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Selection of a Seismometer Site Macquarie Island

by

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PREFACE

by P. M. McGREGOR

In March 1948 the Australian National Antarctic Research Expedition (ANARE) established a permanent scientific station on Macquarie Island (Latitude 54°30'S, longitude 158°59'E). The Bureau of Mineral Resources (BMR), as a member of ANARE, became responsible for observatory programmes in seismology and geomagnetism.

Macquarie Island comprises a plateau, connected by a low lying isthmus to the rocky mass of Wireless Hill-North Head. The plateau is the main bulk of the island rising abruptly from the Southern Ocean. Level sites suitable for building a station and safe anchorages are scarce, and the north end isthmus is the only place where both are available together. Therefore the ANARE station was built there, as was Mawson's 1911-1915 base.

The nearest accessible bedrock to the station was on the southern slopes of Wireless Hill, and during 1948 and 1949 an excavation was made into the hillside, about 20 metres above sea level, where a concrete seismometer vault was erected. Two Wood-Anderson horizontal seismometers and a recorder were installed, and continuous recording commenced in 1950. Records have been obtained from that station ever since.

The island is well placed to record local and regional shocks. It lies on the submarine ridge, which extends south westwards from New Zealand, and which meets the Indian-Antarctic Ridge about 800 km to the south. In common with all others, this submarine ridge is a zone of minor, but important, earthquakes; on average three are felt each year on the Island. The current interest in 'plate tectonics' enhances its value, because it is near the junction of three plates: the Antarctic, Pacific, and Indo-Australian.

Unfortunately the original seismograph vault is a poor site for the operation of modern short-period instruments which could detect and help locate many weaker events not recorded by other stations. The vault is only a few metres from the sea to the east and the west, and high background noise occurs, because of the almost constant high winds and seas to which the island is exposed.

Attempts to operate high-gain seismographs were made in the 1950s and 1960s, but the instruments were removed at various times for re-location at other observatories where their potential could be realized. By 1968, only a vertical Willmore system was left.

With the development of reliable telemetry systems during the 1960s, the possibility arose of operating a seismometer at a site some distance from the ANARE station. Therefore a program was initiated in

1967 to determine whether a significantly quieter site existed on the island. Because the island is no more than 5 km wide, the search was confined to Wireless Hill, the isthmus, and the northernmost 3 km of the plateau.

The search for the site, as described in this report, ended in 1970 when one giving a 3:1 reduction in background noise was found. Initial steps to develop it were taken during the 1970/71 summer, and it is planned to install a vertical seismometer in 1972.

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SUMMARY

Seismological recording has been in progress at Macquarie Island, since 1950. Choice of the seismograph site was severely restricted by logistic problems, and that selected is marred by generally high background noise. As a result many of the weaker regional earthquakes are recorded poorly or not at all.

With the recent advent of reliable telemetry systems, the possibility arose of operating a seismometer at a remote site with lower background noise. The search for a quieter site was begun in 1967 and completed in 1970 when a site on the main plateau was located about 3 km from the ANARE station; at the site the noise level is about one-third that at the original vault. This site will be developed over the next few years.

1. INTRODUCTION

Recording of earth tremors at Macquarie Island has, since the installation of the seismic station in 1950, been subject to heavy microseismic interference. Situated amidst the open expanse of the Southern Ocean, the island is exposed to continuous seas and frequent gales, both of which arrive generally from the west. These wind and sea movements are the main factors in the generation of microseisms on the island.

Both north to south, and east to west horizontal ground motions were recorded by a short-period Wood-Anderson system from 1950 until 1956, when a Grenet vertical seismometer was added to provide clearer observations of compressional wave P phases. This system was replaced in 1961 by a three-component Benioff seismograph. In 1962, the two horizontal seismometers and the recorder were transferred to Mawson, and in early 1963 a BMR recorder was installed in conjunction with the remaining vertical Benioff short-period seismometer. This operation continued until 1967, when the Benioff seismometer was replaced by a Willmore Mk I.

During 1967 a program of site testing began in an effort to find a position where the microseismic noise level was low enough to warrant the establishment of a new seismometer site. The criterion laid down was that the noise level at the site was to be not more than one-half that at the original vault.

The existing seismological station (1970) is situated on the southern face of Wireless Hill, at the northern end of the isthmus upon which the ANARE station has been built (Plate 1). The island proper is a large undulating plateau about 40 km by 3 km with average elevation of 300 metres and lying roughly in a N-S direction. It can be considered a visible extension of the seismically active sub-oceanic ridge running from New Zealand towards the Antarctic continent.

