DEPARTMENT OF
MINERALS AND ENERGY

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1975/133

VISIT TO HONG KONG, JAPAN, USA, CANADA, ENGLAND & POLAND, 1972.

E.J. Polak

Record 1975/133

VISIT TO HONG KONG, JAPAN, USA, CANADA, ENGLAND & POLAND, 1972.

E.J. Polak

CONTENTS

ILLUSTRATIONS

SUMMARY

The author spent two months visiting universities and Government institutions in Hong Kong, Japan, USA, Canada, Great Britain and Poland during 1972. The purpose was to study recent developments in engineering geophysics, hydrogeophysics and rock testing. Detailed accounts are given of these visits in different fields of interest.

1. INTRODUCTION

My overseas visit included Hong Kong, Japan, USA, Canada, Great Britain and Poland. The last two countries were visited during my annual leave, but as I had technical discussions with several organizations in these countries, the results are included in this report.

The purpose of the visit was to investigate the present state of engineering geophysics, hydrogeophysics and rock testing in these countries and its bearing on the proposed work of the Engineering Geophysics Group, in the next three years. At the request of the Commonwealth Department of Works, I collected some information on the interaction of dams with their foundations during earthquakes and investigations on landslides. The Geological Survey of Queensland asked me to investigate methods of establishing the continuity of coal seams in advance of them being worked. I also attended two international meetings, one on soil engineering in Hong Kong (where I presented a technical paper), and the other a meeting of the Society of Exploration Geophysicists in Anaheim, California.

The itinerary is shown on Table 1.

2. VISIT TO HONG KONG

2-1 South East Asian Conference on Soil Engineering

The main purpose of my visit to Hong Kong was to attend the Third South East Asian Conference on Soil Engineering held from November 6th, to November 10th, 1972. The Conference was sponsored by the South East Asian Society of Soil Engineering, the Hong Kong Engineering Society, The Asian Institute of Technology, Bangkok and the Institution of Civil Engineers, London. All conference sessions were held at the City Hall, Hong Kong Island.

The purpose of the Conference was to provide an opportunity for engineers, geologists and geophysicists to meet and discuss problems and developments in the field of soil mechanics, site investigation, and foundation engineering. A full day during the Conference was set aside for arranged excursions (see 2-3).

TABLE 1. Itinerary

Departed	Date	Arrived	Date
Canberra	4/11/72	Hong Kong	4/11/72
Hong Kong	11/11/72	Osaka	11/11/72
Osaka	13/11/72	Kyoto	13/11/72
Kyoto	15/11/72	Kanazawa	15/11/72
Kanazawa	18/11/72	San Francisco	18/11/72
San Francisco	25/11/72	Los Angeles	25/11/72
Los Angeles	2/12/72	Denver	2/12/72
Denver	9/12/72	Toronto	9/12/72
Toronto	11/12/72	Ottawa	11/12/72
Ottawa	14/12/72	London	15/12/72
London	18/12/72	Stoke-on-Trent	18/12/72
Stoke-on-Trent	19/12/72	London	19/12/72
London	20/12/72	Warsaw	20/12/72
Warsaw	22/12/72	Nowy Targ	23/12/72
Nowy Targ	26/12/72	Gliwice	26/12/72
Gliwice	28/12/72	Cracow	28/12/72
Cracow	1/1/73	Warsaw	1/1/73
Warsaw	3/1/73	London	3/1/73
London	4/1/73	Canberra	6/1/73

The Conference was attended by 112 engineers and scientists from 21 countries. State or government instrumentalities were represented by 29 delegates, Universities by 25 and consultants by 58 delegates. The number of papers presented was 47. At the conclusion of the conference it was decided that the Fourth Conference will be held in Bangkok in 1974. Table 2 shows the country of origin of the delegates and the number of delivered papers.

PAPERS PRESENTED AND DISCUSSIONS

Fourty-seven papers were presented to the conference. These were 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 three to four on allied topics; after each group had been presented, the floor was open for discussion for about one hour. This was a very good system for conducting such a conference, as the bulk of the time available was devoted to discussions, which were invariably more fruitful than the papers themselves.

A condition of acceptance of a paper was that each author attended the conference. About ten authors, including three from Australia, did not arrive in Hong Kong, and their papers were not discussed.

TABLE 2. Country of delegates and papers delivered.

Country	Delegates			Papers Prepared
	Government	University	Consultants	
AUSTRALIA	4	2	-	7
BRAZIL	-	1	-	-
BURMA	-	1	-	-
CANADA	-	2	-	3
CHINA	-	-	1	-
ENGLAND	-	-	1	1
FRANCE	-		-	2
GHANA	-	1	-	1
HONG KONG	21	6	36	6
INDIA	-	1	-	8
INDONESIA	1	-	1	-
IRAN	-	1	-	1
ISRAEL	-	1	-	1
JAPAN	1	2	-	3
KOREA	-	-	1	-
MALAYSIA	1	1	4	3
PHILIPPINES	-	-	2	-
SINGAPORE	-	-	8	2
THAILAND	1	1	4	5
TURKEY	-	1	-	-
USA	-	1	-	4
TOTAL	29	25	58	47

The Guest Lecture was delivered by Professor Victor F.B. de Mello of the Sao Paulo University, Brazil - "Thoughts on Soil Engineering applicable to Residual Soils".

Professor T.W. Lambe of the Massachusetts Institute of Technology, USA, prepared the general report of the conference. He considered that the papers were chosen carefully and covered a very wide field of soil mechanics. They indicated that "South East Asia" is able to produce reports and execute construction of engineering projects equal to any other parts of the world. He judged that the best paper at the conference was prepared by H.G. Poulos from Australia. His one complaint was that generally Australians do not write enough case histories. This really became obvious in discussion, when I questioned some of Professor Lambe's statements on the use of geophysics in landslide investigation.

During the conference, I met Mr E.G. Bouwmeester, Manager of the Fugro Ltd, Consulting Geotechnical Engineers and Surveyors, 16 Angulla Park, Singapore 9. They operate the Sonia System of seismic profiling in South East Asia. The description of the system is given in section 13.

2-2 The Conference Tour

A full day excursion had been arranged to study the following:

1. The Hong Kong water system.
2. Landslides.
3. Road tunnels.
4. Kwai Chung container berths.

31 delegates took part in the excursion. Details of the visited installations were explained by D.S. Davies and D.A. Wainwright from the Public Works Department of Hong Kong.

2-2.1 The Hong Kong Water System

Hong Kong has a severe water shortage. Since the construction of Tai Tam Tuk reservoir in 1863, water restrictions have been enforced annually except for 1966/67. That year the consumption reached 125 million gallons per day. By comparison in 1963/64 the water was only supplied for four hours every fourth day.

Hong Kong consists of 236 islands with a total area of 400 sq. miles. The population in 1971 was 3 950 000. Although the average rainfall is 1760 mm per year, there are no large rivers or lakes for water storage, and industrialization has polluted some areas.

Since 1960 following an agreement with the Peoples' Republic of China 10,000 million gallons of water have been imported from Shun Chum reservoir yearly. The water is pumped into Tai Lam Reservoir. With the completion of a dam across the Shek Pik valley on Lantau Island in 1965 additional water was brought to Hong Kong Island by twin submarine pipelines. In the same year a second agreement was made with China to increase the amount of water purchased. To aid distribution, the Indus and Tai Po Tau pumping station, the Shan Tin treatment works and the tunnel under the Lion Rock were completed. However the system still suffered from the lack of storage capacity.

The idea of a reservoir at Plover Cove to provide storage capacity for the system originated in 1958. Construction of the dam separating the cove from the sea commenced in 1965 and was completed in 1970. Water can be pumped through a tunnel from the reservoir into the Tai Po Tau distribution point for use, or in the reverse direction into the Plover Cove reservoir for storage. During my visit branch tunnels were being driven from the main tunnel to tap water from all the streams along the tunnel route. To meet further needs the High Island Water Scheme was devised and is at present under construction. The Scheme will consist of the High Island Reservoir of 6 000 million gallons, a tunnel connecting the reservoir with the Shan Tin treatment works and with the Lower Shing Mun reservoir and two tunnels which will collect water from stream intakes.

During the conference tour we visited the Shan Tin treatment works. These works can treat 80 million gallons per day. Close to the treatment works we entered the portal of the tunnel being driven towards the High Island Reservoir. The tunnel is 13 feet in diameter and is advanced approximately 2 miles. The project is behind schedule as the ground is more disturbed than expected; a very limited geological investigation was carried out before the start of the work.

The next stop on our tour was the Tai Po Tau pumping station, especially the Fabridam across the Tai Po river. A fabridam is a neoprene and nylon sleeve stretching across the river and secured to a concrete foundation. When deflated the water flows over it. During a flood the sleeve is inflated (by pressure of air or water) thus partially obstructing the flow of water and directing it into the intake of a tunnel and to the Shan Tin treatment works. There are several other Fabridams in the system. (Note: The only Fabridam in Australia is on the Koombooloomba dam in Queensland).

We followed the Ting Kok Road, past several textile mills to the Plover Cove reservoir.

The Plover Cove reservoir was constructed in an arm of the Tolo Harbour. A foundation trench, 200 yards wide was dredged to the depth of 70 ft across the sea bed. The one and a quarter mile long dam was raised 36 ft above the sea level by dumping alternate layers of decomposed rock and sand on both sides of the carefully placed impervious core. A rock face provides protection from the waves. Instruments were buried in the dam to give information on the behaviour of the fill both during and after construction. Two subsidiary dams had to be built to close the outflow to the Tolo Channel and a spillway 800 ft wide was blasted out of the island between the subsidiary dams. After the dam was completed, sea water was pumped out and fresh water impounded. There was a temporary increase in salinity of the water when the storage was first linked to the system. The area of the reservoir is nearly 3,000 acres and the gross capacity 39 000 million gallons.

Next we paid a visit to the site of a desalination plant, where it is proposed to build a flash type plant using fuel oil. The test pilot plant has been operating for at least four years and the new plant (40 000 000 gallons per day output) was started. Piles for new plant had been driven. The estimated cost of the plant is $A45 000 000.

2-2.2 The Landslide

Due to steep terrain the construction of streets and apartment buildings generally requires deep cuts and excavations. The slope is cut in steps 5 ft wide at 25 ft intervals, the slope rising at 10 (vertical) to 6 (horizontal). Due to the surface instability caused by washing out of sand and clay by groundwater the net slope is lowered to 40 degrees and an additional protection in the form of rubble drains, pitching, plastering etc. is provided (O'Rorke, 1972). It will be fully discussed in section 9-1.

2-2.3 The Road Tunnel

During the tour we inspected the portals of two existing road tunnels and the site preparation for the construction of a third road tunnel.

1) The Hong Kong Harbour Tunnel

The tunnel was constructed to facilitate the movement of vehicles and pedestrians between Hong Kong Island and Kowloon, on the mainland (Fig. 1). In 1970, 16 700 vehicles and 655 000 pedestrians on average were carried daily on ferries across the main shipping channel. The tunnel was financed by the shareholders of the Hong Kong Harbour Tunnel Co. Ltd.

The tunnel has dual two-lane carriageways, each 22 ft wide. The total length of the tunnel from portal to portal is 6 000 ft. Buildings to house machinery used to provide ventilation in the tunnel are located at each end of the tunnel. Fig. 2 shows the longitudinal section along the northern half of the tunnel and two cross-sections. The tunnel consists of 15 tubes, on average 250 ft long and 34 ft in diameter, welded from 3/8 inch thick steel plate. The tubes were welded in pairs and stiffeners added. After reinforcement, concrete was applied inside and outside and the ends of the tube were made watertight. The unit was towed onto location and carefully sunk into the dredged ditch, the bottom of which had been levelled using screenings. The joint between the new and old units was made watertight and additional ballast added to prevent any movement of the tube during storms. The seal was then taken off the tunnel and the joint concreted. During our visit only one tube was open, allowing one line of traffic in both directions. For details of the tunnel see Phillips (1972); Innes (1971).

2-2.4 The Kia Tak Airport Tunnel

The work on this tunnel had been started using a cut and cover technique. It will require a temporary shift of the existing runway of the International Airport. The preparation of the sites and the construction of the entry ramps has started. The section of the tunnel is similar to that of cut and cover on Fig. 2.

2-2.5 Road and Rail Tunnel under Lion Rock

The tunnels of average length of 1.5 miles run under Lion Rock, joining the Kowloon area with the New Territories. The rail tunnel carries traffic to Canton. The tunnels were driven into solid granite, but a large section had to be concreted to stop water seepage.

2-2.6 Kwai Chung Container Berths

The berths and the back-up area are being reclaimed using material from nearby hills. The total reclaim area is 94 acres. The hills are being cut to provide terraces on which community development such as schools, housing and open space will be placed.

First the soft marine mud had to be dredged to a depth of 80 ft before reaching solid sea bed. This is about three times the normal depth for dredging. Nine million cubic yards of spoil were dumped into the excavated area. During our visit the three container berths were already completed and the associated railway and road work nearly completed.

3. VISIT TO JAPAN

The main purpose of my visit to Japan was to investigate the methods used to predict the interaction of engineering structures with the ground during an earthquake. I also wished to investigate new developments in rock mechanics and in rock and soil testing.

3.1 Osaka

I arrived in Osaka on Saturday 11 November 1972. Due to the late arrival (the plane was diverted and searched in Taiwan) my hotel reservation in Kyoto was cancelled and I had to spend my weekend in Osaka. Fortunately Mr C. Kato, an engineer from the city administration agreed to take me on a tour of the local system of elevated expressways now nearing completion. These are toll roads, on piers up to 1 m diameter allowing for a very fast movement of vehicles across the city. The city was severely damaged during the war and the elevated expressways which are sometimes level with the third floor buildings blend very well with the new factories and apartment buildings. For considerable distances these expressways follow canals and where they cross public parks they are lowered and screened by trees and bushes. Near the Osaka Castle I watched caissons being sunk to a depth of 25 m in the mud of the river Dojima. The walls of the castle consist of large blocks of granite the biggest one has a flat surface of more than 15 m^2. The method used to transport such large blocks in the Ninth Century still defies explanation.

3.2 Kyoto

Kyoto the old capital of Japan is an historical cultural and technical centre rivalling Tokyo. In many aspects there are two schools in Japan which influence work and research in other places, grouped around the two universities located in these centres.

3-2.1 The Disaster Prevention Research Institute was established in 1951 and is affiliated with the Kyoto University. The Institute is located in Uji City about 15 kilometres from the centre of the Kyoto City. The Institute consists of 16 sections and 11 laboratories, observatories etc.

The Sections work very closely and some of their projects overlap. I met several people in a joint session. These were:

Professor Sakuro Murayama - the Director of the Institute and the head of the Subsidence and Failure on Soft Ground Research Section; Research subjects are the theoretical properties of clays, the mechanical properties of sands, rocks and rock masses, the dynamical behaviour of soils and the earth pressure on tunnels.

Professor Ryoichiro Minai - Head of the seismic Ground Structure Systems Research Section, which deals with the dynamical characteristics of ground and with the earthquake waves; the dynamical characteristics of foundations and ground structure systems and aseismic design.

Associate Professor Noritoshi Goto - Head of the Earthquake Motion Research Section, which deals with the generation and propagation of seismic waves and applied seismology.

Professor Minou Wakabayashi - Head of the Earthquake Resistant Structures Section; Current studies include the liquefaction of saturated sand, elastic wave velocities in unconsolidated material and the strength of sand under dynamic loading.

Professor Yoshimichi Kishimoto - Head of the Crustal Movement Research Section. This section investigates the structure of the earth's crust and mantle, crustal movements, micro earthquakes and earthquake mechanisms and the prediction of earthquakes.

The results of these discussions are included in Part 8 of this report.

