In Situ Rock Stress Measurement at Rangipo

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SUMMARY The results of in situ rock stress measurements at the site of the Rangipo underground powerhouse are presented. The Rangipo project is part of the Tongariro Power Development in the central North Island of New Zealand. The rock at the site is greywacke and argillite, mostly unweathered and closely jointed. The measurement technique used was the hollow inclusion triaxial stress gauge, (Rocha et al. 1974 and, Worotnicki and Walton 1976). The results of the five successful tests show that the stress magnitudes are not large and that normal stresses in horizontal directions are slightly greater than those in the vertical direction.

1 INTRODUCTION

In this paper the results of tests to measure the in situ state-of-stress at the site of the Rangipo underground powerhouse are presented. The Rangipo powerhouse, 120 MW generating capacity, is part of the Tongariro Power Development in the central North Island of New Zealand. The powerhouse will be excavated from a deposit of greywacke and argillite, mostly unweathered but closely jointed. The approximate dimensions of the powerhouse excavation are: length 60 m, height 40 m and width 20 m. A downstream serge chamber of similar dimensions is to be excavated 40 m downstream from the powerhouse cavern.

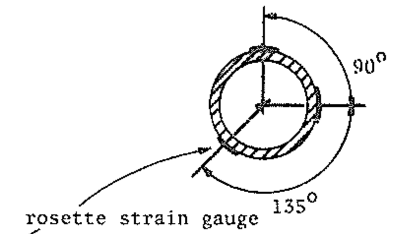
Many techniques have been developed for the measurement of in situ stresses in rock. Most have been applied to rock conditions rather better than those at Rangipo. Considerable difficulty was experienced in adapting existing techniques to the conditions at the Rangipo site. Despite these problems knowledge of the in situ stresses remains an important facet of the input data for underground powerhouse design. In effect these stresses determine the loading on the structure.

The investigation work was a joint effort between the New Zealand Ministry of Works and Development Central Laboratories and the Ministry of Works and Development investigation staff at the powerhouse site. Central Laboratories directed the investigation, developed instruments and techniques. The site staff provided drilling crews and back-up services. The results are also presented in an M.W.D. Central Laboratories Report (Pender 1977).

2 STRESS MEASUREMENT TECHNIQUE

The technique adopted for the measurements was the hollow inclusion triaxial stress gauge, (Rocha et al. 1974 and, Worotnicki and Walton 1976). A number of electrical resistance strain gauges are embedded in a hollow epoxy cylinder. The details of the probe used are shown in Figure 1. The probe is very similar to that developed by Worotnicki and Walton (1976). The thickness of the epoxy cylinder was a few millimetres greater, and air pressure (200 kPa) was used to expel the epoxy from the reservoir at the end of the probe. This probe is cemented into a predrilled Ex hole. The whole assembly is then overcored with a drilling barrel producing a 150 mm diameter core. The overcoring releases the strain in the rock due to the in situ stresses. An elastic analysis of the strain readings gives the in situ stresses, Duncan Fama and Pender (1980).

The above description belies the difficulties experienced in achieving successful measurements. The difficulties were all associated with the jointed nature of the rock. The technique used would certainly not have been appropriate in the most intensely



