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RECORDS

RECORDS 1960 No. 97

BRIBIE ISLAND BRIDGE SITE SEISMIC REFRACTION SURVEY QUEENSLAND 1960

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ABSTRACT

This report describes a geophysical survey to determine the depth to certain geological formations in Pumicestone Channel, Queensland. The object of the survey was to provide data to assist in the design of foundations for a proposed bridge joining Bribie Island and the mainland.

The seismic refraction method was used; it showed that the average depth to rock suitable for the point bearing of piles is 62 ft below an arbitary datum which was 6.4 ft above the State datum.

Correlation of the seismic results with data from auger holes in the bed of the channel shows that the depths determined by the seismic method should be multiplied by a correction factor of (0.78 ± 0.11).

1. INTRODUCTION

At the request of the Co-ordinator General's Department of Queensland, a seismic refraction survey was carried out by the Geophysical Branch of the Bureau of Mineral Resources. The purpose of the survey was to provide information needed for the design of foundations of a bridge which the Queensland government proposes to build across Pumicestone Channel, between Bribie Island and the mainland. The position of the centre of the bridge, referred to the Army co-ordinate system, is 1637375 yds. north and 633155 yds east (Plate 1).

At the bridge site the width of Pumicestone Channel is about 2700 ft, the maximum depth of water below mean sea level is about 35ft, the maximum tide current is about 4 knots, and the difference in height between high and low tides during the Survey was about 4.5 ft.

The geophysical party consisted of W.A. Wiebenga, senior geophysicist, P.E. Mann (party leader), E.E. Jesson, and D.J. Harwood, geophysicists. The Co-ordinator General's Department made available two engineers, acting as surveyors, and two field assistants.

The survey took place between the 9th and 31st of May 1960. Preparatory work on the launches and equipment took 2½ days; geophysical work on the channel took 11 days, and on land, 2 days.

Forty seven water spreads and four land spreads were shot, using altogether about 230 No. 8 instantaneous electric detonators and 150 lb of AN 60 gelignite.

One geophysicist was continuously employed on the computation of results.

2. GEOLOGY

The geology of the bridge site (Watkins, 1960) is known from surface observations and from test bores in the vicinity of the site. (Plate 1).

Mesozoic sediments which outcrop at Toorbul Point are thought to extend under Pumicestone Channel and Bribie Island, but very little is known about their lithology or extent.

The test drilling indicates that the succession is largely sandstone with minor shale, mudstone, and a little coal. From a verbal communication with Dr. J.R. Watkins, it was learned that the beds have a north-easterly dip of between 5 and 10 degrees.

The geological investigations suggest that : -

(a) the recent sand and mud on the bed of the channel are too soft or too thin to support piles.

(b) the rock floor of the channel is probably mainly sediments ranging from shale to sandstone, and should be suitable for point bearing of the piles.

(c) the bedrock sediments are probably not highly weathered.

For the purposes of this report, "bedrock" is defined as the deepest seismic refractor detected. On spread 23, a deeper layer is detected below that called bedrock on adjacent spreads; in this instance the upper layer is called bedrock for continuity of the section. Throughout this report the word "dip" is used to mean the inclination of the refracting layer; this is not necessarily the same as the dip of the bedding planes.

3. METHODS

3.1 Seismic Method

The seismic refraction method was selected as the one most likely to give the depth to the various formations below the bed of the channel, and to suggest how consolidated they are.

In the seismic method an explosive charge, detonated below the surface of the water at the "shot-point", produces seismic waves. These waves are reflected and refracted at boundaries between the various subsurface formations, including the boundary between water and rock. The reflection and refraction of seismic energy at a boundary is governed by laws closely resembling those of optical phenomena, and depends on a contrast between the elastic properties of the materials either side of the boundary. For this survey, the refracted energy only was considered. If energy strikes a boundary at the critical angle, it will travel along the boundary, continuously transmitting energy back to the surface at the critical angle. In the present survey this energy was recorded at the surface by special detectors (geophones) which were floated in line at a specific spacing (the geophone spread).