Professor Michiyasu Shima is the Head of the Landslide Research Section. This section was established to study geological conditions for landslide occurrences, landslide movement and the methods of investigating landslides. Several geophysical methods are used in their work. These are: seismic refraction, natural radioactivity, resistivity, temperature, etc. The discussion is included in part 9.2.

3-2.2 Visit to the Laboratories of the Institute

The Institute has several laboratories on the campus and also several outstation laboratories. The description of some laboratories are given in an outline of the Research Activities of the Disaster Prevention Research Institute, Bull. Disast. Prev. Res. Inst. Kyoto Univ. 21. 1971. I visited several of the laboratories:

(a) Determination of the natural frequency of the ground.

Two different approaches are used.

(i) From microtremors

Plate 3 shows the arrangement of geophones used to determine the natural frequency of the ground. The valley fill consists of several layers of sand clay and gravel. Three component geophones are located in a borehole at several depths, similar geophones are also embedded into outcrops on both sides of the valley. The output from geophones is transmitted to a central station, and continuously recorded on magnetic tape. The data is then fed into a computer to obtain Fourier components.

(ii) From a mechanical oscillator.
An oscillator has been constructed. The oscillator is bolted to a structure or to a concrete block set into the ground. The horizontal force F exerted by the oscillator in the frequency range 2 to 7 Hz, F = 286 f, varies between 1 and 14 tons.

The interpretation of data obtained from recording of micro tremor or oscillator tests are discussed by Yoshikawa, Shima and Irihura (1967).

(b) Shaking tables.

Two shaking tables have been constructed.

The first is operated hydraulically and allows a horizontal movement in one direction with a maximum displacemenf 10 cm. at frequencies 1 to 30 Hz. It has a capacity of 10 tons. The second is operated electro magnetically and allows a horizontal displacement in two directions of 5 cm magnitude at frequencies of 1 to 200 Hz. It has a capacity of 4 tons.

(c) Rock and soil testing laboratories

Ultrasonic pulse laboratory. The main subject being studied at the time of my visit was the dependence of wave velocity on moisture content, porosity, stress and strain in soils. The equipment is similar to the Bureau's ultrasonic equipment but it has additional facilities to measure sonic velocities in highly absorbing media under pressures ranging up to 1000 kg/cm^2.

The laboratory also has a triaxial high capacity press which can exert an axial load of 50 tons. The press is also used for experimental research into the failure of stratified rocks around an excavation.

(d) Slope stability laboratory

A steel channel 400 cm long, 25 cm wide and 50 cm high has been constructed with one wall of glass 6 mm thick. Distances of 5 cm are marked on the glass plate to facilitate the observation. On both ends several overflow pipes are located to keep constant level. These pipes are controlled by two valves. Ten glass piezometer tubes are inserted to show the position of a phreatic surface.

The channel has been used to measure the stability of an embankment, seepage through material, seepage failure at the downstream face, scouring and sliding failure.

3-2.3 The Yodo River Water Management

The rivers in Japan are characterized by their steep gradient and short lengths (see plate 4). Fig. 1 shows longitudinal bed profiles of rivers in Japan and several other countries. The Japan mean annual precipitation is from 100 to 300 cm. The heavy precipitation is mostly caused by the tropical cyclones and the rainy season. Melting snow results often in heavy floods. (Fig. 2 (plate 4) shows that rivers in Japan are characterized by a much higher ratio between minimum and maximum discharge, than rivers in other countries.

The Japanese islands have been divided into several water regimes, organized on similar lines. I visited the Yodo river basin, (area 7281 km^2) which contains more than 10 000 000 people and produces 14 percent of Japan's exports.

The centre of the basin is Lake Biwa (plate: 5). The lake is 104 m deep and has water storage capacity of 27 500 000 000 m^3. The level of the lake is controlled by Satagawa weir. The weir may raise the level of the lake by up to 5 m during flooding.

Below the weir on the river Uji there are two power stations, one the Uji and the other the Amagase with the 73 m high dam. The second outlet from the lake has three power stations. Further downstream below the confluence of Uji, Katsura and Kizu the river is called Yodo.

In the basin of the Yodo river 30 telemetering precipitation observation stations and 23 telemetering water level observation stations were established. These stations transmit by radio automatic readings on each hour to the central recording station. The data is fed into the electronic digital computer, where the calculations of flood run off and optimum discharge from dams are made. Then the instructions for dam and weir operation and flood forecasting are sent by radio. The level of the flood is kept below the capacity of the channel, which for lower Yodo is just below 7000 m^3 (210 000 cusecs).

3.3 Kanazawa

Kanazawa, the capital of Tshikawa Prefecture, with a population of 360 000 lies about 300 km north-east of Osaka on the shore of the Japan Sea. The City was established in 1471 as a Bhuddist Temple.

Kanazawa is an old city with many important buildings of the Edo Period (1603-1867).

The Kanazawa University is located in the gardens of an old castle of which only the outside walls and two gates are left. The university is surrounded by the old city with narrow streets, wooden houses and small shops. The only modern part is near the railway station in the industrial suburbs and the port, where new berths are being constructed to accommodate 60 000 ton tankers.

The name of Little Kyoto which is often applied to the city of Kanazawa, could also be given to the Kanazawa University. The whole teaching staff of the Kanazawa University had initial training at Kyoto and the approach to the rock mechanics is really the same as at the Earthquake Disaster Prevention Research Institute of Kyoto.

At the Kanazawa University I met Professor Yochicka Nishida the Head of the Department of Geotechnique of the Graduate School of Engineering. As we had exchanged letters since 1967, we were soon able to discuss matters of common interest. I made a brief visit to the Geology Department laboratories to see the map making school, petrology and mineralogy and structural and economic geology departments. Later at an official tea I was introduced to Dr Zennosuke Nakagawa, President of the University.

In the engineering campus located in the new part of the city I visited the soil testing laboratories. The main interest lies in the measurement of the properties of clays. About 30 post graduate students studying for a higher degree work in this section. A special part of the laboratory allows students to take measurements on clays, sands and rocks at temperatures as low as -20^{o}C.

A group of students under the guidance of Professor Nishida are constructing a triaxial press which will be capable of applying loads over the frequency range 0.01 to 30 Hz. The press will be used to simulate stresses occurring during an earthquake.

All these investigations are supported by the field measurements whenever practicable. For instance I was able to visit a four day old landslide which occurred after 76 mm of rain fell in one hour. The site had been recognized as a potential landslide area and instruments had been installed to monitor any movement. The slope had been undermined during construction work for river regulation. Although the slope was protected by gunnite and drainage pipes it moved over a total length of about 120 m. Steps taken to achieve slope stabilization were the removal of excess material, better drainage upslope and at the toe, and reapplication of gunnite.

In the vibration testing laboratory Professor K. Ono showed their equipment which is used to measure industrial vibrations and the methods of mounting a mechanically unstable body, which produces vibrations. The effect of vibrations from a passing train on a nearby structure were investigated in my presence.

I spent a lot of time at Kanazawa with the students. I delivered a lecture on geophysics applied to engineering in Australia to a group of about 150 students. The discussion was very wide ranging. I gave also a seminar to 25 post graduate students, who were given in advance copies of my papers from Auckland and the Melbourne meeting of the A & NZ Society of Rock Mechanics and Foundation Engineering. In the evening I was a guest at the annual dinner of the Geotechnical Society.

I left Kanazawa for Tokyo on the way to San Francisco.

4. VISIT TO USA

I spent three weeks in the USA arriving there from Japan on Saturday 18 November 1972 and leaving for Canada on December 9 1972.

In San Francisco I visited the Berkeley University and the Pacific Coast Centre of the US Geological Survey.

In Los Angeles I attended the 42nd International Meeting of the Society of Exploration Geophysicists and visited the San Onofro Nuclear Generating Station and the Scripps Institute of Oceanography.

In Denver I visited the US Geological Survey, the US Bureau of Mines and US Bureau of Reclamation.

4.1 University of California, Berkeley

The University of California comprises several campuses of which I visited one the Berkeley Campus. The main purpose of my visit there was to see and discuss the work being done on the prediction of the interaction between ground and structures during an earthquake, the prediction of the occurrence of an earthquake, the application of geophysics to engineering and hydrological problems.

This work is being carried out by several departments, loosely co-operating. The composite results are generally given at symposia and in the faculties reports.

4.1.1. Faculty of Engineering

Professor R.R. Wiegill is the Dean of Engineering and the Professor of Coastal Engineering. I visited him to obtain permission to meet some of the faculty's professors. Professor Wiegill is concerned with actual construction of piers, harbours, sea defences, but not with the investigations for the structures.

Professor P. Wilde is lecturing in the Department of Civil Engineering on the Ocean and Sea Investigation. Plate 6 is taken from a printed set of his lectures and illustrates well the subject covered by him in the course. His present experimental work is concentrated on air guns, as he considers that the sparker is on the way out. This opinion is not shared by several members of the faculty. Prof. Wilde's (1971) lectures are available at the Engineering Geophysics Group of the Bureau.

Professor G. Raphael is the professor of Dam Construction. His interest lies mostly with the utilization of the data collected during the preliminary assessment of the construction site.

Professor R.E. Goodman is the Professor of Landslide Engineering. The main subject of his investigation is the determination and measurement of the changes in properties of rocks in landslides using seismic, electrical and magnetic techniques as well as strain gauges in the field and model experiments and shear boxes in the laboratory. His major project is the investigation and recording of subaudible noises occurring in the slipzone of models and in the field. The subject will be enlarged in section 9. A record dealing with this investigation is deposited in the library - (Goodman, 1971).

Professor H. Bolton-Seed. The main object of his investigation is the behaviour of the ground during an earthquake and the interaction with the structure above it. The subject of our discussion will be dealt with in section 8.

Professor H.F. Morrison is involved in many aspects of the application of geophysical methods. The following list of research being done during my visit there shows how wide is the coverage.

Mr A. Mozzella is working on the correlation of deep resistivity with earthquake activity across the San Andreas fault zone. The instrument being used is described in section 14 of this report. Associated with this work is R. Alvares working on Electrical Conduction Mechanism in rocks and H. Bayer who is working on use of electrical methods for the delineation of geothermal reservoirs. The marine work concentrates on the following: the monitoring of pollution parameters in San Francisco Bay by U. Conti Self-potential in marine environment by R.F. Corvin and the geophysical and geochemical determination of the engineering properties of marine sediments by T. Hildenbrand. In the seismic studies being carried out by R. Clymer, use is made of the Berkeley earthquake simulator as an artificial elastic wave source. A special shaking table 6 m x 6 m was constructed, it can vibrate in a vertical and one horizontal direction. In the aeromagnetic section the interpretation of three component aeromagnetic data by J. Lourenco (1972) and the design of an optimum airborne electromagnetic system for deep search, are being investigated. In the theoretical research section the following investigations are being carried out the direct and inverse electromagnetic scattering from two dimensional inhomogeneities in a conductive half space by A. Dey (1972). A study of VLF components by D. Trussel and the integral formulation of the induced polarization prospecting by R. Bakbak. The induced polarization (IP) method is playing a major role in their research. Professor Morrison published several papers on inductive coupling. Dr Coggon (1971) now in CSIRO in Sydney produced a report on IP Modelling. Electric IP gave disappointing results as the change in thickness and character of overburden produces greater anomalies than the investigated body. The magnetic IP was a success and they are able to record a change of 10^{-4} gamma.

4.1.2 Department of Seismology

The head of the department is Professor B.A. Bolt. He made all the arrangements for visits to his laboratories, observatories and also acted as contact with the other departments. His Assistant is Mr W.K. Cloud. They operate several seismological observatories all interconnected by telephone. The centre is located at the University.

Prof. Bolt just completed editing two volumes of the Series "Methods in Computational Physics" vol 11 - Seismology, Surface Waves and Earth Oscillation, vol 12 - Seismology; Body Waves and Sources. He helped to organize the Microzonation Conference at Seattle. At the department they are working on the application of the Finite Element Method in geophysics.

4.2 US Geological Survey

The Geological Survey is a part of the US Department of Interior, with headquarters in Washington, D.C. The survey maintains several centers including The Regional Pacific Coast Centre at Middlefield Road, Menlo Park, California and the Denver Centre in the Federal Centre, Denver, Colorado.

4.2.1 US Geological Survey, Regional Pacific Coast Centre

The work of the Pacific Coast Centre is divided among four operating divisions: Topographic, Geological, Water Resources, and Conservation. The three supporting groups are: Computer Centre, Publications and Administration.

In the Geological Division I met Mr B. Wallace who is the Head of the Division, as well as his assistant Mr Bordman and Mr W.E. Davies. They described the work of the Centre and passed me on to Mr J.H. Feth, Staff hydrologist and E.R. Leeson of the Regional Hydrology of the Pacific Coast section of the Water Resources Division. All above positions are administrative.

Mr H.W. Oliver is in charge of regional magnetic and gravity. He has done several surveys over narrow buried channels. This subject is well illustrated by a publication of which he was a co-author (Paterson, Yeend, Oliver, Mattick, 1968). At present he is working on a computer programme for the interpretation of gravity maps of wide buried valleys. It will be published shortly in the US Geological Survey Circular.

Mr L.G. Dutcher is in charge of Artificial Recharge. His belief is that artificial recharge to prevent the entry of sea water into an aquifer is a waste of money. He enlarged on the general approach to the recharge of a delta area in the following three steps:

1) determine the depositional model - are there discrete channels bordered by clay, or is this a randomly laminated sand and gravel deposit.

a) Examine drill holes statistics to determine whether or not sand is normally randon in the system.
b) Examine well hydrographs - relate areas of recharge to water level recovery in the wells to determine, if channels exist or if the deposit is heterogenous.

2) If this is a channel system resistivity will be useful to determine the water quality differences, if they exist across a clay barrier.

3) The main problem seems to be that large drawdowns during a drought can result in the sea water intrusion. This problem is not directly related to the other. Sea water infiltration may be prevented by other well known methods much cheaper than by artificial recharge, which will introduce permanent, not reversible changes in the aquifer.

Mr Dutcher gave me two publications (Moreland 1970, 1972) which deal with artificial recharge. They are deposited in the BMR Library.

Dr S.C. Wolf and Mr K. Blomb are developing a low energy sparker to obtain good penetration and good revolution. It will be discussed in section 13. In their opinion the sparker is going out of use for smaller outputs. It is being taken over by the air gun. The ideal set, according to them, is the EGG Uniboom (new laminated model) and an airgun coupled so that the whole range of frequencies is used. They are developing a three colour recording method, in which the Input pulse is split into three groups of frequencies. Each group is recorded in a separate colour on a single chart. By a careful choice of limits it is possible to record all the "doubles" in different colours and remove them from the final record by filtering.

Mr M. Malony is working on a very high power sparker up to 160 kj. His record from the Puerto Rico trench do not show "push overs" of the crust, as is shown on records from other trenches.

Soil testing laboratory

The only new development there is an attempt to construct a shear box in which the sample fails along the least resistant surface, while in existing shear boxes the failure happens along a predetermined surface depending on the construction of the box.

4.2.2 US Geological Survey, Denver Federal Centre

The Branch of Regional Geophysics in Denver has the biggest concentration of geophysicists employed by the US Geological Survey. Mr M.F. Kane is the Chief of the branch. His particular interest is ground magnetics and he was instrumental in developing a truck mounted magnetometer, extensively used by the US Geological Survey for geological mapping. (Kane, Harwood, Hatch, 1971)

Dr Adel A.R. Zohdy works on the interpretation of resistivity depth probing. This subject is discussed in section 14 of this report.

Dr C. Frischknecht is working on the electromagnetic transient method. He is constructing a receiver working on frequencies 200 to 2000 Hz. The layout consists of a transmitter coil of 28 cables in a 10 to 10 m square and the receiver 3 m square 410 m apart. He and Anderson developed a computer programme to interpret the results.

Mr Hoover is working with Dr Frischknecht and Dr Stanley on the Audiomagnetotelluric method. The receiver measures 8 discrete frequencies between 8Hz and 20 000 Hz. They expect that this method will take over from resistivity depth probing for structures up to 800 m deep.

