Geotechnical Investigations for the Assessment of the Risk of Water Leakage from Pressure Tunnels

J.R. ENEVER
M.Eng.Sc., B.E. (Mining), A.R.M.I.T., member A.G.S.
Senior Principal Research Scientist, CSIRO, Division of Geomechanics
M.B. WOLD
B.Appl.Sc., F.R.M.I.T., member A.G.S.
Senior Research Scientist, CSIRO, Division of Geomechanics
R.J. WALTON
B.Appl. Sc., A.R.M.I.T., member of A.G.S.
Principal Experimental Scientist, CSIRO, Division of Geomechanics

SUMMARY The role of rock stress measurements and borehole pumping tests in the assessment of potential for hydraulic jacking of rock joints and fractures is discussed in relation to three pressure tunnel projects in Australia. Investigations for the siting of steel pressure linings, carried out in varied geological and topographical conditions, have shown that rock stresses and hydraulic jacking potential may vary strongly over short distances within rock masses, with structural effects appearing to have a particularly strong influence on variability. The results of these studies suggest that conventional methods of design for placement of steel linings should be supplemented by direct field measurements to assist in reducing the risk of water leakage from pressure tunnels, and the economical placement of full pressure linings.

1. INTRODUCTION

In the planning and construction of hydro-electric power stations, the design of the headrace pressure tunnel brings together geotechnical risk and economic considerations in a very direct way. The specification of lining requirements can have very significant impact on the placement and design of the machine hall and other excavations, and greatly affect the cost of the pressure tunnel itself. This is particularly true in situations of extreme topographic relief which are common to hydro-electric schemes. Bearing in mind the overall project aspects of efficiency in construction, long term operation, serviceability and safety, a general aim is to minimize the length of the full pressure lining requirements, while achieving an adequately low level of risk of water leakage.

Pressure tunnels which are unlined or have concrete linings, over the major portion of their length, have been widely used in hydro-electric schemes for many years. For instance, three Norwegian unlined pressure shafts were described by Vogt (1922). Provided that suitable conditions are encountered, with no significantly permeable rock structures or erosional paths intersecting the tunnel, and sufficiently high rock stress conditions to overcome hydraulic pressures, low leakage rates and satisfactory long term service have been achieved. However, failures do occur. An early example of hydraulic fracture of the tunnel wall and related leakage, associated with insufficient overburden stress, was at Herlandsfoss, Norway, in 1919 (Selmer-Olsen, 1970). A landslide initiated by increased pore pressure resulting from power tunnel leakage at the Fisher hydro-electric scheme, Tasmania, was described by Paterson et al (1975). More recently, failure of a reinforced concrete pressure tunnel lining and leakage to the surface was described by Sharma et al (1991).

The potential for development of leakage paths by hydraulic jacking of joints and fractures is a prime consideration for pressure-tunnel designers. Essentially, hydraulic jacking can occur when the hydraulic pressure exceeds the normal stress acting across a fissure. The rock stress conditions at any depth will be a function of overburden and tectonic forces, as modified by rock structural features, topography and groundwater. Empirical design criteria for depth of cover, incorporating topography, developed in Norway (Bergh-Christensen and Dannevig, 1971) and Australia (Dann et al, 1964) have been used successfully for many projects. Modern numerical stress analysis methods have confirmed these criteria; however, modelling methods require quantitative stress data as input, and direct measurement of stress conditions can be considered essential for their implementation. However, for the assessment of risk of water leakage, rock stress measurements and hydraulic jacking tests by borehole pumping are directly applicable in their own right.
This paper presents examples of recent stress- and hydraulic jacking measurements, carried out by CSIRO in Australia for design of pressure tunnels. Results are discussed in terms of stress variability associated with structural and topographic features, and their impact on tunnel lining requirements for the prevention of leakage.

2. STRESS MEASUREMENT AND VARIABILITY OF STRESS ESTIMATE

The empirical design rules such as the Norwegian Criterion have been shown to successfully predict adequate cover ratios for many projects, including slopes up to about 55 degrees from horizontal, and are thus very useful for preliminary layout design. By comparison, the use of design methods incorporating numerical stress analysis is much more explicit in the demands it places on rock stress and structural input data. A basic assumption for assessment of hydraulic jacking potential is that the hydraulic pressure within the discontinuity is less than the normal stress acting across it. This ignores any tensile strength component, as might exist for a healed joint, and although pumping tests sometimes reveal initial tensile strength, it is probably well to treat the joints as having no inherent strength. Furthermore, the orientation of the discontinuity with respect to the local stress tensor is obviously important, and for favourable orientations it is possible for the hydraulic pressure to exceed the minimum principal stress without causing hydraulic jacking. However, the question is raised as to the variability in joint spacing and orientation, and of the variability of the stress tensor as measured from point to point in the rock mass. There is ample evidence that stresses vary significantly in magnitude and direction over relatively small distances (e.g. Enever et al, 1990), particularly in metamorphic rock masses of the type in which hydro-electric schemes may often be found. Thus assessment of jacking potential based on measurement and model analysis of stress, must include consideration of the variation in measured stresses. Experience shows that this can be a difficult task, and aspects of the problem are discussed below.

