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REPORT ON THE FIFTH AUSTRALIA-NEW ZEALAND CONFERENCE ON SOIL MECHANICS AND FOUNDATION ENGINEERING, AUCKLAND, FEBRUARY 1967

by

E.J. BEST and E.J. POLAK

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SUMMARY

The authors attended the Fifth Australia-New Zealand Conference on Soil Mechanics and Foundation Engineering. They list all papers presented to the Conference, and describe a trip to various dams and power stations. They end with comments on the status of Engineering Geology in New Zealand.

1. INTRODUCTION

The Fifth Australia-New Zealand Conference on Soil Mechanics and Foundation Engineering was held in Auckland, New Zealand, over the period 13th to 17th February 1967. The Conference was sponsored jointly by the New Zealand Institution of Engineers; the Institution of Engineers, Australia; the New Zealand and Australian National Societies of Soil Mechanics and Foundation Engineering; the University of Auckland; and the New Zealand Government. All conference sessions were held at the University of Auckland.

The purpose of the conference was to provide an opportunity for engineers, geologists, and geophysicists to meet and discuss problems and developments in the fields of soil mechanics, site investigation, and foundation engineering. A half-day during the conference was set aside for arranged excursions, and following the conference there were three post-conference tours arranged to give delegates the opportunity of visiting major engineering projects in New Zealand.

The conference was attended by 171 engineers and scientists, mainly from New Zealand and Australia, (102 and 59 delegates respectively); there were also 3 delegates from Canada, 3 from India, and one each from England, Hong Kong, U.S.A. and Romania. Universities were represented by 42 delegates, state or government instrumentalities by 82 delegates, and consultants by 47 delegates.

It was decided that the Sixth Conference be held in Melbourne in 1971.

2. PAPERS PRESENTED AND DISCUSSIONS

Thirty-three papers were presented to the conference. These were all printed and circulated to delegates several weeks before the conference, and authors were restricted to presenting their papers in ten minutes. Papers were presented in groups of two or three on allied topics; after each group had been presented, the floor was open for discussion for about an hour. This was a very good system for conducting such a conference, as the bulk of the time available was devoted to discussions, which invariably were more fruitful than the papers presented.

As in previous Soil Mechanics and Foundation Engineering Conferences, there was an overwhelming bias towards the field of soil mechanics. Of the 33 papers presented, two were on the use of geophysical methods in determining rock properties, one was on methods of site investigation for a damsite, two described foundation treatment for earth and rockfill dams, and one described several foundation problems encountered in major buildings in Auckland; all other pepers were on various aspects of soil mechanics. This is not to say that the soil mechanics papers were trivial or academic. Most of the papers described field methods and examples, or laboratory methods which could be useful for correlation with field data. The fault for the imbalance of these conferences lies with the engineering geologists, geophysicists, and construction engineers who either do not publish details of any new or improved methods they use, or do not have the opportunity or inclination to analyse and correlate information obtained in the course of their work. This conference is one of the few opportunities that foundation engineers and engineering geologists and geophysicists have of meeting with each other and with workers in closely-associated fields; perhaps a more direct approach from the committee organising the next conference, stressing the foundation engineering aspect, could improve the balance of future conferences.

Following is a list of the papers presented to the conference. Papers of particular interest to engineering geologists are marked with an asterisk, and notes on a few of these papers are appended. Copies of the papers presented are held in the Bureau Library.

* BEST, E.J., & HILL, J.K.

Site investigation techniques used at Corin damsite, Cotter River, A.C.T.

* INGHAM, C.E.

The measurement of Young's modulus by seismic methods.

* POLAK, E.J.

The effect of geological environment on the properties of foundation rocks.

* LUMB, P.

Statistical methods in soil investigations.

This describes how the reliability of a soil investigation may be assessed qualitatively by statistical methods. The methods are illustrated using common problems, and numerial illustrations are given. One particularly relevant example given is the estimation of the quantity and size of boulders in a soil containing randomly-distributed large boulders; the probability of a borehole missing a boulder can also be calculated.

* WESLEY, L.D.

The use of the Dutch penetrometer in clays.

* LANG, J.G.

Longitudinal variations of soil disturbance within tube samples.

This paper illustrates variations in results of triaxial compression tests on "undisturbed" samples resulting directly from the sampling method. Variations such as this must constantly be borne in mind when relating laboratory test results to the field situation.

CLEGG, B., & PAUL, M.J.

The effect of compaction method on the pore pressure in laboratory test specimens.

* HERZOG, A.

Evidence for skeleton-matrix structure in clays stabilised with Portland cement.

Experiments show that as little as 2.5 per cent by volume of cement in montmorillonite will result in the formation of a rigid, interconnected skeleton within the clay matrix.

DUNCAN, J.M.

Undrained strength and porewater pressures in anisotropic clays.

MORGAN, J.R.

Shear strength of a kaolin.

TROLLOPE, D.H., & BROWN, E.T.

An analytical relationship between saturated soil strength and stress history.

MORRIS, P.O., & COCHRANE, R.H.A.

Road subgrade compaction requirements - a study of density, moisture and strength of subgrades of Victorian roads constructed prior to 1935.

* SCHUMANN, E.E.

The effect of environment on soil moisture suction, with particular reference to domestic houses in a semi-arid climate.

HOLLAND, J.E., & KASSIFF, G.

The effect of suction changes on the strain developed in a model pipe buried in expansive clay.

* MARTIN, G.R.

The dynamic response of cohesive earth dams to earthquakes.

* TAYLOR, F.G.

Dam foundations: recent Victorian practice for earth and rock-fill dams.

An analysis of grout takes in various types of rock for three damsites is included in the paper, and although the geological terms are not well-defined, the analysis is a definite step in the right direction. The paper also describes current foundation treatment practice in Victoria; the adopted cut-off wall construction came under severe criticism by other engineers at the conference.

* GALLOWAY, J.H.H.

Installed instruments in Matahina earth dam.

This paper deals with a large earth dam which was built on very difficult foundations. The major problem was leakage through the foundation, and because of this the dam and foundations were well-instrumented during construction. The apprehensiveness of engineers concerning the leakage problem has been justified, as a considerable amount of water is passing the dam; also, an area of the transition zone has recently failed due to piping. The dam was visited during the post-conference tour, and a fuller description of the dam is given in a later section of this report.

* KOTOWICZ, M.S.

The design and construction of the bentonite cut-off trench in Khancoban dam.

Several methods of placing the trench were assessed by large-scale field tests before deciding on the finally-adopted method. Instrumentation and behaviour of the dam after completion are also described.

MOORE, P.J.

An oedometer for static and dynamic loading.

DAVIS, E.H.

A discussion of theories of plasticity and limit analysis in relation to the failure of soil masses.

GERRARD, C.

Stresses and displacements in layered, cross-anisotropic, elastic systems.

POULOS, H.G.

The use of the sector method for calculating stresses and displacements in an elastic mass.

SHEPHERD, R., & DONALD, R.A.H.

Foundation deformation effects on structural dynamic analysis.

COFFEY, D.D. & FITZHARDINGE, C.F.R.

A nomographic solution for the design of spread footings on sand from field penetration tests.

* TAYLOR, P.W.

Design of spread footings for earthquake loading.

PHILLIPS, J.T. & HOADLEY, P.J.

Failure testing of slender piles at Sydney airport.

* TAYLOR, D.K.

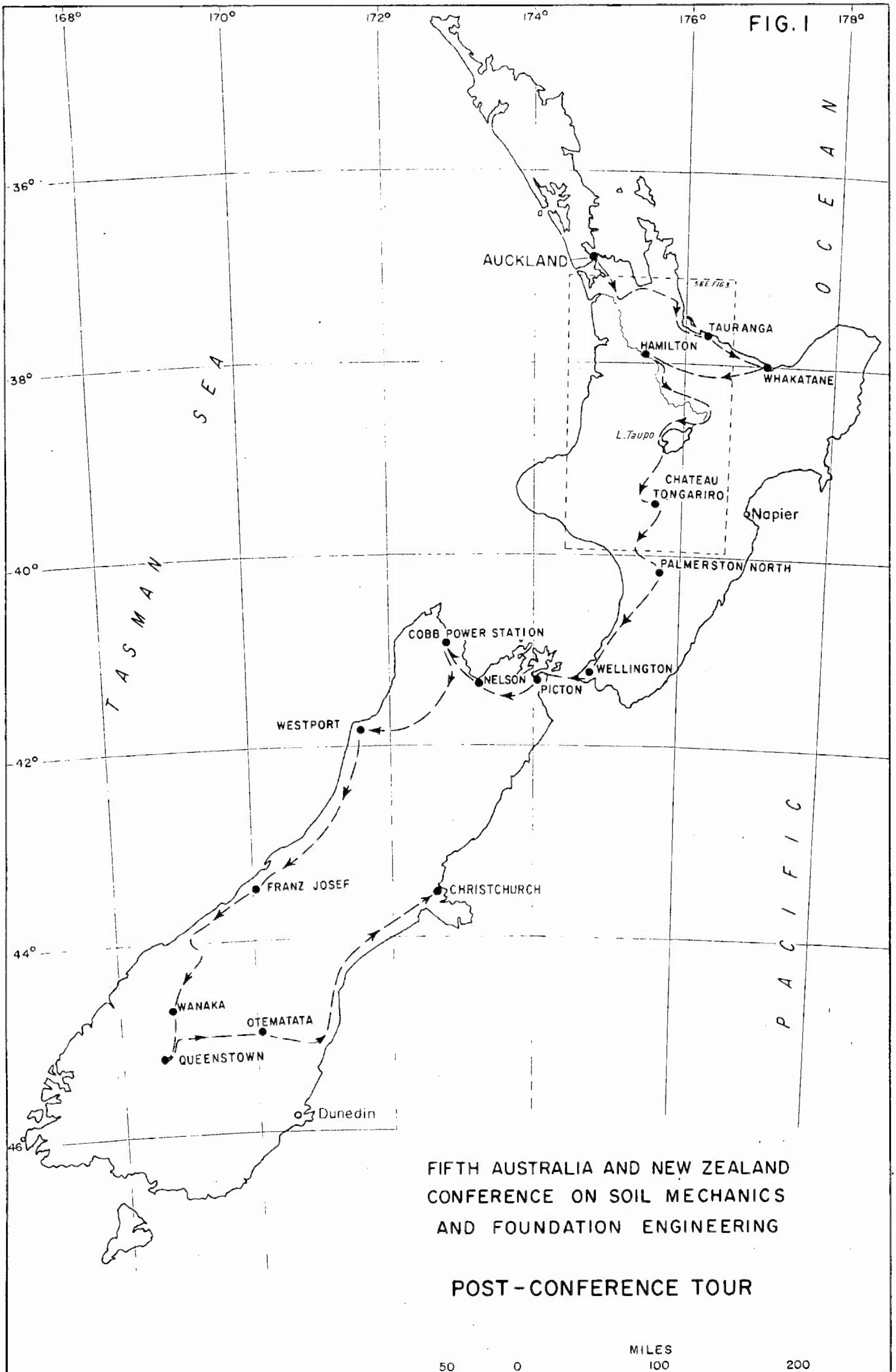
Notes on observation of building settlements.