Dr W.D. Stanley's work is connected with ground water investigations using several geophysical methods. His Ph.D Thesis (Stanley, 1971, 1972) "An Integrated Geophysical Study related to Groundwater Conditions in Cache Valley, Utah and Idaho" has been deposited in the BMR Library.

W.S. Keys is in charge of borehole logging. He is a co-author of the book "Application of Borehole Geophysics to Water Resources Investigation". My main interest was to find the latest information dealing with the Redox or Eh logs. The log measures the reduction-oxidation process in the bore. After a very encouraging start the development work stopped mostly due to the lack of staff able to continue the research. Research will start again when the staff is available. Information of Redox logging is available from the book by Pirson (1970).

4.3 US Bureau of Mines

Dr Obert is the Chief Adviser to the Bureau of Mines and he is also in charge of the Rock Mechanics Group of the Bureau. His main interest at present lies in the propagation of seismic pulses between bores.

Mr N. Nicholls is in charge of rock testing in the Bureau.

4.3.1 Laboratory Testing. Mr C.F. Johnson

a) the main project is the investigation of the soundness of the roof in a mine by use of a sonic technique (see 12-3)

b) Other projects include measurement of ultrasonic P,S and bar velocities (see 10-2)

4.3.2 Field testing of rocks - Mr R.D. Munson

a) Dynamic properties of rocks, including the attenuation are measured using equipment described in section 12.

b) Holography -G.L. Fitzpatrick The main purpose of this method is determination of cavities, their size and shape in pillars in underground mines. After many years of laboratory investigation the method is being tested in two mines (section 12).

4.3.3 Correlation of field and laboratory tests. Mr B.T. Brady

The behaviour of fractured oil shale pillars and the development of criteria for design of underground room and pillar mining is the main work of the group. The instrumentation include a new stiff test press manufactured by MTS System Corporation, Minneapolis, as a part of a so called Servo Control Rock Mech. Testing System of 600 000 lbs capacity. The total system costs $US 55 000

4.3.4 Overcoring technique. Dr V.E. Hooker and Mr J. Aggson

Their research on the overcoring technique and equipment has been completed (Hooker, Bickel, 1972).

The equipment consists of a three component borehole gauge; three model P-350 strain indicators, an orientation and placement tool, a biaxial cell to determine the modulus of elasticity and drilling and overcoring equipment. The three component borehole gauge will not be produced commercially. The Bureau of Mines can supply all the instructions and blueprints. The approximate cost of fabricating one set is about $US 600, the required Vishoy P-350 strain indicator also cost $US 600.

In situ rock temperature measurements show that diurnal temperature variations are significant to a depth of less than 1 metre. An overcoring device was used to measure stresses dependent on the temperature, the stresses can vary up to 1690 psi due to temperature change (Hooker and Duvall, 1971).

4.3.5 Rock burst research Mr J. Huck

The research has been completed. Their second system has been installed in a mine in Pennsylvannia (see 12).

4.3.6 Infrared detection of temperature. Mr P.L. Russel

This group is evaluating the use of hand-held scanner for the detection of changes in temperature due to the underground flow of water (Russell, 1972) the spontaneous ignition of coal in mines and the surface, parting of the roof, etc. The Close Focus Viewer CFV - on loan from the US Army has been used, and it is superior to the Hughes Aircraft Co. Oceanside California model Probeye, (cost $US 8000).

4.4 US Bureau of Reclamation

The Denver Section is the main technical groups in the Bureau. All the design of dams, the model testing and rock testing is done there. I started my journey from the top. Mr M. Howard, the head of the Denver Section. Mr J.R. Julian assistant to Mr Howard, Mr N. Warner - Leader of the Research Section and Mr E. Rohrer - head of the rock testing laboratories took me to visit:

4.4.1 Model Section

a) All the proposed dams are modelled in scales 1 inch = 8 ft for small dams up to 1 inch = 100 ft for the Hoover Dam. These models are tested in the applied static pressures, but the testing will be discontinued as computer modelling is taking the place of model testing. A large shaking table was constructed also for dynamic testing, but was never used for this purpose as it is used to test the material used for construction of dams.

b) Hydraulic model test. The outflow from turbines, the spillways and the inflow to turbines are tested in the laboratory which is the second largest in the world.

4.4.2 Rock testing laboratory

Consists of several tens of testing machines for tests on cores from 2 to 24 inches in diameter using pressures of 30 000 psi to 45 000 000 psi. Testing machines are placed in rooms with different temperatures and humidity. One room had 12 compressive presses which had held concrete cores under the same pressure for last 8 months. I did not see any new method of rock testing.

4.4.3 Rock Mechanics Section- Division of General Research

- Mr D.L. Misterek - The research at present is concentrated on tunneling. A booklet, "A Research Program for rapid underground constructions", describes the work in the Stillwater tunnel. This book and a book by Ross and Hustrulid "Development of a Tunnel Boreability Index" were deposited in the BMR Library.

4.4.4 Applied Physics Section - Mr T.E. Backstrom

This section is working on remote sensing to locate cavities in limestone. The results were not conclusive.

4.4.5 Division of Design-

Mr M.A. Jabara is responsible for the design of spillways and has had some experience with the application of seismic to dam design. All the spillways in the USA are concrete lined, and so geophysics was not used. He acted as an advisor on cement grouting in Greece on a dam constructed in limestone.

4.4.6 Design Geologist Mr Malcolm Logan

Design Geophysicist Mr Andris Viksne

We discussed the investigation and sealing of limestone caverns in the Anchor Dam in Wyoming. Acoustical holography (section 12) seismic resonance (see 11.2.1) and electromagnetic subsurface profiling (11.4.5) were used.

4.5 Meeting of the Society of Exploration Geophysicists

The 42nd Annual International Meeting of the S.E.G. took place at Anaheim, California, Nov 26-30 1972. More than 3400 geophysicists attended the meeting, and 139 papers were read. The large number of papers required running four parallel series of lectures. It would be difficult to discuss all the papers here. The abstracts are in the Engineering Geophysics Group of the Bureau. Some of the papers were preprinted. The list of them is in appendix B and the copies are in the Eng. Geoph. Group.

The exhibition area had 84 stands showing the recent advances in geophysical instrumentation. It would be futile to discuss the exhibits in this part, some of them will be discussed in sections 8 to 15.

4.6 San Onofro Nuclear Generating Station

San Onofro Nuclear Generating Station was constructed by the Southern California Edison Co. and San Diego Gas and Electric Co. It is located on the coast approximately 5 miles southeast of the City of San Clemente, California. The site is 40 hectares in area.

Pleistocene Terrace Deposits of sand and gravel overlie San Mateo sandstone of Pliocene age. The San Mateo formation is more than 100 m thick. Offshore probing established boulders beneath the sand. Several faults cross the area, but all of them seem to be Pre-Pleistocene.

A consideration of the seismic risk at the site was based on 22 major earthquakes recorded in the area since 1869. It was found that an earthquake with an intensity of IX might be expected once per 600 years, and an intensity VIII quake once per 100 years.

Following Kanai (1962) it is estimated that a magnitude VIII shock on the San Andreas fault would produce at the site a horizontal ground acceleration of 0.25 g at a period of 0.3 seconds and intensity of about IX. All the structures important to nuclear safety were designed to handle an acceleration value of 0.5 g and all other structures of 0.25 g. By comparison the corresponding figure of the City of Los Angelos building codes is 0.10 to 0.13 g and for steam power plants of 0.20 g.

The hydrological investigations indicate that the cooler water discharged one kilometre offshore will not be drawn into onshore water wells.

A wall 8 m high above mean sea level has been constructed to protect the plant from tsunamis.

The power station went into production in 1967 and its net power output is 429 000 KW (about one-eighth of the Snowy Mountains scheme). The fuel used in the reactor is composed of small pellets of uranium dioxide (UO_2) (Plate 6). The reactor vessel contains nearly 6.7 million of these pellets fitted into 28 000 stainless steel rods forming the reactor core ten feet high and ten feet in diameter. During the operation pressurized water (to allow the rise of temperature to $600^{o}F$ without boiling) is circulated through the core. The hot water then passes through the tubes of another boiler to change water into steam. The steam generated is then used in a conventional steam-electric plant.

In the USA 38 nuclear power stations produce 3% of all electric power compared with 47% from coal, 23% from gas, 17% hydroelectric and 10% from oil.

4.7 Aseismic construction of high rise office buildings

The Uniform Building code of State of California puts severe restrictions on the method of construction of high buildings. Plate 7 shows three types of construction.

The fifty two storey Twin-tower Atlantic Richfield Plaza was prefabricated and the frame was welded together to allow the top of the building to sway up to 1.5 m. During construction welding was rigorously tested using an ultrasonic pulse technique.

The Transamerica Building in San Francisco is 261 m high with a base of 53 m square. To increase its stability the cross-section is reduced between the second and fifth floor by use of perimeter transfer trusses. From the 5th to 60th floor the outside wall slopes inwards at an angle of 84^{o}. Lateral loads are carried by the exterior frames and to the 45th floor by 8 interior frames. Above the 45th floor the number of interior frames is reduced to four. The biggest drawback of the construction is the limited area of the upper floors; the building is useless for occupation from 48th to floor 60.

The third method of construction is also shown here. The welded frame forms the outside of the building to allow the suspension of walls. The movement of the walls is free, and so cracking is avoided.

4.8 Scripps Institute of Oceanography (SIO)

The Institute is located about 5 miles north of San Diego. It is reached after a pleasant drive from Los Angeles, passing on the way villages and townships of Spanish California. The country is open, undulating and with big family residences including the White House of Pacific.

Approaching the steep cliffs of the shore the most prominent feature visible is the pier. It is 330 m long. The pier was constructed during the First World War and shows the resulting wear. The pier is used for laboratories by the University of California, for fishing and as a boat harbour by people from La Jolla and San Diego and as a pumping station for recirculating of salt water.

In the laboratories measurements of sea temperatures, salinity evaporation, wave movement are done, and investigation of plankton and mussel growth, pollution, corrosion and durability of material are also carried out.

In the Deep Sea Drilling Project we saw the cores from the fourth leg of the expedition. The cores came from bores 1300 m deep located in more than 6000 m of water. The Geological Research Division investigates the structure, the stratigraphy and the geological history of the Bay of Bengal. The work includes deep seismic refraction.

The Hydraulic Laboratory houses a wind-wave channel 40 m x 3 m x 3 m with a simulated beach, a 20 m x 15 m wave basin with a beach and a 40 m glass walled wave and current channel. All research installations are instrumented and connected to an IBM 1130 computer.

We also inspected the construction of the long period sea floor seismograph the Remote Underwater Manipulator and Aquarium-Museum.

We heard lectures delivered by W.C. Anderson on marine physics, C.H. Gibson on fluid dynamics and O.E. Weser on marine sedimentation.

Further information on SIO can be obtained from yearly reports. The 1971 report is in The Engineering Geophysics Group of the BMR.

5. VISIT TO CANADA

I spent five days in Canada arriving there on Saturday 9th December 1972 from Chicago. On Sunday I visited the Niagara Falls and three hydro-electric stations. On Monday I visited the Geological Survey of Canada; on Tuesday the Water Resources Directorate and on Wednesday the Rock Mechanics Laboratory of the Mining Research Centre. On Thursday I returned to Toronto, where I met Mr Andrew formerly a geophysicist with the Engineering Geophysics Group of the BMR now the Director of Pollution with the Brunswick State Government. I completed the official part of my overseas visit and started my leave.

5.1 The Geological Survey of Canada

The Geological Survey of Canada is a branch of the Science and Technology Sector of the Department of Energy, Mines and Resources. The organization employs 700 staff of which 295 are university graduates. It is divided into 7 divisions. I visited the Resources Geophysics and Geochemistry Division (RGGD) and the Terrain Sciences Division.

The recent reorganization of the Department and removal of the staff of old Inland Waters Branch to the Water Resources Directorate of the Department of Environments left the Geological Survey understaffed.

5.1.1 Resource Geophysics and Geochemistry Division

The division is responsible for national surveys geophysical and geochemical which are necessary to prepare an inventory of mineral resources. In connexion with this aspect the division is responsible for development and testing of geophysical and geochemical methods and equipment.

Dr A.G. Darnley is the Chief of the Division and Dr J.S. Scott is the Assistant Chief. They took the responsibility to arrange my visit to other divisions and departments in Ottawa.

Dr L.S. Collett is in charge of electrical work in the Survey. His main investigation at present is the electrical and EM properties of rocks and their bearing on IP work and recognition of these rocks from the decay curves. In the permafrost area he used a high frequency of 10^4 to 10^6 Hz to detect cavities and cracks in the bedrock. The spacing between the transmitting and receiving coils was only 2 m. The cavities (3 ohm m) in permanently frozen ground (resistivity 1000 to 100 000 ohm m) were at depths up to 10 m.

Dr J.A. Hunter is an engineering geophysicist. He used seismic refraction in the permafrost area where the velocity contrast is in ratio 1 to 5. All their effort is directed at present to work on the proposed oil pipelines from the North. The group is too small to work effectively.

5.1.2 The Terrain Sciences Division (TSD)

The Earth Physics Branch of the Division is concerned with the gravity, magnetic, measurement of radioactivity and heat flow.

Dr Gibbs formerly of the BMR is the head of the gravity section.

Dr A. Jessop is in charge of the Geothermal section. They measure temperature in bores specially drilled for this purpose to a depth of about 600 m. The measurements are made by a thermistor probe suspended on four conductors, A-B for the thermistor, BC to test for a change in resistance of the cable, CD to test for leakage of the probe. (The details are given in the paper by Jessop (1968)). The heat conductivity of the samples from bores is measured in a divided bar instrument constructed in their workshop. The working diagrams of the instrument are in the Engineering Geophysics Group. To obtain a sample 1 cm thick with perfectly parallel faces the sample is rotated below the cutting saw. The polishing is not required. For measuring the heat conductivity from percussive drilled bores, chips are placed in a container and the pores are filled with distilled water and detergent or silicone oil.

5.2 Water Resources Directorate

I visited only the Hydrology Research Division of the Water Resources Directorate, Department of Environment. It was the Inland Waters Branch of the Department of Energy, Mines and Resources. The head of the Division is Mr D.H. Lennox. The Division consists of four sections: Eastern Research Section, Western Research Section, Computer Research Section and Maritime Research Section. We discussed two aspects of their work: The investigation for water in the prairies and salt water intrusions.

5.2.1 In the Canadian prairies, geophysics has two main uses in groundwater exploration; delineation of the preglacial drainage pattern and mapping the location and extent of buried permeable deposits. Seismic refraction, magnetic, resistivity and gravity methods were used. Details of the use of geophysics in these areas are given in Lennox 1962; Lennox & Carlson, 1967a; Lennox and Carlson 1967b.

5.2.2 Detection of salt water intrusion

This is the work of the Maritime Research Section. I met Dr H. Lazreg there. The main object of the group is investigations of the intrusions of sea water into aquifers in the North East Provinces of Canada. They use resistivity and IP and they are convinced that intrusions of salt water produce a very high negative IP effect. This effect is indicated more clearly on the time domain IP than on resistivity depth probes. Also they claim that it is possible to see an IP effect due to the water table. Unfortunately on the curves I was shown, this IP effect is indicated on one point of measurement only.

The VLF measurements in the area produced contouring similar to the resistivity results. The use of the equatorial dipole - dipole method speeds up the investigation of the discontinuity of conductivities in a shallow aquifer, then Wenner depth probing is used to determine layering. The Wenner arrangement is used more often than Schlumberger. The album of standard Wenner curves is being prepared by Lazreg based on the data from the Moonee-Orelana book.