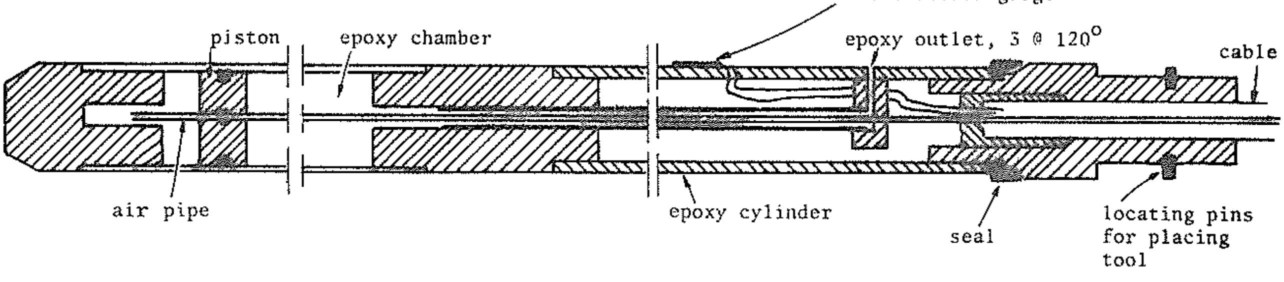


Figure 1 Hollow inclusion triaxial stress gauge

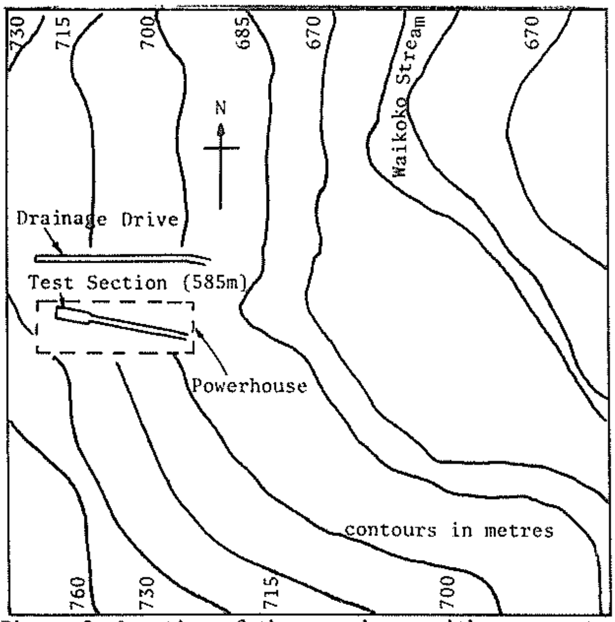


Figure 2 Location of the powerhouse with respect to the surrounding topography

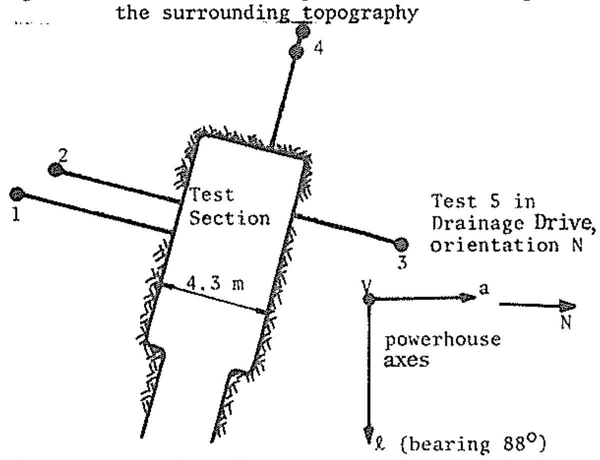


Figure 3 Location of stress measurement points

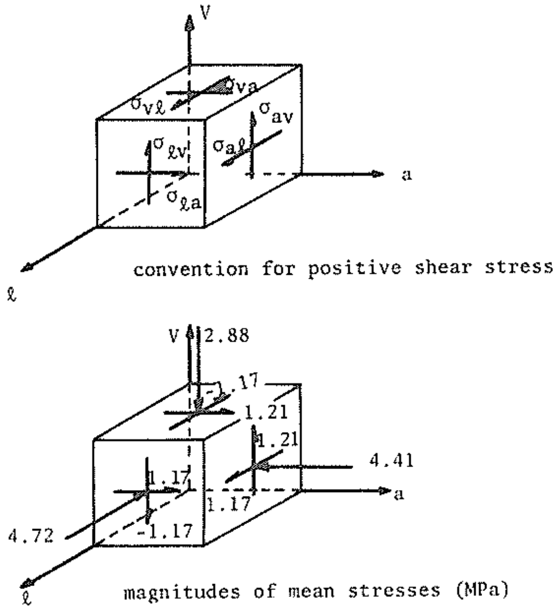


Figure 4 Stress components acting on planes orthogonal to the powerhouse coordinate axes