This paper emphasises the need to measure the settlement of buildings to check the actual behaviour against the settlement estimated from theoretical considerations. The paper describes various field methods which can be used, difficulties which may be encountered, and some results of observing building settlements.

* STRACHAN, C.M.

Compaction of loose gravels for building foundations in the Hutt Valley.

The state of compaction of sub-surface strata must be considered when designing earthquake-resistant foundations. In the instance cited, 10 feet of gravel was excavated and recompacted to form an 8½-foot layer. The



FIFTH AUSTRALIA AND NEW ZEALAND CONFERENCE ON SOIL MECHANICS AND FOUNDATION ENGINEERING

POST-CONFERENCE TOUR

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effect of a severe earthquake on the original gravel would probably have caused differential compaction and settlement, which could have been disastrous for any buildings founded on the gravel.

PILE, K.C.

The settlement of two buildings on partially saturated clays.

* TAYLOR, P.W., CALLANDER, R.A., BECA, G.S., TONKIN, R.M., & ENTRICAN, G.C.

Major building foundations in Auckland City - a symposium.

The foundations of five major builtings are described in detail. Although they are all sited within a radius of 400 feet, foundation conditions were very different at each site, and the foundations adopted therefore varied widely.

* MATICH, M.A.J., & DOUGLAS, M.C.

Stability of cuts in overconsolidated clay on the Don Valley Parkway.

PARRY, R.H.G., & MACLEOD, J.H.

Investigation of slip failure in flood level at Launceston, Tasmania.

NEWLAND, P.L.

A note on the slices method of stability analysis.

* ROWE, P.W.

Foundation failures on layered deposits in relation to site investigation practice. (Address by special guest of the Conference).

3. POST-CONFERENCE TOUR

Three post-conference tours were arranged by the organising committee. The shortest was a 5-day tour from Auckland to Wellington, which was common to the other two tours. From Wellington there was the option of returning to Auckland in two days by another route, or continuing on to the South Island for a further seven days. Both of the authors went on the 12-day tour which covered the North and South Islands; the route taken is shown in Fig. 1.

Most of the engineering projects visited during the tour were connected with the development of electric power. A brief summary of New Zealand's electricity supply will therefore be given before going on to a detailed description of the tour.

The electricity supply of New Zealand

North Island development. The main complex of hydro-electric stations is along the Waikato River. The $27\frac{3}{4}$-mile long river starts from Lake Taupo, in the centre of the Island, and flows north to the Tasman Sea.

not far from Auckland. It descends from an altitude of 1172 feet at Lake Taupo, and 1100 feet of its descent is used for the production of power; the total capacity of the Waikato development is 864,000 kw from eight power stations.

The flow of the Waikato River will be augmented when the Tongariro River and the tributaries of the Rangitikei River are diverted into Lake Taupo, as part of the Tongariro Power Development Scheme. Several new stations will be established, and the additional water will be used to generate more power at the existing stations on the Waikato River.

There are two other sources of power in the Waikato River area. At Wairakei, a few miles north of Lake Taupo, geothermal steam has been harnessed to generate 175,000 kw of electricity; water from the Waikato River is used for cooling on this project. At Meremere, on the lower reaches of the Waikato, a steam turbine station, producing 180,000 kw of power, uses coal from nearby open-cut fields.

On the Rangitaiki River, the Matahina power project has just been completed, while further south, near Wellington, three stations operate using water from Lakes Waikaremoana (124,000 kw) and Manakao (19,200 kw).

Two oil-fired power stations, with a combined capacity of 290,000 kw, will be completed late in 1967.

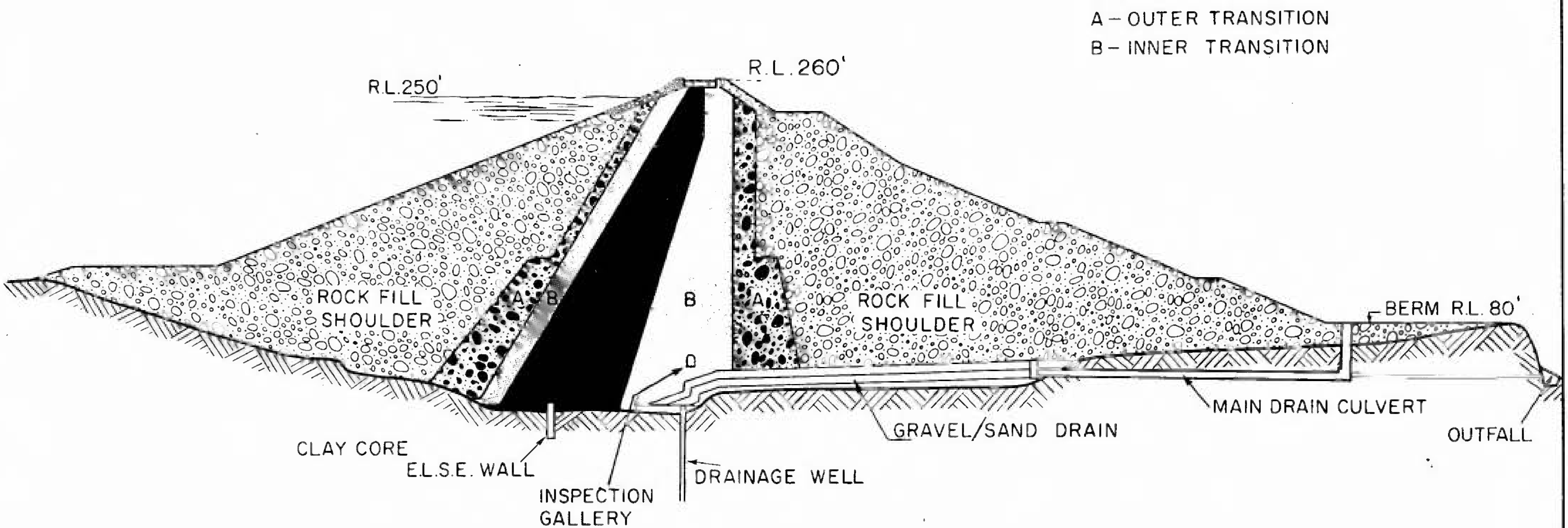
South Island Development. All state-owned power stations in the South Island generate hydro-electric power. The Waitaki River is the most developed river system at the moment, with three completed stations and a fourth under construction. The Clutha River is to be developed in the near future, though at the moment only one power station has been constructed (Roxburgh). A large scheme of hydro-electric development is under investigation and construction on the Southern Lakes; water from Manapouri Lake will supply a power station sited at sea level.

Apart from these major developments, there is a power scheme on the Cobb River in Nelson province, and four other small stations with a combined capacity of 69,000 kw.

A summary of the major stations, constructed or under construction is given in Table 1.

National Grid. The voltages used in the State network are 220,000 volts for two main grids, and 110,000 and 66,000 volts for other lines.

Since 1965, the northern and southern networks have been connected by a 500,000 volt direct current transmission system. This link is 379 miles long and includes 65 miles of submarine cable. The inter-island link balances the two hydro-electric systems, as the maximum river flows occur at different times of the year on the North and South Islands, and the incidence of peak load is also different.



CROSS-SECTION OF MATAHINA EARTH DAM

FIG. 2

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Auckland to Whakatane (Saturday 18th February)

We left Auckland along the Great South Road, which is a partly-completed, new motorway, costing £NZ60 million. After crossing the Bombay Hills, the road enters the Waikato River valley, which has a coal-burning power station at Meremere and open-cut coal mining at Maramarua. Farther east, the road crosses the Hauraki Plains, the area reclaimed from marshes as a soldiers' settlement after the 1st World War; the foundations for bridges, silos, etc. in the reclaimed area are a particular problem for engineers.

The road then climbs the Kainai Hills with extensive softwood plantations nearby and well-developed timber milling facilities. From the top of the pass, 1520 feet above sea level, the road descends to the Bay of Plenty, passing the old gold mining centre of Waiki. This area produced £NZ25 million of gold during the 70 years of its history, which ended in 1950. From here, the road follows the coast and passes through the rich dairying district of Katikati to Tauranga, the largest timber port in New Zealand. Several major structures are under construction in the town, including a new airport.

From Tauranga, we travelled towards Whakatane along the coast road, which follows a narrow strip of land between the sea and a prominent fault escarpment. To the left, the smoking volcano on White Island could be seen, marking the north-eastern end of the geothermal belt; to the right, the volcanic cone of Mount Edgecombe could be seen rising to 2946 feet from the plains of the Rangitaiki River. Before reaching Whakatane, we turned inland along the Rangitaiki River. Before reaching Whakatane, we turned inland along the Rangitaiki River valley, and visited the Matahina Power Project. After a visit of 2½ hours, we continued to Whakatane, where we stayed for the night.

Matahina Dam and Power Station. Construction of the Matahina project was completed in August 1966, and power production is scheduled to commence in April 1967.

Matahina Dam is an earth-cored rockfill dam with a small concrete section at the penstock intake and spillway gates. It has a crest length of 1400 feet and a maximum height above foundations of 260 feet. It contains 5½ million cubic yards of material, including 600,000 yards of core material and 3,800,000 yards of rockfill.