The arrival time of the refracted energy, measured from the shot instant, is plotted for each individual geophone, against the horizontal distance of the geophone from the shot-point. The slope of each section of this "time-distance" curve is a measure of the velocity of seismic waves in the successive formation layers, and from this data it is possible to compute the depth to these layers.

3.2. Computations

The computation method used is the "Method of Differences" (Heiland, 1946, P.548). In this method if A is the shot-point at one end of a spread, the time taken for the energy to reach a point B within the spread is T_{AB} and to reach a point C beyond the spread is T_{AC}. Similarly when shooting from C the time for the energy to reach B is T_{CB}, and to reach A is T_{CA}. The energy paths from A to C and C to A are identical, and the times T_{AC} and T_{CA}, known as the "reciprocal times", should be equal.

The depth is computed from the vertical travel-time T_D which is defined as

$$T_D = \frac{1}{2} (T_{AB} + T_{CB} - T_{AC})$$

The depth D is then given by

$$D = V_a T_D$$

where V_a is a conversion factor representing the apparent velocity of the materials between the surface and the boundary under consideration, and allows for the energy paths not being vertical. On a water survey of this type, the use of geophones to measure the reciprocal times is not practicable owing to the tide current. Consequently the reciprocal time was found by extrapolation of the time-distance curves. Except in cases where the geophone spread drifted appreciably between shots, this method proved entirely satisfactory. When the spreads did drift (spreads 3, 7, and 10), the observations were not used for depth determinations.

Travel times must be corrected to allow for variations in the tide and the depth of shot. For convenience, the bottom of the water was used as a datum for computation purposes. On the seismic cross-section, however, the depths shown are related to an arbitrary datum which is about 9 ft above the mean low-tide level observed during the survey.

To correct the travel times to a water bottom datum, a correction

$$\frac{dws - ds}{Vw} + \frac{dwg}{Vw} \text{ is subtracted}$$

where

where	dws	is depth of water at the shot-point
	dwg	is depth of water at the geophone
	ds	is depth of shot
	Vw	is velocity of seismic waves in water, (i.e. 5000ft/sec).

3.3. Topographical Surveying

To locate the position of the geophone spreads, two surveyors set up their theodolites at each end of a known base line on the shore, and observed the bearings of points on the geophone spread, relative to the base line. The points observed were marker buoys at the ends of the geophone spread, and a marker buoy supporting the explosive charge. Bearings were measured at a pre-arranged signal from the recording boat.

4. EQUIPMENT AND TECHNIQUE

The seismic equipment used was a 12-channel Midwestern seismograph suitable for reflection or refraction surveys. It was mounted in and operated from a 33-ft launch. The geophones were of a velocity-sensitive floating type with a natural frequency of 20 c/s.

A 15-ft launch was used as a shooting boat. For transmission of the shot instant and for communications between the shooting boat and the recording boat, two Traeger type 51MA transceivers were used on a frequency of 2140 kc/s.

Owing to the tide currents, it was not practicable to work with the geophone spreads along the line of the bridge site. Consequently, the recording boat would anchor up stream from the site, with the geophone spread carried down by the tide behind the boat, so that the spread was approximately perpendicular to the bridge centre-line.

The shooting boat would then place and fire the shots at the down stream end of the spread. At the other end, the shots were placed from the recording boat by letting the tide carry them down from the boat to the required position where they were held in place by tension on the firing line.

The distances from shot to geophone spread were accurately calculated from the direct water-wave, which is indentified by its high frequency; for these calculations a value of 5000 ft/sec was assumed for the velocity of seismic waves in water.

Plate 1 shows the positions of the geophone spreads. In several places (e.g. spreads 22, 25, 34, and 35) the spreads are bunched closely together, and in other places gaps have been left. This distribution is due to the uneven tide currents dragging the cables and boats away from the desired position.

