Preliminary Geological and Foundation Investigations for a Nuclear Power Station at Jervis Bay, N.S.W.

By

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SUMMARY. The investigation to determine the optimum site location for the power station is described in this report. The work has included geological mapping, land and marine geophysical surveys, auger and diamond drilling, water pressure testing, field ripping tests and laboratory testing of samples. In addition it has been necessary to evaluate the possible seismic risk as a result of fault movement in the area.

The paper demonstrates how the various techniques contribute to an understanding of the geology of the area and shows the limitations of certain methods of investigation. This work has resulted in the selection of the area with the highest quality foundation material as the preferred site and has enabled a comparison to be made of different circulating water arrangements. The engineering properties of the rock are discussed in relation to the possible effect of loading by the station structures.

I. INTRODUCTION

In 1969, the Australian Atomic Energy Commission sought the assistance of the Electricity Commission of New South Wales to investigate sites suitable for the construction of a nuclear power station in Commonwealth Territory on the south-eastern shores of Jervis Bay. After the examination of several possible sites, work was concentrated on an area close to Murrays Beach. This paper describes the geological and geophysical investigations which have been carried out in order to determine the site with the optimum foundation conditions for the station and also to compare the geological aspects of the possible circulating water configurations which have been proposed. It is emphasised that this has been a preliminary study and further detailed work will be required for design.

II. TOPOGRAPHY

The area chosen for detailed investigation is located on the east coast of New South Wales about 120 miles by road south of Sydney (Fig. 1). Murrays Beach is situated immediately west of Governor Head which, with Bowen Island, forms the southern entrance to Jervis Bay. The site lies on the northern shore of the Bherwerre Peninsula which constitutes the Commonwealth Territory, Jervis Bay. The peninsula is dominated by a north-west/south-east trending ridge covered by low scrub and reaching an elevation of 550 feet above sea level. This ridge is flanked on either side by lower country which is densely wooded.

Murrays Beach is a small inlet about 1500 feet wide formed in the sheltered area west of Governor Head and south-west of Bowen Island. To the west and south-west of the beach the ground gradually rises to an elevation of 90 feet above sea level. This wooded area has been chosen as the proposed site. Between the site and the Tasman Sea lies a north-south trending ridge which reaches a height of 205 feet with cliffs averaging 130 feet in height on the ocean side.

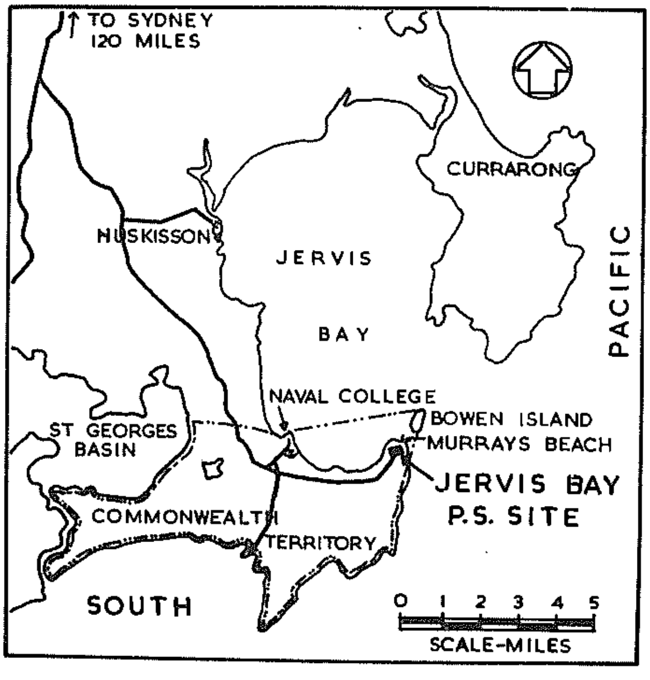

Fig. 1
Location of Power Station Site, Murrays Beach

III. REGIONAL GEOLOGY

Jervis Bay is located on the southern side of the Sydney Basin, which is composed of rocks of Permian and Triassic age. The Bherwerre Peninsula is underlain by a thick series of medium to coarse grained sandstones which are considered to belong to the

Permian Conjola Formation. In the area the Conjola Formation is believed to have a thickness of about 1400 feet (Ref. 1). With the exception of deposits of recent dune sand and soil, the Conjola Formation sandstones are the only rock-types which have been recognised close to the station site.