The two most commonly used methods of stress measurement are stress relief by overcoring, and hydraulic fracturing. The individual results are, in essence, point measurements. In overcoring, the commonly used CSIRO HI cell, for instance, measures stresses acting in an essentially intact cylindrical volume of rock of about 150 mm diameter and 250 mm long. It can be argued that in a jointed rock mass, this method may tend to overestimate the stress level because the intact rock, having a higher effective stiffness than surrounding jointed regions, will be more highly stressed. There will be a critical joint spacing, below which measurements cannot be made, based on the length of the HI cell. Typically, in a stress measurement program, measurements will be made at a number of points within each of several boreholes, the overall spacing of which should match the scale of the excavation and the scales of significant structural features.

The hydraulic fracturing stress measurement method commonly involves a length of borehole of 500 to 1500 mm, and cracks extending several metres into the surrounding rock, and thus samples a considerably larger volume of rock than that by overcoring. Nevertheless, for measurement of rock stress, defect free lengths of borehole are required, and the danger of overestimating stress is again present. Furthermore, on the scales of the excavation and of the major structural features, these dimensions may be small, and the hydraulic fracturing may still be seen as a point measurement. Conceptually, a mean stress tensor could be derived from the point values, using for example, the method described by Walker et al (1990). However, for the problem of hydraulic jacking potential, the minimum principal stress is of critical importance. As a suggested approach, the distribution of normal stress magnitudes and orientations, from the point measurements, should be assessed conjointly with the distributions of discontinuity orientations and the expected hydraulic pressure to obtain a probability function for jacking occurrence. The problem remains to calibrate this probability against real performance.

On the other hand, the long term shut-in pressure from the fracturing test may be taken as a reasonable measure of the stress normal to the fracture created. This principle can be applied for the direct measurement of hydraulic jacking potential using the pumping test, which is the most direct form of risk assessment for the design assumptions. In this method, joints or joint families of known orientation are isolated by packers, and the flow rates at a range of constant pressures are measured over several cycles. The discontinuous transition from low to high leakage rates marks the onset of hydraulic jacking, with differences between initial and subsequent cycles, if evident, providing a measure of tensile strength of the joint. Jacking pressures should be broadly consistent with stress measurements, after adjusting for orientation of the discontinuities, although in view of the suggested concentrations of stress in intact sections of rock between structural features, it could be expected that jacking pressures in the discontinuities could tend to be lower on average than the intact rock stresses.

3 RECENT FIELD INVESTIGATIONS

3.1 General

Stress and hydraulic jacking measurements, from the surface and from underground, have been recently carried out by the CSIRO for three pressure tunnel projects in Australia, to provide the project designers with quantitative data for lining specification. The projects are (locations, Figure 1):

1. the King River hydro-electric development on Tasmania's west coast,
2. the Boomerang Creek water tunnel on the central coast of New South Wales,
3. the Tully Millstream hydro-electric project in northern Queensland, the proposal for which is currently under review by the Queensland and Australian Governments.

These cases provide quite different examples of geological and topographical environment, and of anticipated hydraulic pressures in operation. They indicate the value of in situ measurements in refining knowledge of stress conditions and jacking potential for the purpose of pressure tunnel design.

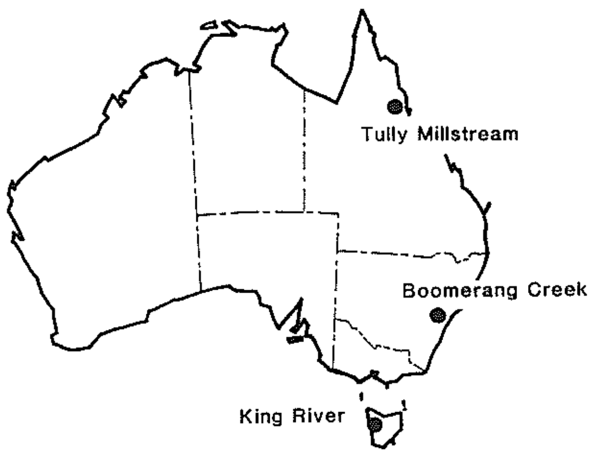


Figure 1 Locations of pressure tunnels subject to investigation

3.2 King River

Construction of the King River project involved a 7 km long pressure tunnel, linking water storages with a surface power station. The pressure tunnel was constructed by drill and blast to a horseshoe profile of 7.2 m crown diameter, with a total change in elevation from source to power station of 200 m. The lower portion of the tunnel is located in a sequence of highly structured volcanics.