5. RESULTS

Plate 2 is a cross-section, along the centre-line of the bridge site, showing the results of the seismic work. The marked depths on the diagram are those determined for that point on each geophone spread nearest the bridge centre-line.

Throughout the survey an arbitrary elevation datum was used. Measurements showed that this was 6.4 ft above State datum. It was also 4.5 ft above mean high-level and 9.0 ft above mean low-level of tides observed during the survey.

Survey monument B_2, at the north-eastern end of the bridge site, is used as the zero point for distance measured along the bridge centre-line (see "horizontal distance" column, Plate 2). The cross-section will be considered in three parts:

(1) Between B_2 and 900 ft.

(2) Between 900 ft and 2200 ft.

(3) Between 2200 ft and the Toorbul end of the bridge site.

Part (1)

Between B_2 and 900 ft there are two layers below the channel bottom. The upper layer with an average thickness of about 30 ft has a seismic velocity of 5000 to 6000 ft/sec. The top of this layer rises steeply near the shore 250 ft from B_2. The test auger holes showed that this layer is composed of mud and unconsolidated sand and clay. Below this layer is bedrock, with a seismic velocity of 12,000 to 13,000 ft/sec. and average depth of about 55 to 60 ft; the auger holes showed that this is sandstone. The high seismic velocity shows that it is well consolidated and should be suitable for point bearing of piles. Both these layers are mainly flat bedded. On spread 50, a land spread at the north-east end of the bridge site, an additional thin layer is shown above the other two. Its low seismic velocity (1600 ft/sec) shows that it is sand above the water table.

Part (2)

In the second part of the cross-section, between 900 and 2200 ft, three layers are indicated below the channel bottom. The top layer, like that in the first part of the section, is composed of mud and unconsolidated sand and clay, and has an average thickness of about 35 ft. The intermediate layer, which was not found on the first part of the section, has a seismic velocity of 7500 to 10,400 ft/sec and a thickness ranging from 25 to 80 ft. The auger holes showed that this material is sandstone, which the seismic velocities show is hard enough for point bearing of piles.

The bedrock over this part of the cross-section has seismic velocities between 11,200 and 13,400 ft/sec; presumably it is a continuation of the sandstone bedrock on the first part of the cross-section.

At two places (1150 ft and 1800 ft) in this second part of the cross-section, the intermediate layer was not detected. As it was recorded on spreads adjacent to these two places, it may still be present but too thin to be recorded as "first arrival" energy (i.e. energy from other layers is arriving at the geophones first and masking the energy from this intermediate layer). A theoretical consideration (Leet, 1950) shows that for a 3-layer case with seismic velocities of 5000, 8000, 12,000 ft/sec where the top 5000 ft/sec layer is 30 ft thick, then the intermediate 8000 ft/sec layer must be at least 20 ft thick to be recorded as a "first arrival".

At the 1150 ft point the bedrock apparently rises in a sharp ridge. This may have resulted in the intermediate layer being completely pinched out, but more probably there is still a thin intermediate layer present.

At the 1800 ft point there is apparently a similar ridge in the bedrock. Here the intermediate layer is probably pinched out altogether. This is suggested also by the depths to the intermediate layer measured at the 1550 and 1650 ft points (53 ft and 62 ft respectively); if the line joining these points is extrapolated to the 1800 ft point it joins the upper boundary of the bedrock.

The upper boundary of the bedrock in this second part is rather irregular.

Part (3)

The third part of the cross-section, from about 2200 ft to the south-western end of the bridge site, shows three layers below the water bottom. The intermediate layer is between 27 and 40 ft thick and has a seismic velocity between 6000 and 7000 ft/sec. The test auger holes show that this layer is stiff clay which would be unsuitable for point bearing of piles. The bottom bedrock layer, which has a seismic velocity of about 10,500 ft/sec and whose upper surface is from 70 to 90 ft deep, is presumed to be a continuation of the sandstone bedrock on the other parts of the cross-section. This layer should be suitable for point bearing of piles.

