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BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD No. 1961-162

BELL CREEK 17.3M DAM SITE SEISMIC REFRACTION SURVEY, QUEENSLAND 1959

by

E.E. Jesson, W.A. Wiebenga, and J.C. Dooley

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ABSTRACT

This Record describes a seismic survey made by the Bureau of Mineral Resources on the Bell Creek 17.3M dam site in central Queensland. This dam site is one of several under consideration by the Irrigation and Water Supply Commission of Queensland for the development of the Callide Valley.

The depth to bedrock was found to average about 50 to 60 ft, with values rangeing from 17 to 112 ft.

Dynamic elastic properties of the bedrock were derived from a consideration of the "ground-roll" waves.

1. INTRODUCTION

The Irrigation and Water Supply Commission (I.W.S.C.) of Queensland proposes building a dam to provide water for a possible future power station operating on local coal deposits in the Callide Valley area of Central Queensland. One possible site selected by the I.W.S.C. has been designated the 17.3M site on Bell Creek (Plate 1); it is situated about 17 miles north of the township of Biloela, which has approximate coordinates 345800 yards east, 963250 yards north on the Monto 4-mile map.

The I.W.S.C. requested the Bureau of Mineral Resources to make a survey to determine the nature and depth of foundation rock at the Bell Creek site. Such a survey was undertaken by the Geophysical Branch of the Bureau, the party consisting of E.E. Jesson (party leader and geophysicist), B.J. Bamber (geophysicist) and J.P. Pigott (geophysical assistant).

The I.W.S.C. provided four field hands and additional transport, and did the topographical surveying.

The field work, using the seismic refraction method, was done between 19th and 26th October 1959.

2. GEOLOGY

The site is situated in a narrow section of an alluvial valley with steep banks 40 to 50 ft high flanking the creek channel. The banks then rise gently within the survey area to a height of about 150 ft above the creek.

The geology of the area is known from I.W.S.C. investigations (Dunlop, 1959). At the time the results of the seismic survey were interpreted, no test drilling had been done.

In this Record the term 'bedrock' will refer to the deepest recorded seismic refractor. The term 'overburden' will refer to soil, sand, gravel, scree material, and weathered or decomposed bedrock.

The bedrock in the area consists of pyroclastic and epiclastic rocks, essentially rhyolitic in character. The epiclasts, which occur principally on the right bank (facing down-stream), range in grain size from that of a tuffaceous sandstone to that of a volcanic conglomerate. These epiclasts will, of course, have a fairly high porosity. The pyroclasts, predominant on the left bank, range between a fine and a coarse grained tuff. The pyroclasts are jointed with a general spacing of joints from 2 to 3 ft, but this is very variable.

Across the valley of the creek there is a flood channel on each side of the main stream. These regions are covered with gravel and sand. The right bank is largely covered with scree material.

3. METHODS AND EQUIPMENT

The seismic refraction technique was used in this survey. The method has been described in a report on the Moogerah dam site, Queensland (Polak and Mann, 1959). The dynamic properties of rocks are considered in an Appendix to the present Record.

The seismic recording equipment used in the survey consisted on a 12-channel portable shallow reflection-refraction seismograph manufactured by the Midwestern Geophysical Laboratory, Tulsa, U.S.A. Midwestern geophones, having a natural frequency of about 8 c/s, were used to record the vertical movement of the earth. Southwestern Industrial Electronics horizontal geophones having a natural frequency of 6 c/s were used to measure the transverse wave velocity.

4. RESULTS

The locations of the seismic traverses are shown on Plate 2.

The following tentative identification is made between the seismic longitudinal velocities and the rock types in the dam site area.

Seismic velocity (ft/sec)	Rock type
1700 - 3000	soil, sand, scree material.
4000 - 5000	water-saturated sand and gravel.
6000 - 10,000	weathered bedrock.
10,000 - 16,000	slightly weathered to unweathered bedrock.

The seismic refraction work has been interpreted to give the depth to bedrock; the results in the form of cross-sections are shown on Plate 2.