In the Jervis Bay area there is superimposed on the general structure of the Sydney Basin a series of broad folds. An anticlinal axis forms the south-east trending ridge along the centre of the Bherwerre Peninsula and another anticline follows the east coast.

IV. PREVIOUS INVESTIGATIONS

The first geological study of the Commonwealth Territory, Jervis Bay, was carried out by Perry & Dickins (Ref. 2) and Twist (Ref. 3) has reported on a reconnaisance study of the Nowra-Jervis Bay area. Jackson (Ref. 4) has examined the engineering geology and economic resources of the Territory. Prior to the investigation at Murrays Beach, work was carried out by the Electricity Commission of New South Wales on a site at Scottish Rocks about one mile south-west of the Murrays Beach site (Ref. 5).

V. FIELD INVESTIGATIONS

Rock exposures in the area of Murrays Beach are limited to outcrops along the coast and a few rocky knolls protruding through the sandy overburden on the ridge to the east and south of the site. Geological mapping of all accessible outcrops was carried out on a scale of 1:1200. The cliff-forming coastline south of Governor Head was mapped from the sea as part of the investigation of the geological structure of the area (Ref. 6).

In order to determine the level of bedrock in the proposed station area and to give an indication of the relative properties of the sub-surface materials, a seismic survey was carried out by a geophysical party from the Bureau of Mineral Resources led by E.J. Polak and P. Hill. This survey used two 24-channel seismic refraction sets with a 10 foot geophone spacing (Ref. 7). Seismic traverses were in general at a spacing of 200 feet.

The nature of the materials underlying the floor of Jervis Bay west of Murrays Beach was examined by a marine sparker survey carried out by Messrs. Carter, Albani and Johnson of the University of New South Wales.

A total of 49 N-size diamond drill holes supported by 67 auger holes to refusal have been drilled in the Murrays Beach area. The location of these holes was based on the results of the geophysical surveys, possible location of proposed structures and specific geological problems which emerged during the investigation. In overburden and unconsolidated material too weak to core, standard penetration tests were carried out at regular intervals and in rock several holes were water pressure tested in order to determine joint tightness and the extent of possible water inflows into excavations. All cores were logged in detail and photographed in colour.

A bulldozer was used in conjunction with a single channel engineering seismograph to estimate the depth of rippable material in the station area.

Several possible sources of construction materials were examined as a result of a survey by the Geological Survey of New South Wales (Ref. 8).

VI. LABORATORY INVESTIGATIONS

At an early stage of the investigation, photogeological interpretation of the area was carried out using both black and white and colour aerial photographs. Selected core samples were petrographically examined with special emphasis placed on their engineering properties and core samples were tested for their resistance to simulated accelerated weathering, unconfined compressive strength and sonic velocity. The elastic moduli of several samples were determined by the laboratory of the School of Civil Engineering, University of Sydney. Some limited testing of soil samples was carried out.

VII. SITE GEOLOGY

(a) Lithology

The field and laboratory investigations revealed that the geology of the area around Murrays Beach is essentially simple, consisting of a series of sandstones and silty sandstones dipping to the north-west at 3° to 4° to the horizontal. Although the rocks all belong to the same formation, they can be divided for the purpose of this investigation into three horizons which have been called the Upper White Sandstone, the Intermediate Grey Silty Sandstone and the Lower Light Grey Sandstone. The bedrock is overlain by sand, some of which is derived from the underlying rocks and the remainder is dune sand. Over most of the area the average thickness of sand is 10 feet but south of Murrays Beach up to 69 feet of sand was encountered. The greater depth is thought to be due to the decomposition of the silty sandstone bedrock where it is close to and above sea level.

The Upper White Sandstone is exposed along the shoreline west of Murrays Beach and forms the upper section of the cliff at Governor Head. The top of the band has not been recognised but the greatest thickness encountered was 69 feet. The sandstone is almost pure white containing 80-90% of quartz. In some places 10-20% of fine dark interstitial material in the rock close to the base of the formation has produced a buff colour. The quartz grains form an interlocking mosaic and consolidation has been achieved by pressure welding - a slight recrystallisation of the grains along their boundaries under pressure. The uniform size and shape of the quartz grains has produced a rock with poorly developed bedding. The rock tends to be friable and the rounding of sharp corners by wave action has produced a characteristic knobbly weathering pattern close to sea level. The contact between the Upper White Sandstone and the underlying rocks is exposed in the cliffs south of Governor Head and this contact was also located in 25 of the diamond drill holes. Stratum contours of this contact are given in Figure 2. In most cases the contact is quite sharp with a distinct change in colour from white or buff to mid-grey accompanied by a general decrease in grain size.