On spread 23 a deeper layer is indicated at a depth of 124 ft with a seismic velocity of 14,500 ft/sec.

Spreads 48 and 51, which are land spreads on the south-western end of the bridge site, show a thin surface layer of seismic velocity 2000 ft/sec. Below this layer is a layer with a seismic velocity of 5500 ft/sec which corresponds to the unconsolidated sand and clay typical of the rest of the cross-section. The intermediate layer of stiff clay, in this third part of the section, thus tapers away to the south-west.

Except for a step between spreads 24 and 37, the bedrock in this third part of the cross-section has a north-easterly dip of about 8 degrees. This is the only part of the whole cross-section which confirms the 5 to 10-degree north-easterly dip described by Dr. Watkins.

General

Spreads 17 and 18 are not shown on the cross-section because they are too far from the bridge centre-line. The depths to the bedrock at the end of the spreads nearest the bridge centre-line are 105 and 100 ft respectively. Similarly spread 51, on the south-west bank, is not shown, but will be considered in relation to an adjacent test bore (see 6. Accuracy and Correlations).

The individual spreads show that generally, the dip in the direction of the spreads is less than about 3 in 100 (approximately $1\frac{1}{2}$ degrees). However, the dip is not consistent; on about half the spreads it is downwards to the north-west, and on the rest, downwards to the south-east.

Seven spreads show a dip greater than 3 in 100. These are spreads 9, 32, 37, and 42 with north-westerly dip of about 5 in 100, and spreads 11, 15, and 44 with south-easterly dip of about 7 in 100 (approximately 4 degrees). From the cross-section it can be seen that, with the exception of spread 44, the spreads with dips greater than 3 in 100 along the direction of the spread, are close to points where the cross-section shows similar changes in the attitude of the bedrock in a direction along the bridge centre-line.

The irregularities in the attitude of the bedrock both along and perpendicular to the bridge centre-line, suggest that the bedrock was subject to uneven erosion of the softer beds in the early stages of the channel's formation.

6. ACCURACY AND CORRELATIONS

The accuracy of the depth determinations is evaluated as follows: -

(a) Many of the spreads are closely bunched together in groups. Six of these groups of two or more spreads are examined to see how closely the depths indicated by the individual spreads agree with the mean value of the group. This gives an idea of the consistency, or relative accuracy of the calculated depths.

(b) The layer suitable for point bearing of piles is considered. The true depths to this layer (determined by auger drilling) are correlated with the depths calculated from the seismic spread(s) nearest to each auger hole. This gives an idea of the true accuracy of the calculated depths.

(a) Spreads 22, 25, 34, and 35 are closely grouped together; the individual values of depth to the intermediate layer differ from their mean value (54.5 ft) by $2\frac{1}{2}$, $2\frac{1}{2}$, 10, and $15\frac{1}{2}$ per cent respectively. For the bedrock, depths calculated from the first three of these traverses differ from their mean value (91 ft) by 1, 4, and 3 per cent respectively; no value was determined for spread 35.

Using the groups of spreads 22,25,34,35; 13,26,46; 12,20,30; 14,29,30; 1,43; and 5,6,41; and assuming that the average of a group of depth determinations gives the true depth for the group, the root-mean-square percentage error in individual depth determinations is $7\frac{1}{2}$ per cent, computed from 23 observations. The maximum individual depth error is $17\frac{1}{2}$ per cent; this is on spread 20 where the mean depth to bedrock in the group is 98 ft and the observed depth for spread 20 is 115 ft. This shows that the relative accuracy of depth determinations is good.

Even though the relative accuracy of determinations is good the true accuracy may be much less. This could arise if there were intermediate-velocity layers too thin to be detected; such layers could introduce more-or-less constant errors into all the determinations, through an error in V_a (see section 3.2 Computations).