From the outset of investigation for the project there was concern that near the lower, power station, end of the tunnel, relatively high water pressure and well developed discontinuity sets could lead to hydraulic jacking of the discontinuities, and unacceptable leakage. The initial design strategy called for a steel pressure lining to be installed upstream from the power station, for a distance that would ensure that hydraulic jacking would not occur. This was based on the notion that any potential jacking surfaces upstream from the upper end of the steel lining would be held closed by the in situ stress, against the maximum water pressure attainable.

During the initial investigation from the surface, hydraulic fracture stress measurements were undertaken in two boreholes, located on the proposed tunnel alignment (Enever et al, 1987a). One of these holes was located near to the critical point at which the rock stress magnitude, based on depth of overburden, would be expected to just balance the hydraulic jacking pressure. Hydraulic fracturing tests undertaken at about 20 m above the projected tunnel level indicated some very low shut-in pressures, in relation to the anticipated overburden pressure and in-service water pressure. Shut-in pressure in this context can be taken as a measure of the minimum stress magnitude in the rock mass. Based on this observation, it was decided to conduct more detailed investigations from within the tunnel when it had been advanced from the power station site to near the anticipated maximum extent of the steel pressure lining. The underground investigation involved overcoring stress measurements using the CSIRO HI cell (Walton and Crawford, 1987), and pumping tests on selected joints with different orientations (Enever et al, 1987b). The sites for these measurements are shown on Figure 2.

The overcoring results indicated the existence of a stress field which varied dramatically from point to point over distances as small as 2 m. Very low magnitudes of minimum stress component, even small tensions, were measured at some points. The variability was attributed to the influence of geological structures prevalent in the rock mass. The measured stresses were compared with the orientations of the joints surveyed in the tunnel in the vicinity of the measurements, and with the design water pressure (1.8-2.3 MPa), to assess hydraulic jacking

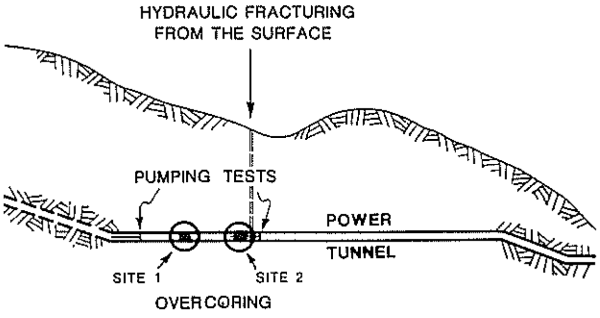


Figure 2 King River pressure tunnel. Vertical section, showing sites for overcoring and pumping tests.

potential (Bowling - personal communication). The results are summarized in Figure 3.

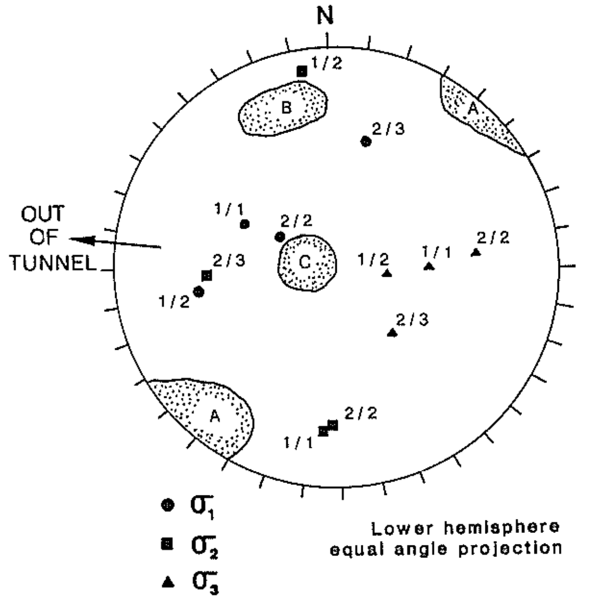
Direct measurement of the hydraulic jacking pressures were made by pumping tests conducted in two boreholes drilled sub-parallel to the tunnel, one of which extended from the end of the tunnel. Using packers to isolate variously orientated joints, these tests demonstrated joint opening and flow at pressures both above and below the design water pressure. Although the majority of both the stress measurements and the pumping test results indicated that the in situ stresses would be adequate to prevent hydraulic jacking, the inherent variability in the data suggested some risk of leakage. Subsequently, a decision was made to place a steel lining from the power station to the vicinity of the investigation site.