The depth to bedrock is generally between 40 and 60 ft. The south end of Traverse X shows that overburden thickness increases to between 90 and 110 ft. This is probably due to an increased thickness of weathered bedrock. A similar but smaller thickening also occurs at the northern end of this traverse.

Traverses A and B show a thinning of overburden to the east and west of the main traverse. The cross-sections for Traverses B and X indicate that in the region of the junction of these two traverses, there is a well developed band of water-bearing sand and gravel (characteristic velocity 4000 to 5000 ft/sec).

It may also be seen that a velocity of about 9000 ft/sec for the material underlying these gravels is greater than the velocity (about 7000 ft/sec) for the remainder of the area. This suggests that either the weathering of the bedrock is less advanced in the creek bed, possibly owing to mechanic erosion partially balancing the advance of weathering, or more probably that this material differs from the surrounding material and corresponds with the very hard and firmly cemented rhyolitic detritus reported by Dunlop (1959).

The computed thickness of overburden has been used to construct the overburden isopach plan (Plate 2). This plan shows a zone of thick overburden cutting Traverse X at stations 17 to 19 and cutting Traverse B obliquely between stations 7 and 10. This may well correspond to the old bed of a creek, visible on the surface, which feeds into Bell Creek.

The errors in the computed depth to bedrock are difficult to ascertain as there is no drilling information, but it may be taken approximately as the sum of the percentage errors in the two factors (the time-depth and apparent velocity) used to compute the depth. The time-depth is probably reliable to within 1 millisecond or 10 per cent. The error in the determination of the apparent velocity will be somewhere between 10 and 20 per cent. This figure is based on comparisons of the apparent velocities found at adjacent points on the survey area. Hence the error in the determination of the depth to bedrock will be about 20 per cent.

The seismic velocity in the bedrock changes abruptly on the flanks of the creek, at both ends of Traverse X. Between stations 2 and 6 on the northern end of the traverse, the comparatively low velocity of 11,000 ft/sec suggests a shear zone in the bedrock. Between stations 24 and 38, the velocity rangeing between 11,700 and 13,000 ft/sec suggests either a shear zone or a change in bedrock type.

A geophone spread, using the horizontal geophones to determine the transverse velocity of the bedrock, was placed between stations 2 and 9 on Traverse X. Because of the shear zone in this region, the transverse velocity determination is doubtful and has not been used to determine Poisson's Ratio.

However, some of the normal records shot to give the depth information show ground-roll waves, characterised by their low frequency. These waves have been used to determine Poisson's ratio as discussed in the Appendix, and give a value :

$$\sigma = 0.31 \pm 0.03$$

with a corresponding Young's modulus

$$E = 6.2 \times 10^6 \text{ lb/in.}^2,$$ corresponding to a longitudinal seismic velocity of 15,350 ft/sec.

5. CONCLUSIONS AND RECOMMENDATIONS

The geophysical survey provided information about the depth to bedrock. The overburden thickness ranges from 17 to 112 ft and averages between 50 and 60 ft. The maximum overburden thickness is 112 ft at station 35 on Traverse X. Shear zones probably exist between stations 2 and 6, and between stations 24 and 38, on Traverse X.

The value of Poisson's ratio for the unweathered bedrock is 0.31 ± 0.03. The corresponding value for Young's modulus is 6.2 x 10^6 lb/in.^{2} or 42.7 x 10^{10} dyn/cm^2.

It is recommended that some test drilling be done to give control of the seismic interpretation. Suggested positions for test drilling are in the creek bed region between X_{16} and X_{13} and also between B_8 and B_{14} to check the interpretation of differences between this region and the remainder of the area. Several holes could be drilled in other parts of the area for comparison.

6. REFERENCES

DUNLOP, R.A.,	1959	Bell Creek 17.3 A.M.T.H. Memorandum to Senior Planning Engineer, Irrigation and Water Supply Commission, Queensland.
POLAK, E.J., and MANN, P.E.,	1959	A Seismic refraction survey at the Moogerah dam site near Kalbar, Queensland. Bur. Min. Resour. Aust. Rec. 1959-62.