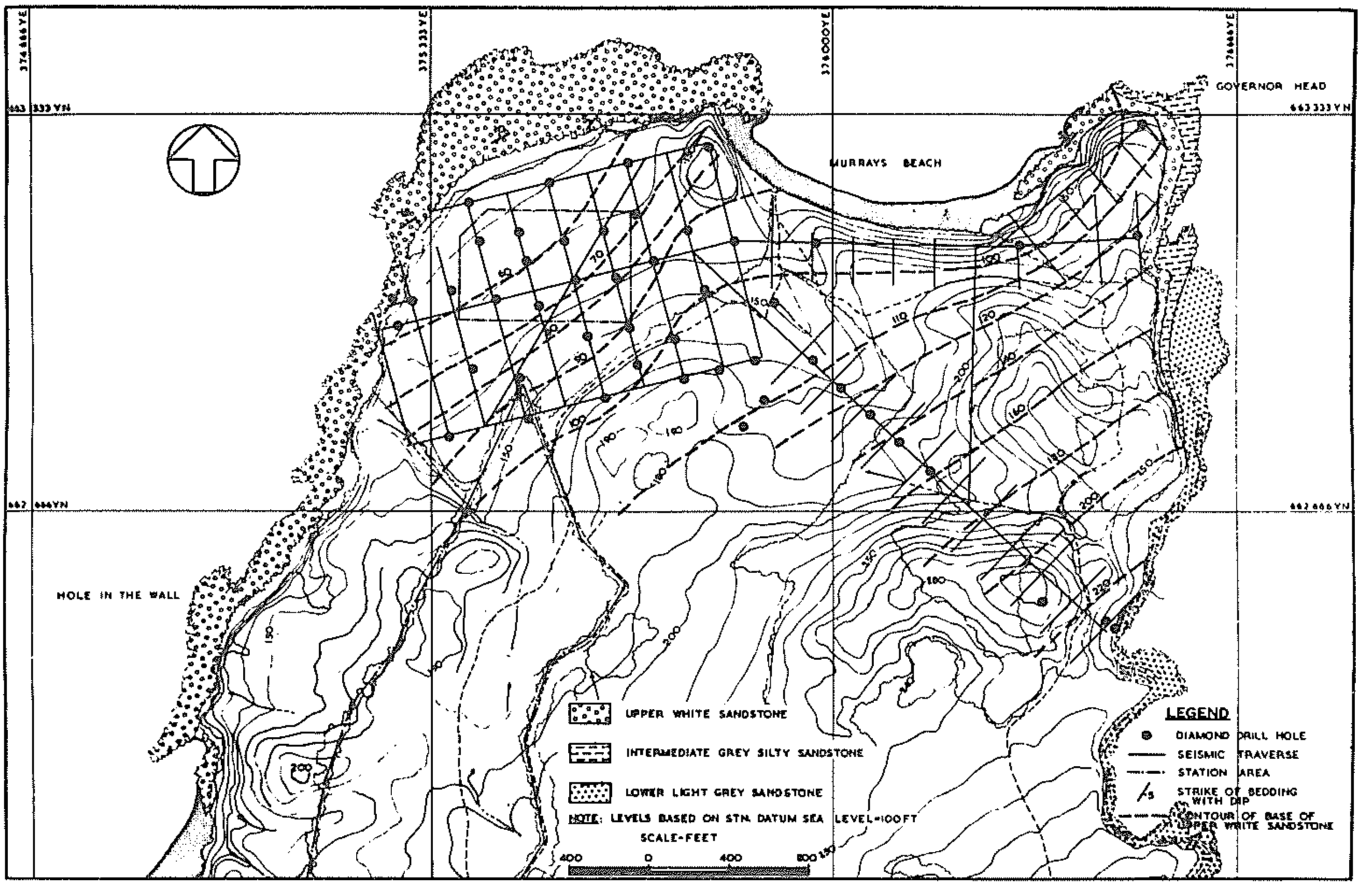

Fig. 2
Location of Site Investigation and Simplified Geology

In the cliffs south of Governor Head, the Upper White Sandstone is underlain by a massive mid-grey coloured, medium-grained silty sandstone band. This band has also been located in 34 diamond drill holes. Where the contacts above and below this stratum were recognised the thickness of the band ranges from 29 feet to 56 feet. The Intermediate Grey Silty Sandstone generally contains a higher silt content than the sandstones lying above and below, but there is considerable variation within the band with the content of clay minerals ranging from 10-70%. This band ranges in colour from light grey to dark grey and obviously represents a period of deposition in which there were some variations in local conditions. Petrographic examination shows that the quartz grains are separated by clay minerals. Although these minerals (kaolinite and illite) have low expansive properties, the band is not strong and loose blocks of silty sandstone disintegrate rapidly.

The base of the cliffs at Governor Head and most of the cliffs on the ocean coastline to the south are made up of a light grey, medium to coarse-grained sandstone which underlies the Intermediate Grey Silty Sandstone. The thickness of the Lower Light Grey Sandstone is not known but at least 150 feet have been penetrated in drilling. The rock is uniform, light to mid-grey in colour with large scale banding more strongly developed than in the other rocks. These rocks contain up to 10% of alkali feldspar and 15% of iron oxide minerals. The presence of the feldspar and the iron has resulted in a much stronger bond between the individual grains and also a strong matrix. Some pressure welding is also evident.

(b) Structure

The uniform nature of the rock types has resulted in poorly developed bedding over most of the area. However, on the cliffs where the rocks have been exposed to weathering, the bedding planes are more prominent. On Bowen Island, there is uniform dip to the west of 2^{o} to 3^{o}, while south of Governor Head the westerly dip increases to 15^{o} and then decreases to an anticlinal crest about 1.4 miles south of Governor Head. Beyond the crest, the sandstone dips to the east and at Steamers Beach the anticlinal axis is again found.

The proposed station area is therefore on the western limb of an anticline whose axis trends north-east. In the drill cores bedding is not well developed but, by plotting the levels of the contacts between the rock types, the general bedding attitude shows a general north-westerly dip of between 3^{o} and 6^{o} to the horizontal. Some very gentle subsidiary folding may be present.