Also, the boundaries between layers may not be sharp. More probably there is a gradual transition zone which would make depth determinations undertain.

(b) In the correlation between true depths to the layer suitable for point bearing of piles (from the auger holes) and calculated depth (from the seismic results) the ratio of auger depth to seismic depth was calculated for each hole. The mean value of this ratio was 0.78 and the root-mean-square error in this ratio was 0.11; that is: -

$$(\text{auger depth}) = (\text{seismic depth}) \times (0.78 \pm 0.11)$$

To check the validity of this empirical rule, consider spread 51, on the south-western end of the bridge site, which is close to a diamond drill hole (test bore No. 2). At a point on the spread near the hole the seismic depth to the layer suitable for point bearing of piles is 64 ft. Using the formula above, this gives the true depth as

$$64(0.78 \pm 0.11) = 50 \pm 7 \text{ ft.}$$

The log of the test bore shows a boundary at 49 ft. Above the boundary there is light grey/white fine argillacious sandstone, and below it there is light grey fine sandstone.

7. CONCLUSIONS

The seismic survey shows that there is rock suitable for the point bearing of piles at an average calculated depth of 62 ft along the centre-line of the proposed bridge site. The low values of dip measured along the individual geophone spreads shows that there is no major depth variation within 200 ft of the bridge centre-line.

Correlation of the seismic and auger data shows that the depths calculated from the seismic results should be multiplied by a correction factor (0.78 ± 0.11); the true average depth to suitable rock is therefore