3.3 Boomerang Creek Tunnel

The Boomerang Creek Tunnel has been constructed to join the Mangrove Creek Reservoir to the Upper Wyong River as part of a water supply strategy for the Central Coast area of NSW. The circular machine-bored tunnel is 11 km long and approximately 3 m in diameter, and is located predominantly in massive, gently dipping sandstones and interbedded sandstone and siltstone. The lower 2 km of the tunnel, nearer to the Wyong river, is located in a well defined mountain ridge. The tunnel has been designed to perform as a pressure tunnel during downstream flow from the reservoir to river under gravity, and upstream flow under pumping pressure when water is being pumped from river to reservoir.

The initial design concept involved the installation of a full steel pressure lining for a short distance upstream from the lower portal, to guard against the chance of water leakage in the region of very low cover, followed by a "leak proof" concrete lining further upstream, where the tunnel is located within the ridge. In this region, the concern was for the potential existence of a very low horizontal stress within the ridge at the level of the tunnel; much less than the corresponding overburden pressure based on depth of cover. If existent, this low magnitude of stress could result in hydraulic jacking of joints intersecting the tunnel, and/or the formation of hydraulically induced fractures, by the static and dynamic water pressures in the tunnel in service.

During the initial site investigation from the surface, hydraulic fracture stress measurements were carried out in one drillhole located approximately midway along the length of the tunnel sector located within the ridge (Lun et al, 1987). Tests in this hole at the projected tunnel level indicated that the horizontal stress field was not as low as feared, and that the need for a tunnel lining, other than for support purposes, could probably be avoided. This was based on the notion that the stress magnitudes would be high enough to prevent either hydraulic jacking or fracture formation.



STRESS MAGNITUDES

TEST No.	SITE	σ_1 (MPa)	σ_2 (MPa)	σ_3 (MPa)
1/1	1	8.6	3.6	-0.2*
1/2	1	14.2	9.9	2.3
2/2	2	9.9	4.9	0.1
2/3	2	2.9	0.7	-0.4*

JOINT SETS (POLES TO PLANES) IN THE VICINITY OF THE STRESS MEASUREMENT SITES

* TENSILE STRESS

Figure 3 King River. Stereographic projection showing orientation of principal stresses from overcoring measurements, and poles to planes of joint sets

To confirm this indication, overcoring stress measurements using the CSIRO HI cell were carried out at four locations along the tunnel as it neared completion (Walton and Enever, 1989). The measurement sites were:

(a) near the mid-point of the tunnel under maximum depth of cover, relatively remote from the influence of surface topography,

(b) close to the location of the from-surface measurements, and

(c) at two sites near the region envisaged for the steel lining, near the lower portal.

The main results for sites 2, 3 and 4 are summarized in Figure 4 and Table 1. The results from the site closest to the surface hydraulic fracturing tests (site 2) confirmed the conclusion that the horizontal stresses within the ridge were not generally low in terms of the likelihood of hydraulic jacking or fracturing. The results from further downstream, near the lower portal (sites 3 and 4), indicated a consistently uniform stress field with a minimum principal stress magnitude large enough to prevent leakage upstream of the point already designated as the limit for full pressure lining. The influence of topography on stresses was apparent, with a low measured vertical stress component

TABLE I

BOOMERANG CREEK.
PLANNED WATER PRESSURES AND MEASURED STRESSES AT THREE TEST SITES

Site No.	Storage head pressure (MPa)	Max. steady state pumping head (MPa)	σ_3 (MPa)	Measured vertical stress (MPa)	Calculated vertical stress (MPa)	Ratio: measured / calculated vertical stress
2	0.6	0.88	2.87	3.28	4.35	0.75
3	0.6	0.88	1.15	1.75	2.40	0.73
4	0.6	0.88	1.11	1.32	2.35	0.56

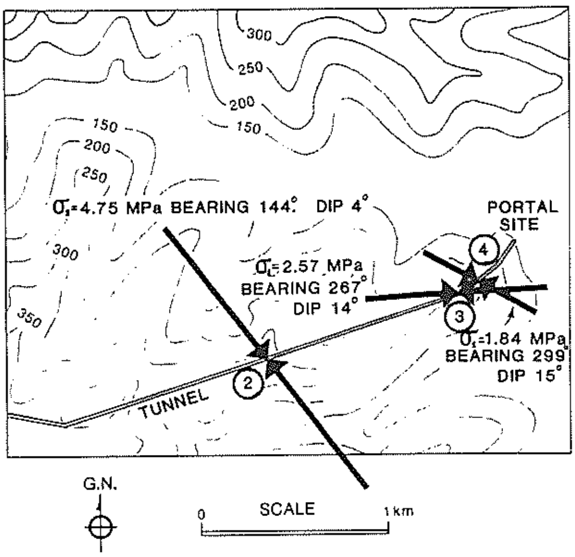


Figure 4a Boomerang Creek. Plan showing topographic contours. Sub-horizontal stresses at three overcoring test sites are indicated.