APPENDIX

DERIVATION OF ELASTIC PROPERTIES OF ROCKS FROM GROUND-ROLL WAVES

1. Theoretical considerations

Polak and Mann (1959) described a method of determining the elastic properties of rocks when the velocities of the longitudinal and transverse seismic waves are known. The longitudinal velocity (V_p) of bedrock is determined during the course of a seismic refraction survey, but determination of the transverse velocity (V_s) requires special geophones and the shooting of special spreads.

After the arrival of the body waves on the normal spreads, a complex low-frequency ground movement is recorded by the geophones, which is generally known as "ground roll". Investigation has shown that this is the same phenomenon as the surface waves arising from earthquakes, and that Rayleigh waves form the main part of this movement (Ewing, Jardetzky, and Press, 1957, p. 200). Under favourable conditions, dispersion curves showing the variation of velocity with wavelength of the ground roll can be plotted, and these show good agreement with theoretical dispersion curves calculated from known or assumed characteristics of the various rock types at different depths.

Rayleigh waves are propagated near the surface but are attenuated rapidly with depth, so their velocity (V_R) depends on the elastic properties of the material within a depth of one or two wavelengths. The Rayleigh wave velocity (V_o) in a homogeneous material can be determined readily, and is about $0.92V_s$. V_o/V_p and V_o/V_s are functions of Poisson's ratio, and have been calculated by Knopoff (op. cit., 34). V_o/V_p and V_s/V_p are plotted as functions of Poisson's ratio in Fig.1.

This suggests the possibility of using the ground-roll velocity to determine Poisson's ratio for bedrock in engineering problems. From Poisson's ratio and V_p the other elastic moduli, such as Young's modulus, bulk modulus, and rigidity modulus can be calculated (Polak and Mann, 1959).

In a simple two-layer case, such as overburden and bedrock, and using suffixes 1, 2 to represent overburden and bedrock respectively, the observed Rayleigh wave velocity V_R approaches the velocity for overburden (V_{01}) when the wavelength (L) is short compared with the overburden thickness H; and it approaches the velocity for bedrock (V_{02}) when L is large compared with H. Intermediate values of V_R depend on the properties of both layers, and are difficult to calculate; however, this has been done for selected cases by earthquake investigators, and several theoretical dispersion curves are given by Ewing *et al.* (op. cit., 205). These all assume Poisson's ratio = 0.25.

The usual method of drawing dispersion curves is to plot V_R as a function of L or L/H; thus the curve has the value V_{01} at L/H = 0, and approaches V_{02} asymptotically as L/H approaches infinity (It should be noted that the velocity determined from a geophone spread is the phase velocity, not the group velocity which is normally used in earthquake studies where recording stations are too far apart to permit phase-velocity determinations).

As we wish to determine V_{02}, it is more convenient to plot $x = H/L$ as the abscissa, and $r = V_R/V_{p2}$ as the ordinate. If the observed velocities are plotted in this form, the dispersion curve should approach $r_o = V_{02}/V_{p2}$ as x becomes small, and by extrapolating the curve to cut the vertical axis a value of r_0 can be estimated.

Some theoretical dispersion curves from various sources have been plotted in this form in Fig. 2. The main characteristic on which the form of these curves depends is the ratio of the seismic velocities in the media, $q = V_{p1}/V_{p2}$. The value of q is shown for each curve (actually V_{s1}/V_{s2} is the more significant parameter, but as these curves were calculated for Poisson's ratio = 0.25 in both layers, then $V_{p1}/V_{p2} = V_{s1}/V_{s2}$). The fact that the curves for q = 0.45 and q = 0.32 intersect in the region of x = 0.09 is caused by the different density contrast $p = \rho_1/\rho_2$ assumed in the two cases. The curve for conditions q = .45, p = .83 for x less than 0.1 calculated by Lee, but omitted from Fig.2 to avoid confusion, does not intersect his curve for q = 0.32 as does the other curve for q = 0.45 mentioned above and shown in Fig. 2.