The foundations of the site are composed of late Tertiary sediments and greywacke. On top of these beds is a sheet of ignimbrite rock which forms the abutments of the dam. The sequence has been faulted, and the Waiohau Fault, which passes through the west abutment, has controlled the course of the Rangitaiki River. Foundation preparation consisted of excavating the sediments in the valley floor to expose the Lukes Farm Beds, which have a low permeability. No real cut-off was possible in the Tertiary sediments, as the basement rock is over 80 feet below the river. The design of the dam depends upon adequate drainage of water in the foundation rock.

The core of the dam consists of weathered greywacke from a borrow area one mile from the dam. It slopes steeply upstream, and is bounded by transition zones composed of weathered ignimbrite (see Fig. 2).

The downstream transition zone is thick and contains more material than the core itself. Fresh ignimbrite is used for the rockfill zones. One large quarry only provided all the material for the rockfill and transition zones, the latter being composed of the near-surface rock which was stockpiled for this purpose.

The concrete structures at the dam required over 100,000 cubic yeards of concrete. The main structure is the intake dam which is located on top of the spur forming the west abutment; it contains two intake gates which lead to the penstocks. There are two concrete covered steel penstocks, 16½ feet in diameter, leading to two Francis turbines in the powerhouse with a total output of 35,000 kW. The spillway, which is adjacent to the intake dam, has three radial gates, and is a concrete lined channel with a deflector at the bottom. The capacity of the spillway is 70,000 cusecs (cubic feet per second).

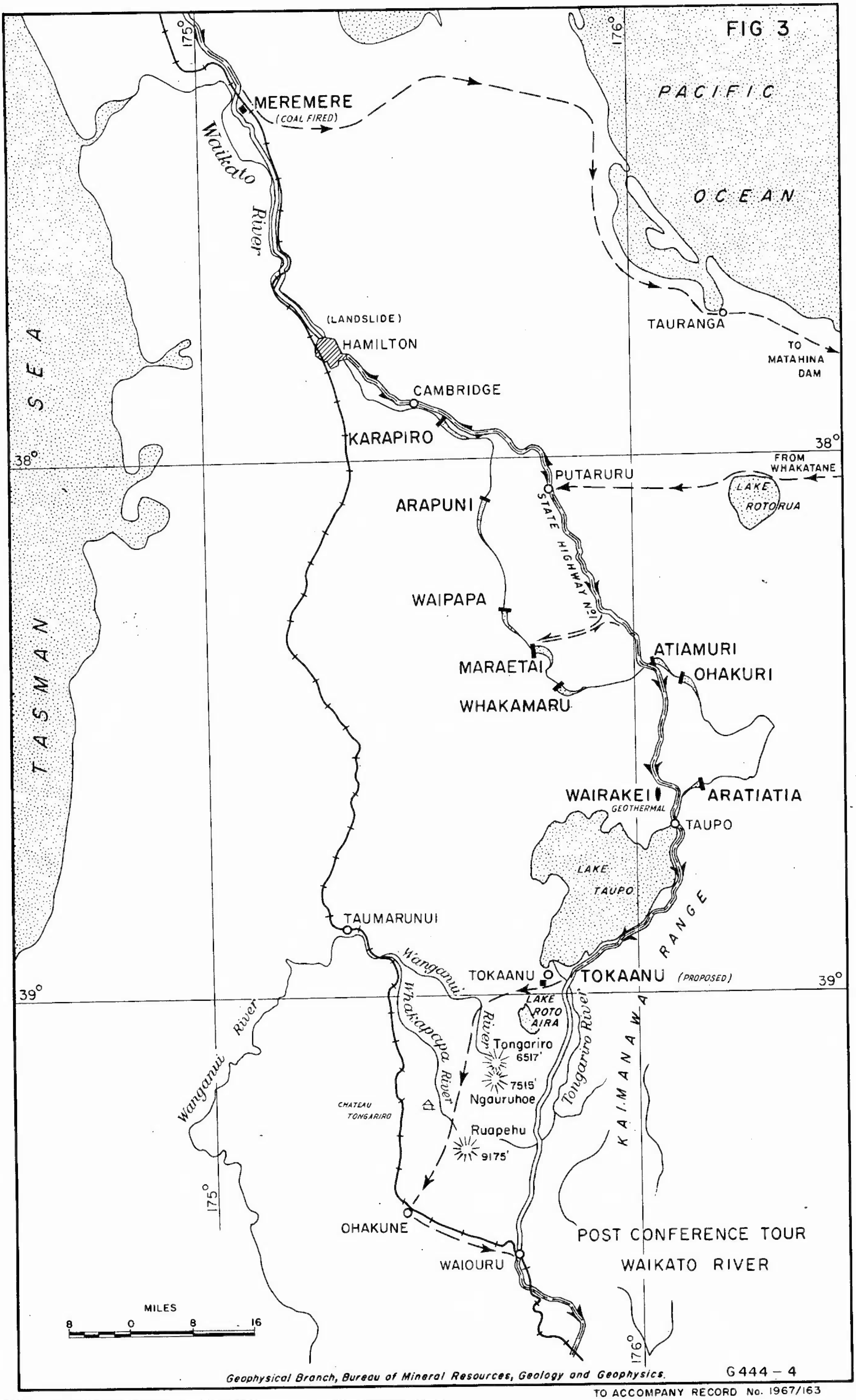
Consolidation grouting was generally restricted to 30-foot holes beneath the concrete structures. The grout curtain, however, was a major undertaking which is not finished yet. The curtain extends to a depth of over 200 feet below the surface in places, and laterally extends into the abutments for several hundred feet beyond the dam. Holes are nominally spaced at 5-foot centres, though this has been reduced to 2½ feet in places. Various types of drilling equipment were tried, and a downhole percussion hammer was found to be the most satisfactory; an average rate of 25 feet per hour was achieved with this equipment in a 4-inch hole. Grout takes were high, over 250,000 bags of cement having been used in the grout curtain so far. Even so, a considerable amount of water is leaking past the dam; a total flow of 20 cusecs is flowing through the drainage system (i.e. 11 million gallons per day), and more water is almost certainly leaking past the dam which is not intercepted by drains.

At the end of the first season of core placement, holes were drilled into the core zone foundations, and drilling water was lost in some areas. A little grouting was done, but not very much for fear of blocking the drainage system. After this, the core was placed with a higher moisture content, and more stringent foundation treatment was carried out.

The dam and foundations are well-instrumented, and since construction was completed, they have acted satisfactorily. However, very recently some piping has occurred in the downstream transition zone, and collapse has taken place in one isolated area. The cause of this was being investigated at the time of the tour, and the reservoir had been lowered as a safety precaution.

Whakatane to Rotorua (Sunday, 19th February)

The route followed the previous day was retraced as far as Te Teko; from there, the tour continued towards Rotorua. As the road climbs up to the hills, the country changes from agricultural to forestry. From Lake Rotoehu, the road follows the famous Hongis Track to Lake Rotoiti and then to Rotorua.



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The remainder of the day was spent in the Rotorua area, visiting some of the locations where geothermal activity is evident at the surface. Some time was spent at Pohutu geyser and the nearby boiling mud pools. Flows of steam are evident in many places scattered throughout the town, and many houses use them as a source of heat and hot water. We also visited Te Wairoa, a village which was buried by the eruption of Mount Tarawere early in the century.

Rotorua-Hamilton-Lake Taupo (Monday, 20th February)

The road to Hamilton climbs the Mamaku Range via the Hemo Gorge, where the bush land has been brought under forestry cultivation. The country then opens into rich farmland, which was originally quite useless until a cobalt deficiency was recognised and rectified.

The city of Hamilton is sited on the banks of the Waikato River, which is deep enough to allow large boats to arrive here from the sea. In the city, we visited new university buildings under construction, the Meat Industry Research Station and a landslide area on the river bank where a new house in a suburban street was damaged beyond repair.

We left Hamilton after lunch to travel to Taupo. During the afternoon we visited several of the dams and power stations of the Waikato River development project (Fig. 3), which will be described briefly below. During the evening, we visited Karapiti Blowhole, which is a natural vent 19 inches in diameter producing 50,000 pounds of steam per hour at a temperature of 270°F and a pressure of 470 p.s.i. It is one of the few natural steam vents in New Zealand which emits dry steam.

Karapiro Dam. Karapiro Dam is an arch dam with gravity section at the intake and spillway. It has a crest length of 1100 feet, and creates a working head of 100 feet for power generation. The penstocks, which are incorporated in the dam, are 21 feet in diameter, and 12,000 cusecs of water are required to drive the three turbines at maximum output (90,000 kW total). The reservoir formed by the dam is 15 miles long and extends back to the tailrace of Arapuni Dam.

Arapuni Dam. Arapuni Dam is a 210-foot high concrete structure which was built across the Arapuni Gorge. The scheme utilises an old watercourse which leads away from the river at the damsite and rejoins it again at the bottom of the gorge. This watercourse provides a natural headrace, and the intake and spillway is located ¾ mile down the watercourse from the dam. Eight steel-lined tunnel penstocks, each 12-feet in diameter, feed the water under a head of 175 feet into the power station, which is located in the gorge.

Waipapa Dam. Waipapa Dam and power station are sited at the head of the reservoir behind Arapuni Dam. Selection of a suitable damsite was very difficult, as the river has cut through the ignimbrite sheet covering the general area and exposed the underlying alluvial deposits. Seven sites were investigated over a 4-mile stretch of river, and the deciding factor for selecting the present site was the presence of a rock bar, 60 feet wide, in the valley floor. An earth dam was considered the type of dam most suited to the site, the core being founded on the rock bar and the shoulders on the alluvium.