5.3 Rock Mechanic Laboratory, Mining Research Centre

The laboratory is located at Bell Corner, about 30 miles from the City. On the way there our car slid from the road and was bogged in the snow for several hours. I lost quite a lot of time and met only Mr G.E. Larocque and Mr T.S. Cochrane. They completed the design of the equipment for detecting rock bursts and they are testing it in a mine. The equipment is the same as that designed in Denver (see 12). They use Danish (Bruel & Kyaer) accelerometers claiming that they are more stable and they do not change characteristics when subjected to high accelerations. They measured the acceleration from a 500 lbs explosives shot at a distance of 3 metres. They used a Potts probe to insert the accelometer into a shothole. The recording is done on a 14 track tape recorder.

The rock testing laboratory is similar to any comparable relatively small rock testing laboratory.

6. VISIT TO ENGLAND

I arrived at London on Friday 15 December 1972. I spent Friday visiting the Institute of Geological Sciences. On Monday morning I went to the H.Q. of the National Coal Board and then I travelled to Birmingham to meet the Professor of Geophysics D.H. Griffiths. During the night I went to Stoke on Trent to visit the West Midlands Technical Services, National Coal Board.

On Tuesday night I returned to London for further talks at the Institute of Geological Sciences.

6.1 Institute of Geological Sciences, Natural Environment Research Council

I met Dr W. Bullerwell the Chief Geophysicist and then I went through the different branches, meeting several people.

6.1.1 Mr D.A. Grey - Chief Hydrologist.

This branch has carried out an investigation for a dam in limestone in Pennines, north of Sheffield. Movement of water in joints and cavities below the water table was investigated. The bores were drilled into the limestone well below the proposed excavation and:

a) temperature and conductivity logs were run during pumping.
b) a flowmeter was run at different rate of pumping
c) temperature and conductivity were recorded during the recovery
d) the change in the water table was recorded
e) borehole television was used.

The results indicated that there was considerable flow between the river and some boreholes, but there was no flow in the area outside of the reservoir site. Using the flowmeter, resistivity logs and borehole television, the bands of high permeability have been delineated and during construction these bands were grouted with cement slurry.

6.1.2 Similar types of investigations were carried out in the chalk area South of London. Considerable flow of water exists there through the joints, but the chalk is resistant to solution or abrasion no cavities were found. The chemical analysis gave an indication of pollution. (Tate, Robertson, Grey - 1971).

6.1.3 One of the applications of bore logging in hydrology is to investigate the salinity of inland water and then use the data to prevent saline waters entering the productive wells. (Tate, Robertson, 1971).

6.1.4 <u>Shallow Seismic Profiling</u>.

<u>Mr D.M. McCann</u>

The results of their work on the canals were given in a letter to Nature vol. 223, no. 5203 pp 293 - 295, July 19, 1969.

They used a gas gun as a signal source in subsequent surveys, but they found difficulties in shallow water, and so they returned to the use of a sparker. The method which they found most convenient was to advance the transmitter and receiver from a centre point in opposite directions obtaining reflections ranging from the vertical to wide angle reflections as well as refraction. They used 6 kj in 12 ft of water, with a 4000 volts supply. In fresh water they used copper sulphate instead of salt to avoid build up in gas pressure. They fired a sparker just below the bottom of a steel boat filled with sand. It provided a much stronger pulse.

6.2 <u>Department of Geology and Geophysics</u>. University of Birmingham.

I met Professor D.H. Griffith, Drs King and Owen.

6.2.1 <u>Location of cavities</u>

The current path method - two current electrodes are introduced in the ground with the leads far removed to avoid interference. As a sensor a bar coil, mounted on a theodolite, and free to move vertically and horizontally, is used. Any distortion of the electric field is detected. This distortion is due to eddy currents round the high resistance body. The instrument was used in the old mines area, and it is claimed that several tunnels were located using it.

6.2.2 Shallow seismic reflection

They use shallow reflection equipment to map bedrock at a depth of about 5 m. An electromagnetic vibrator of variable frequency (up to 200 Hz) is used producing a push of approximately 25 kg. It is manufactured in England and costs £ E800 with an oscillator and a power supply of about 300 W. The recording is done on a 14 channel digital tape recorder. The tape is played back on a blow ink twelve channel recorder with a paper speed of up to 1 m/sec. The record is of very high quality.

6.2.3 Resistivity investigation

They conducted several surveys for groundwater in the glacial drift of Central England. They generally use the tri-potential depth probing in the grid with single measurements between the tri-potential probes. The interpretation is done by a set of log-log curves, checked with the precalculated curves of Orellana and Mooney (1966) and Flathe (1965).

6.2.4 I.P. due to the clay content of a sandstone bed

In an investigation of the relation between electrical resistivity and porosity of Bunter Sandstone an attempt is being made to determine the corrections using the I.P. effect produced by clay in the sandstone. Laboratory measurements are conducted using glass balls and mixtures of clays. They contour the areas between boreholes in a form of the clay content. Borehole logging is used in the investigation (Worthington, 1971).

6.2.5 Determination of permeability

The method depends upon the extraction of water from a saturated sandstone sample when it is subjected to a centrifugal force for a given period of time. (Worthington and Barker, 1972).

6.3 The National Coal Board

6.3.1 The Headquarters in London

Mr A.M. Clarke, Deputy Chief Geologist

The National Coal Board does not employ geophysicists. All geophysical work is done on contract with geological supervision. The H.Q. is more an advisory body, all the preparations, contract supervision and evaluation is done on a divisional basis. Four geophysical methods are used with emphasis on seismic refraction and gravity methods.

Support was given to the University of Leeds to carry out a complete evaluation of gravity and resistivity methods. The following investigations are being carried out.

Sherratt K.M. - An Appraisal of Geological Fault detection by Resistivity Method.

Hallowell, E.G. - An investigation into the use of high resolution gravity surveys for the determination of rock density in the solving of detailed geological problem.

The microfilms are available on application to Dr G.M. Habberjan from the University of Leeds.

A NCB supported study of the channel waves in coal seams was carried out by Dr G.S. Halliday of the Geophysical Services International. The results proved, according to M. Clarke, that Dr Krey's (1965) approach to the problem is not correct. Unfortunately I was unable to obtain any results.

A tender document is being prepared for the continuation of the research and field tests.

Mr P.L. Runsby - Senior Geologist - Coal Logging

All the work on the logging of the NCB is carried out by the British Plaster Board (BPB Instruments Ltd). They also prepared a short course on interpretation of logs. The bases of the course are discussed in the Can Inst. of Mining and Metallurgy International Meeting. D.R. Reeves - In situ analysis of coal by borehole logging technique (a copy in Engineering Geophysics Group).

6.3.2 West Midlands Regional Services, Chatterley Whitfield Tunstall, Stoke on Trent.

Mr R.H. Hoare and Dr N. Barnsley.

They just completed a survey consisting of 36 km of seismic reflection traverses. The traverses are located in three areas of Central England. Normal oilfield procedure was adopted; shots and geophones in line, 12 geophones per channel placed at interval of 9 m in line with the shots. Mixing resulted in many reflections.

7. VISIT TO POLAND

I interrupted my visit to England and flew to Poland on December 20 to avoid the Christmas rush. I landed in Warsaw and was met there by Dr Dabrowski, from the Geological Institute of Poland. I visited the Institute on the 20 and 21 of December, 1972 and again on January 2, 1973.

I left Warsaw on the night train for Nowy Targ on Friday 21. On Sunday 23 I visited the Niedzica Dam Site, accompanied by the resident engineer. On Boxing Day I drove to Gliwice to prepare for a visit to the Central Technical Services Laboratories of the General Institute of Mining, Zabrze on 27 December 1972.

On Friday 28, I went to the Institute of Petroleum, Cracow. On January 2, 1973, I met Dr (now Professor) Thiel from the Institute of Hydro-engineering, Gdansk, and left Warsaw for London on January 3 and London for Australia on January 4.

7.1 The Geological Institute of Poland

The Institute is similar in organization to the BMR and has similar functions. The Director is Professor R. Osika; I visited their Geophysical Branch, and the Engineering and Applied Geophysics Groups. I met Dabrowski, Kuruczyn, Wybraniec, Skorupa and Bachan. They are group leaders with a staff of 5 to 8 geophysicists in each group concerned with particular problems or developments. Dabrowski is in charge of regional gravity; Kuruczyn, resistivity depth profiling interpretation; Wybraniec, electro-magnetic; and Bachan resistivity measurements between bores. Technical notes from my visit are included in parts 9, 11 and 14.

7.2 Institute of Petroleum, Cracow

I met there, Dr J. Dzwinel, head of the electrical methods section and Dr A. Kostecki, head mathematician.

Electrical methods are used more often in oil exploration in Poland than in Western countries. This is due to their lower cost, and to the geological difficulties of disturbing layers in the Carpathian Flysh affecting seismic methods. Therefore, the electrical methods are more fully understood, and their theoretical background is deeply studied. This is assisted by the availability of the staff with university training. The policy is to make places for all university graduates; as a result the offices are overcrowded, but there is a large pool of people being trained. They can remove the pressure of work, and allow more thorough study of problems and development of new equipment, etc. The Institute of Petroleum is concerned more with research, than the actual finding of oil and gas. The field surveys are mostly carried out by Przedsiebiorstwo Geofizyki Stosowanej, an independent state-operated organization (Applied Geophysics Services).

On the new work there I discussed:

1. the transient electromagnetic-method using shaped pulses and variable frequency;
2. the electric charge method to find an orebody and/or continuity of strata between bores;
3. the measurement of derivatives of electric fields to locate vertical anomalies of limited thickness.

7.3 Institute of Hydro-Engineering

The Institute, a branch of the Polish Academy of Sciences, is investigating problems of hydraulic structures and coastal engineering. The Institute consists of four sections.

1. The Department of Inland Water Hydraulics deals with open channel hydraulics; hydrology-filtration; hydro-thermal problems and fluid mechanics.
2. The Department of Maritime Hydraulics is concerned with sea dynamics; dynamics of coastal processes; and harbour water hydraulics.
3. The Department of Soil Mechanics has several sections: Experimental and Applied Soil Mechanics, and Clay Structures and Hydrogeology.
4. The Department of Applied Physics and Chemistry covers the physics and chemistry of soils, sea water conversion, water chemistry and nuclear physics application.

The official description of the Institute in English is on BMR file no. 73/1494.

I was unable to go to Gdansk to see the laboratories, but Professor St. Huckel, the director of the Institute arranged for Dr K. Thiel to come to Warsaw for discussion of topics of common interest. Dr Thiel was a coordinator of the site investigations for the dam at Niedzica. The methods of investigation and the design calculations of the proposed dam have provided the basis for a textbook which is used in the engineering departments of the Polish Technical Universities (Thiel, 1967). Niedzica dam site is fully discussed in 7.4.

During his work on the Carpathian Flysh, Dr Thiel also investigated the stability of slopes. This subject is included in part 9 - Landslides.

7.4 Niedzica Dam Site

The idea of the construction of a dam in this area originated in 1934 when a large flood destroyed villages along a 200 km stretch of the river Dunajec. The purpose of the dam is to control flooding, produce power and equalize the flow of water for boating in the Pieniny National Park, starting just below the proposed dam.

The geology of the site is very complicated. Thin layers of limestone of Upper to Lower Jurassic (Malm to Dogger) are overlain by Flysh. The beds are steeply dipping. The steep cliffs of the gorge contain several caves, one of them is passable to about 1 kilometer. Considerable exploration work has been done in the area: diamond coring, shaft and tunnel driving and costeaning.

In the geophysical work seismic refraction was done to determine the depth of weathering, character of the bedrock and the lithological changes in the bedrock. In the investigation both longitudinal and transverse waves were recorded and modulii of elasticity were obtained. Similar work was carried out in the tunnel beneath the river and between the bores. The dynamic modulii compare well with the static results.

The resistivity surveying in the constant spacing of 50 and 100 m and depth probing (Schlumberger) were used. With the crossed field method (part 14) the limestones were delineated. An experiment was carried out blanketing the limestones with a 30 cm thick layer of clay, and checking with resistivity and S.P. the water percolation through the blanket.

The research into the construction of the cut-off indicated that the cost of the grouting will be about 10 per centum of the cost of the dam. This cost is more than double that of anyeother dam so far constructed. The results of the grouting research are in publications: Thiel, 1966; Glab, Jaworski, Thiel, 1965; Dziewanski, 1969.

Several other localities for a dam were investigated because the proposal to build the Niedzica dam met with strong opposition because the reservoir would cover protected wooden churches from 13th century, the Pliocene flora reservation, and probably undermine the foundations of two 14th century castles. The microclimatic changes due to thermic effect of water in the reservoir may also influence the flora and fauna of the National Park in Pieniny.

7.5 Central Technical Services, General Institute of Mining

The organization is a scientific service group, which carries out applied research in coal mining. The group I visited is attached to the Zabrze Region of the State Coal Mines, with an annual production of 25 million tonnes.

My interest was in rock burst, subsidence, roof control and the treatment of mine waters.

I met there:

L. Jaworski, Min. Eng., Director Zabrze Region, State Coal Mines.
J. Kucharczyk, Min. Eng., Director, Rybnik Region, State Coal Mines.
A. Kluszczynski, Min. Eng. Supervisor, Central Technical Services, Zabze.
J. Breakere, Min. Eng., Assistant-Supervisor.

7.5.1 Rock bursts, roof control and subsidence

The present status of research into these problems in Poland is given in two volumes edited by Kidybinski, Szecowka, Liernierski (1972). Volume 1, part 1, deals in seven papers with the effects of the geological factors on the tectonic behaviour of the rocks, the seismology of the coal mine and the interpretation of seismic waves. The geophysical methods used in the investigation were seismic reflection and refraction, electrical (resistivity, magneto telluric and radio) gravity and magnetic. This section is followed by six papers in Part 2 dealing with the dynamic effects of rock pressure in the vicinity of the mined area.

Volume 2 deals with the recording of the rock bursts, and the method of their control. The method of the control of the rock bursts is highly successful lowering the number of rock bursts from 1 rock burst per 1 000 000 tonnes of yearly output in 1959 to 1 rock burst per 13 000 000 tonnes in 1970.

The methods of location of epicenters of rock bursts is included in section 12 of this record.

The subject of roof control is dealt with in the Memoir of the First Polish Symposium on Damage from Mining Operations, arranged by the Institution of Mining Engineers and Technicians at Katowice in 1969.

7.5.2 The treatment of mine waters

This is a part of a program started in 1966 with the help of the United Nations Special Fund.

The investigation consists of three parts;

1. Technical and economical problems of purification of open channels and the self-purification agents in surface water.

2. Control of inflow of cooling water from power stations into rivers.

3. Control of salinity of industrial waters.

Area chosen for investigation (inset plate 8) is roughly one ninth of the total area of Poland (300 000 km^2) but it contains 11 000 000 people (one third of Poland's 33 million), and three-quarters of the industrial potential. The location of the inflow of impure waters into the natural streams and rivers was mapped. Plate 8 shows the points of entry of polluted water into streams. Seven control stations, some on the banks of the river, other on barges, continuously record and then transmit by radio the results to a central station. All stations contain the Honeywell W20 sampling system and the Beck and Taylor oxygen monitoring system. The cost of the instruments was $US.625000.

The main pollution in the Silesia district comes from coal mines, further north from zinc and lead mines, woollen mills and paper manufacturing. The discharge of water from these industries adds 1500 tonnes per day of salt to the water system.

In the flow of the rivers the salts undergo chemical changes in presence of organic matter resulting in the desulphurization (H_2S) and precipitation of Ca and Mg $(HCO_3)_2$. Seven water quality correction stations are proposed. Location of these stations are shown on plate 8. Three of these stations are under construction. The first one at the Dembiensko Coal Mine will start operating in 1974.

Each correction station uses a process depending on several stages of flash evaporation. The system was patented by the General Institute of Mining. As a final product a salt concentration of 35 per centum is delivered to the chemical plant for further processing. Pure water is returned to rivers. The plants are expected to be self-supporting with the sale of concentrated brine to chemical factories covering the costs of operations. A levy of 1 cent per tonne of coal produced provides funds for construction of plants.