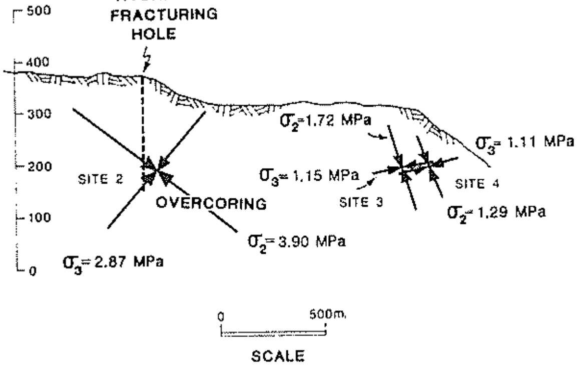


Figure 4b Boomerang Creek. Vertical projection along tunnel alignment, showing intermediate and minor principal stress at three overcoring test sites.

compared to that estimated from depth of cover. This supports the conventional wisdom for pressure tunnel design under ridges or "noses" between valleys, which calls for a notional smoothing of the peaks and an effective reduction of overburden height.

The results of the testing program in this instance confirmed the design strategy calling for a limited extent of steel pressure lining, in conjunction with an essentially unlined tunnel beyond a critical point, based on the measured in situ stress state. Concrete lining could be based on ground support requirements alone, resulting in a substantial cost saving.

3.4 Tully Millstream Project

The Tully Millstream hydro-electric scheme, currently under review by the Federal Government, State Government and Wet Tropics Management Authority, is located on the Tully River in North Queensland. All engineering work on the scheme has been halted pending the outcome of the scheme review. If it goes ahead, the project will involve construction of a large underground power station chamber and a number of service tunnels, including a high pressure headrace tunnel. The headrace tunnel as currently envisaged would have a total change in elevation of 656 m, with a maximum water head on entry to the power station of approximately 690 m. The entire complex will be sited in a volcanic sequence, with a number of well developed joint sets and some prominent shear zones. A generalized longitudinal section is shown in Figure 5, demonstrating the topography of the region.

In light of the high water pressures involved, the concept from the outset of the project has been for the pressure tunnel to be constructed with a section of steel lined penstock at the lower, power station end.

During an initial site investigation from the surface, hydraulic fracture stress measurements and pumping tests on specific joints were undertaken in two drillholes, one of which was located close to the originally proposed power station site (Strata-Tek Pty. Ltd., 1988). The results from these tests indicated a very variable stress field, particularly with regard to orientation, apparently reflecting the influence of topography. The measurements suggested that at the level of the proposed power station, the minimum horizontal stress would approximate the theoretical overburden pressure, based on depth of cover. Subsequently, a comprehensive program of testing was conducted from an exploratory tunnel constructed to within close proximity to the likely location of the power station (Enever and Edgoose, 1991; Walton and Litterbach, 1991; Wold, 1991). The investigations involved overcoring stress measurements using the CSIRO HI cell, hydraulic fracturing using the CSIRO Minifrac System, and pumping tests on selected joints in a 250 m long sub-horizontal hole drilled ahead of the tunnel end. The hydraulic fracturing, which was carried out in three mutually orthoganal drillholes, represented the first civil engineering application of the Minifrac System, which has recently been developed by CSIRO for use in 38 mm diameter holes (Wold et al,1989; Enever et al,1990).

The overcoring and hydraulic fracturing measurements indicated that the stress field varied in both magnitude and direction from

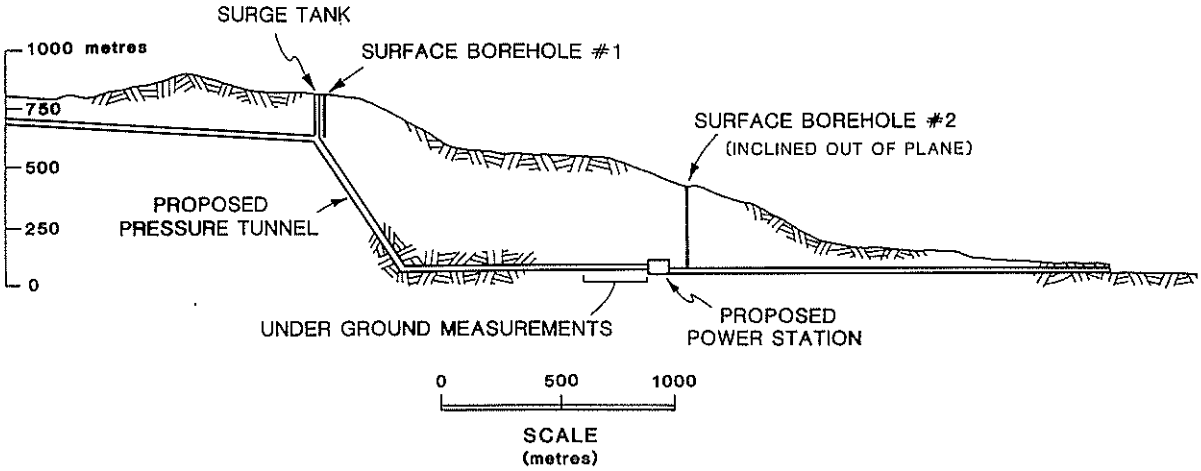


Figure 5 Tully Millstream. Vertical projection of Exploratory Tunnel, showing topography and location of measurement site.