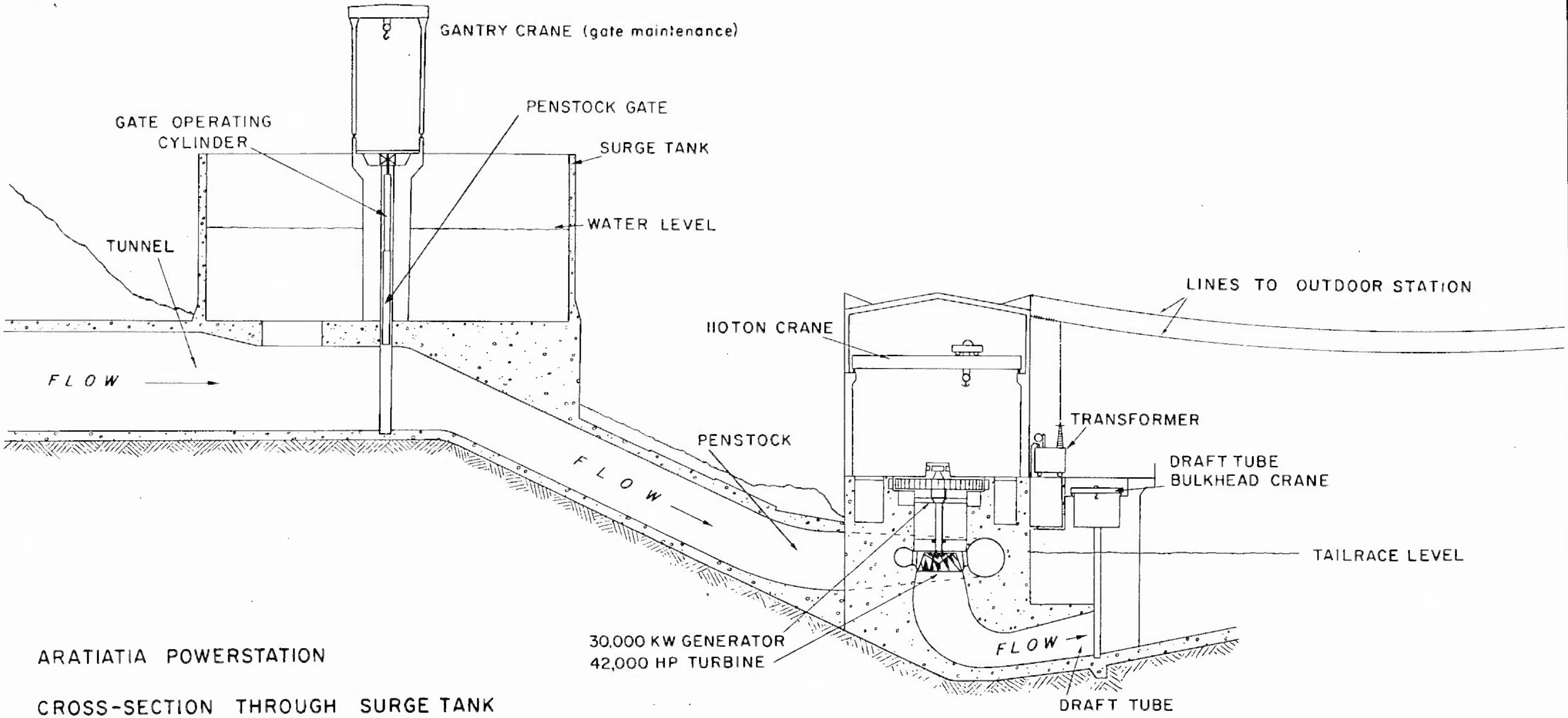
Unexpected difficulties were encountered during construction, owing to the presence of a bed of silt, 20 feet thick, overlying the rock bar; no samples of this bed had been obtained during the site investigation. Tests had to be carried out to determine whether the silt would be strong enough to support the shoulders of the dam, and gullies and crevices in the rock bar containing this silt were carefully cleaned out by hand. Almost 6,000 cubic yards of concrete were required to backfill the excavations in the rock foundation. The final dam contains 500,000 cubic yards of earth, has an average height of 110 feet above foundations, and is 480 feet long. A gated spillway is located on the left bank, and the intake and powerhouse on the right bank.

Maraetai Dam. Maraetai Dam is seven miles upstream of Waipapa Dam, and is a curved concrete gravity dam which was completed in 1954. Several years ago, it was decided to double the generating capacity by building another power station 1500 feet downstream; a concrete-lined headrace was to be constructed from the reservoir to supply the 5 metal penstocks with water. Work started on the project, but was stopped indefinitely by a change in government when only the headrace had been completed. Two of the 36,000 kw generating sets already delivered were subsequently used at Matahina Dam. Work has recently recommenced at Maraetai, however, and construction of the penstocks and power station is now well under way. The extra power (180,000 kw) is obtained from the same volume of reservoir as previously used by the first stage development, and is therefore only to be generated at peak periods of demand.

Atiamuri Dam. Atiamuri Dam is a combined concrete gravity and earth-fill dam. The concrete section is 560 feet long, with a maximum height above foundations of 143 feet, and the earth-fill section on the left bank is 850 feet long and 100 feet high. The dam contains 154,000 cubic yards of concrete and 420,000 cubic yards of earth fill. The core of the earth-fill section consists of unsilicified pumice breccia which was taken from a borrow area half a mile from the site; compacted sand forms the shoulders of the earth dam.

Foundation treatment for the earth-fill section was considerable and costly, owing to the extensive alluvial deposits overlying the volcanic bedrock. The alluvial deposits were excavated down to the ground water level below the core zone; this entailed the removal of 300,000 cubic yards of material. In the bottom of this trench, a much narrower trench was excavated down to the bedrock. This was then backfilled with concrete to form a 5-foot thick, reinforced concrete cut-off wall across the full length of the earth dam. In order to excavate this cut-off trench, a special drainage gallery was excavated in the bedrock, in which high capacity pumps were installed. Pumping from this gallery was maintained until the water level in the alluvium had been lowered sufficiently for excavation and concreting to be carried out in the cut-off. Further foundation treatment included extensive grouting from a gallery built on top of the cut-off wall - this continued during placement of the core on and around the gallery.

Aratiatia Power Station. Aratiatia Power Station is the first station downstream from Lake Taupo. Because the Waikato River falls 93 feet in half a mile in this area, the scheme does not include a large dam. Instead, the river is controlled by a concrete spillway block with two



ARATIATIA POWERSTATION

CROSS-SECTION THROUGH SURGE TANK
PENSTOCK AND POWERHOUSE

FEET
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FIG. 4

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30-foot high radial gates, and water flows to the power station through a concrete intake structure and a 1210-foot long tunnel. A quarter of the tunnel, which is 30 feet in diameter throughout, was constructed in an open trench, the remainder being excavated in solid rock; the tunnel is lined with reinforced concrete.

At the power station end of the tunnel is a surge tank 55 feet high and 120 feet in diameter (see Fig. 4). The tank is built of high-strength concrete, which was prestressed and post-tensioned vertically and horizontally; it was constructed using the slipforming technique, which was new to New Zealand at the time of construction.

Lake Taupo. Lake Taupo is a natural reservoir for all stations along the Waikato River, having a surface area of 238 square miles and a catchment area of 1250 square miles. Control gates have been built at its outlet, near the town of Taupo, to stabilise the volume of water available throughout the year.

Lake Taupo to Tongariro (Tuesday 21st February)

Most of the morning was spent at the Wairakei geothermal field, which is about 5 miles north of Lake Taupo. After inspecting the power generating plant, we continued south along the shores of Lake Taupo for 30 miles to Tokaanu. Close by is the new construction town of Turangi, which is the present base for the construction of the Tongariro Hydro-Electric Scheme. We spent some time at the well-equipped information centre, where we were introduced to the proposed scheme, and after some technical discussion with the resident engineers, we visited briefly the construction work at the Tokaanu power station and penstock line, Wanganui damsite and Otamangakau damsite. The night was spent at the Chateau Tongariro, which is on the slopes of Mount Ruapehu; to the north, the steaming crater of Mount Ngauruhoe, 7515 feet above sea level, could be seen.

Wairakei Geothermal Power Project. Wairakei is in the middle of the New Zealand volcanic belt, which extends from White Island in the Bay of Plenty to Mount Ngauruhoe; the belt is 150 miles long and 30 miles wide. The scheme is based on tapping a vast underground hot-water system, believed to result from contact of groundwater with very hot, perhaps molten, rock.

The best flows of steam are obtained from ignimbrite, which generally is present at depths greater than 2000 feet below ground surface. The ignimbrite is overlain by a layer of hard, well-consolidated but permeable pumice breccia, which is about 1400 feet thick. Above this is some 200 feet of mudstone, which forms an impermeable cap-rock, and at the surface is a sequence of lightly consolidated pumice breccia. The high-temperature water seeps through faults and cracks in the ignimbrite up into the overlying porous strata; drilling through the mudstone releases the high pressure, causing the water to boil and produce steam. Steam can be obtained at shallow depths by drilling into the porous pumice breccia, but high pressure steam can only be obtained by drilling below 2000 feet and intersecting one of the near-vertical cracks in the ignimbrite. Fig. 5 shows a cross-section through a typical production hole.

The first step in drilling a production well is the construction of a reinforced-concrete cellar to support the drill rig and to accommodate the well head equipment. The surface formation around the well is then consolidated by grouting to a depth of 100 feet; this prevents steam rising to the surface outside the casing.

A typical production well has three strings of casing firmly cemented to the country rock, with a fourth string of slotted casing installed as a liner. The first (outer) string is driven to 80 feet, and the second (anchor) string is cemented into the mudstone and carries the well-head equipment. The third (production) string is 8 inches in diameter, and generally penetrates to a depth of about 1500 feet. Production is then obtained from the open hole below the production casing, using the slotted liner. Investigation wells have an intermediate string between the anchor and production strings, taken down to about 1000 feet, which provides an additional safeguard when drilling in unknown country.

While at Wairakei, we visited the site of a well in which steam penetrated the casing seal in the mudstone during drilling. The site was hurriedly abandoned, and it is now the location of a crater, about 150 feet across, full of hot water. The ground is continually vibrating as the steam forces its way into the near-surface rock, and there are geysers of hot water shooting into the air at about one minute intervals.