The pollution of the rivers will be reduced by 60 per centum, when all the plants are completed. Further reduction will be obtained by introduction of oxidized effluents from sewerage installations and by the addition of unpolluted water from special flood control reservoirs.

8. STRUCTURE - GROUND INTERACTION

Japan and California are two main centres in which the research on the limitation of damage due to the earthquake is carried out. I was lucky enough to meet in each of these centres one of the most prominent men in this research: Professor Bolton Seed at Berkeley and Professor Sakuro Murayama of Kyoto.

8.1 Many building codes considered that the dynamic response of a structure to an earthquake depends mostly on the dynamic characteristics of the structure itself. The dynamic characteristics of the foundation soil and any coupling between the structure and foundation were ignored.

8.2 It was soon evident that during many earthquakes the building of the same construction suffered different kind of damage depending on the soil conditions. The conclusions have been reached that the stiff foundations on soft ground suffer less than flexible foundation on the same ground and vice versa a flexible building on firm rock suffers less than stiff building on the same location.

8.3 The Earthquake Damage Potential (EDP) seems to depend on many factors, and may be expressed as a formula:

EDP = F(St, Ss, h_w, G, C) where

St = soil type (liquefaction, loss of strength compaction, etc.)

Ss = magnitude and frequency of seismic disturbance, geological structure, seismic trend of the area.

h_w = water table elevation.

G = geology - the two most important points which decide the magnitude of the damage are the seismic velocity and density of rock and the rock layering.

C = the construction.

For full discussion on the influence of foundation rock the reader is referred to following publications which are deposited in the BMR library: Rainer, 1970; Seed, 1969; Seed & Idriss, 1970. See also Parton, Smith, 1971; Seed, Idriss & Dezfulian, 1970. Borcherdt 1970.

8.4 The determination of natural frequency of the ground, as carried out at the Disaster Prevention Institute at Kyoto is described in 3.2.2. A comparative study of results obtained by application of several methods is given by Yoshikaure, Shima, Irikura, 1967.

8.5 According to Professor Bolton Seed, to determine the response of the ground it is necessary to know the modulus of rigidity G and the Poisson's ratio of the ground within 300 m of the ground surface. The determination to the depth of 70 m is done using two boreholes 70 to 100 m apart and measuring direct transmission of the longitudinal and traverse waves. At a depth larger than 300 m the sand and gravel will behave as a sandstone. Between these two depths the properties are determined by the seismic refraction method. It is necessary to remember that the modulus of rigidity determined at low stresses in the seismic work is higher than that at high stresses during an earthquake, but there exist graphs to estimate the corrections. The determination of modulus of rigidity in a shear box is not accurate enough and should not be used. Accurate estimates of the modulus of rigidity may be done from the size analysis of the samples.

8.6 Two general approaches are being used in analytical investigations of the soil-structure interaction at present, one of them is called the continuous elastic foundation technique (Chopra, Perumalswami, 1969; Rainer 1970, 1971) the second one uses the finite element method (Clough, Chopra 1966; Finn, Khanna, 1966.)

8.7 The data required for the above consideration are taken from so called microzoning investigations. In the preparation of the microzoning maps the co-operation of scientists working in the fields of geology, soil mechanics, engineering-seismology and geophysics is necessary. As an example of a microzoning investigation I was given at Berkeley a Bulletin of the NZDSIR (Grant Taylor, Northey, Adams, 1970). A special microzoning conference was held in Seattle.

8.8 Special investigations were carried out on the seismic effects on dams. During an earthquake the amplitude of vibration at the top of a dam becomes relatively large due to the multiple reflections of waves. The theoretical and experimental investigation of this effect was carried out by Kanai and Yoshirawa (1964). The paper gives references to the development of the theory.

A special conference on the seismic effects on dams was held in San Francisco in November 1969. I deposited a copy of the Proceedings in the BMR library (US Army Eng. Waterways, Exp. Station, 1969).

8.9 Preprints of the Building Standard Law and Standards of Aseismic Civil Engineering Constructions in Japan have been deposited in the Engineering Geophysics Group of the BMR.

9. LANDSLIDES

During my tour I discussed investigation of landslides in four countries, in Hong Kong, Japan, USA and Poland. I met people who carry out research on these problems.

9.1 In Hong Kong the hilly country with terraces made to construct high rise apartments completely changed the hydrology of the area and lowered the stability of the slopes in the weathered to highly weathered granite. In general no investigation to check the possibility of a landslide is carried out in advance, the slopes are protected with gunnite, asphalt, rock debris or concrete blocks. The walls made of gunnite or asphalt are also protected by short drainage pipes of small diameter. Unfortunately these pipes are blocked with wooden pegs by playing children, and built up pressure damages the cladding.

9.2 In Japan the art of investigation and protection against landslides goes back at least eight centuries, as determined by carbon dating. The steep mountains terraced for rice fields and irrigation water for the terrace lowered the stability of the slopes. Also bigger rice crops brought about an increase in the concentration of population in these areas. This was followed by economical development; landslides triggered off by the reservoir water from dams, by the constructions of highways, railways and canals.

The research work on landslides in Japan is carried out by several institutions incorporated into the Japan Society of Landslide Research. The society has 1200 members, publishes a quarterly journal, organizes lectures, courses, tours and meetings. The members of the society come from the fields of geology, geophysics, geography, civil engineering, forestry and agriculture, working at the universities, ministries, railways, ports, canals, etc.

The National Conference on Landslide Control is an organization of 44 prefectures for the purpose of technical enhancement of member governments by exchange of research information on landslides and development of joint landslide prevention works.

The National Conference prepared a detailed study of the landslides in for of a sequentional plan of investigation and control work.

9.2.1 Investigation for Landslides

A Preliminary survey

(i) Seismic method

a - seismic refraction
b - seismic reflection
c - measurement of sliding noise.

(ii) Resistivity method

a - Specific resistance logging
b - Resistivity depth probing.

(iii) Natural radioactivity method

a - logging
b - Surface leakage of radon and thorium through faults and crushed zones.

B. Detailed survey

(i) Test boring.
(ii) Determinations of sliding surface.
(a) from geological evidence
(b) from bores using a sinker, a deforming casing or a stress gauge pipe.
(iii) Surface of the ground movement.

(a) from aerial photography or photogrammetry
(b) use of tensometer
(c) use of tiltmeter.

(iv) Ground water survey.
(a) ground water pressure, pore pressure and ground water level.
(b) distribution of ground water; surface water, underground water pumping test, ground water tracing and ground water quality.

(v) Soil test
(a) Physical tests.
(b) Mechanical tests.
(c) Sounding.

9.2.2 Landslide control work

The landslide control work may be divided into precaution control and prevention control. Precaution control consists of transfer of inhabitants, relocation of houses, roads, railways and even rivers. The prevention work would consist of suppression work and restraint work. The suppression work may take the form of a change of topography, ground water, and soil characteristics. The restraint work consists of engineering control works.

The engineering methods used in suppression and restraint work are:

1. Soil removal.
2. Soil drainage.
3. Underground drainage.
4. Interception of drainage (chemical injections or wall construction).
5. Piling work.
6. Retaining wall and cribwork.
7. Removal of high pressure gases in volcanic areas.

The Disaster Prevention Research Institute at Kyoto acts as a clearing centre for the theoretical research on landslides carried out at the Japanese universities. Their Bulletin contains several papers giving the results of investigations.

9.3 The College of Engineering of the Department of Civil Engineering, University of California, Berkeley, conducted a series of experiments of recording seismic waves generated by landslide movement and faults or rocks during a loading test.

Landslide tests were made at four sites. On each site bores were drilled to accommodate detectors. The recorded noise level was highest near the sliding surface. The noise is not readily detectable on landslides occurring in unconsolidated sediments. Rock blocks produce acoustic energy which can be detected at the surface.

Geophones connected to a central recorder were placed on a surface of a landslide. From the times of arrival of seismic waves the location of the origin of these waves were found using a computer programme. (Cadman, Goodman and von Alstine, 1967). Several laboratory model experiments have also been carried out (Cadman & Goodman, 1967). These tests indicate that in deep landslides the early noise comes from above the slide; in thin landslides the noise originates from beneath the slide surface, in both cases the noise occurring just before the failure comes from the actual slide surface. The instrumentation is similar to that used in rock bursts (part 12.2).

9.4 In the Institute of Hydro-Engineering at Gdansk, Poland, the research work is going on the classification and origin of landslides, or stability and protection of slopes.

9.4.1 Plate 10 shows the proposed classification of landslides (Dobosz, Thiel, 1971). Landslides are divided into three groups: creep, slide and falls. Then each group is divided according to the form of the slip surface and the geological factors affecting the stability.

Landslides may occur due to external or internal change of conditions. The external forces may be natural (earthquakes) or introduced by human element (change in slope, undercut, change in load, introduction of or removal of water). The internal forces are the decrease of the shear strength either by physical or chemical weathering. Landslides are generally induced by more than one factor, but water may be the significant one.

Laboratory and field experiment carried out indicated that some methods of computation are more suitable to solution of stability of some types on landslides. These are:

for the planar slide surface - Taylor (1960)
for rotational surface - Bishop (1955) or Fellonius Paterson
for the broken surface - Nonveiller (1965)
for all surfaces but requiring the use of high capacities computer, The Morgenstern - Price (1965) Method is used.

All these methods consider a two-dimensional deformation for the three dimensional deformation the method of Wittke (1964) or Londle (1968) are advocated.

All these methods were developed to determine the stability of soil slopes. The stability of rock slopes is much more difficult to solve as the conditions are more complex and often impossible to define.

10. LABORATORY ROCK AND SOIL TESTING

The methods of testing the quality of a rock for engineering purposes do not differ in equipment and procedure in six countries I visited and they are the same as used in Australia. The difference is in the number and in the size of the equipment, the number of pick-ups and recording channels etc.

10.1 The static method is used in all countries and some of the presses are capable of a pressure of 45 000 000 psi. Sections of this record have already given details of some of these laboratories, for example Section 3.2.2 deals with labratories at the Disaster Prevention Research Institute, Sections 4.3.1 to 4.3.3 and 4.4.2 to 4.4.3 in USA and 5.3 in Canada.

10.2 Dynamic testing methods vary more between different laboratories and in Japan each laboratory is equipped with facilities for measuring the dynamic properties under changing pressure sinusoidally or sporadic in frequencies up to 200 Hz (sec section 3.2.2). The pressure and vibration may be supplied in one, two or three perpendicular directions.

A very interesting work was carried out by Murayama, Yagi, Ishii on the determination of dynamic properties of naturally and artificially weathered granite. The paper is in Japanese, some of the results are reproduced on Plates 11 & 12.

The bar velocity is measured on slim cores with a pulse with a frequency of 8 kHz (Johnson, 1967). The measurements of the Q values is done by recording on a digital tape recorder the spectrum of the received wave, then the data is analysed by a HP 5451 A Fourier Analyzer.

10.3 Soil testing.

There is a bigger variability between the soil testing laboratories. The Japanese laboratories were described in section 3.2.2, the USA in 4.2.1 and 4.3 in England 6.2.5. A novel method of determination of the percentage of fines in a soil sample is done at the Institute of Geological Sciences, London, by measuring the change in resistivity of water in which the sample is being washed.

Section 11 - Limestone Foundations - Location of Cavities and Leakage from Reservoir

11-1.1 The location of cavities in a solid rock by the use of geophysical methods appears on the forward programme of the Engineering Geophysics Group of the Bureau.

In 1975 or 1976 a survey may be conducted in Papua on a dam site located in limestone. Cavernous limestone forms the base of the dam and one of the abutments.

Although it is not programmed at present, a survey over a wide area may be required in Northern Territory to locate cavities in limestone at a depth of about 1000 m. Some of these cavities may contain fresh water, while others are filled with sand and clay.

The discussion on the application of geophysics to locate cavities in limestone were carried out in:

Los Angeles	- US Geological Survey
Denver	- US Geological Survey
	- US Bureau of Mines
	- US Bureau of Reclamation
Ottawa	- Geological Survey Canada
London	- Geological Survey of Great Britain
Birmingham	- Dept. of Geology, University of Birmingham
Warsaw	- Geological Survey of Poland
Cracow	- Institute of Petroleum
Gliwice	- Central Technical Organization, Zabrze Branch

11.1.2 In the last two years there has been a considerable advance in the publication of books and papers dealing with karst, its hydrology and engineering. The two best known are Jennings (1971) and Sweeting (1972).

Limestone terrain is found to be difficult in urban development (Knight, 1971). We have an example in the construction of the Treasury Building in Canberra. In the construction of major works throughout the world considerable effort has been made to solve the problem of cavities, some of them were corrected, others still require a solution.

May be the best known examples of the difficulties met in locating dams on limestone ground are Anchor Reservoir, Wyoming; Kopili, India; Niedzica, Poland; and in Jugoslavia. At all these locations geophysics was applied with varying degrees of success and we will deal with these applications here. However, geophysics was not used to investigate the Amistad dam site, Texas. The entire concrete section of the dam and the embarkment on the US side is founded on limestone of Cretaceous age. There are a few minor faults and several sink holes and caverns in the area of the dam all structurally controlled.

In the construction of the dam, the solution cavities were cleaned out and backfilled with concrete. Shallow cut-off trenches were also constructed in area of old river channels. During the filling of the reservoir, leakage through the cavities increased but it is hoped that the total leakage will not exceed the quantity of water which must be released to flow down into Mexico.

11.2 Seismic Methods

Seismic refraction, seismic reflection, resonance methods, and shallow profiling have been used from time to time to find the cavities. Examples of the different techniques to site investigation will now be given.

11.2.1 Seismic refraction

The Anchor Reservoir in Wyoming was completed in 1961 but all the attempts so far to fill it have failed. Under pressure of water, sink holes form and drain the water away. Plugging of holes is only temporary as other cavities appear to prevent the impounding of water.

Extensive seismic refraction and gravity (sec-11-3) work was carried out over the floor of the valley (Godson, Watkins, 1968). A seismic resonance method was also used. The method had been evaluated before over lava flow tunnels and shallow nuclear cavities (Watkins, Godson, Watson, 1967). In practice a seismic spread is placed along the floor of the valley a shot fired in line, and the gains of the seismograph are adjusted so that a continuous trace is obtained on the records. After the arrival of the refracted wave a train of waves resulting from the oscillation of the air in the cavity is recorded on traces from geophones placed close to the cavity. If the Vs is also recorded the diameter "D" of the cavity may be estimated from the formula:

$$D = V_s/1.55f.$$

where Vs = shear wave velocity, f = resonant frequency. The formula gives the size of cavity one third of that determined from radial oscillations of a cylindrical hole in an infinite solid (Biot, 1952).

NIEDZICA dam site is in Southern Poland on the Dunajec river. The proposed concrete dam will be 60 m high and 400 m long. The foundation rock is limestone (Thiel, 1971). The rock consists of beds of limestone 3 to 20 cm thick interbedded with layers of mudstone 1 to 5 mm thick. Several large faults divide the limestone into four large blocks. These large blocks in turn are divided by jointing into small cubes 4 to 16 cm size. The joints are open or partly filled with products of weathering.

The seismic refraction method has also been used to determine the depth of weathering, velocities and modulii of elasticity of the bedrock. Three arrangements of geophone spreads were used: 1) seismic profiling 2) borehole shooting 3) mean time method - by shooting on the surface and placing the geophones in a tunnel.

Measurements also were taken of the velocity between two boreholes 0.5 to 2 m apart, using a sparker as a wave source, and a piezoelectric crystal as a receiver. Frequencies from 2 to 20 kHz were used. Longitudinal and transverse waves were recorded.

11.2.2 Seismic reflection method

Cook (1964) discusses the application of the seismic reflection method for location of solution cavities in salt. The cavities are the results of the brine solution method of mining of salt deposits.