The predominant rock types are ultramafic gabbro, dolerite, basalt, etc. Delineation of structural features has been severely limited by heavy weathering, and in places by a thick covering of vegetation and alluvium.

Wireless Hill is a highly weathered rock mass rising to a maximum height of 100 metres. At some stage it was probably separated from the plateau by the sea. During this time the wave-cut isthmus was formed; it is now covered with alluvium and vegetation.

In 1967, tests were made at three sites on Wireless Hill close to the vault (Major, in prep.). These showed no reduction in noise level compared with the normal seismometer position in the vault.

Connelly made further tests in 1968 at eight sites on Wireless Hill and the central isthmus. He found some improvement in several places, but not sufficient to warrant further development (Connelly, 1971).

The isthmus was fully surveyed by McCue during 1969, when he tested ten sites between Tent Hill and Wireless Hill. Noise caused by radio frequency pickup was experienced close to the base radio transmitter aerials. The isthmus was shown to be unsuitable owing to surf noise and local noises caused by wind-blown vegetation, animal movements (particularly seals), and camp activities (tractor etc.). McCue also conducted nine tests on the plateau in an area north of a line joining Eagle Point and Nuggets Point (Plate 1). The survey area was restricted to the north of this line, because of logistical problems to be considered in the establishment of any future chosen site. These include limits on:

(a) Length of telemetry cable available.

(b) Manpower transportation of materials.

(c) Availability of on-site concreting materials.

McCue's tests were made more arduous by the availability of only one seismometer, necessitating the return of the remote seismograph to the vault for control recording after each day's testing. One good site was found where the noise level was nearly 60 percent less than at the vault. Time lapses between plateau recording and vault recording prevented a definite conclusion being reached on the selection of this site (McCue, 1971).

A second seismometer (Willmore Mk II) was made available during 1970, and this enabled the Mk I to be used for remote recording simultaneous with recording in the vault. Thus direct comparisons of plateau sites and the vault were possible. The techniques employed will be discussed presently. Nine plateau sites were chosen by the author in 1970; the sites were designated 70 P1 through 70 P9. However, 70 P2 was abandoned early in the testing program, because it was prone to severe flooding. Three of the other eight were selected for thorough testing in order to establish the best possible site within the operational area.

2. EQUIPMENT AND PROCEDURE

Equipment taken into the field for each test comprised:

(a) Willmore Mk I seismometer (T = 1.0 s).

(b) BMR operational amplifier.

(c) Esterline-Angus clockwork drive paper chart recorder, accessories, and chart paper.

(d) Twin core insulated cable (15 metres).

(e) Assorted tools, first aid kit, and rations.

(f) Foam rubber padding and plastic sheeting for instruments.

This equipment was carried in a waterproof back-pack mounted on a light steel pack-frame, and with digging tools and extra waterproof clothing weighed about 30 kg.

The vault seismograph consisted of:

(a) Willmore Mk II seismometer (T = 1.0 s).

(b) Benioff galvanometer (T = 0.2 s).

(c) BMR recorder with chart speed of 30 mm/min.

Three factors influenced the decision to use any particular day for field testing on the plateau:

1. The magnetic conditions which determined the days on which the writer was required to make observations of the magnetic elements (normally twice a week).

2. Weather conditions - normal requirements for a good microseismically active day were:

   (a) a local gale during actual testing, or -

   (b) a strong easterly sea swell (usually produced by a 'southerly change' where the wind veers from the west to east to west again, or -

   (c) a strong westerly sea swell formed immediately after a gale. This swell quite often bands around North Head and forms a large east coast surf as far south as Nuggets Point.

3. Other station duties, e.g. 'slushy'.

The decision to test was made each morning after examining the newly processed magnetic and seismic records which showed the activity of the previous 24 hours. After making a calibration recording at the vault on the field seismograph (the two seismometers effectively on the same spot) the first plateau site was usually reached between 1 p.m. and

2 p.m. depending on distance and weather conditions. As most testing took place between July and September, and Macquarie Island local standard time is UT + 12 hours, the daylight hours available for field tests were between noon and 6 p.m.

An average of 2 to 4 sites could be tested per day depending on:

(a) distance between sites ≏ up to 2 km.

(b) instrument difficulties - such as loose or broken cables and connectors, penetration of instruments and connectors by water, broken seismometer spokes owing to metal fatigue caused by repeated clamping of the mass, broken or unbalanced pen elements.