Widely spaced high angle jointing is developed throughout the Bherwerre Peninsula. The joint directions indicated on the aerial photographs and measured on the ground in the Governors Head/Murrays Beach area show azimuth maxima between 325^{o} and 025^{o}

and between 065° and 115°. Joints are normally tight with no infilling. No extensive area of close jointing was located by the drill holes.

The Ulladulla 1:250,000 geological map shows the geological structures on the south-western side of Jervis Bay to be truncated by a major fault which crosses the ocean coastline about one mile south-east of the proposed station site. In order to assess the significance of this fault and associated fractures on the proposed station site, a detailed examination was made of the faulting in the area (Ref. 6). This study found that, although a number of faults can be recognised in the cliffs south of Governor Head, the fault planes are narrow, the displacement along individual faults is less than 10 feet and the movement has had little effect on the surrounding strata. These faults in general strike north-east, dip to the west at between 35° and 50° to the horizontal and in almost every case in which movement can be measured, the faulting is reverse, i.e., compressional. The faulting is parallel to the anticline in this area and it is considered that any movement is of a minor nature and that it took place under the regional compressional stresses that caused the folding in this area during the Jurassic period. No faults were found which would significantly affect the structural level of the geological formations in the station area.

VIII. ENGINEERING PROPERTIES OF ROCKS

The power station structures will be founded on the Upper White Sandstone. This material proved to be relatively easy to drill and core recovery was good. Seismic velocities in the Upper White Sandstone ranged from 3,000 feet per second to 10,000 feet per second. With the exception of a thin upper layer of highly weathered rock which was extremely friable and not suitable for testing, it was found that the Upper White Sandstone could be divided into two groups as shown in Table I.

TABLE I

STRENGTH OF UPPER WHITE SANDSTONE

	Unconfined Compressive Strength p.s.i.	Secant Modulus* p.s.i. x 10^6
Samples taken from above the lowest 10 feet of the stratum	1822-9300	0.12 - 1.5
Samples taken from the lowest 10 feet of the stratum	390-2050	0.12

* At 318 p.s.i. (approx. 20 tons per square foot)

The ripping tests showed that a D9 bulldozer could probably rip this rock in areas where the seismic velocity was below 6000 feet per second. During the test the ripped material broke up into its component grains and both these conclusions have been confirmed during the excavation of the site.