He considers two cases:

1. A strong reflection from the roof of the cavity, if the roof is reasonably flat.
2. A sharp decrease of the pulse amplitude if the wave passed through the cavity during the travel to or from a reflecting horizon located below the cavity.

If the cavity is filled with fluid the shear waves should be used and the higher attenuation or even complete disappearance of the pulse may be a clear indication of the existence of the cavity.

This method was developed from the sonar caliper tool which is inserted into a salt solution cavity through borehole. The sonde sends a high frequency signal, which is reflected from the side of the cavity to be picked up by the sonde. The sonde sends the signal to the surface where it is recorded on a screen. The sonde is rotated 360° to determine the shape and dimension of the cavity. (Chisholm, Patterson, 1958; Myers, 1960; Wiercheyko, 1972).

11.2.3 Acoustical Holography

The method depends on direct transmission of a seismic pulse (Fitzpatrik, 1972; 1973; Fitzpatrik, Nicholls, Munson, 1972; Bendix, 1972). The method is discussed in Section 12, continuity of coal seams, rock bursts and pillar support.

11.3 Gravity and Magnetic Method

A gravity minimum is shown over a cavity if of sufficient size in relation to the depth. Colley (1963) gives several curves showing the sizes of the gravity anomaly expected over cavities of different volume located at different depths. He also shows some field results which may suggest the existence of caves.

The theoretical investigation and some practical application of gravity for cavity location is given by Newmann (1967).

Godson and Watkin (1968) give the data of a gravity survey over the Anchor Reservoir floor (sec 11-2.1) where considerable correlation exists between the gravity anomaly and seismic resonance interpretation.

Considerable theoretical development on the determination of cavities and old workings was carried out in Poland (Fajklewicz, 1972). The work using gravimeters, torsion balances and gradient meters was done in coal basins and over old lead and zinc mines of Olkusz. Provisional patent rights were issued, the details will be disclosed shortly.

Magnetic method has been used to determine cavities (tombs) in archeology (Rainey, Ralph, 1966). Micromagnetic measurements are used, where magnetometer readings are taken at intervals of 1 m. Cavities in limestone filled with slightly magnetic clay were detected by the magnetic method at a dam site in Eastern Germany, but the data has not been published.

11.4 Electrical Method

Electrical methods have been widely used in the karst areas of Yugoslavia, India, Poland and USA. For general background of the method reference is made to Keller and Frischknecht, (1966).

11.4.1 Arandjelovic (1966) found four resistivity layers existing in the limestone areas of Yugoslavia.

top layer	- Karstified and altered limestone with terra rossa, humus, etc.	Low resistivity.
second layer	- Karstified limestone above the water table	Higher resistivity.
third layer	- as above but below the water table	Lower resistivity.
fourth layer	- non-karstified solid limestone	Very high resistivity.

The interpretation of depth to the groundwater level and the base of karstification obtained from resistivity depth probing agrees with the depth obtained from drilling and logging.

The karstified limestone shows very high electrical anisotropy. The conductivity is greatest along the bedding and smallest perpendicular to the bedding. A solid rock has a high resistivity and rock full of fissures and caverns filled with water, clay etc., shows low resistivity. This property allows the determination of the direction of their karstification and fissuring at different depths to be determined by use of a "circular sounding" diagram (Arandjelovic, 1966) or "polar" diagram (Dutta, Rose, Saikia, 1970).

11.4.2 On the Kopili Hydro-Electric Project, Assam, India (Dutta et al., 1970; Banerjee, Nath, 1967) it was found that a cavity above the water table is a highly resistive body enclosed in the lower resistivity bed. Continuous resistivity profiling using a Schlumberger electrode arrangement may give a distorted picture in cases of thin limestone sheets. Therefore, a "combination profiling" (Dutta et al., 1970) has been introduced by placing one of the current electrodes at infinity broadside to the spread. The cavernous zones are clearly delineated by this method.

The second arrangement of electrodes used (Banerjee et al., 1967) was the potential gradient. The current electrodes were placed 400 m apart and with potential electrodes 20 m apart the central part of the electric field was covered. The spacing of 20 m was determined from Wenner depth profiling, indicating the thickness of karstification. A large potential drop indicates the existence of a cavity. The authors state in conclusion that the location of a cavity is possible if the depth of burial and the size of cavity are in a ratio not higher than 10 to 1.

11.4.3 Depth probing and constant profiling resistivity surveys were carried out on the proposed site of the Niedzica dam site. The main purpose there was resistivity mapping of areas of steeply dipping limestones enclosed between mudstones.

A method of "crossed fields" (Dzwinel, 1972) has been developed. The arrangement of electrodes is given in section 14. As a further development the second derivative of the electrical field is measured. The derivative may be measured along one or two profiles, sometimes over a plane. The method has not been described, but the results which I saw are very encouraging (Dzwinel, pers. comm.).

A special set-up of electrodes to locate narrow zones of different resistivity was used by Apparoa, Roy (1973). This special set-up was the well known Laterolog arrangement. Better discrimination occurs in the case of the lower resistivity zone in the higher resistivity than in the reverse case, and therefore the water filled caves would be easier to detect than the cavities above the water table.

Habberjam (1969) conducted model experiments on the location of a cavity using the Wenner and the tripotential resistivity technique. He indicates the expected rise of the anomaly depending on the size of the cavity, depth of burial and resistivity contrast.

Near Bellefonte, Pennsylvania (Richards, 1971) the solution cavities and channels in limestones occur at the intersection of major joints and along contacts. These contacts and fracture patterns were mapped on air photographs. A detailed resistivity survey was carried out with constant spacing traversing and Wenner and Lee depth probing, using the Habberjam (1970) method of association matrices and curves. Considering that air-filled caverns will be shown as high resistivity bodies while mud-filled caverns would act as a conductivity body, three bores were sunk. The bore drilled on the resistivity high and Habberjam's association parameter low proved an air-filled cavity, while the two placed on resistivity lows did not encounter cavities.

The existence of a cavity (a different resistivity body) between two boreholes can be determined by a method in which several spontaneous potential (S.P. curves) logs are run in one of the bore holes with a current electrode in the second bore stationary at different levels for each log (Bachan, Geological Survey, Warsaw, pers. comm.). Qualitative interpretation is possible of the continuity of beds between the boreholes from the differences in the S.P. curves resulting from the transmission, diffraction and "reflection" of the electric lines.

11.4.4 An interesting electro-magnetic method is being developed in England. An electrical field is established between two electrodes (Griffiths, pers. comm.). As a sensor unit, a coil mounted on a theodolite, free to move horizontally and vertically is used. Any distortion in the electric field is detected by a change in current flow. This distortion is due to the eddy currents round the high resistivity body. The instrument was used in the old mines area, and it is claimed that several old tunnels were located using it.

11.4.5 On the Teton Dam Site, Newdale, Idaho under a layer of wind sand or loess of thickness 3 or more metres lies a thin layer of caliche. Beneath it is a layer of weathered rhyolite. This layer is cut by buried fluvial channels. The Electro-magnetic Subsurface Profiling (ESP) method developed by the Geophysical Survey Systems, North Billerica, Massachussetts was used. No data has been disclosed on the instrument. The results are in the form of statistical analysis of reflections. The more reflections, the more possibilities of the existence of discontinuities. The results were not tested by drilling.

11.4.6 In the permafrost area of Canada the Geological Survey of Canada used high frequency electromagnetic method to detect cavities and cracks in the bedrock. The frequency used was 10^4 to 10^6 Hz.

The same method was used to determine cavities under the runway of the Vienna airport.

11.5 <u>Plotting the extensions of cavities</u>

Several geophysical methods have been used to plot the extention of the cavities after they were located. We will not discuss here the salt solution or radioactive tracers methods, which are used to show whether the stream of water connects two cavities. On the same principle is based a seismic method in which an explosive charge (Arandjelovic, 1969) is released in the stream of water and exploded later at a predetermined time. The arrival times of the seismic waves produced by the explosion and recorded on several geophones above the ground allow the computation of the co-ordinates of the explosion and therefore the extension of the cavity.

If a located cavity contains either a stream of water or is filled with clay of lower resistivity than the country rock, it may be followed by use of the well known method "Mise a la masse".

Seggern and Adams (1969) located points on the ground surface over an underground cavity and determined the depth to the cavity. They sent a 1200 Hz signal into a 20 inch diameter loop antenna underground in the cavity and they detected it on the surface 130 m away by another loop antenna moving along traverses. The location directly above the transmitting point is found by the "no dip" of the receiving coil (Roeschlein, 1960).

11.6 Leakage from a reservoir

11.6.1 The seepage of water from a reservoir results in considerable modification of the natural electric field. The electric field may be measured using the same method which is applied to the bore logging. The leaking water produces a so called "streaming potential". The methods were applied qualitatively and quantitatively in the United States, India, Russia, Poland and Yugoslavia. The theoretical investigations (Moid Uddin. 1964; Ogilvy, Ayed, Bogoslovsky, 1969) were followed by the field investigation (Bogoslovsky, Ogilvy, 1970a, 1970b, 1972).

11.6.2 Thermolito afterbay of the Oroville Dam, California is located on alluvium. The top of the alluvium consists of soil of low permeability. Beneath this impermeable layer there is about 20 m of permeable sand. (Amimoto, Nelson, 1970). During the construction, this impermeable layer was broken through at some locations. On filling in the reservoir it was noted that the water table has risen in area around the reservoir.

A constant resistivity traversing was done by towing an assembly along the bottom of the afterbay. Several electrode spacings were used. The areas of high resistivity were those in which the impermeable blanket either did not exist, or was not effective.

Resistivity traversing is also used to control the efficiency of grouting in the area of water leakage. The resistivity of the cement grout is lower than that of the rock which is to be grouted. The drop of resistivity after grouting would indicate the percentage of voids filled with the grout. The method is quite common, and was used by Fritsch (1953, 1954, 1956) in Yugoslavia and Austria.

On the proposed dam site located in sandstone on the river San in Southern Poland close spaced resistivity traverses were placed in the area of the proposed grout curtain. A map of apparent resistivity was plotted. The map indicated low resistivity in areas where joints were infilled with clay.

The joints, were flushed with fresh water, the change in resistivity showed the efficiency of removal of clay. A high resistivity grout was pumped and subsequent change of resistivity indicated a continuous zone of high resistivity along the grout bores with the gradual decrease in resistivity with increasing distance from the bores up to the 15 m limit of grouting (Thiel, pers. comm.).

11.6.3 Measurements of temperature were used to determine the seepage of water from the reservoir of the Alvin R. Bush Dam in Pennsylvania (Trautwein, 1970). A thermistor probe of 12 mm diameter was lowered into the piezometer tubes and the temperature was read with an accuracy of 0.5 degrees. The readings were taken during the winter months, when the difference in temperature between the water in the reservoir and the groundwater is at a maximum. The measurements located the area of leakage through the foundation rock and the path of leakage was determined by jointing. The movement of water was rapid, as there was a small difference in temperature between the water in the reservoir and in the piezometer tube along the path and in the toe of the dam.

12. ROCK MECHANICS APPLIED TO MINING.

12-1. Seismic determination of continuity of coal seams.

National Coal Board in UK conducted a series of investigations on the continuity of coal seams, location of faults in advance of working etc. They employed several investigators from Germany and France. This discussion presents the position of the research as it was at the end of 1972.

There are two ways in which the seismic method is used in underground mining.

12-1.1 The method using the transmission of seismic waves is also called the Borges Method. Seismic waves are generated in a coal seam, the waves travel in all directions and are recorded on geophones placed in roadways, workings etc. The attenuation of the seismic energy is measured. It is assumed that the attenuation is higher in places where the wave crosses a fault.

So far the tests have met with a very limited success and the results were not conclusive, slow and requiring access to both sides of the investigated panel. Special difficulties were met with adaptation of the equipment to conform with the safety requirements in mines. A novel method of recording was developed; a panel of twelve millivoltmeters was connected, through a set of matched amplifiers to the geophones placed on several locations. A fast moving 16 mm camera photographed the panel and on the film the amplitude of the pulse was read from the millivoltmeters. The results obtained in English mines are discussed by Saul, and Higson (1971). The authors use extensively the results obtained in French mines by Schwaetzer (1965) and in Germany.

12-1.2 Another method which depends on the transmission of waves uses channel waves (Krey, 1963). The method was developed in Germany, but some tests were carried out in England Although several conclusive results were obtained the method proved to be sometimes unreliable. Tests with reflected channel waves were also carried out. In this mode reflections from faults 100 m distant were obtained under the condition that the geometry of the layout of the test obeyed all optical laws. In transmission mode the channel waves were recorded at distances of 1500 m in undisturbed coal seams.

12-1.3 The reflections of seismic waves from faults and discontinuities in front of workings in coal mining were used in France (Codet, Damotte, Erb, Leverque, Layotte, 1970). Longitudinal waves were used at frequencies 600 to 1200 Hz. The method has a resolving power of 1 m and a distance of investigation of 100 m. A computer programme to interpret reflections is given by (Durbaum, 1971).

The US Bureau of Mines gave to the Bendix Research Laboratories a contract to determine the feasibility of using ultrasonic signals and seismic impulses to predict the presence of marked discontinuities in advance of workings. The final report of the work was deposited in the BMR Library (Gupte 1972).

12-1.4 In addition high frequency electromagnetic waves are used to locate the limits of salt plugs and the existence of brine chambers in salt mines of Germany. Frequencies of 3 to 5 MHz are used in reflection and transmission mode (Nickel, 1972).

12 - 2 Rock Bursts and Pillar Support

Development of rock burst recording equipment is carried out in many countries and has reached the stage of installation of such equipment in mines. I saw parts of some equipment in laboratories in the US Bureau of Mines, Denver; the Mines Department in Ottawa and a complete set in the Central Institute of Mining in Poland.

12 - 2.1 Rock bursts instrumentation in Poland.

In the coal mining area of Silesia (see inset plate 9) a layer of sandstone overlies the coal seams. During exploitation of the coal, removal of the support from under the sandstone roof increases the stresses. Failure of the roof releases these stresses, but transfers the weight onto the coal face support endangering the men and machinery. The sudden release of the pressure is generally preceded by inaudible cracking noises. By picking up and amplifying these sounds it is possible to determine the location of the accumulation of stresses and by changing the rate of advance of workings remove the danger of roof falls (see also 7-5).

Originally the output of the geophones was optically recorded, records were then read and the location of excessive stresses determined by calculations. The process was lengthy and often the results were available after the actual collapse happened. The system now consists of a magnetic tape with eleven data channels connected to eight geophones by a telephone or by a UHF radio. The records are processed automatically using a Variam 620L computer.

12 - 2.2 Rock burst research in the USA and Canada.

The main application of the instrumentation in the United States and Canada is to determine the size of the roof supporting pillars in coal, oil shale (Brady, Hookes, Agapito, 1973) and metal mines. Besides recording the cracks of overstressed pillars, the seismic velocity at ultrasonic frequencies is measured across the pillars. Two similar types of this equipment are installed in mines of each country. The results are reduced using computers on site. (Blake, 1971).

12 - 3 Roof soundness in mines.

The US Bureau of Mines is testing equipment constructed especially to determine the partings in the roof of mine workings and in tunnels above the zone of roof bolting. The instrumentation consists of an air gun with an extended barrel terminating in a hammer. A pellet propelled by compressed air hits the hammer sending a high frequency (about 2.5 KHz) pulse as a longitudinal wave. The wave is polarized at a parting and reflected as a shear wave to be picked up by a Barium Titanate transducer mounted on the side of the barrel. The signal is recorded on a CRO together with the moment of inpact. Depth of penetration is approximately 2 m from the end of a bolthole. A lack of reflections indicate sound roof conditions.