(c) weather conditions - tests were carried out in winds up to 60 knots and in varying degrees of precipitation including fog, rain, sleet, hail, and drift snow. Best conditions existed on dry days with good surf on either the west or east coast.

3. SURVEYS

Reconnaissance survey

Between 17 July and 20 August, 15 tests were made at the 8 sites within the operational area. Seven vault calibrations were completed in this period by running the field and fixed seismographs simultaneously in the vault and obtaining a conversion factor to equate microseism amplitudes. This was done by scaling amplitudes on both records at five second intervals.

At each site a hole was dug to an average depth of 45 cm, the seismometer was wrapped in protective plastic, and then partly buried in a vertical position. After unclamping and testing for freedom of mass movement, the seismometer was completely buried under compacted earth brought flush with the surface. The recording apparatus was placed to the leeward of the site and tests were made for signal strength and damping. The observer usually remained motionless at the site and placed control time marks on the records (correct to a few seconds), or else moved away during exceptionally cold weather to keep warm and prepare future sites.

Final survey

Three sites (70/P3, 70/P5 and 70/P7) were chosen from the original eight after analysis as detailed below. These were then standardized by embedding a four-gallon steel drum with both ends removed in several cm of concrete at a depth of a metre, so that the top was about 30 cm below the surface. During each test the seismometer was placed on the level concrete base and the drum was covered by a hardwood slab so that it could be completely covered by compacted rock and soil (see Plate 2).

After construction of the standard pits, a series of detailed tests was made on the three sites between 21 August and 4 September.

Every endeavour was made to complete a set of tests at the three sites each day so that if the noise level at the vault was excessive, direct determinations of the noise ratios between the sites could be obtained. However, this was necessary on only one occasion.

Six such sets were completed with vault calibrations done before and after the survey. To save time and enable completion of the three tests each day, the field equipment was stored in a small hut at the edge of the plateau, unless instrument failures necessitated its return to camp.

After each day's testing, the anemographs were studied in the meteorological office and hourly wind speeds and directions were listed and compared with personal estimates noted on the plateau. Wind speeds at plateau level were obtained from interpolation of the six-hourly balloon soundings. These indicated that plateau wind speeds were usually up to ten knots higher than isthmus wind speeds. This was confirmed by personal estimates. The condition of the sea was noted before and after field work.

4. RESULTS

Scaling of both field and vault records was a long and tedious process and to allow more time for normal observatory duties sites were elimated by the following method:

(a) During the reconnaissance survey noise levels at the sites were composed directly by making tests at 2 or 3 sites on one day.

(b) By inspection, it soon became obvious which sites were the most promising, and detailed site/vault analyses were done on records from them in the same way as the calibrations were made. Table 1 shows typical results obtained from the two best sites under varying conditions of wind and sea:

Table 1

SITE	WIND SPEED (KNOTS)	WIND DIRN.	SEA COND. (WEST)	SEA COND. (EAST)	SITE/VAULT NOISE RATIO
70/P3	20 - 30	W	Moderate-Rough	Slight	0.6
70/P5	20 - 30	WNW	Moderate-Rough	Slight	0.4
70/P3	50 - 60	W	Rough	Moderate	0.8
70/P5	50 - 60	W	Rough	Moderate	0.6

Further tests and analyses were done on 70/P3, because of the site's advantage in being closer to the station area than 70/P5 was. Promising results were obtained, although conditions were not severe (see Table 2).

Table 2

70/P3	0 - 5	S W	Rough	Slight	0.4
70/P3	5 - 10	S W	Slight	Moderate	0.3

These results indicated that although the 70/P3 to vault noise ratio was close to the required limit of 0.5, a careful set of tests comparing 70/P3 and 70/P5 under more standardized site conditions was warranted. It was believed that part of the cause of higher noise levels at 70/P3 could have been the ground conditions which were:

70/P3 - compact clay and boulder, damp, and surface nearly level with very low clumpy moss-like vegetation.

70/P5 - hard compact, but highly fractured in situ rock, dry and relatively level surface, but with a few low rock outcrops.

These different ground conditions probably reacted in different ways to surface winds. The wind flow over the two sites was noted by observation of fog movements on days when the plateau was enveloped by heavy cloud, and in general it was smooth and even.

In the detailed survey, a third site 70/P7 was included in the daily sequence of tests. It was chosen mainly because of its very smooth wind flow characteristics. It lies on a saddle between Boot Hill and North Mountain where prevailing westerly winds are smoothly funnelled through to the east. First tests on this site were promising. However, the ground consists of glacial clay which at that time was dry, but after a thaw the surrounding hills discharged a vast amount of water, and this site eventually became flooded and had to be abandoned.