It will be seen that for q greater than about 0.4, curves extrapolated from values of x about 0.1 or 0.2 should give a reasonable estimate of r_o; however, for q less than about 0.4, r would need to be known for values of x considerably smaller than this to enable reasonable extrapolation to x = 0.

Thus in considering whether this method can be applied to a given area, the factors required are that x should be reasonably small and that the velocity contrast between overburden and bedrock should not be too marked. In this connexion it is important to note that the change in V_p at the water table is not significant, as there is no associated change in V_s which is the principal factor affecting the velocity of Rayleigh waves (op. cit., 200).

2. Application to the present survey

Table 1 lists the relevant data for the present survey; V_R and L were measured from the ground-roll waves on the seismograms. H and V_p were of course obtained from the first refraction arrivals as shown on Plate 2; average values have been taken for each spread.

Three layers can be distinguished over most of the area on the basis of seismic velocities. The existence of three layers could give a dispersion curve differing somewhat from the nearest two-layer case; however, provided that the thickness and velocity of each layer conform to the conditions prescribed above, it should still be possible to extrapolate the curve satisfactorily. The top layer averages about 10 ft thick; as L ranges from about 200 to 400 ft, this is about 0.02 to 0.05 L, and it is assumed that this low-velocity layer will not seriously affect the extrapolation. In the vicinity of the intersection of Traverses B and X a considerable thickness of material of velocity 4400 to 5000 ft/sec has been interpreted as water-bearing sand and gravel; it is possible that the value of V_s for this saturated material is considerably lower than would be expected from the corresponding V_p.

Table 1 also shows the values of q which range from 0.33 to 0.68. To calculate q, V_{p1} is taken as the main overburden velocity; i.e., that immediately overlying basement.

The data from Table 1 are plotted in Fig.3. It will be seen that all points lie reasonably close to a mean dispersion curve, including the points derived from Traverses B and X near their intersection (points No. 1, 2, 3, 11, and 12). Moreover, there is no systematic difference between the data with low and high values of q. This suggests that the Rayleigh waves depend on the average characteristics of the material in the area and are not affected much by local variations.

The data seem to be fitted best by a curve approximately parallel to the theoretical one for q = 0.50, which is plotted as a broken line on Fig.3. This curve cuts the axis at r_o = 0.485, corresponding to a value of 0.31 for Poisson's ratio. This is taken as an average value of Poisson's ratio for the bedrock.

Taking the average bedrock velocity as 15,350 ft/sec, and assuming a density of 2.7 g/c.c. (0.098 lb/in.^{3}), we get

$$V_s = 8000 \text{ ft/sec}$$

$$E = 6.2 \times 10^6 \text{ lb/in}^2.$$

The formula for E can be written in the form:

$$E = k V_s^2 \, d \, (1 + \sigma)$$

where d = density

σ = Poisson's ratio

and k is a constant.

From the scatter of the points in Fig.3 and the extent of extrapolation, the standard deviation of the estimated value of r_o is estimated visually as ± 0.03, or about 0.07 r_o. The corresponding error in σ is about ± 0.03. The ratio V_o/V_s varies only slightly with σ ; therefore we may take the error in V_s as ± 0.07V_s. The error in d may be about ± 0.1 or ± 0.04d. Thus the resulting fractional error in E is estimated as :-

$$(2 \times 0.07) + 0.04 + \frac{0.03}{1.3} = \pm 0.20$$

i.e. an accuracy of about 20 per cent. Allowing for errors in estimating average depths and velocities the error may be about 20 to 25 per cent.

Using an empirical relation, E may be estimated from V_p with an accuracy of ± 30 per cent (Mann, 1961). The value so obtained is

$$E = 6.4 \times 10^6 \text{ lb/in.}^2$$

which is in good agreement with the above.

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TABLE 1.