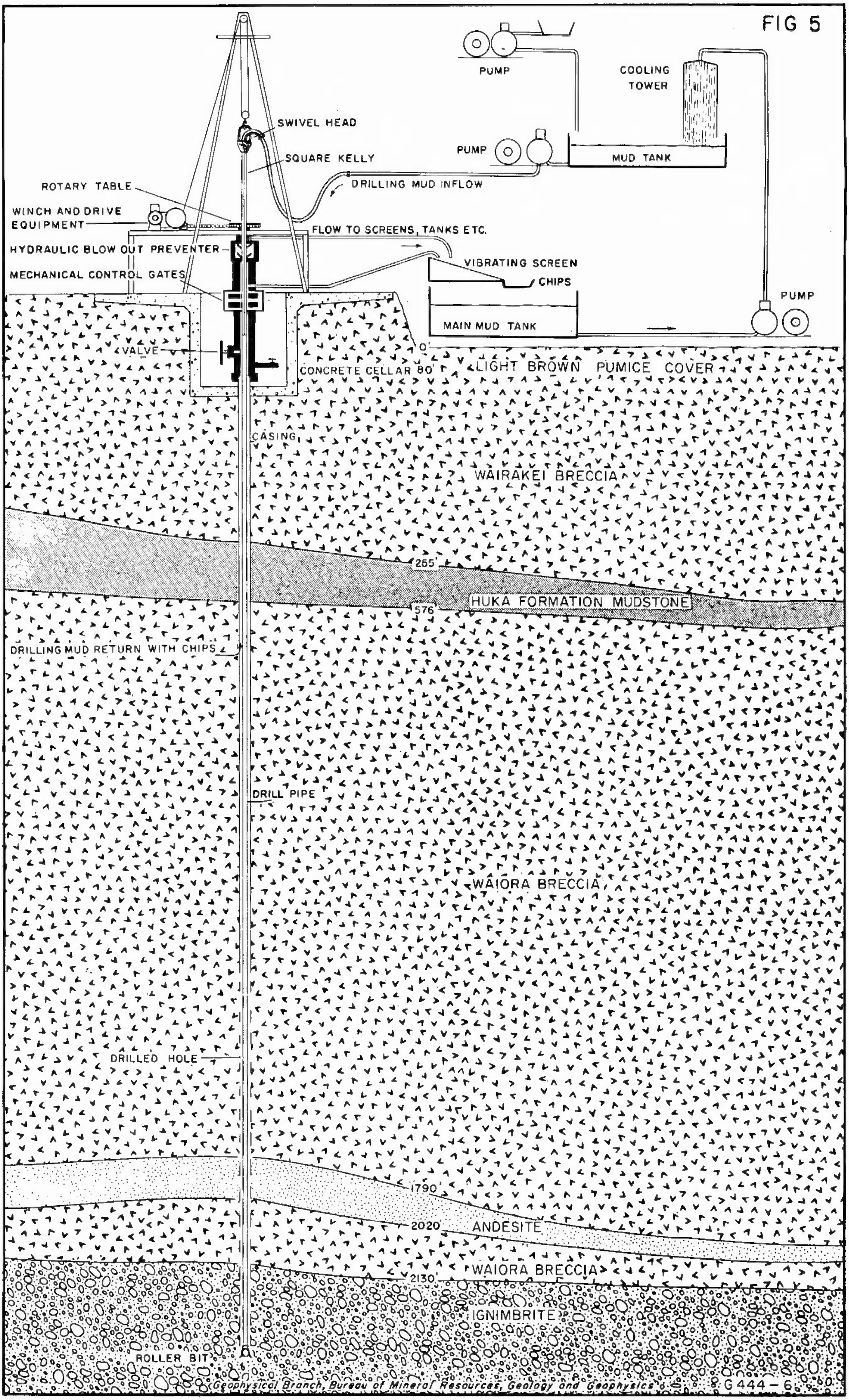
Drilling techniques used at Wairakei are essentially the same as those used in drilling oil wells. Drilling fluid is circulated to lift rock cuttings and balance the pressure of formation fluids, but as it absorbs much heat during circulation, a cooling system is necessary to keep the temperature of the inflow below 40°C (see Fig. 5).

Of the 90 wells drilled at Wairakei up to 1965, 60 supply the steam required. Most wells produce a mixture of water and steam, ranging up to 800,000 pounds per hour. Before the steam is used for power generation, it is passed through centrifugal separators to remove the water, which is then used in the silencers.

Measurements over the years indicate that, while temperatures have remained constant, there has been a decline in pressures; with the decline in pressure there has also been a related decline in the output of individual wells. This means that more wells will have to be drilled until the field reaches stability under operating conditions.

The production wells are between one and two miles from the two generating stations, which are located on the bank of the Waikato River; the need for large volumes of cooling water has determined the location of the power station near the river. Steam is transported from the field through five 20-inch and three 30-inch mains; totalling 12 miles, to the turbo-alternators at the power station. The capacity of the generating plant at present is 175,000 kw.

Geothermal investigations are being carried out in five other areas; they are at Te Mihi, Ngawha Springs, Waitapu, Orakeikorako and Tauhara.



TO ACCOMPANY RECORD No. 1967/163

Tongariro Hydro-Electric Power Development

Basically, the scheme consists of augmenting the flow of water into Lake Taupo by diverting water from three adjacent catchment areas. In this way, not only will the output of the Waikato River stations be considerably increased, but several power stations can be built to utilise the head of the diverted rivers before they enter Lake Taupo.

Five stages go to make up the scheme as it is envisaged at the present time (see Fig. 6). Three of these stages are at present under construction (western diversions, Tokaanu power project, and Moawhango diversions), while the other two, involving the construction of power houses on the Tongariro River, are planned for the future.

Western Diversions. This part of the scheme consists of intercepting seven tributaries of the Wanganui River and diverting the water to Lake Roto Aira. The waters from these streams are collected by 6½ miles of tunnel and discharged into the headwaters of the Wanganui river. One mile downstream from the tunnel outlet is the confluence of the Wanganui River and Otamangakau Stream As there is no suitable damsite downstream of this confluence, two dams are being constructed just upstream from the river junction. The Wanganui Dam will be a concrete dam, 100 feet high, with an overflow spillway controlled by two 66-foot gates. The foundations consist of irregularly jointed andesite, and excavation was necessary to a maximum depth of 30 feet below river level; most of the excavation was carried out by ripping. The Otamangakau Dam will be an earthfill dam, 100 feet high. The foundations consist of andesite and volcanic shower material, overlain by 10 feet of overburden, and material for the dam is being won from an area of weathered sandstone one mile from the damsite. The reservoirs formed by these dams will be linked by an open canal, and the combined waters will be carried to Lake Roto Aira by an aqueduct four miles long.

Tokaanu Power Project. This phase consists of using the augmented waters from Lake Roto Aira to generate power, utilising a head of 681 feet. Water from Lake Roto Aira will be led by means of a dredged intake channel into an 18,000 foot long circular tunnel, which will be 21½ feet in diameter and fully lined with concrete. From the outlet portal in the hillside above the power station, the water will pass through four steel penstocks, 8½ feet in diameter and 1300 feet long. Foundations for the power station and penstock line are of weathered andesite; at the time of the inspection, the founding level for the power station had not been decided upon, as excavation by bulldozers was still in progress. The tailrace will discharge into Lake Taupo along a dredged channel 2½ miles long. One of the investigation drill holes along the tailrace intercepted hot water 30-feet below the surface.

An additional feature of this phase of the scheme will be the diversion of 1000 cusecs of water from the Tongariro River into Lake Roto Aira. This diversion consists of 8000 feet of 17½-foot diameter tunnel, leading into an aqueduct 18,000 feet long. This aqueduct (the Poutu Canal) will discharge into Lake Roto Aira immediately upstream from a small concrete gravity dam, which will control the lake's natural outfall.

Moawhango Diversion. This phase will divert the headwaters of the Moawhango River and several tributaries of the Whangaehu River into the Tongariro River catchment. Water from various streams will be intercepted by stream bed intakes, and the combined water will be carried by pipeline and a 4000-foot tunnel into the Moawhango River. As it is not possible to divert the collected water into the Tongariro catchment without pumping, two dams will be constructed on the Moawhango River; one in the lower gorge will be a concrete gravity dam 200 feet high, while the other will be a rockfill dam, 220 feet high and at an elevation 130 feet above the upper dam; it will have a head of 250 feet and will use off-peak power. Water from the upper reservoir will then be fed under gravity into the Tongariro catchment through a concrete-lined tunnel, 9½ miles long and 11 feet in diameter.

Tongariro to Wellington (Wednesday 22nd February)

From Tongariro, the road traverses a high plateau, more than 2000 feet above sea level, and crosses to the Rangitikei River catchment. Here, the plains are deeply dissected and there are several extensive terraces visible for many miles along the sides of the valley. The rejuvenation of the river is evident in places by deeply-incised meanders. A succession of soft, weak, mudstone, several hundred feet thick, crops out extensively in the valley. This gives rise to many unstable slopes, and the scars of hugh landslides, some quite recent, are visible from the road.

After following the Rangitikei River, the road reaches the coast and follows the coastal plain southwards towards Wellington. The plain steadily narrows until, close to Wellington, deep cuts have been necessary for the road and many tunnels for the railway line. Wellington is built on very hilly country and is more a collection of semi-isolated suburbs than a city; it is not a very favourable location for a capital city for this and other reasons (such as an inclement climate and the impossibility of locating an international airport within 25 miles of the city). Access to the city is being improved considerably by the construction of an elevated expressway.

Wellington to Nelson (Thursday 23rd February)

We crossed to the South Island from Wellington on the inter-Island steamer. The harbour at Wellington is large (an area of 20,000 acres) and deep, and handles the largest tonnage of any ports in New Zealand. After two hours' sailing across Cook Strait, the steamer entered the Marlborough Sounds; after another hour's sailing the steamer berthed at Picton, the South Island terminus.

After lunch we commenced the tour by coach of the South Island by travelling to Nelson. En route we passed through Blenheim, Havelock and Canvastown (an old mining area for gold and scheelite). Nelson is the centre of a fruit-growing district, which exports large quantities of applies, pears, stone fruit and tomatoes; the district also grows tobacco and hops and produces most of New Zealand's needs. An interesting natural feature of Nelson is a boulder bank 8 miles long and

TONGARIRO HYDRO-ELECTRIC DEVELOPMENT

about 300 yards offshore. Its origin is not known, though there are two current theories; one is that it is a remnant structure in situ of a particular rock sequence, while the other explanation is that the bank was built by deposition of current-carried boulders.

Nelson to Westport (Friday 24th February)

During the morning, we travelled the 70 miles to the Cobb Power Scheme, passing the fertile alluvial flats at the head of Tasman Bay on the way. On the way, we also visited a marble quarry, which is a major source of facing stone for buildings in Wellington; the marble fines are milled and used as fertiliser.