The results of six sets of tests at sites 70/P3 and 70/P5 are given in Table 3:

Table 3

SITE (SEE MAP)	WIND SPEED (KNOTS)	WIND DIRN	SEA COND. (WEST)	SEA COND. (EAST)	SITE/VAULT NOISE RATIO
70/P3	10 - 20	NW to W	Slight - Moderate	Slight	0.6
70/P5	20 - 30	NW to W	Slight - Moderate	Slight	0.4
70/P3	10 - 20	W	Slight - Moderate	Slight	0.2 *
70/P5	10 - 20	W	Slight - Moderate	Slight	0.3
70/P3	20 - 30	WSW	Slight - Moderate	Slight	0.3
70/P5	20 - 30	WSW	Slight - Moderate	Slight	0.3
70/P3	20 - 30	NW	Moderate - Rough	Slight - Moderate	0.3
70/P5	20 - 30	NW	Moderate - Rough	Slight - Moderate	0.4
70/P3	20 - 30	WNW	Rough	Moderate - Rough	Direct Comparison
70/P5	20 - 30	WNW	Rough	Moderate - Rough	P5/P3=0.7
70/P3	40	NW	Moderate - Rough	Slight	0.5
70/P5	40	NW	Moderate - Rough	Slight	0.5

* Results suspect

5. CONCLUSION

The following factors had to be considered when deciding which site was to be chosen for development:

1. Site/vault noise ratio in relation to the stipulated limit of 0.5 under usual conditions.
2. Distance from isthmus and amount of cable available.
3. Limits on manpower and time for developing the site.
4. Explosives requirements.
5. Depth to bedrock.
6. Availability of on-site concreting material.
7. Drainage.

A comparison of sites $70/P_3$ and $70/P_5$ is given in Table 4:

Table 4

	$70/P_3$	$70/P_5$
SITE/VAULT RATIO	<0.5 under average conditions	<0.5 under all conditions
DISTANCE TO BASE	1.6 km	3 km
WIND FLOW	Exposed but smooth	Relatively sheltered but smooth
GROUND	Glacial boulder and till - bedrock not reached	Compact fractured rock
DRAINAGE	Fair	Good

This shows that site $70/P_5$ met the technical and logistic requirements, and it is recommended for development as a seismometer site.

6. REFERENCES

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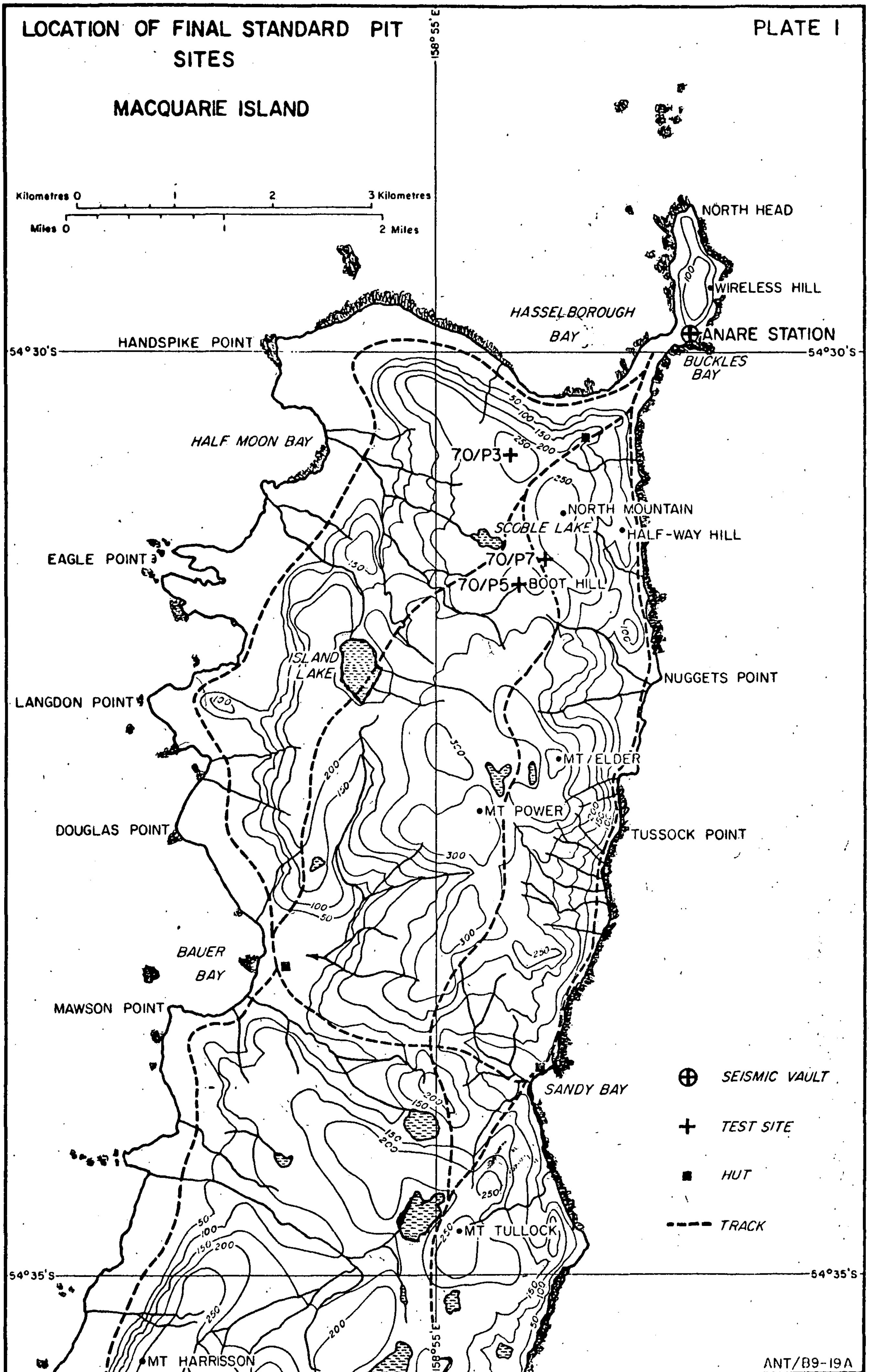