Observation No.	Location	q (V_{p1}/V_{p2})	L (ft)	H (ft)	V_R (ft/sec)	V_p (ft/sec)	r (V_R/V_p)	X (H/L)
1	B_2-B_{12}	.33	275	36	6,200	15,100	.41	.13
2	"	.33	355	36	6,100	15,100	.41	.10
3	"	.33	370	36	6,700	15,100	.44	.095
4	A12-A22	.40	195	34	6,100	15,500	.39	.175
5	C10-C20	.45	260	53	5,200	14,400	.36	.205
6	"	.45	185	53	5,400	14,400	.37	.285
7	C1-C10	.48	215	59	4,700	14,700	.32	.275
8	B_{12}-B_{22}	.60	240	32	6,800	16,000	.43	.135
9	X_9-X_{19}	.60	190	52	4,800	14,500	.33	.275
10	"	.60	220	52	4,900	14,500	.34	.235
11	X_{24}-X_{29}	.68	200	65	3,600	11,700	.31	.325
12	X_{19}-X_{24}	.59	185	54	5,000	15,600	.32	.29

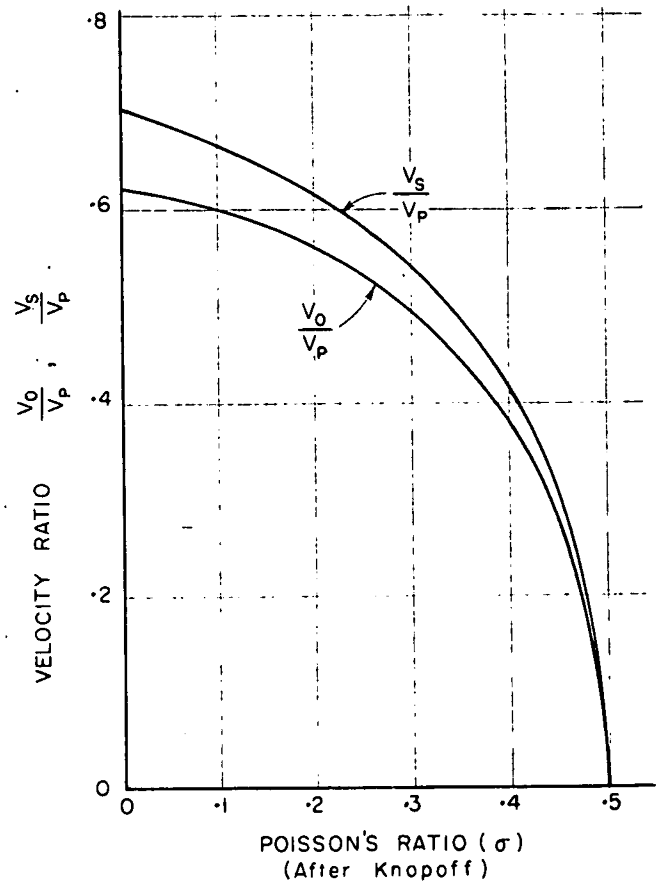


FIG. 1.