$$62\ (0.78 \pm 0.11) = 48 \pm 7 \text{ ft}$$

8. ACKNOWLEDGEMENTS

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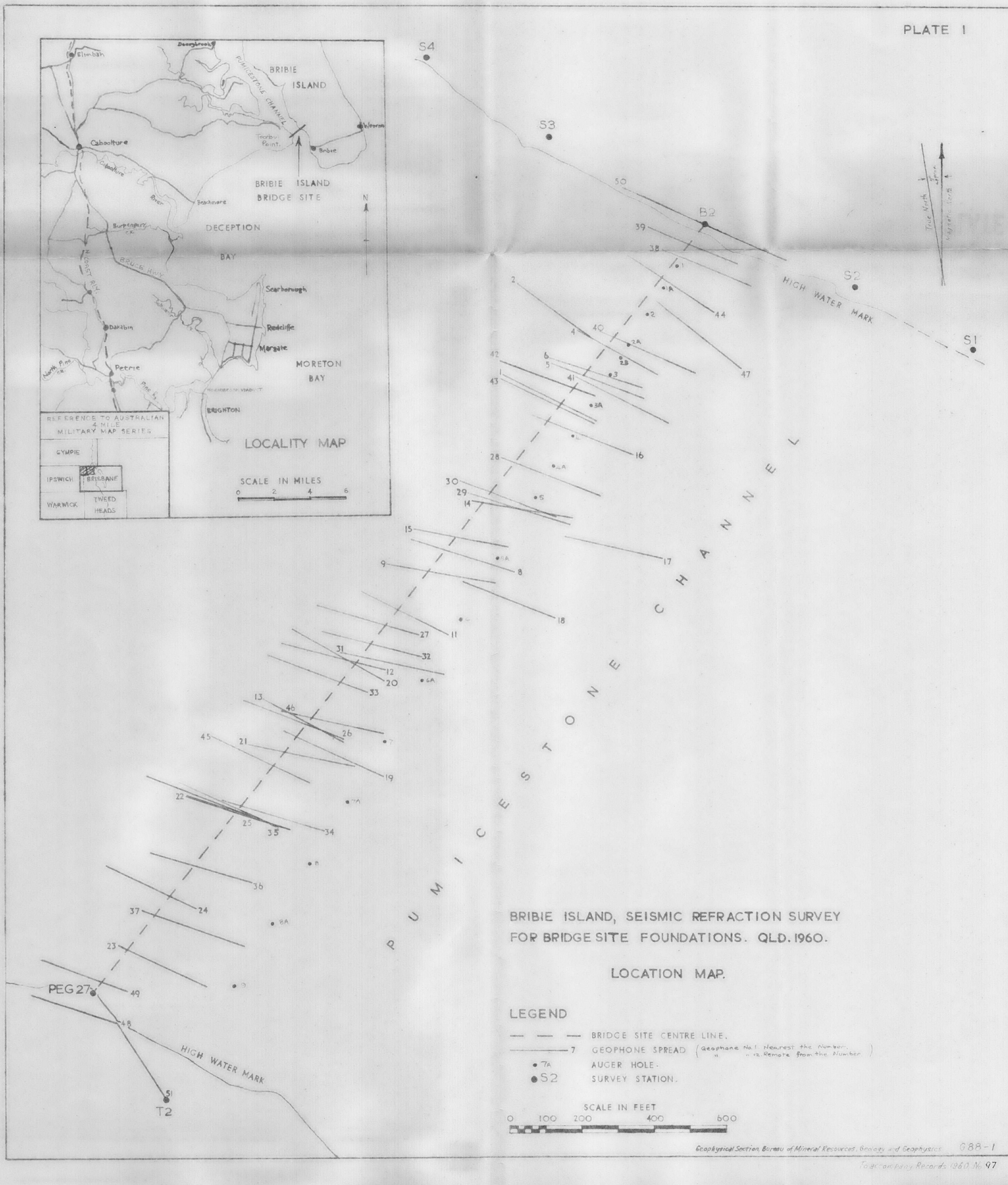
PLATE 1
BRIBIE ISLAND, SEISMIC REFRACTION SURVEY
FOR BRIDGE SITE FOUNDATIONS. QLD. 1960.
LOCATION MAP.
LEGEND
BRIDGE SITE CENTRE LINE.
GEOPHONE SPREAD
AUGER HOLE.
SURVEY STATION.
SCALE IN FEET
0 100 200 400 600
PUMICESTONE CHANNEL
HIGH WATER MARK
HIGH WATER MARK
S1
S2
S3
S4
B2
PEG 27
T2
True North
Magnetic North
LOCALITY MAP
BRIBIE ISLAND
BRIBIE ISLAND BRIDGE SITE
DECEPTION BAY
MORETON BAY
PUMICESTONE CHANNEL
Caboolture
Scarborough
Redcliffe
Margate
Petrie
BRIGHTON
SCALE IN MILES
0 2 4 6
REFERENCE TO AUSTRALIAN 4 MILE MILITARY MAP SERIES
GYMPIE
IPSWICH
BRISBANE
WARWICK
TWEED HEADS
Geophysical Section Bureau of Mineral Resources, Geology and Geophysics
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CORRECTION FACTOR:—
CORRELATION WITH AUGER HOLES GIVES
AUGER DEPTHS = SEISMIC DEPTHS X (0.78 ± 0.11).

LEGEND.

WATER BOTTOM.
ROCK BOUNDARY CONSIDERED SUITABLE FOR POINT BEARING OF PILES.
BOUNDARY BETWEEN LAYERS
10,000 SEISMIC VELOCITY IN FEET/SECOND
SEA WATER
INTERMEDIATE LAYER

BRIBIE ISLAND, SEISMIC REFRACTION SURVEY FOR BRIDGE SITE FOUNDATIONS. QLD. 1960

SEISMIC SECTION ALONG BRIDGE CENTRE LINE.

ARBITRARY REFERENCE DATUM 6.4 FEET ABOVE STATE DATUM.
4.5 " " MEAN OBSERVED HIGH TIDE.
9.0 " " " LOW "

HORIZONTAL & VERTICAL SCALE IN FEET.
0 50 100 200 300