12 - 4 Seismic Holography

The US Bureau of Mines is conducting the tests of the acoustical holography with the object of locating and determining the size and the shape of underground objects. By use of only the source-object-detector travel times the relative phases of the arriving signals are calculated. This process eliminates not only the necessity for recording and processing entire signals (which normally includes digitizing) but also removes the interference of shear and surface waves.

The first test was to map a 33 m diameter cavity made by an explosion. The cavity was filled with blast shattered material characterized by lower seismic velocities. The frequency recorded was 140 Hz giving the wave length of 16 m.

In the tests 441 geophones are used placed in a rectangular array of 60 m square. The experiment is described in Fitzpatrick, Nicholls, Munron (1972) & Fitzpatrick (1972).

Special difficulties were found with object which are transparent to seismic waves like rock inclusions, cavities filled with liquid, etc. The application of special filters may lead to wrong conclusions due to the difficulties of proper adjustment of filters. The Gabor process of subtraction holography can be used. The details are given in Fitzpatrick (1973).

13 - SEISMIC AND CONTINUOUS PROFILING.

13 - 1 Seismic refraction and reflection techniques are used extensively in solving engineering foundation problems, investigating tunnels, roads, canals, hydrology etc. The equipment is mostly constructed in the USA but I saw some which were French, Swedish and Russian built. The methods of interpretation are similar to ours. Several aspects of work are worth mentioning here.

13 - 1.1 Instrumentation - The number of organizations which use the single geophone engineering seismographs is on the increase. This is the result of wider applications of engineering geophysics in close populated areas and great improvements in the equipment used. The Geological Survey of Canada and the Highways Department of California conducted extensive comparisons of results obtained with single and multiple channels seismic refraction equipment. The results compare favourably. (Stephens, 1972).

Enhancement engineering seismographs have increased the possibilities of using these instruments in the reflection mode and spectacular results were obtained in the Canadian permafrost area. Some reflections were obtained also with the normal engineering seismograph using two geophones connected inversely in parallel; a lack of a signal indicated the possibility of a reflection.

On larger engineering projects multiple channel equipment is used generally with magnetic recording. In USA, Canada, Poland the same equipment is used for rock burst investigations or in seismic refraction.

Recording of the shear waves on these projects has become a standard practice and the determination of the dynamic properties of rocks and comparing them with the static values has been perfected. The gap existing between the values of the static and dynamic properties has been narrowed (see plate 11) indicating that considerable errors were made in the initial stages of the development of the methods of measurement.

13 - 1.2 At the Exhibition of equipment at the Annual Meeting of the S.E.G. the 3-D Velocity Logging System was shown. This consists of a well-probe containing two transducers - a magnetostrictive transmitter and a receiver, which can be either magnetostrictive or piezo-electric. The spacing between the transducer and receiver can be varied. The signal from the receiver is displayed on the CRO which is synchronised with the transmitter. A special recording system has been developed and it is described in Geyer, Myung (1970).

13 - 1.3 The generation of the seismic wave is done with a hammer blow, use of explosives or vibrators.

The magnetic recording and the enhancement seismograph allow stacking, therefore more accurate arrival times are obtained even with slight blows. A shear wave can be recognized more easily by reversing the direction of a set of horizontal hammer blows.

Stephens (1972) gives the comparison of results obtained using several kinds of explosives. He reached a conclusion that the low velocity explosive (AMFO) gives better results when fired in the near surface low velocity material than the high velocity explosive fired in the same conditions. Moreover, the high velocity material produces severe electrical crossfeed when fired close to the surface. To remove this crossfeed the geophone cables are shielded and grounded through the instruments terminals.

The use of mechanical, electrical or compressed air driver in urban areas is on the increase. The use of Vibroseis for a large engineering work is described by Mossman, Hein and Dalton (1971).

13 - 2 Continuous seismic profiling.

The development of the continuous seismic profiling is being carried out in several organizations in countries I visited. Several different wave generating sources are used the sparker and the air gun are most common. My main interest was in the shallow water profiling.

13 - 2.1 US Geological Survey at Manlo Park developed a high resolution sparker set. It consists of a copper rod inserted into a tube (1½ in. internal diameter) with electrodes drilled through the copper rod and cut flush with the outer surface of the tube. The electrodes are 1/8 in dia welding rods and the power is limited to 10 joules per electrode. The total power used is 100 to 400 joules. The "wear out" of electrodes is about 4 hours. The penetration of about 60 m is obtained with the resolution of 15 cm. The difficulty lies in finding the outer tube material which will not shatter near the tip of the electrode. The records are clean and full of details. Other development carried out in the group is mentioned in 4 - 1.2 (recording sparker results in three colours). A similar set-up is produced commercially by Del Norte.

13 - 2.2 The Institute of the Geological Sciences in London developed a system which measures seismic velocities in sediments at the bottom of the sea. A complete summary of this work with the discussion on the properties of the sediments is contained in McCann Taylor Smith (1973). Similar results of the in-situ determination of sea-floor sediments was given by Lee (1972) at the meeting of SEG. at Anahaim.

13 - 2.3 University of Birmingham fitted a sparker just below the bottom of a steel boat filled with sand. The records obtained shows much greater penetration.

13 - 2.4 In Hong Kong we visited the Cesco (Coastal Engineering Survey Consultants) Ship. Four ships of the same type were specially constructed to take a 7.5 kW.s sparker unit. The length of a pulse varies in steps between 0.3 and 5.3 millisecond at frequencies of 1.5, 3 and 6kHz. The reflected signal is picked up amplified in programmed amplifier, and filtered. The recording is done on an electro-chemical recorder. Stacking of signals is possible.

The receiver is located on a sledge, the depth of floating is controlled remotely by air cylinders.

The records are processed in Holland by a computer using punched cards obtained with a pencil follower.

13 - 2.5 The use of air guns in on the increase. The Bolt Associate stand on the SEG meeting displayed several records with penetration of 100 m in 5 m of water. An assembly of an air gun placed close to the surface of water reduces the bubble pulse. A complete set of an air gun with a capacity changeable between 1 and 40 cu in with an electronic firing control and spares costs about $US5000, Compressor is not included in the cost.

13 - 2.6 Mr C.S. Clay of the University of Wisconsin is using air-guns in 3 m of water. The gun in size 1 to 10 m inch. is used to penetrate a thin layer of mud containing air bubbles. Recording is done on two channel tape recorder. The depth of penetration is 40 m.

13 - 2.7 The water pressure of 40 psi from a high velocity explosive material will kill fish at a distance of 1 m. From an air-gun a pressure of 146 psi will not harm the fish as the relatively slow increase in pressure allows the fish to adjust to this increase. A pressure of 146 psi at a distance of 1 m results from firing a seven air-guns of total capacity of 240 cu inch. The effect of black powder firing is similar to that of an air gun.

14 - ELECTRICAL METHOD

14 - 1 General

Discussions on the application of electrical methods to hydrology and civil engineering were made in:

JAPAN. The application of resistivity surveys to the landslide investigation is discussed in section 9.

USA Application to the control of the recharge of aquifers was discussed at the US Geological survey at Menlo Park. Electrical surveys techniques and interpretation was discussed at the international meeting of the Society of Exploration Geophysics at Anrahaim, at the US Geological Survey, Denver and the Bureau of Reclamation, Denver.

CANADA. In the Water Resources Directorate in Ottawa I discussed the application of resistivity to control intrusions of salt water into sea shore aquifers and the resistivity work in the open plains of Canada.

UK At the Institute of the Geological Sciences in London I discussed the electrical methods applied to locating ground water in chalk. At the Birmingham University I discussed the "current path" method and the relationship of the IP effect to the clay content in an aquifer and the effect of the different electrode configuration, as well as electrical logging of water bores.

POLAND. At the Geological Institute of Poland I discussed the application of different electrode configurations to the solution of specific problems. One specific problem was the use of S.P. and resistivity methods in the limestone terrain of Chinese Mongolia and the use of resistivity measurements between two bores.

At the institute of Petroleum resistivity depth probing; shaped pulse induced polarization and electro magnetic and electrical logging for oil and gas were discussed.

At the Institute of Hydro Engineering the results of resistivity depth probing in the limestone terrain of the Niedzica dam site were disclosed to me.

14-2 RESISTIVITY DEPTH PROBING

14 - 2.1 ELECTRODE CONFIGURATION

The method of positioning the electrodes is the main part of the field procedure. During the visit several electrode arrangements not commonly used in Australia were discussed. Some of those are useful in general cases, while others were used to solve special problems.

The Wenner electrode configuration, (Plate 12 Fig. 1) was introduced in 1915 (Wenner, 1915) and from the beginning was accepted generally especially in the English speaking countries. Slight modification were introduced to detect near surface inhomogeneity. (Lee arrangement Plate 12 Fig. 2).

The development of Schlumberger method (Plate 12 Fig. 3) (Schlumberger, Schlumberger, 1932) saw a great advancement in the resistivity depth probing especially at great depths.

The Schlumberger arrangement was followed by the dipole - dipole system (Alpin et al. 1966.) (plate 12, Fig. 4) which is nothing more than an Eltran system. The disadvantage of the method is the requirement of a much more powerful current source. There are several geometries of the electrode arrangement and some of them have smaller equivalent depth of penetration than others.

The theoretical background of the different dipole - dipole arrangements has not been completely solved and a bitter controversy exists between the groups in the Colorado School of Mines (G. Keller) and the US Geological Survey (A. Zohdy) Keller delivered a lecture at the 42nd Inter. Meeting of the SEG giving the curves for corrections of geometry of dipoles, but Zohdy pointed out that the corrections would work only in a homogeneous layered earth.

The Schlumberger arrangement has a greater depth of investigation and the depth equals roughly half of the spacing between the current electrodes. In the Wenner arrangement a spacing of 1.386 a is required to equal the effective depth of investigation of the Schlumberger arrangements. For dipole - dipole the depth of investigation is equal to the spacing between centres of dipoles for azimuthal, half of the spacing for polar (radial) and 2/3 of the spacing for perpendicular.

These three electrode arrangements are used in majority of surveys and they are often combined. The Schlumberger or Wenner is used for close spacing followed by dipole- dipole for larger spacing in deep electrical probing. From these arrangements several modifications were evolved to provide the following advantages:

1. Distinguishing the near surface irregularities
2. Obtaining better resolution
3. Increasing the depth of investigation
4. Simplification of field procedure.

As the Wenner arrangement measures larger voltages than Schlumberger it is more accurate when used in the low resistivity areas. I noted in Canada an evident return to the Wenner array. It is used in the areas of the sea water intrusions into aquifers and an album of the three layer theoretical curves was published in 1973, (Lazreg, 1972).

At the Dept. of Geology, University of Birmingham they consider that the Wenner electrode arrangement is superior to others and it is more amenable to modifications. The noise and the telluric currents are amplified in the Wenner arrangement, but with a special care or with a continuous recording the use of the Wenner will not lead to errors.

The Wenner arrangement has been modified to provide information on inhomogeneities. Jakosky (1950) introduces the fifth electrode to obtain three curves on each location.

Teisseyre (1951) introduced on additional potential electrode outside the Wenner system (Plate 12 Fig. 5) and later Carpenter and Habberjan (1956) interchanged one inside potential electrode with the outside current electrode introducing the so called tripotential electrode arrangement. (Plate 12 fig. 6).

The asymmetrical method (Plate 12, fig. 7) gives results equivalent to the Wenner arrangement, but lowers the number of electrodes to be moved during the field work. In one modification only the nearby current electrode is moved away from the pair of stationary potential electrodes giving a modified Schlumberger arrangement.

Plate 12 fig. 8 shows the potential-drop ratio. The popularity of this arrangement has increased in cases where an infinite resistivity bed is overlain by a high resistivity bed and the point of inflection is difficult to locate. The arrangement shown on fig. 9 (plate 13) is used often on resistivity surveys, over large areas where two or more teams are working together. A publication by Zohdy (1969) gives the details.

The three arrangements shown on figs 10 to 12 (Plate 14) are used to increase the depth of investigation or to increase the sensitivity to thin and steeply dipping bodies.

Fig. 13 (Plate 13) gives the modification of an arrangement advocated by Kunetz (1966) this arrangement was used on the dam site in Niedzica (see 7 - 4) to locate the steeply dipping beds of limestone and high resistivity dry cavities.

Arrangements in plate 13 fig. 14 a to c are used to locate thin horizontal high resistivity beds (aquifers) in a column of lower resistivity strata.

14 - 2.2 Equipment for resistivity depth probing.

The IP equipment is generally used for any depth probing. The most common frequency used is 0.1 Hz. As a receiver a continuous recording system is applied (Stanley 1971).

Prof. Morrison of the Berkeley University is constructing deep resistivity equipment to determine earthquake activity in the San Andreas Fault zone. The details of the proposed equipment are in the Eng. Geoph. Group. The generator produces 85 KVA, while the transmitter produces 800 volt and up to 100 A mps. The period of the pulse is 2 to 6 seconds.

14 - 2.3 Resistivity depth probing interpretation.

The most commonly used method of interpretation is to compare a field measured curve with the theoretical pre-calculated curve. If both curves coincide throughout the whole length it is easy to find the parameters of the electrical environments in which the measurements were carried out.

The many publications so far used are mostly confined to the four horizontal layers cases, although several publications give limited number of examples of five and six layers and sloping interfaces.

Not only these curves represent limited number examples of relatively thick beds showing pronounced differences in resistivity, but also the personal attitude of the interpreter plays a major role. To remove this personal factor the inverse method of interpretation has been introduced. Several programmes of these kind have been introduced lately for example: Anderson and Zhody (1973) Vozoff (1958).

The second improvement is the so called method of axiliary points. It follows the Hummel principle (Hummel 1932) of equivalence of many layered electrical sections to a less layered earth. The electrical parameters of the section can be estimated with the use of help curves. The limitation of the method is clearly shown in case of thin low resistivity beds and also with the several layers case, there exists on addition of errors.

To the same group of methods belong the monographic methods of interpretation. They were developed before the last world war (Tagg, 1934, Rosenberg, 1940 and Longacre, 1945) but their popularity decreased considerably, a short revival came in sixties especially in the connexion with the interpretation of the magnetotelluric curves. The advantage of these methods is that it is possible to apply the methods to distorted and incomplete curves, in cases where the theoretical curves superposition is very difficult and doubtful. These methods are used mainly on engineering jobs of shallow investigation like roads, bridges etc.

Moore (1945) proposed a method of a graphical interpretation of depth probing in shallow resistivity used in road construction investigation. The method proved successful narrow channels buried below glacial deposits were delineated at great accuracy. Similar method was proposed by Narayan Sonkar et al (1967) using a Wenner arrangement a depth probe is plotted using the relation.

$$a/pa = \frac{1}{2\pi} \frac{DV}{I}$$

where a = spacing
pa = apparent resistivity
DV = difference of potential
I = applied current

Using this relation the curve is changed into the length of straight lines at the different angles to the axis. The reciprocal of the angle is the apparent resistivity. The points of the change of the slope projected on the axis give the depth to the interfaces. For the two layers system for small (k = .3) the errors of determination are less than 10 per cent.

CONCLUSIONS

My overseas visit was the first one done by a member of the Engineering Geophysics Group of the BMR. The number of institutions visited and the themes discussed, covered a very wide field resulting in an oversize record.

The two conferences I attended were very different in subjects and in the organization. In my opinion the one in Hong Kong (South East Asian Conference on Soil Engineering) was much better organized. The preprinting of the papers, short introduction and long discussions were much more useful than the method used in Anaheim (42nd International Meeting Society of Exploration Geophysicists) with three parallel sessions, switching from one lecture room to another. In this case so similar to the Annual meeting of ANZAAS. The main gain was from the discussions, making contacts with other geophysicists, designers and manufacturers, not the actual papers, which really provided a general insight into the "state of the art" in a branch of geophysics.

The contacts with other institutions and organizations in six countries indicated that friendly cooperation does exist and all of them are willing to contribute in an exchange of information, data and plans for future work.