Four core samples of the Upper White Sandstone withstood 300 cycles of simulated accelerated weathering without appreciable effect but two samples gave losses of 55% after the sodium sulphate soundness test and there was a loss of up to 88% after the Los Angeles abrasion test.

The Intermediate Grey Silty Sandstone is of variable lithology and generally has a lower strength than the Upper White Sandstone. Due to the higher velocities in the overlying white sandstone, it was not possible to define the extent of the Silty Sandstone layer by seismic methods.

The silty sandstone is soft enabling rapid drilling but core recovery in this material was relatively poor, probably due to the presence of hard chert pebbles which caused grinding in the friable silty matrix.

The unconfined compressive strength of samples from this band ranged from 360 p.s.i. to 8,130 p.s.i. Sixty percent of the samples gave strengths below 2,000 p.s.i. Secant moduli values ranged from 0.10 - 0.60 x 10^6 p.s.i. at a loading of 318 p.s.i.

Weathering in the Intermediate Grey Silty Sandstone is moderate with the exception of an area south of Murrays Beach where the Upper White Sandstone is missing and there is up to 50 feet of completely to highly weathered silty sandstone.

A much slower rate of drilling in the Lower Light Grey Sandstone indicated that this rock type is much harder than the other rock formations present in the area. Unconfined compressive testing of samples gave a range in strength from 5240 - 14,000 p.s.i. The Secant Modulus at a loading of 318 p.s.i. ranged from 0.9 - 3.6 x 10^6 p.s.i.

A sample of the Lower Light Grey Sandstone gave a loss of 6% after the sodium sulphate test and a loss of 33% in the Los Angeles abrasion test.

IX. EARTHQUAKE RISK

The seismicity of the Sydney Basin has been summarised by Doyle, Cleary & Gray (Ref. 9) and the possible seismic risk at Jervis Bay has been studied by Underwood (Ref. 10). With the exception of the shaking centred in the Robertson area some 40 miles to the north-west in 1961, no earthquake of significant size has been recorded from the area around Jervis Bay. Underwood concluded that the most likely source of shaking which might have damaging effects on a power station at Murrays Beach would be an earthquake resulting from movement along the major fault south-east of the station. However, the site investigation indicates that this major fault does not exist and that there is no evidence of any fault movement in recent geological time. The seismic risk in the Jervis Bay area is therefore considered to be low, but in order to evaluate any shaking which may occur, it is proposed to install a long period continuous recording seismograph close to the station site.

X. SELECTION OF THE MOST SUITABLE STATION LOCATION

From consideration of the maximum water levels, cooling water pumping costs and site geology, the station site level (grade level) has been fixed at 15 feet above mean sea level (R.L. 115 ft.). The optimum position of the station, having regard for foundations, is the site where -

(i) rock capable of supporting the station structure is close to R.L. 115 ft.;

(ii) where there is a minimum of excavation to R.L. 115 ft.; and

(iii) where there is a maximum thicness of good quality rock below R.L. 115 ft.

Other factors which have to be taken into consideration are the length and position of the circulating water canals and the preservation of the countryside around the station area.

The level of the top of good quality rock is indicated by the drill holes sunk in the area and the seismic survey has been used to interpolate between drill holes. The usefulness of the seismic work has been limited by the presence of the relatively weaker band of Intermediate Grey Silty Sandstone below the Upper White Sandstone. Where the Upper White Sandstone is thick, the seismic survey located the top of bedrock but failed to indicate the weaker band. On the other hand, where the white sandstone is thin the seismic work sometimes picked up the upper level and at other times located the interface between the Intermediate Grey Silty Sandstone and the Lower Light Grey Sandstone. Thus the interface depths appear to vary greatly and in this situation the seismic work is difficult to interpret.

As the rocks in the Murrays Beach area dip to the north-west, the maximum depth of the Upper White Sandstone is found on the headland to the west of the beach. In this area it has been found that the seismic survey corresponds closely with the drill hole information. In order to preserve a nature strip along the coastline the station site should be at least 150 feet from the sea and with this provision, the station site has been located as shown in Figure 3. The drilling in this area indicates a thickness of Upper White Sandstone below grade level ranging from 26 feet at the south-east corner to 55 feet in the north-west corner. If the reactor and turbine house were located at the western end of the station area, there would be a minimum of 45 feet of good quality white sandstone below grade level.