From the Cobb Scheme, we retraced our steps to Motueka, and then travelled south towards Murchison and the Buller River. This area was the centre of a gold rush last century which started in 1870 with the discovery of gold at Murchison, and along the road there are relics and tailing dumps of this earlier activity. Near Murchison, a fault with a displacement of 13 feet - a result of the 1929 earthquake - is still visible. Downstream from Murchison, the road enters the Buller Gorge. Major reconstruction of the road is in progress in this very difficult country, much cutting and filling being necessary. Leaving the gorge, the road follows open country to Westport, which is the leading coal port for the West Coast.

Cobb River Power Scheme

The Cobb Scheme consists of an earth and rockfill dam, 125 feet high and 670 feet long, a tunnel just over $1\frac{1}{2}$ miles long, two penstocks each $1\frac{1}{4}$ miles long, and a power station with four 300-kw and two 10,000-kw generators. The dam is sited on the Cobb River, and has a spillway consisting of four concrete culverts with a combined capacity of 30,000 cusecs. The tunnel intake is at the bottom of the dam, and the 5-foot diameter tunnel is lined for 1570 feet from the intake. The remainder of the tunnel is unlined, except for 400 feet at the outlet end.

The gross head of the scheme is 1945 feet, the highest of any scheme in New Zealand. This allows the generation of a considerable amount of power from a small flow, one cusec of water generating about 120 kw of power. Power from the scheme was originally used in the Nelson-Marlborough area, but in 1956 it was linked to the main South Island system.

Westport to Franz Josef Glacier (Saturday 25th February)

From Westport we travelled south along the coastal alluvial plain towards Greymouth and Hokitika. The alluvium was derived from the gold-bearing mountains through which we passed the previous day, and there has been intensive working for alluvial gold all along the coastal plain. Charleston, which now consists of a few cottages, had a population of 10,000 for seven years at the end of last century. There are the remains of many other ghost towns and scars of old mine dumps throughout the area.

We stopped during the morning at the "Pancake Rocks" which are a natural geological feature. A thick sequence of well-bedded limestone crops out in the cliffs, and continual erosion by the sea has caused differential erosion in the sequence, thus accentuating the layering. The cliffs also exhibit typical limestone weathering and a natural blow-hole has formed some 100 yards from the cliff edge.

At Hokitika, we visited the workshop where all the New Zealand greenstone is cut, polished and mounted. The source of the greenstone is an area of amphibolite high up in the mountains, and the rock is transported from the source area by helicopter. The nearby Arahura River drains the source area, and it was from the bed of this river that the Maoris obtained the greenstone from which they fashioned their weapons, tools and ornaments.

The road south from Hokitika towards Franz Josef Glacier passes through more old gold workings before entering undulating country with some dairying. At Waiho we turned off the main road and drove to the Franz Josef Hotel, where we stayed for the night. We went up to the Franz Josef Glacier, which decends from an altitude of 8800 feet to only 750 feet above sea level; the lower reaches are therefore well below bush level, and the rain forest contrasts strangly with the mass of ice. Another contrast is the emergence, just downstream of the end of the glacier, of a hot mineral spring. The glacier moves at a rate ranging from 2 to 15 feet per day, and in recent years has receded several hundred yards upstream.

<u>Franz Josef Glacier to Wanaka</u> (Sunday 26th February)

The route covered on this day included some of the most recent roadworks over very difficult terrain. We followed State Highway 6 for 50 miles south of Franz Josef to Paringa, which is the beginning of the difficult section. From Paringa to Haast (a distance of 36 miles) the highway has been under construction intermittently since 1929. In this area, the foothills of the Southern Alps extend to the coast, and the rainfall is very high (up to 200 inches per annum). Road construction was therefore slow and expensive, owing to the steep terrain and the many fast flowing creeks and rivers which had to be crossed. Bailey bridging was obten used for temporary access, but the main creeks were finally put through wide-span, concrete-arch culverts, some of them being almost 200 feet long. The major bridging feat on this section of road was the construction of the Haast Rivermouth Bridge which is 2417 feet long. As in the case of all bridges in this remote area, Callander-Hamilton steel trusses were used because of the ease of transportation. The foundations of the bridge piers consist of a total of 178 pre-cast concrete piles, each 50 feet long, the groups being capped by pre-cast concrete units to keep concreting in the river bed to a minimum. The height of the deck provides for a maximum flood of 400,000 cusecs; the maximum flood recorded to date would have been 10 feet below deck level. The bridge was constructed between 1960 and 1962 at a cost of £276,000.

From the Haast bridge, the highway turns inland and crosses the Southern Alps at the Haast Pass. This pass, which is at an elevation of only 1847 feet above sea level, was discovered by the explorer Julius von Haast, and is the only feasible access route to the West Coast from Otago. The Haast Pass section of the highway was completed in 1960.

Once over the pass, the road descends gradually down to Lake Wanaka, which it folows for a few miles. The road then crosses over to Lake Hawea and finally back again to Wanaka, which is situated at the outlet of the lake. Lake Wanaka is 30 miles long and over 1000 feet deep in places; it is the fourth largest lake in New Zealand, and its outlet is the Clutha River, the largest river in the country.

<u>Wanaka to Queenstown</u> (Monday 27th February)

From Wanaka, the tour followed the upper Clutha valley to Cromwell, where a detour was made to visit the Roxburgh Dam and power station. After returning to Cromwell, where we had lunch, the tour continued to Queenstown, following the Kawarau river for much of the way. The area has been extensively worked for gold, and piles of dredged gravels are almost continuous along the major rivers. Before arriving at Queenstown, we made a detour to Coronet Peak, where we took a chair lift to the summit. From the top we had an excellent panoramic view of the Alps, Lake Wakatipu, and a series of jagged peaks called the Remarkables.

<u>Roxburgh Power Scheme.</u> At the time of construction, Roxburgh was the largest power station in New Zealand, and even now it is second only to Benmore; it has a generating capacity of 320,000 kW. The scheme is situated on the Clutha River, and the concrete gravity dam is 1200 feet long and 250 feet high. Incorporated in the structure are three spillways, each 50 feet wide and 600 feet long, with a combined capacity of 150,000 cusecs (the long term average flow of the river is 17,700 cusecs). Each spillway has a vertical-lift gate, weighing 135 tons, to control the overflow. The powerhouse is sited immediately below the dam, and is supplied with water by eight steel penstocks with diameters of 18 feet.

Prior to construction of the dam, the river was diverted through a cut 1800 feet long, 100 feet wide, and 60 feet deep; this was excavated to 20 feet below river level, and a total of 525,000 cubic yards of rock and spoil was removed. The upstream cofferdam was 90 feet high and contained 250,000 cubic yards of rock and silt, while the downstream cofferdam was 60 feet high and contained 70,000 cubic yards of spoil. A concrete plant, capable of batching 160 cubic yards of concrete per hour, was constructed at the site, and produced the 1,500,000 cubic yards of concrete used in the dam and power house. Concrete was transported by two flying foxes with 5-cubic yard buckets.

<u>Queenstown to Otematata</u> (Tuesday 28th February)

From Queenstown, the route retraces that taken the previous two days until the turn-off to the east a few miles south of Wanaka. The road then passes through sheep country which becomes progressivly more desolate and rises steadily to the Lindis Pass (3180 feet above sea level). The open, tussock-covered hills are divided into a few large sheep stations; few homesteads are passed on the road. From the divide, the road descends into the Waitaki River basin, which is being developed to produce large amounts of hydro-electric power and water for irrigation. We stopped for lunch at Otematata and spent the afternoon visiting Aviemore and Benmore Dams.

Waitaki Hydro-Electric Development. The Waitaki River is fed by three lakes (Tekapo, Pukaki and Ohau) at the foothills of the Southern Alps, the lakes in turn being supplied by snow- and glacier-melt from the mountains. The hydro-electric potential of the river has long been recognised, and several power projects have alrady been completed in the middle reaches of the river. Plans have been proposed for harnessing the upper reaches, and it is expected that the lower reaches will eventually be developed for power generation (see Fig. 7).

