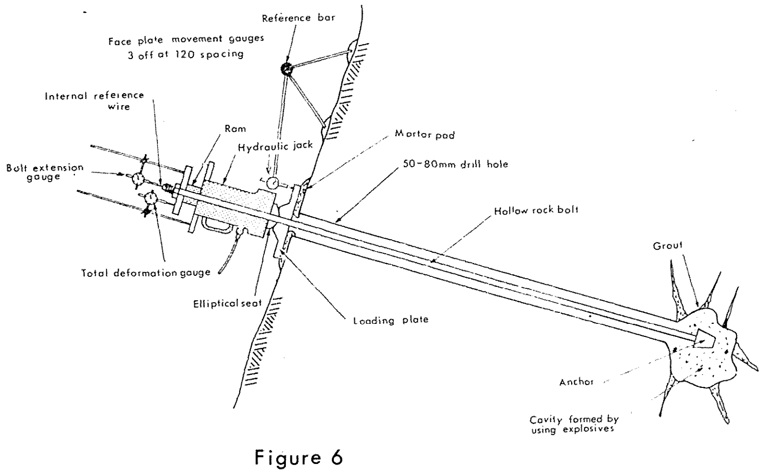
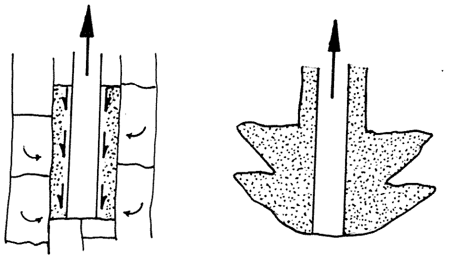
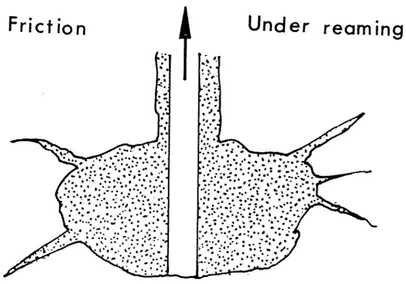


Figure 6



Friction

Under reaming



Blasting

Anchorages

Figure 7

5 ROCK MASS DEFORMATIONAL RESPONSE

From the plate bearing jacking test the rock mass deformational modulus plus the face plate and anchorage moduli are obtained. All these measured field moduli are then compared with the appropriate moduli obtained from the numerical model operated on with the measured laboratory parameters. Fig. 4.

Chappell (1983d) reports on the performance of the plate bearing jacking tests on a wide range of rock mass material. It is found that the apparatus is inexpensive simple and easy to operate. The results are significant in that prediction of the deformational response of difficult and complex rock masses is possible, Chappell (1983a). A parameter which has been mentioned but has not been discussed in detail here is insitu stress. This parameter fortunately is much easier to measure now than it was say five years ago Chappell (1983c).

A wide range of soft to hard rock masses have been tested using the above plate bearing jacking method. When these tests are performed by the author the rock mass is always classified using the Geomechanics rock mass rating, RMR. It is felt that a stage will be reached when the rock mass deformational modulus is routinely performed on all significant geotechnical problems.

Bieniawski (1978) correlates measurements of the rock mass deformational modulus with the Geomechanics rock mass rating. Unfortunately, Bieniawski's results cover only rock masses with rock mass ratings greater than 50 which is the range of fair, good, and very good rock masses. Experience at the Snowy Mountains Engineering Corporation covers the range of rock masses from very poor, poor, fair, good, very good and finds that the rock mass classification in the very poor to poor range is inadequate. It is felt that this area needs closer consideration;however from the experiences and analyses performed the following correlation between rock mass rating and rock mass deformational response is suggested. Also included in the table are recommended values of Poisson's ratio to use on a preliminary basis for rock mass evaluation.

Rock mass rating	Description	Rock mass deform. GPa	Recom. Poisson's ratio before failure or deform. mech. occur
?	Extr. poor	< 0.05	0.45
0 - 19	Very poor	0.05 → 0.5	0.4
20 - 39	Poor	0.5 → 1	0.35
40 - 59	Fair	1 → 5	0.3
60 - 79	Good	5 → 25	0.25
80 - 100	Very good	25 → 50	0.23
?	Extr. good	> 50	0.2

6 REFERENCES

ALEXANDER, L.G. (1981). Flatjack tests of modulus and stress of claystone. Weak Rock, Soft, Fractured and Weathered Rock. Edited Koichi Akai, pp 1443-1450, A.A. Balkema, Rotterdam.

CHAPPELL, B.A. & MAURICE, R. (1980). Determination of mass moduli for slope design. Proc. Third N.Z. and Australian Geomechanics Conference, Wellington, pp 2.93-2.100.

CHAPPELL, B.A. and KLENOWSKI, G. (1983a). Excavation and stabilisation of difficult slopes. Paper submitted to Geotechnique for publication.

CHAPPELL, B.A. and BOSLER, J. Equivalent material and deformational response. Paper submitted to Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. for publication. (1983b).

CHAPPELL, B.A. WILLIAMS, J. & POLLARD, T. (1983c). Stress and Slabbing in Massive Rock. Paper submitted to Engineering Geology.

CHAPPELL, B.A. (1984). Deformation mechanisms of a rock Mass. Proc. Fourth N.Z. and Australian Geomechanics Conference, Perth.

CHAPPELL, B.A. (1983d). Field testing for rock mass deformational response. Paper submitted for publication in ASCE, J. of Geotech. Eng. Div.

GOODMAN, R.E. (1980). Introduction to rock mechanics. Chichester: John Wiley & Sons.

MULLER, L. (1974). Rock mass behaviour - determination and application in engineering practice. Proc. 3rd Congr. Rock Mech., Vol. 1 pp 205-215. International Society for Rock Mechanics, Denver.

SCHNEIDER, B. (1969). Evaluation of geological factors in rock engineering. Rock Mechanics - Theory and Practice. Eleventh Symp. on Rock Mech. Berkeley, pp 43-56.

VAN HEERDON, W.L. (1976). Insitu rock mass property tests. Proc. Symp. Exploration for Rock Engng. Edited Bieniawski Z.T., Vol. 1, pp 147-157. A.A. Balkema, Rotterdam.

BIENIAWSKI, Z.T. Determining rock mass deformability: Experience from case histories. Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. Vol. 15. pp 237-247.