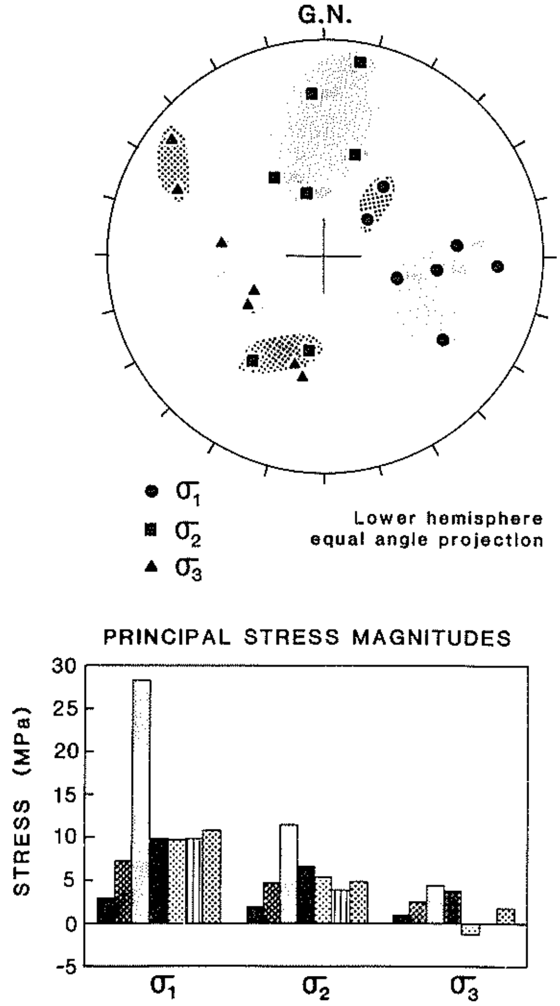


Figure 6a Tully Millstream. Principal stress orientations (lower hemisphere equal angle projection) and magnitudes from overcoring measurements.

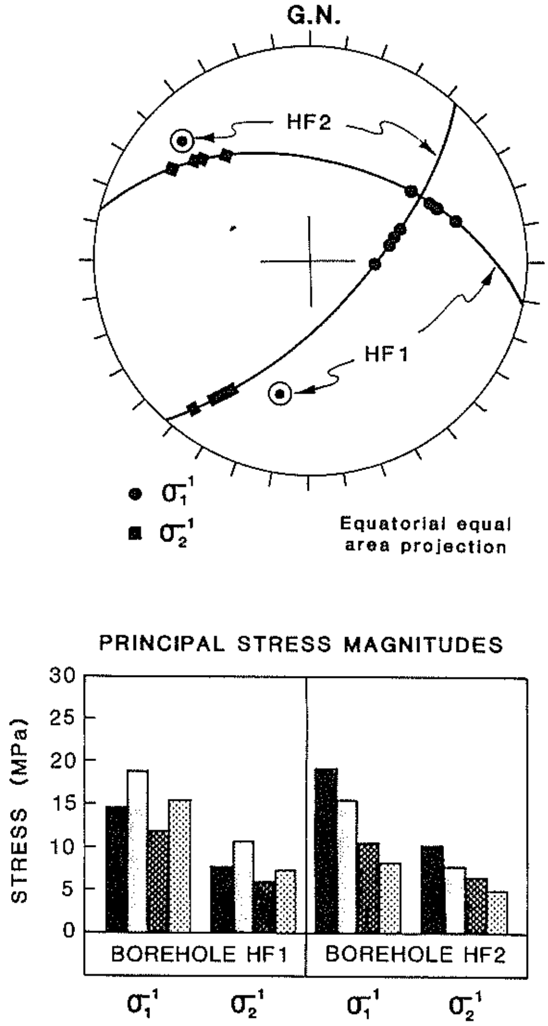


Figure 6b Tully Millstream. Secondary principal stress orientations (equatorial equal area projection) and magnitudes from hydraulic fracture tests.