XI. PERFORMANCE OF THE FOUNDATION ROCKS

The jointing at the selected station site is tight, the materials are reasonably uniform and it is considered that for a preliminary estimation of settlement the foundation can be treated as composed of several horizontal layers behaving in an elastic manner.

The settlement of a semi-infinite elastic medium with uniform strata can be calculated using the Steinbrenner approximation by which the settlement of a multi-layered mass is estimated by using the stress distribution for a homogeneous half-space, but using the relevant elastic parameters of each layer to calculate the settlement within each layer, the sum of such settlements being the surface settlement.

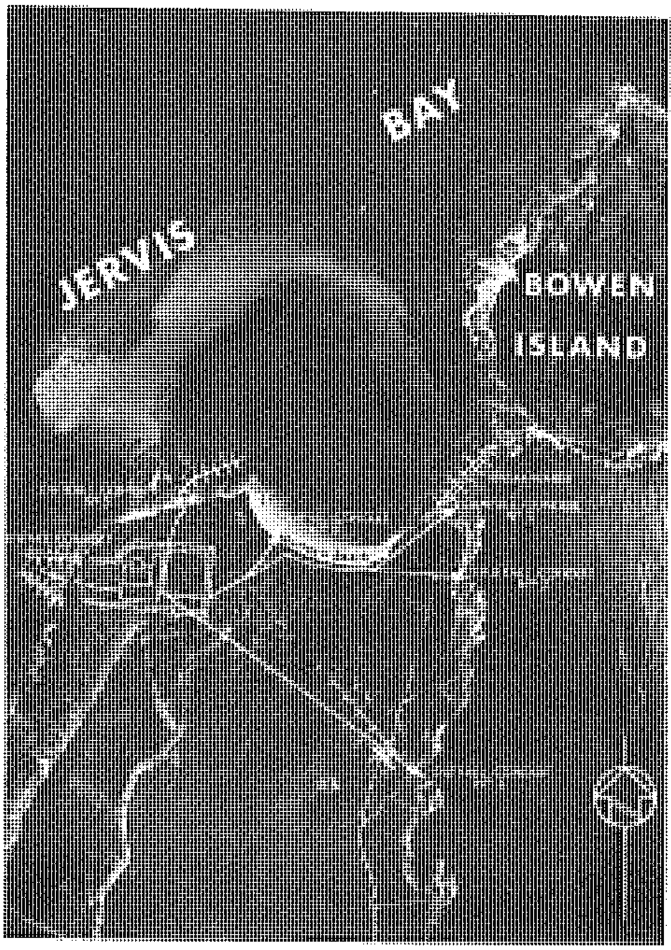

Fig. 3
Site Layout showing Five Alternative Circulating Water Conduit Locations

Based on the rock testing carried out on core samples from the station area, the following average Elastic Moduli values can be assumed:

Main part of Upper White Sandstone
0.2×10^6 p.s.i.

Base of Upper White Sandstone and Intermediate Grey Silty Sandstone
0.1×10^6 p.s.i.

Lower Light Grey Sandstone
1.3×10^6 p.s.i.

Using these values a typical column footing in the turbine house with dimensions 10 feet by 10 feet bearing a load of 2,500 tons would settle about 0.3 inches, if based on 20 feet of Upper White Sandstone and 50 feet of Intermediate Grey Silty Sandstone. If, however, the footing is located directly on the Intermediate Grey Silty Sandstone, the settlement would be about 0.5 inches and the load at the surface would be close to the ultimate unconfined compressive strength of the weathered rock.

A 150 foot diameter circular reactor building with an average loading of 5 tons per square foot would settle about 0.6 inches if sited on 20 feet of Upper White Sandstone overlying 50 feet of Intermediate Grey Silty Sandstone and also about 0.6 inches if located directly on the Intermediate Grey Silty Sandstone. The loadings in this case are well below the ultimate unconfined compressive strength of the rock.

XII. CIRCULATING WATER SYSTEM

The alternative locations for intake and outfall canals which have been considered for this station are shown on Figure 3.