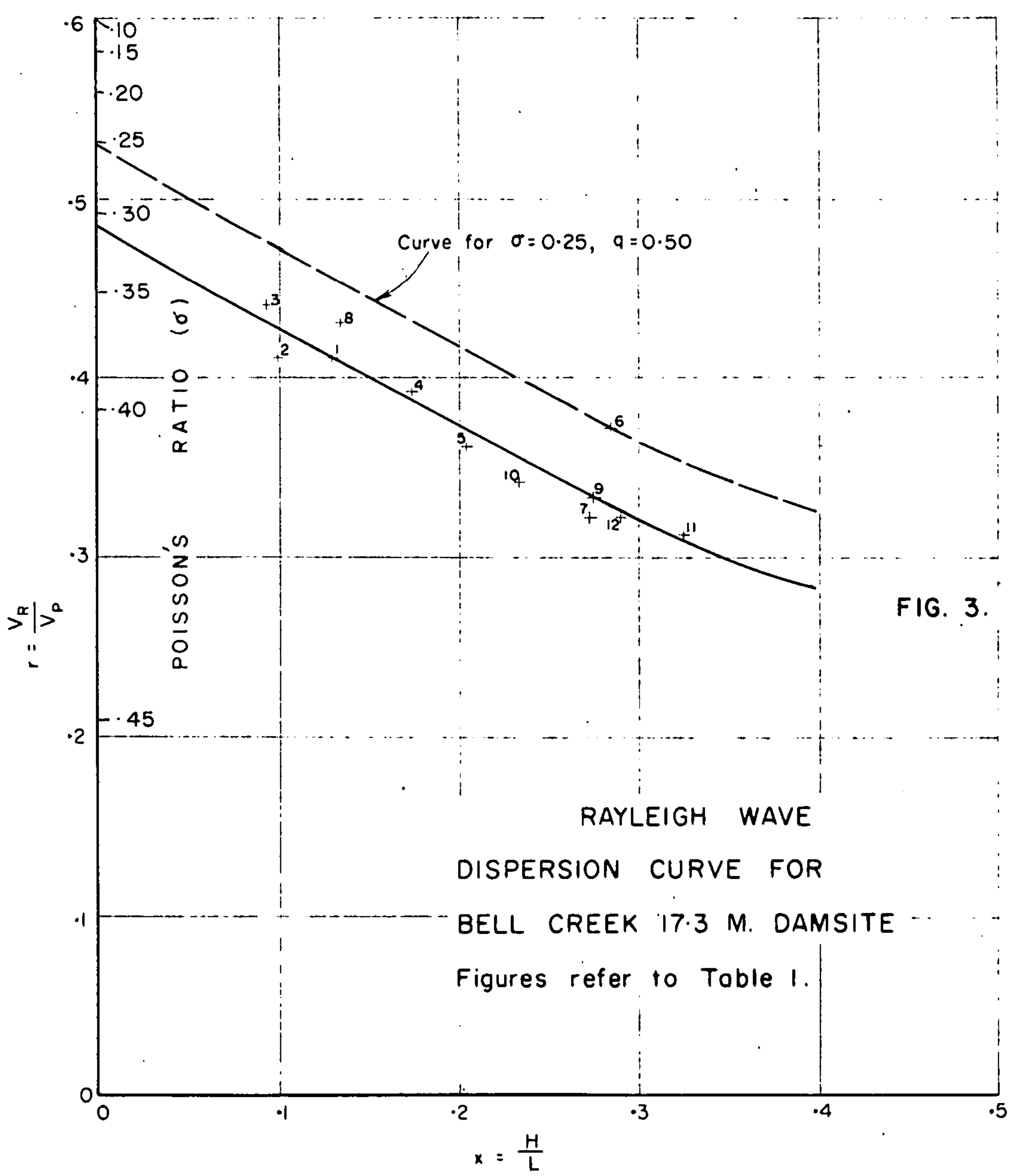