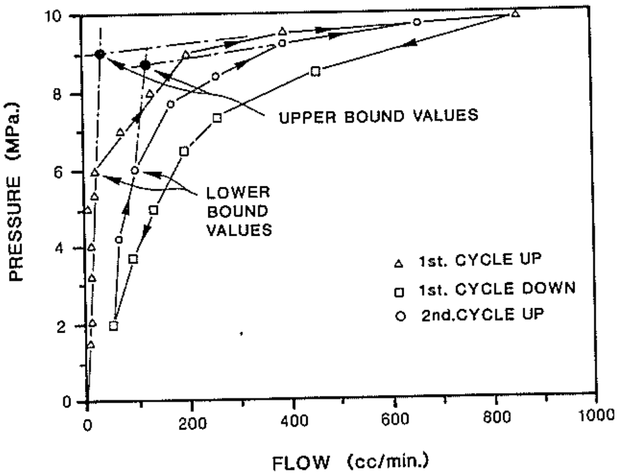


Figure 7 Tully Millstream. Flow vs pressure for initial and second pumping cycle, showing hydraulic jacking pressure, upper and lower bound estimates.

point to point (Figure 6). Both techniques showed the presence of low minimum principal stresses at some points in the rock mass, and high maximum principal stresses at other points. As at King River, this was thought to be related to the influence of structural discontinuities, and to the topography. In terms of the potential for water leakage, some of the measured stress components were low enough, with respect to the maximum anticipated water pressure, to suggest hydraulic jacking of unfavourably oriented discontinuities. This was confirmed by the results of the direct pumping tests, which showed that some joints could be opened at relatively low pressures (Figure 7). However, there was no clear relationship between the orientations of these critical joints, and the measured orientations of the stress field. Likewise, there was no clear spatial relationship between the measured hydraulic jacking pressures and distance into the borehole. Vertical depth of cover was not a dominant variable, at least over the depth range investigated.

4. DISCUSSION AND CONCLUSIONS

The King River project exemplifies the very low rock stresses that can exist at the lower end of pressure tunnels for surface power stations in steep terrain. In this situation, a steel pressure lining is generally recognized as inevitable from the outset, and the geotechnical problem is to determine how far upstream to proceed with the lining. While the majority of stress and pumping measurements in the region selected for investigation suggested adequate resistance to leakage, the occurrence of very low stress components within some units of the rock mass indicated the need for steel lining to this vicinity, at a point above that otherwise considered necessary. This was confirmed by the low pumping pressures required to initiate hydraulic jacking in certain cases.

Like King River, the Boomerang Creek project involves a pressure tunnel under low cover in the region of the downstream portal, with a steel pressure lining considered necessary in this region. However, in this case the more systematic stress field measured over the region of investigation, and the consistent magnitudes of the minimum stress component near the planned extent of the steel lining confirmed the adequacy of the original lining strategy with regard to steel lining placement.

Compared to the two examples where the pressure tunnel intersected the surface, the planned siting of the Tully Millstream power station under more than 300 m vertical cover might be expected to provide significant confinement of the pressure tunnel by overburden stress, reducing the potential for leakage by hydraulic jacking and lessening lining requirements. However, measured stresses were highly variable, with low minimum stress levels compared to those expected from overburden. The pumping tests indicated correspondingly low jacking pressures. These results can be expected to significantly influence the strategy adopted by the designers of the pressure tunnel lining.

The high variability of stress magnitude and direction in the hard jointed rock at King River and at Tully Millstream, was in marked contrast to the more uniform and systematic stresses at Boomerang Creek, where the sediments were relatively homogeneous. Since at all sites topography is a major feature, this suggests that geological structure has an overriding influence on stress variability, compared to topographical effects.

With respect to site investigation techniques, hydraulic fracture and pumping tests undertaken from the surface were very valuable in that they gave an early indication (with respect to the design procedure) of the general stress regime at critical locations. This knowledge was significantly expanded by the stress and pumping test programs from underground, from where more comprehensive investigations could be undertaken.

It is concluded that programs of stress measurement and direct pumping tests are very important for the assessment of leakage potential for pressure tunnel projects. Because of the generally close proximity of the tunnels to the surface topography, and of the effects of geologic structures in the rock mass, stress fields vary significantly across the regions of interest, and may not be adequately predicted from a priori considerations. Self evidently, mapping of structural discontinuities is essential, and the orientations of joint and fracture planes should be considered in conjunction with the stress field orientations, since the stress components normal to the planes are the critical factor in assessing the risk of hydraulic jacking. Hydraulic pumping of individually isolated, orientated joints is the most direct test of jacking potential.

5. ACKNOWLEDGMENTS

The authors acknowledge, with thanks, the support of the Hydroelectric Commission, Tasmania, the Public Works Department, NSW, and Golder Associates in conjunction with the Queensland Electricity Commission, in the conduct of these field studies. They are grateful to Mr. N. Litterbach of Mining Measurement Services, and Mr. J. Edgoose of Strata-Tek Pty. Ltd., and to their CSIRO colleagues, for their contributions to the field measurements.