The intake canal will probably be situated to the west of the station site and will involve the excavation of a channel in the floor of Jervis Bay. The invert level of this channel will depend on the location of the outfall and examination of the possible recirculation between outfall and intake canals if a bay outfall is selected. Drilling on the shore at the intake has penetrated white sandstone to a depth of 50 feet below sea level and the marine sparker survey indicated a depth of 20 feet of sand above bedrock about 500 feet offshore. Depending on the invert level chosen, it would appear likely that about half the excavation required for the intake canal would be in sand and the remainder in white sandstone.

A total of five outfall routes has been examined (Fig. 3). Outfalls 1, 2 and 3 discharge into the ocean and Outfalls 4 and 5 into Jervis Bay. The geological investigation has shown that of the two channels into the Bay, Outfall 5 would be preferable as a maximum depth of excavation of 25 feet would be required and the invert of the canal would be on Upper White Sandstone. Outfall 4 would involve excavation to a maximum depth of 35 feet. The invert would be close to the top of the Intermediate Grey Silty Sandstone and the channel would pass through deep sand at Murrays Beach.

Of the ocean outfalls, Outfalls 1 and 2 would be constructed in deep sand and weathered silty sandstone south of Murrays Beach. At the eastern end of Murrays Beach, Outfall 1 would involve an open canal to Governor Head and Outfall 2 a short tunnel to the coast just south of Governor Head. In both cases, excavation would be carried out in the relatively weak rocks close to the contact between the Upper White Sandstone and the Intermediate Grey Silty Sandstone.

It has been considered that, if either Outfalls 1 or 2 were to be adopted and if cooling water must be prevented from entering the bay, it would be necessary to construct a breakwater between Governor Head and Bowen Island. Investigation of the breakwater site has shown that it would be located on a shelf of Lower Light Grey Sandstone averaging 20 feet below sea level. The rock from the excavation of Outfalls 1 or 2 would not be suitable for the construction of the breakwater and there is no available site for the establishment of a quarry in suitable rock close to the power station area.

Outfall 3 involves the construction of a tunnel between the station site and the ocean coast about half a mile south of Governor Head. The geological investigation has shown that the first 1,000 feet of this route would be excavated in deeply weathered silty sandstone and may be more economically constructed by cut and cover methods, the remainder of the tunnel - about 2,000 feet - would be through strong Lower Light Grey Sandstone.

The drilling and testing along this tunnel line has shown that the rock is sound and joints are widely spaced and tight. Minimal support should be required for the tunnel in the Lower Light Grey Sandstone and groundwater inflows should be small.

The ocean portal of Outfall 3 has been provisionally located in a cliff which drops sheer from 130 feet above sea level to about 20 feet below sea level. To minimise wave surge in the tunnel, a 'surge tank' would be required at the tunnel portal and this tank would discharge below sea level. The rock in this area is strong light grey sandstone which is cut by widely spaced minor faulting with the fault planes dipping to the west at about 40°. Both vertical and angled drilling close to the cliff face indicates that these fault planes are narrow and tight and should not present a great problem in the design of the portal structure.

XII. CONCLUSIONS

The geology of the area south-west of Governor Head has been examined using a combination of several field investigation methods supported by appropriate laboratory testing. This has shown that the area is composed of surface sand underlain by a series of sandstone and silty sandstones which dip gently to the north-west.

The rocks can be divided into three layers with the relatively strong Upper White Sandstone underlain by a somewhat weaker Intermediate Grey Silty Sandstone and the very strong Lower Light Grey Sandstone. The presence of the middle weaker layer has complicated the interpretation of the seismic survey especially when the Upper White Sandstone is thin.

Examination of the geological structures in the area has failed to locate the presence of any active major faulting. This supports the general conclusion that the seismic risk in the Jervis Bay area is low.

A station site has been selected in which the top of the Upper White Sandstone stratum is close to station grade level and there is a depth of at least 45 feet of this rock below grade level near the main station structures. In this way, the station loads are widely distributed on the weaker and more deformable Intermediate Grey Silty Sandstone.

The properties of the materials found along the alternative outfall routes has been examined. Of the bay outfalls, No. 5 is geologically preferable, while of the ocean outfalls, No. 3 appears to have fewer construction difficulties even although it requires some 3,000 feet of tunnel.

XIII. ACKNOWLEDGEMENTS

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