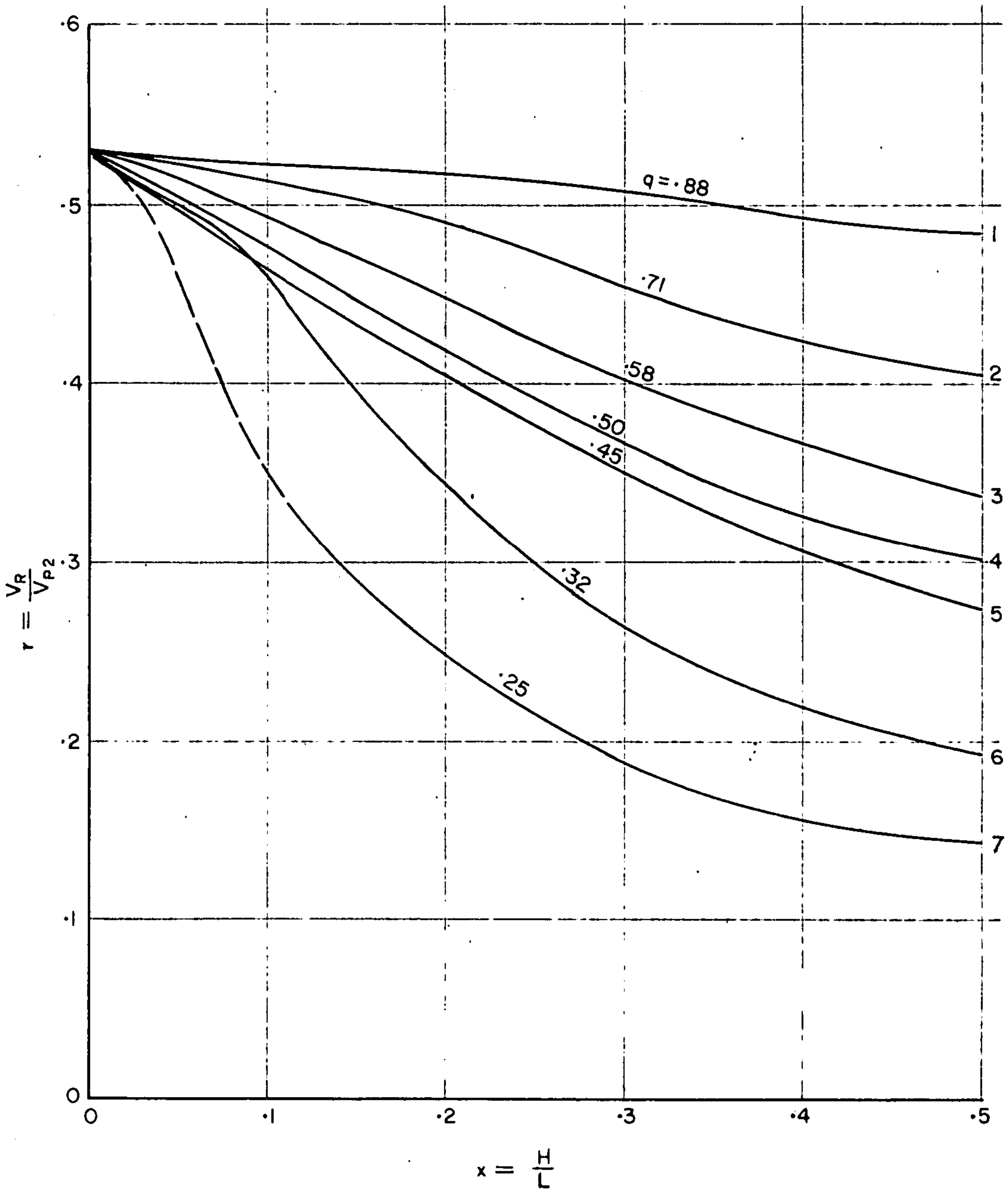