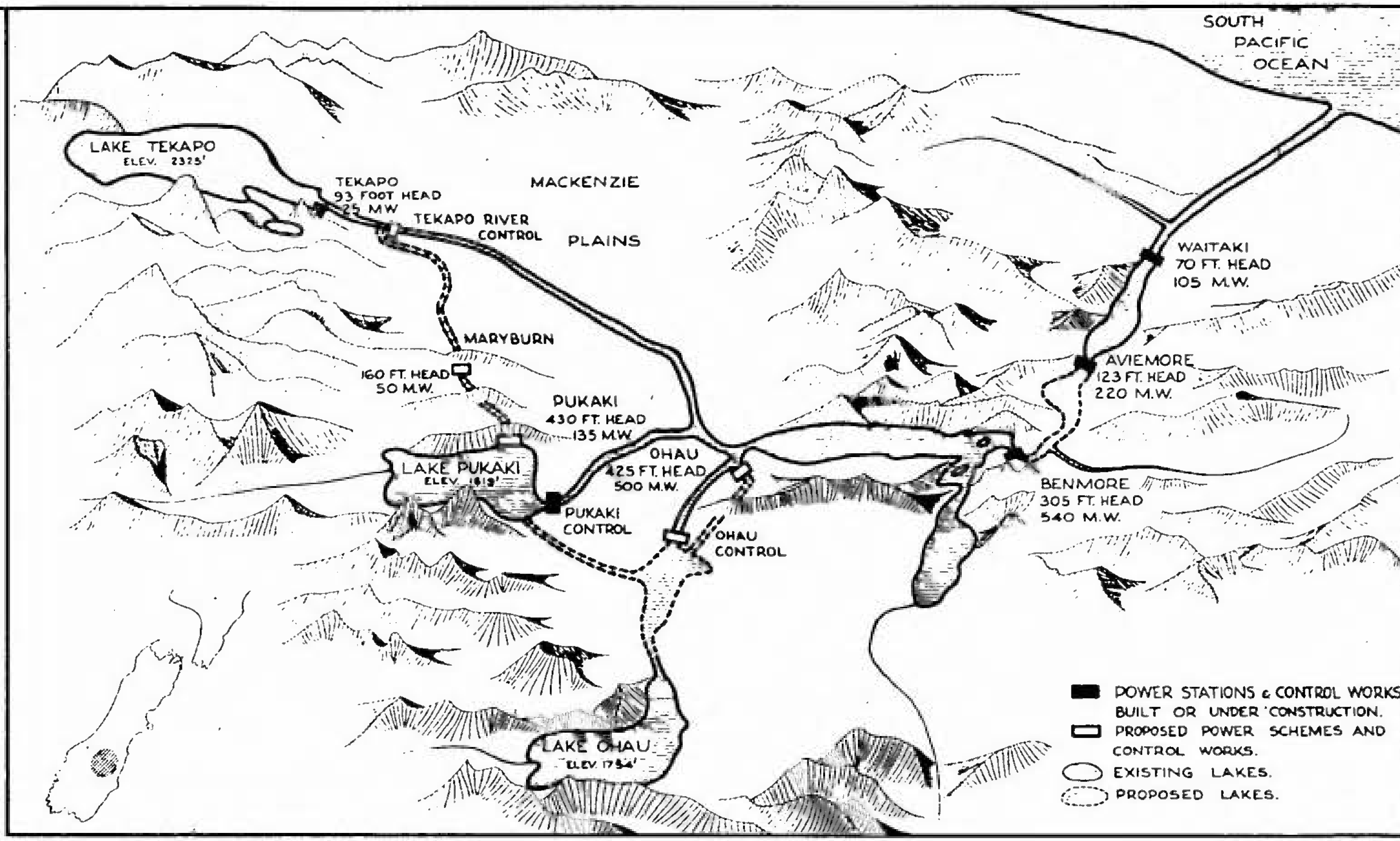
Works completed to date include the Waitaki dam and power station, and the Benmore Dam and power station; these, together with the partially-constructed Aviemore Dam and power station, fully utilise the head of the river between 1200 feet and 650 feet above sea level. On the upper reaches, control works have been constructed at the outlets of Lake Tekapo and Lake Pukaki to regulate the flow of water from the spring thaws. It is proposed that the water from Lake Tekapo will be diverted by canals into Lake Pukaki, passing through the power stations on the way, and then the combined waters of the two lakes will be diverted into the Ohau River catchment, passing through another power station before entering the river. A dam on the Ohau River will then control the combined water of the three lakes, and the head between this dam and Lake Benmore will be harnessed in two more power stations. No definite proposals have been formulated as yet for the development of the lower reaches of the river below Waitaki Dam.

Waitaki Dam. The structure is a curved concrete gravity dam, 120 feet high, with intakes, power house, and tailrace incorporated into its southern end. The main dam has an overflow spillway 1160 feet long, which has a discharge capacity of 190,000 cusecs; the normal river flow is 12,000 cusecs. It was the first dam in New Zealand built across a major river where diversion of the river during construction was not possible; and it was the last dam to be built using pick and shovel methods for foundation excavation (a total of 737,100 cubic yards of material was removed).

Construction was carried out by building a cofferdam half way across the river, and constructing one half of the dam with 11 sluices through which the river could flow while the other half was being built. Closing the gates on completion of the dam was not entirely successful, as three of the sluices leaked badly. Special structures had to be manoeuvred into position behind the gates from the downstream end, thus confining the flow of water while the sluices were concreted.

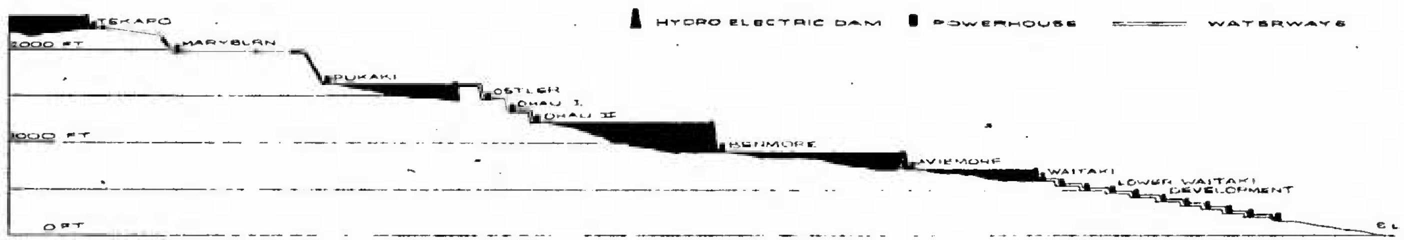
The scheme was completed in 1934, and had an output of 30,000 kW - this supplied almost half of the demand for power in the South Island at that time. Since then, the output has been increased by the installation of five 15,000 kW generators at various times between 1940 and 1954; extra

FIG. 7A



PROPOSED WAITAKI BASIN DEVELOPMENT

FIG. 7B



LONGITUDINAL SECTION : WAITAKI RIVER SYSTEM SHOWING PRESENT AND PROPOSED DEVELOPMENTS FOR HYDRO-ELECTRICITY

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics.

TO ACCOMPANY RECORD No. 1967/163

G444-8

water to generate this power was provided by the control dams at Lakes Tekapo and Pukaki. Then in 1959, it was decided to strengthen the dam with a system of pre-stressed cables, installed from the crest and anchored in the foundation rock; this work was completed in 1961.

<u>Benmore Dam</u>. The dam is sited just downstream from the confluence of the Waitaki River and Ahuriri River. When a power station at Benmore was considered in 1946 (and subsequently rejected in favour of the Roxburgh scheme), a site 3-miles upstream from the present site was considered for the construction of a concrete gravity dam. The rapid development of earth-moving equipment since that time, however, resulted in an earth dam at the present site being cheaper than a concrete dam at the upstream site.

The dam consists of an impermeable core zone of clayey gravel, supported on both sides by shoulders of river gravel. Normal river gravel was placed and compacted for the bulk of the shoulders, though the top 120 feet of the upstream zone is composed of clean gravel; this is to permit rapid drainage of water in the zone during periods of quick drawdown in the reservoir. The dam has a maximum height of 360 feet and a crest length of 2700 feet, and contains 16 million cubic yards of material. Diversion of the river during construction was carried out by constructing two concrete culverts (each 41 feet high, 25 feet wide, and 1440 feet long) in the valley floor.

The spillway is located on a ridge forming the left abutment. It is a massive concrete structure, 124 feet high, with four steel, radial gates to control the overflow of water; the maximum discharge capacity is 120,000 cusecs. The spillway also has two sluice gates at the base of the structure which can discharge a further 60,000 cusecs of water. The spillway chute is concrete-lined, and has a concrete deflector at the bottom which throws the water in an arc, thus dissipating its energy. Construction of the spillway required the excavation of 600,000 cubic yards of rock, and the placing of 120,000 cubic yards of concrete.

On the right abutment of the dam is the intake block and penstock slope. There are six penstocks, each 17½ feet in diameter, made of prestressed concrete. The penstocks were fabricated on site in 8-foot lengths, which were winched into position on the penstock slope; a total of 318 such units were cast and assembled at the site.

At peak load, 24,000 cusecs of water pass through the penstocks to the six turbines and generate a total of 540,000 kw of power. Transformers step up the power from 16,000 volts to 110,000 volts to supply the converter equipment, while two more transformers step it up to 220,000 volts to supply the South Island grid. The converter station near the power house changes the alternating current into direct current at 500,000 volts for transmission to the North Island.

<u>Aviemore Dam</u>. This is a combined concrete and earth dam, at present under construction, the design of which was dictated by the geological conditions at the site. The left abutment of the dam consists of hard, tightly-jointed greywacke, while the right bank is composed of compacted silt and clay, overlain by gravels. A major regional fault, which has downthrown the greywacke at least 1000 feet below the right bank, passes

along the valley floor beneath the gravels (see Fig. 8a). Because of the wide variation in foundation conditions, it was decided to construct a concrete gravity section on the greywacke bedrock and an earth dam on the silt and the fault zone.

The diversion tunnel was excavated in the greywacke of the left bank; it is a concrete-lined, horseshoe-shaped tunnel 1250 feet long, 41 feet high, and 28 feet wide. The tunnel was excavated in three stages. First two drives were excavated along the line of each side wall about 25 feet above final floor level. The top half of the tunnel was then excavated from these drives, and steel girders were placed to support the roof. Finally the bottom half of the tunnel was excavated. Upstream and downstream cofferdams were placed to divert the river; these were cheaply constructed, and protracted pumping was subsequently necessary to dewater the site.

The concrete dam has a crest length of 1100 feet and a maximum height of 186 feet, and it contains 600,000 cubic yards of concrete. It incorporates an overflow spillway with a capacity of 120,000 cusecs and is regulated by five radial steel gates. Sluices are also incorporated near the base of the dam. The foundations were not consolidation-grouted at all, and a grout curtain only 100 feet deep was necessary; grout takes were very low. Concrete aggregate is obtained by screening gravel from river flats 3 miles upstream; no crushing is necessary.

The earth dam will be 1500 feet long and will contain about 1½ million cubic yards of material. The core material is being derived from a nearby outcrop of coal measures, and consists of silt and puggy material. It contains patches of highly plastic material, so it is necessary to mix the core material in the borrow area and stockpile it before transportation to the dam. It is placed at a moisture content of 2% wet of optimum. The shoulders of the earth dam consist of river gravel, and two filter zones are also incorporated near the sloping core (see Fig. 8b). No grouting was necessary below the earth dam section.

The power station is being constructed immediately downstream from the concrete section of the dam (see Fig. 8c). The four turbines are supplied by steel penstocks, 23 feet in diameter, and the total output of the station will be 220,000 kw.

Otematata to Christchurch (Wednesday 1st March)

During the last day of the tour, we travelled through the upper reaches of the Waitaki catchment and visited several areas of future development of the Waitaki scheme. We crossed the Ohau River at the location of the proposed dam, and continued on to the Lake Pukaki control dam. From here to Lake Tekapo, the road crosses rich alluvial soil of the MacKenzie Plains. Rainfall in the area is low, however, and irrigation water from the proposed Waitaki development will considerably increase the yield of the crops. At Tekapo, we inspected the control dam and power station, which has an output of 25,200 kw from a working head of 93 feet; this was the last hydro-electric engineering structure we inspected on the tour.