jointed rock at the site. Also the jointing pattern was not regular. Although the analysis of joint data, (Hegan 1977), showed that three dominant joint directions were indicated the spread of joint directions was very large. A considerable amount of investigation drilling with an NMLC core barrel was done in an attempt to locate suitable blocks of rock for the measurements. Cores in excess of 400-500 mm long were regarded as indicative of suitable rock for the stress measurements. Two localities were found: the test section at the west end of the powerhouse and in the drainage drive near the east end of the powerhouse. The final selection of the stress measurement position was chosen by considering the jointing pattern revealed in the NMLC cores from holes nearby. In principle the core from the Ex pilot hole in which the stress measurement probe was to be cemented should indicate if the rock is satisfactory. However it was found that because of the small diameter of Ex core this is often broken in the drilling process.

The presence of joints also lead to problems during the overcoring. The standard procedure of using a diatube did not work at all well. The cause of trouble was the unexpected presence of a joint near the front of the core during the overcoring process. The drilling action of the diatube tended to twist and vibrate the core and eventually break the stress measurement probe. For this reason a double tube coring barrel was constructed, the inner tube of which was mounted on bearings so that the core was not twisted. This greatly increased the success rate of the measurements which involved overcoring runs of 500 to 750 mm.

The main indication that an overcoring run had been successful was the variation of the strain readings with the penetration of the drilling barrel. The type of plot shown by Worotnicki and Walton (1976), in which some of the strain components rise to a peak and then settle down to a steady value, is required. Some of the pieces of overcore were cut through with a diamond saw to check that the bond between the rock and epoxy had not failed. Generally this was not a problem as the relatively low levels of the in situ stresses meant that the tensile stress set up at the epoxy/rock interface during the release of the strain in the rock was small.

3 RESULTS

The topography of the ground surface above the site and position of the powerhouse are shown in Figure 2. In Figure 3 the positions of the stress measurements are shown. The results of the five measurements are given in Table I. Presented are the calculated principal stresses and also the normal and shear stresses which act on three orthogonal planes relative to the powerhouse axes, Figure 4. The measured strains were reduced to stresses using the analysis of Duncan Fama and Pender (1980). The properties of the rock were taken as E 67.0 GPa and ν = 0.25. These figures were indicated by the extensive testing done by Bryant (1977) on NMLC cores from the site. The properties of the epoxy were taken as E 3.45 GPa and ν = 0.40. The six stress components were then reduced to principal stresses and principal stress directions.

The principal stress results are rather variable. The mean and standard deviation have been calculated. It is seen that the level of confidence decreases as the magnitude of the stresses decreases. The results for test three have the unlikely result that the minor principal stress is close to zero. This is reflected in the fact that the standard deviation for σ_3 is nearly the same magnitude as the mean value

TABLE I

RESULTS OF STRESS MEASUREMENTS (units MPa)

Test	σ_1	σ_2	σ_3	σ_{aa}	σ_{vv}	$\sigma_{\ell\ell}$	σ_{av}	$\sigma_{v\ell}$	$\sigma_{\ell a}$
1	8.76	5.79	0.75	5.30	2.58	7.52	1.37	-2.67	1.20
2	7.90	2.81	1.51	7.90	1.60	2.78	0.48	0.28	0.09
3	5.96	3.45	-0.07	3.28	3.11	2.77	2.27	-0.52	1.82
4	6.46	3.59	2.35	3.43	2.21	6.46	-0.08	0.30	-0.05
5	8.33	1.52	0.77	2.12	4.90	4.06	2.01	-3.25	2.80
Mean	7.48	3.43	1.06	4.41	2.88	4.72	1.21	-1.17	1.17
Standard Deviation	1.21	1.55	0.91	2.26	1.26	2.17	1.00	1.68	1.20

for σ_3. The principal stress directions are plotted with respect to the powerhouse axes, Figure 4a, in Figure 5. Once again a large amount of scatter is evident.