6. REFERENCES

Berg - Christensen, J. and Dannevig, N.T. (1971). Engineering geological considerations concerning the unlined pressure shaft at the Mauranger Power Project. A/S GEOTEAM Report No. 2398.03. Oslo, 1971.

Dann, H.E., Hartwig, W.P. and Hunter, J.R. (1964). Unlined tunnels of the Snowy Mountains Hydro-electric Authority, Australia. Jnl. of Power Division, Proc. ASCE. October 1964. pp. 47 - 79.

Enever, J. R., Wooltorton, B. and Johnson, M. (1987a). The application of hydraulic fracturing to the assessment of lining requirements for a pressure tunnel. Proc. VI Australian Tunnelling Conf. Melbourne, March, 1987. pp 109 - 118.

Enever, J. R., Litterbach, N. and Dean, A. (1987b). Pumping tests in the King River power tunnel. Site Investigation Report No. 44, CSIRO Division of Geoemchanics, Aust. November, 1987. 24 p.

Enever, J.R., Wold, M.B. and Walton, R.J. (1990). Scale effects influencing hydraulic fracturing and overcoring stress measurements. Scale Effects in Rock Masses, Pinto da Cunha (ed.) Balkema, Rotterdam, 1990. pp 317 - 326.

Enever, J. R. and Edgoose, J. (1991). Rock stress measurement and hydraulic jacking measurements at the Tully Power Station Site, Tully-Millstream Hydroelectric Project, North Queensland. Vol.1, Part C: Hydraulic jacking tests. CSIRO Division of Geomechanics Internal Report - New Series No. 66. 17 p.

Lun, P.T.W., Enever, J.R., Helm, D.C., Tan, C.P. and Coulthard, M.A. (1987). Stress measurements/stress analysis for the Mangrove Creek Dam - Upper Wyong River pressure tunnel. CSIRO Division of Geoemchanics, Aust., Site Investigation Report No. 38.

Paterson, S.J., Hale, G.E.A. and Ikin, D.B. (1975). Stabilizing a landslide above Fisher penstock, Tasmania. Proc. 2nd Aust. - New Zealand Conf. on Geomechanics. Brisbane, 1975. pp 314 - 318.

Selmer - Olsen, R. (1970). Experience with unlined pressure shafts in Norway. Proc. Int. Symp. on Large Permanent Underground Openings. Oslo. Ed. Brekke and Jorstad. pp. 327 - 332.

Sharma, V.M., Singh, R.B., Kuberan, R., Moza, K.K. and Sharma, T. (1991). In situ stress measurement for design of tunnels. Proc. 7th ISRM Congress, Aachen, Sept., pp 1355-1358.

Strata-Tek Pty. Ltd. (1988). Tully-Millstream Hydro-electric Scheme. A report on hydraulic fracture testing to define in situ stress conditions. Report to Snowy Mountains Engineering Corporation, September 1988. 47 p plus appendices.

Vogt, J.H.L. (1922). Tryktunneler og geologi. Norges Geol. Undersokelse nr. 93, Oslo.

Walker, J.R., Martin, C.D., and Dzik, E.J. (1990). Technical note. Confidence intervals for in situ stress measurements. Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. Vol. 27, No. 2, pp. 139 - 141.

Walton, R.J. and Crawford, G.R. (1987). Rock stress measurements at the King River power tunnel, Tasmania - Part 1: overcoring measurements. CSIRO Division of Geomechanics, Aust. Site Investigation Report No. 43. October, 1987. 37 p.

Walton, R.J. and Enever, J.R. (1989). Rock stress measurements by overcoring at the Boomerang Creek tunnel, NSW. CSIRO Division of Geomechanics Internal Report No.4, 45 p.

Walton, R.J. and Litterbach, N. (1991). Rock stress measurement and hydraulic jacking measurements at the Tully Power Station Site, Tully-Millstream Hydroelectric Project, North Queensland. Vol.1, Part A: Stress measurement by overcoring. CSIRO Division of Geomechanics Internal Report - New Series No. 66, 60 p.

Wold, M.B., Enever, J.R. and Crawford, G.R. (1989) Stress measurements in a burst-prone heterogeneous rock mass using a novel miniature hydraulic fracturing tool. Rock Mechanics as a Guide for Efficient Utilization of Natural Resources, Khair (ed.). 1989 Balkema, Rotterdam. pp. 435 - 442.

Wold, M.B. (1991). Rock stress measurement and hydraulic jacking measurements at the Tully Power Station Stie, Tully-Millstream Hydroelectric Project, North Queensland. Vol.1, Part B: Stress measurements by hydraulic fracturing. CSIRO Division of Geomechanics Internal Report - New Series No. 66, 21 p.