FIG 8A

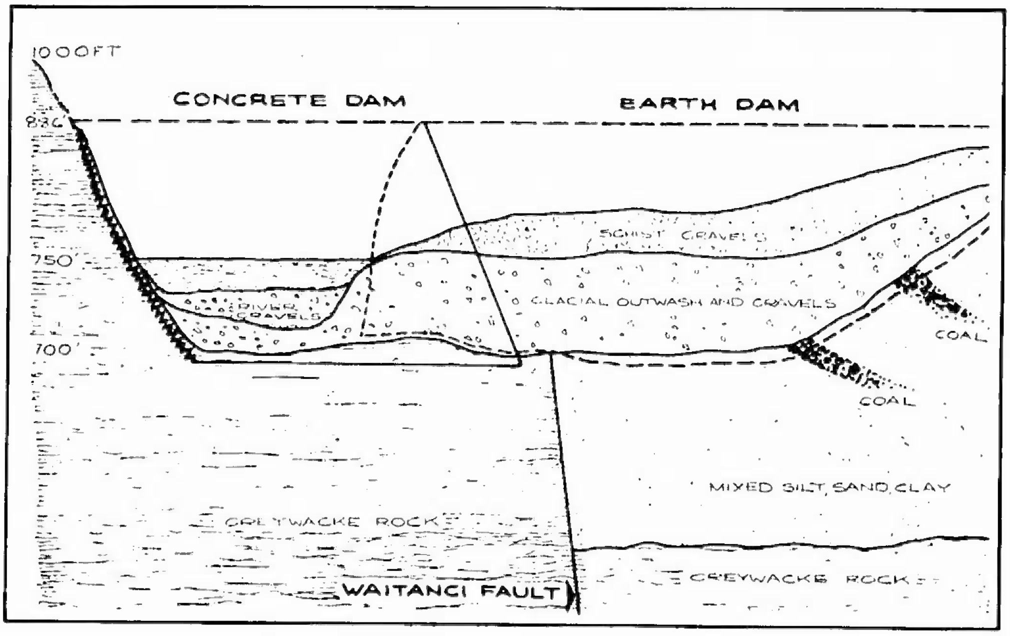
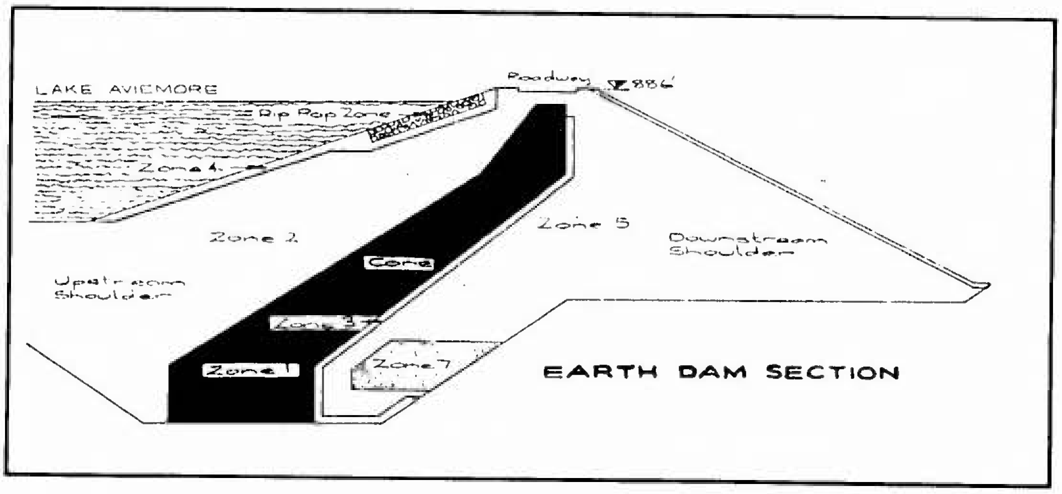
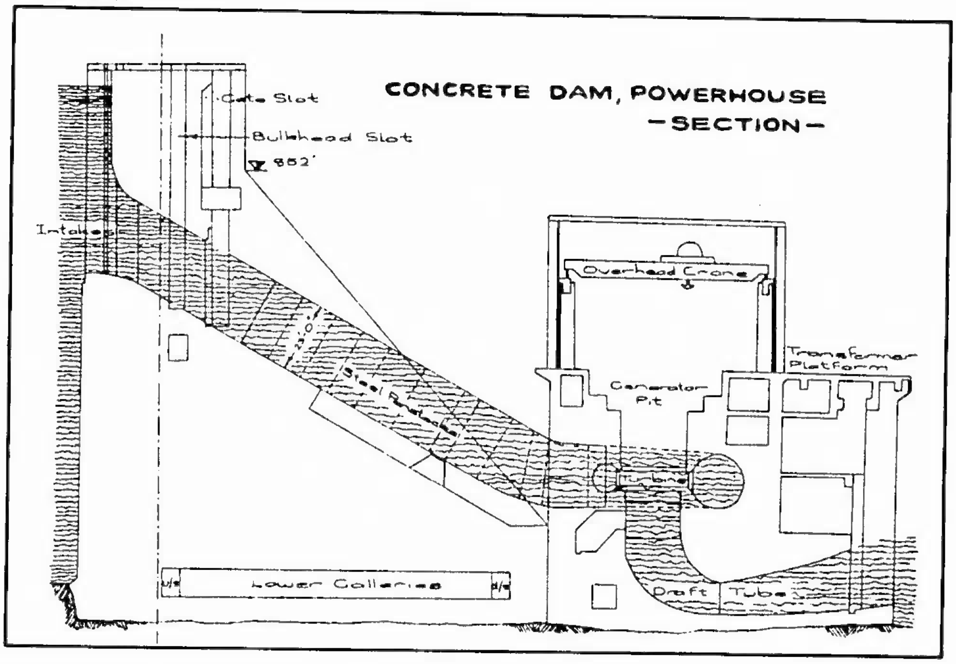


FIG 8B



AVIEMORE DAM

FIG 8C



From Tekapo, we continued on to reach the east coast at Timaru. After lunch we completed the last hundred miles of the tour along the rich coastal plain to Christchurch.

4. ENGINEERING GEOLOGY IN NEW ZEALAND

Throughout the tour we were accompanied by at least one engineer who worked in the particular area through which we were passing at any time; we were therefore well-informed on any details from the civil engineering viewpoint. Also, when visiting any of the major projects, a senior construction engineer was always on hand to discuss the engineering aspects. However, the authors were the only non-engineers on the tours, and only on one day were we accompanied by a local geologist. It was therefore impossible to obtain other than general information on the application of engineering geology to the projects visited; in particular it was difficult to determine the scope of engineering geology in site investigations, and the techniques used.

From the limited information obtained by questioning the engineers, it appears that, at least until very recently, the geologist has played a subordinate role in site investigations. The planning of investigations, including the location of drill holes, has generally been carried out by engineers, and the geologist is called upon only to make geological observations as required. All geological services are provided by the New Zealand Geological Survey, which has no special section devoted solely to engineering geology. This means that many of the field geologists employed by the survey have, at some time or other, carried out mapping or drill core logging for engineering projects; of these geologists only two have been engaged on such work long enough to have gained any real experience of geology applied to engineering. Added to this, the Survey is so understaffed in comparison with the programme of work that none of the engineering geological investigations have been written up, even as internal reports. The lack of specialised engineering geologists also means that the provision of geological services during construction of even major projects is minimal. The only sign of improvement in this situation at the present is the allocation of one geologist to work full-time on the Tongariro scheme. As mentioned earlier in the report, much of the scheme has already been investigated, and construction of two dams, a tunnel, a penstock line and a power-house is already underway. A significant pointer on the site investigation of this scheme is that the depth of excavation at the power house is not known to any degree of certainty; at the moment, bulldozers are excavating the weathered rock, and there is no sign of adequate foundation rock in the present cut.

The lack of engineering geological services on the major New Zealand projects is all the more surprising, in view of the complex and difficult foundation conditions frequently encountered. A number of major engineering structures are necessarily located in extremely adverse conditions; e.g. the Tongariro scheme is in an active volcanic area. Matahina Dam is another project built at a difficult site; from the information gained during the tour, it seems that the site was grossly under-investigated; such a dam would never have been built in Australia on the limited foundation information available. While the unique problems present in New Zealand make comparisons with Australian conditions impossible, site investigations should certainly be as thorough as present Australian practice, if not more so. The extra expense would be more than justified by economies in construction or by more reliable safety factors.

Table 1: Summary of Power Stations in New Zealand

Power Station	Generating capacity in kw Constructed	Under Construction	Type of Dam	Date of Commission
NORTH ISLAND				
KARAPIRO	90,000		Concrete	1947
ARAPUNI	157,800		Concrete	1929
WAIPAPA	51,000		Earth	1961
MARAETAI Stage 1	180,000		Concrete	1954
MARAETAI Stage 2		180,000	Concrete	1971
WHAKAMARU	100,000		Concrete	1956
ATIAMURI	84,000		Concrete-earth	1958
OHAKURI	112,000		Earth	1961
ARATIATIA	90,000		Concrete	1964
MATAHINA	72,000		Rockfill	1967
TOKAANU		200,000	Concrete	1971
WAIKAREMOANA	124,000		?	1948
MANGAKAO	19,200		?	1924
WAIRAKEI	175,000		(Geothermal)	1958
WAIRAKEI		150,000	"	1974
MEREMERE	180,000		(Coal)	?
MARSDEN	240,000		(Oil)	1967
OTAHUHU	50,000		"	1967
SOUTH ISLAND				
WAITAKI	105,000		Concrete	1935-54
TEKAPO	25,200		Concrete	1951
BENMORE	540,000		Earth	1965
AVIEMORE		220,000	Concrete-earth	1968
ROXBURGH	320,000		Concrete	1956-62
COBB	32,000		Rockfill	1944-52
COLERIDGE	34,500		?	1915
MONOWAI	6,000		?	1936
ARNOLD	3,000		?	1937
HIGHBANK	25,000		?	1945
MANAPOURI		700,000	?	?
TOTAL	2,815,700	1,450,000		