FIG. 3.

RAYLEIGH WAVE
DISPERSION CURVE FOR
BELL CREEK 17·3 M. DAMSITE
Figures refer to Table I.

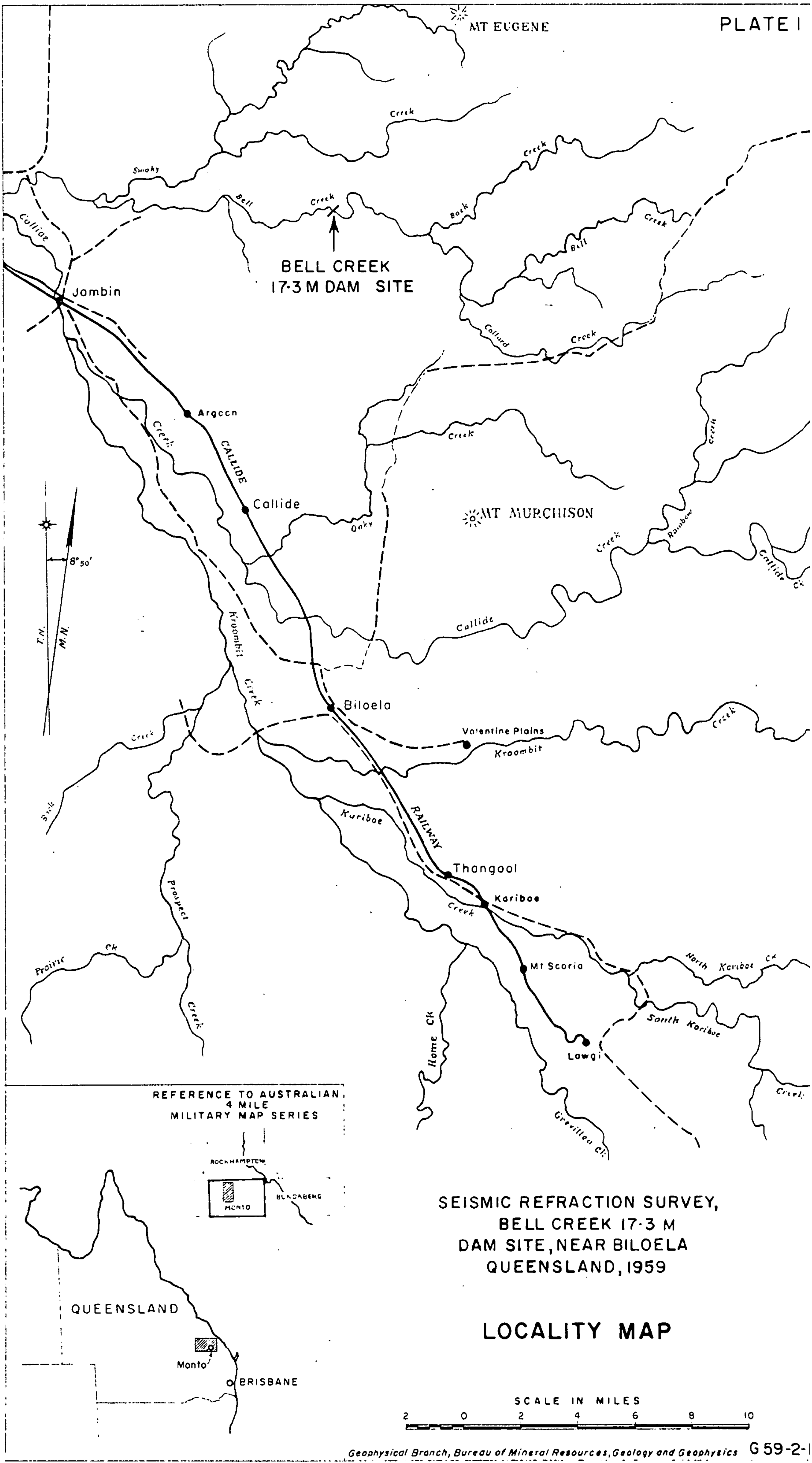


Curve No.	$q = \frac{V_{P1}}{V_{P2}}$	$p = \frac{\rho_1}{\rho_2}$	REFERENCE
1	·88	·92	LEE, 1934
2	·71	1·00	SEZAWA, 1927
3	·58	1·00	SEZAWA, 1927
4	·50	1·00	SEZAWA, 1927
5	·45	1·00	SEZAWA, 1927
6	·32	·72	LEE, 1934
7	·22	1·00	KANAI, 1951

FIG. 2

THEORETICAL RAYLEIGH WAVE DISPERSION CURVES.

PLATE I



SEISMIC REFRACTION SURVEY,
BELL CREEK 17·3 M
DAM SITE, NEAR BILOELA
QUEENSLAND, 1959

LOCALITY MAP

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics G 59-2-I

SEISMIC REFRACTION SURVEY,
BELL CREEK 17·3 M. DAM SITE,
NEAR BILOELA, QUEENSLAND, 1959

TRAVERSE LOCATION WITH OVERBURDEN ISOPACH PLAN AND CROSS- SECTIONS

(AFTER IWSC PLAN [illegible])