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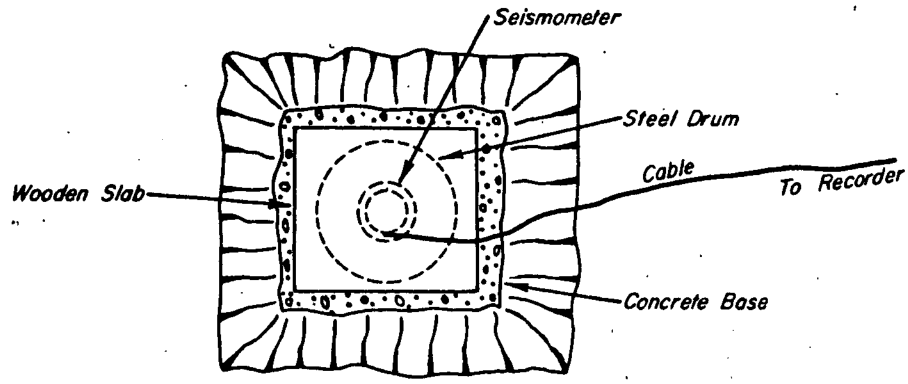
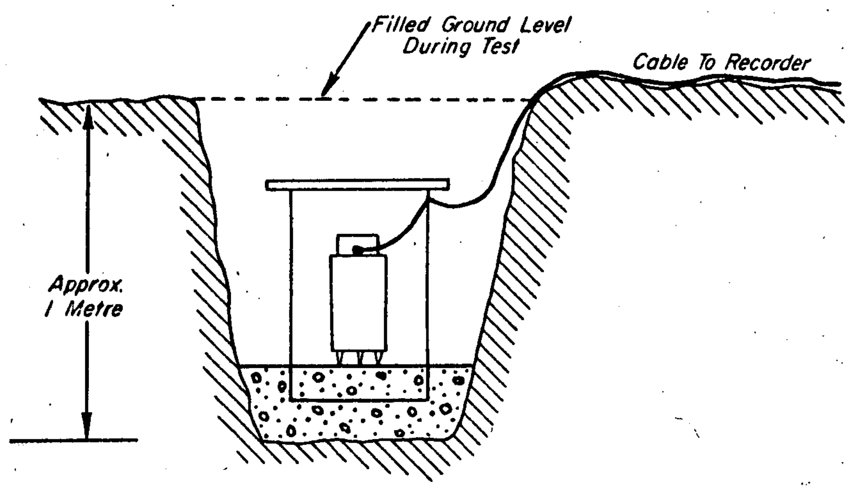


PLAN
(Open Pit)



SECTION
(Open Pit)

STANDARD SEISMOMETER PIT CONSTRUCTION

(MACQUARIE ISLAND)