This scatter of results is also present when the principal stresses are reduced to normal and shear stresses acting on planes orthogonal to the powerhouse axes. As with the principal stresses the relative magnitude of the uncertainty rises as the average value of the stresses decreases. The average value of the vertical stress, 2.88 MPa, correlates reasonably well with the depth of overburden at the site, although the complexity of the overlying topography, Figure 2, makes it difficult to decide exactly what is the equivalent overburden depth. These calculations suggest that the normal stress levels in the horizontal directions are a little greater

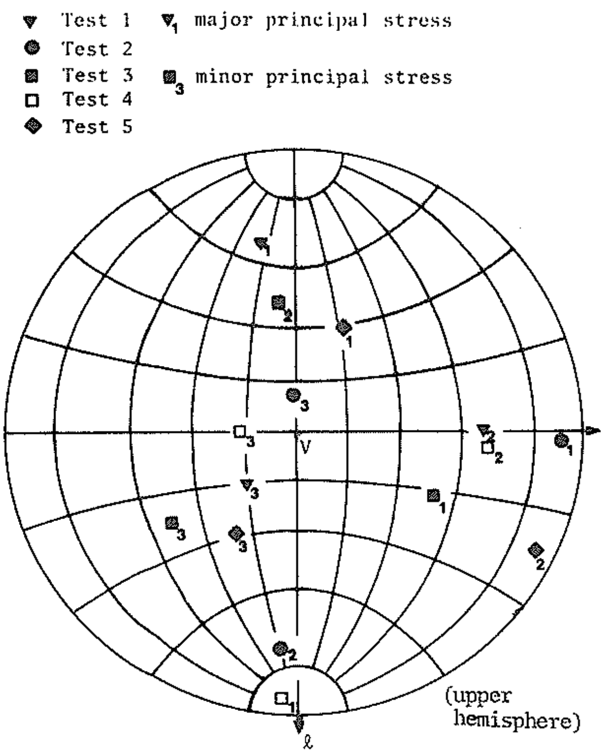


Figure 5 Orientation of the major principal stress directions with respect to the powerhouse

than those in the vertical direction. The level of the scatter from one result set to another precludes any more definite statement. The ground surface above the site contains the stream valley shown in Figure 2. Such a valley configuration would be expected to give a gravitational stress field beneath the bottom of the valley which had the horizontal stresses slightly higher than the vertical stresses. Thus it is unlikely that the stresses measured are of tectonic origin.

The variability of stress results could be a consequence of difficulties in the measurement technique, variability in the rock properties or true variations in the rock stress from point to point. It is not clear what the explanation is, although the consistent results obtained by Bryant (1977) suggests that the rock properties are unlikely to be the cause. The rock in which the measurements were made was the best rock at the site. The properties of the more intensely jointed rock from which the bulk of the powerhouse had to be excavated are clearly inferior to those of the rock on which the measurements were made. Thus the variability evident in Table I has another dimension not explored with these measurements. It is assumed that this better quality rock is stiffer and would be better capable of supporting differences in principal stress than the more intensely jointed material. The principal stress magnitudes elsewhere in the rock would thus tend to be more equal.

4 CONCLUSIONS

Existing rock stress measurement techniques have been applied to the difficult rock conditions at the site of the Rangipo powerhouse. The use of a double tube drilling barrel increased the success rate of the overcoring.

Five measurements were obtained. The results from these indicated much scatter both in the magnitude of the principal stresses and the principal stress directions. The results indicate that the normal stress in the horizontal direction is slightly greater than that in the vertical direction. Because of the topography of the ground surface above the site this stress condition is probably of gravitational rather than tectonic origin.

5 ACKNOWLEDGEMENTS

These stress measurements would not have been possible without the painstaking work of the drilling

crews at the site. In particular Mr J. Chapman exhibited much insight into the nature of the overcoring operation and suggested the use of the double tube overcoring barrel.

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