Generally I found that our advances in engineering geophysics and hydrogeophysics is on a level with the advances in other countries, although in instrumentation and the number of people engaged in the work we are behind the other countries. There is generally a shortage of trained geophysicists in most of the institutions in the USA, Canada and Great Britain. In Japan I was amazed at the large number of post-graduate students continuing after the first degree in civil engineering. In Poland the method of bonding university graduates helped to overfill most of the research organizations and release senior staff to carry out theoretical development.

Many organizations were keen to obtain information on the results from our work and during the meeting at Hong Kong a statement was made that Australians do not release enough case histories.

In my opinion a member of the Engineering Geophysics Group should visit other countries organizations and attend meetings at at least 3 year intervals.

16. REFERENCES

(BMR - denotes publications deposited in the BMR Library; ENG. references available from the Engineering Geophys Group)

AMIMOTO, P.Y., & NELSON, J.S., 1970 - Surveying reservoir leakage using waterborne electrical resistivity method. Bull. Ass. Eng. Geol. 7, 1-9.

ALPIN, L.M., 1966 - Dipole methods for measuring earth conductivity. Consultants Bureau, New York.

APPARAO, A., & ROY, A., 1972 - Field Results for D.C. Resistivity Profiling with two electrode array. Geol exploration, 11, 21-44.

ARANDJELOVIC, D., 1966 - Geophysical methods used in solving some geological problems encountered in the construction of the Trelisnjica Water Power Plant in Yugoslavia. Geophysical Prospecting 16(1), 80-97.

ARANDJELOVIC, D., 1969 - A possible way of tracing groundwater flows in karst. Geophysical Prospecting 17, 404-418.

BANERJEE, S.L., & NATH, R., 1967 - Electrical resistivity studies of Kopili Reservoir Area (Assam). Symp. on Site Investigation for foundation, 10, Roorkee, 105-111.

BENDIX RESEARCH LAB., 1972 - Seismic holography for underground viewing. Bendix Report No. 6276.

BIOT, M.A., 1952 - Propagation of Elastic Wares in a Cylindrical Bore Containing a Fluid. Journ. of Appl. Physics, 23, 927-1005.

BISHOP, A.W., 1955 - The Use of the Slip Circle in the Stability analysis of slopes. Geotechnique 15.

BLAKE, W., 1971 - Rock Bursts Research of the Galena Mine Wallace, Tdaka. U.S. Bureau of Mines. Techn. Project Res. (BMR)

BLUME, J.A., 1970 - An Engineering Intensity Scale for Earthquake and other Ground Motion. Bull. Seism. So. Am GO, 217-229

BOGOSLOVSKY, V.A., & OGILVY, A.A., 1970a - Application of Geophysical Methods for studying the technical status of Earth Dams. Geophysical Prospecting 18, 758-773

BOGOSLOVSKY, V.A., & OGILVY, A.A., 1970b - Natural Potential Anomalies as a Quantitative index of the rate of seepage from water reservoir. Geophysical Prospecting 18(2), 261-268.

BOGOSLOVSKY, V.A., & OGILVY, A.A., 1972 - The study of Streaming potentials on fissured media models. Geophysical Prospecting 20(1), 109-117.

BORCHERDT, R.D., 1970 - Effects of Local Geology on ground motion near San Francisco Bay. Bull. Seism. So. Am 60, 29-61. (BMR)

BRADY, B.T. HOOKER, V.E. AGA PITO JFT - 1973 - Laboratory and in situ Mechanised Behaviour Studies of Fractured Oil Shale Pillars, AIME Annual Meeting 1973. (ENG)

BUREAU OF RECLAMATION 1971 - STILLWATER Tunnel - A practical laboratory. U.S. Dept. of Interior.

CADMAN, J.D., & GOODMAN, R.E., 1967 - Landslide Noise, Science 158, 1182-1184.

CADMAN, J.D., GOODMAN, R.E., & ALSTINE, C van, 1967 - Research on Subaudible Noise in Landslides, Dept of Civil Eng. Univ. of California Berkeley. (BMR)

CARPENTER, E.W., & HABBERJAN, G.M., 1956 - A tripotential Method of Resistivity Prospecting Geophysics, 21, 455-469.

CHISHOLM, T.P., & PATTERSON, G.D., 1958 - Sonar Caliper Simplifies L.P.G. Storage Surveys. The Petrol. Eng. January, 1958, B-90.

CHOPRA, A.K., & PERUMALSWAMI, P.R., 1969 - Dam Foundation Interaction during Earthquake. Fourth World Conf. on Earthquake Eng., Santiago.

CLOUGH, R.W., & CHOPRA, A.K., 1966 - Earthquake Stress Analysis in Earth Dams. Journ. Eng. Mech. Dis. ASCE, 92, 197-212

CODET, P., DAMOTTE, B., ERB, E., LAVERGNE, M & LAYOTTE, P.C., Geophy. Prospecting 19, 776-790.

COGGON, J.H., 1971 - Induced Polarisation Anomalies. Univ. of Calif. Berkeley. Ph.D. thesis. (ENG)

COLLEY, G.C., 1963 - The detection of caves by gravity measurements. Geophysical Prospecting 11(1), 1-9.

COOK, J.C., 1964 - Progress in mapping underground solution cavities with seismic shear waves. Trans. A.I.M.E., vol. 229, 26-32.

COOK, J.C., 1965 - Seismic mapping of underground cavities using reflection amplitudes. Geophysics, 30, (4), 527-538.

DEY, A., 1972 - Finite Source Electromagnetic Response of layered and inhomogeneous Earth Models. Univ. of Calif. Berkeley, Ph.D. Thesis. (ENG)

DOBOSZ THIEL, 1971 - Problem of Determination of Slopes Stability Rosprawy Hydrotechnic 29, 173-208. (ENG)

DURBAUM, H., 1971 - Zur Konstruktion der Reflexion elemente in der Untertageseismik. Gluckauf 11/1971, 377-383.

DUTTA, N.P., BOSE, R.N., & SAIKIA, B.C., 1970 - Detection of solution channels in limestone by electrical resistivity method. Geophysical prospecting 18(3), 405-414.

DZWINEL, J., 1972 - Elektryczne Metody Poszukiwawcze in ZARYS GEOFIZYKI STOSOWANEJ. FAJKLEWICZ, Z. Editor, Warszawa.

DZIEWANSKI, J., 1969 - Grout Curtain at one of the Storage Dams situated in Rocks of the Carpathian Flysh Facies (in Polish). Odwadnianie Kopaln i Geotechnika, (2) 137-160.

FAJKLEWICZ, Z., 1972 - ZARYS GEOFIZYKI STOSOWANEJ. WYDAWNICTWO GEOLOGICZNE WARSAW.

FINN, W.D., & KHANNA, J., 1966 - Dynamic Response of Earth Dam Third Earthquake Symposium ROORKEE, India.

FITZPATRICK, G.I., 1972 - First-arrival seismic holography. In Acoustical Holography. Edit. G. Wade Plenum Publish. Comp.

FITZPATRICK, G.I., NICHOLLS, H.R., & MUNSON, R.D., 1972 - An experiment in seismic holography. U.S. Bureau of Mines, Rept. of Inv. 7607. (BMR)

FITZPATRICK, G.I., 1973 - Phase-contrast enhancement without spacial filters for seismic holography. U.S. Bureau of Mines, Rept. of Inv. 7721. (BMR)

FRITSCH, V., 1953 - Geoelektrische Uberprufung der Baugrund-verfestigung durch Zementinjektionen. Geofisica pura e appl. 25, 207-

FRITSCH, V., 1954 - Geoelektrische Baugrunduntersuchung Bautechnik 31, 318-322.

FRITSCH, V., 1956 - Geoelektrische Baugrunduntersuchungen in Jugoslavien und Oesterreich. Geophysical Prospecting 4, 24-36.

GASSINIS, R., 1958 - A practical Criterion for Converting between Apparent Resistivities Diagrams obtained with different arrangement of electrodes. Annali Geofisica 11, 237-236.

GEYER, R.L., MYUNG, J.I., 1970 - The 3-D velocity Log a tool for in-situ determination of the Elastic Moduli of Rocks. 12th Annual Sym. Rock. Mech. Univ. of Missouri. Rolla. (ENG)

GLAB, W; JAWANSKI & THIEL, K., 1965 - Research on the Sealing of the Dam Foundation with Cement-Bentonite Grouts (in Polish). Osr. Wyd. Warsaw.

GODSON, R.H., & WATKINS, J.S., 1968 - Seismic Resonance Investigation of a near surface cavity in Anchor Reservoir, Wyoming. Bull. the Ass. of Eng. Geol. vol. 5(1), 27-36.

GRANT TAYLOR, T.L., NORTHEY, R.D., & ADAMS, R.A, 1970 - Microzoning for Earthquake Effects in the Panatahanui Area Bull. NZ DSIR.

GOODMAN, R.E., 1971 - Research on Subaudible Noise in Landslides. Univ. of California, Berkeley. (BMR)

GUPTA, R.R., 1972 - Seismic Determination of Geological Discontinuities ahead of Rapid Excavation. Advanced Research Project Agency. Report no 6311. (BMR)

HABBERJAM, G.M., 1969 - The location of spherical cavities using a tripotential resistivity technique. Geophysics, 34, 780-784.

HABBERJAM, G.M., 1970 - The Association of resistivity soundings. Geophysical Prospecting 18(2), 199-214.

HEILAND, C.A., 1946 - GEOPHYSICAL PROSPECTING, Prentice Hall, New York.

HOOKER, V.E., & DUVALL, W.I., 1971 - In situ Temperature Stress Investigations in Rock Quarries, U.S. Bureau of Mines, R.I. 7589.

HOOKER, V.E., & BICKEL, D.L., 1972 - Overcoring Equipment and Techniques. U.S. Bureau of Mines Seminar Report TT 10002. (BMR)

HUMMEL, J.N., 1932 - A theoretical Study of Apparent Resistivity in Surface Potential Method. Trans. AIMME 97, 392-422.

INNES, K.W., 1971 - Design and Construction of the Hong Kong Cross-Harbour Tunnel. Tunnels & Tunnelling 3(4), 249-255.

INS. MIN. ENG., 1969 - Damage Control from Mining Operations. Inst. of Mining Eng. & Techn. KATOWICE.

JAKOSKY, J.J., 1950 - EXPLORATION GEOPHYSICS. Trijie Publ, Los Angeles.

JENNINGS, J.M., 1971 - KARST, MIT Press.

JESSOP, A.M., 1968 - Three measurement of Heat flow in Eastern Canada. Con. J. Earth Sci. 5, 61-68.

JOHNSON, C.F., - A Pulse Technique for Direct Measurement of Bore Velocity - Reprint, source unknown. (ENG)

KANAI, K., 1962 - On the Spectrum of Strong Earthquake Motions. Bull. Earth. Research Inst. Kyoto 40, 71-90.

KANAI, K., & JOSHIZAWA, S., 1964 - Some New Problems of Seismic Vibrations of a Structure (Care of a Dam). Bull. Earth. Research Inst. Kyoto 42, 237-242.

KANE, M.F., HARWOOD, D.S., HATCH, N.L., 1971 - Continuous Magnetic Profiles near Ground Level (15-1) as a Means of Discriminating and Correlating Rock Units, Geol. Soc. Am. Bull. 82, 2449-2456.

KIDYBINSKI, A., SZECOWKA, Z & LICZNERSKI, E., 1972 - Problems of Geodynamics and Rock Bursts (in Polish). Polish Academy of Science.

KELLER, G.V., & FRISCHKNECHT, F.C., 1966 - ELECTRICAL METHODS IN GEOPHYSICAL PROSPECTING, Pergamon Press, Oxford.

KNIGHT, F.J., 1971 - Geologic problems of Urban growth in Limestone Terrains of Pennsylvania. Bull. Ass. Eng. Geol. 8, 91-101.

KOBORI, T., MINAI, R., & INOVE, J., 1970 - On the Earthquake Response of Structural Systems Considering the Interaction Effects of the Ground. Bull. Dis. Prev. Res. Inst. Kyoto 20, 105-125.

KREY, T.C., 1965 - Channel Waves as a Tool of Applied Geophysics in Coal Mining. Geophysics, 28, 701-714.

KUNETZ, G., 1966 - PRINCIPLES OF DIRECT CURRENT RESISTIVITY PROSPECTING. Geopublication Associates.

LAZREG, H., 1972 - Master Curves for the Wenner Array. Water Resources Branch, OTTAWA.

LEE, H.J., 1972 - In-situ Determination of Seafloor Soil Engineering Properties, 42 Ann. Meeting SEG Anaheim.

LENNOX, D.H., 1962 - Geophysical Methods of Location Aquifers in the Prairies. Proc. of Hydrology Symposium no. 3 N. Res. Coun. Canada.

LENNOX, D.H., & CARLSON, V., 1967 - Geophysical Exploration for Burried Valleys in an Area North of Two Hills, Alberta, Geophysics 32(2) 331-362.

LENNOX, D.H., & CARLSON, V., 1967 - Integration of Geophysical Methods for Ground Water Exploration in the Prairie Provinces, Canada, Mining - Groundwater Geophysics 1967.

LONDE, P., 1968 - STABILITE' des massifs rocheux Application aux barrages Annales d'ILTBTP no. 251.

LONGACRE, W.A., 1945 - A Study of the Problems of Depth Determinations by means of Earth Resistivity Measurements Trans. AIME 164, 179.

LOVE, C.L., 1966 - A geophysical study of a highway problem in limestone terrain. Calif. Div. of Highway Research Rep. MaR. 642730.

LOVRENCO, J.S., 1972 - Analysis of Three-component Magnetic Data. Univ. of Calif. Berkeley, Ph.D. thesis. (BMR)

McCANN, D.M., TAYLOR SMITH, D. - 1973 - Geotechnical Mapping of Sea-floor Sediments by use of geophysical techniques. Trans. Inst. Mining & Metal. November, 1973, B155-167.

MOID UDDIN, A., 1964 - A Laboratory Study of Streaming potentials. Geophysical Prospecting 12, 49-64.

MOORE, R.W., 1945 - An Empirical Method of Interpretation of Earth Resistivity Measurements. Trans. AIME 164, 197-202.

MORELAND, J.A., 1970 - Artificial Recharge Yucalpa Cal. U.S. Geol. Surv. Water Res. Div. Rep. 5020-33. (BMR)

MORELAND, J.A., 1972 - Artificial Recharge in the Upper Santa Ana valley Southern California U.S. Geol. Survey Water Res. Div. Rep. 5027-06. (BMR)

MORGENSTERN, N.R., & PRICE, V.R., 1965 - The Analysis of the Stability of General Slip Surfaces, Geotechnique 15, 79-93.

MOSSMAN, R.W., HEIM, G.E., DALTON, F.N., 1971 - Vibroseis Application to Engineering Work in an Urban area. 41st Annual Meeting Soc. Expl. Geogl. Houston. (ENG)

MURAYAMA, S., YAGI, N., ISHII, Y., (?) On the strength characteristics of weathered Arenite (Origin and date unknown). (ENG)

MYERS, A.J., 1960 - Sonar Measurements of Brine Cavity Shapes. The Dow Chemical Co., Tulsa, Okla.

NICKEL, H., 1972 - Moglichkeiten und Grenzen der Hochfrequenz Absorption Methode Beim einsatz unter Tage. Gesellschaft Deutscher Metallhutten-und Bergleute, Heft 24 (ENG)

NEUMANN, R., 1967 - La gravimetrie de haute precision application aux recherches de cavites. Geophysical Prospecting 15 (1), 116-134.

NONVEILLER, E., 1965 - The Stability Analysis of slopes with a slip Surface of General Shape. Proc. fourth Int. Conf. Soil Mech. Foun. Eng. 522-525.

OGILVY, A.A., AYED, M.A., & BOGOSLOVSKY, V.A., 1969 - Geophysical studies of water leakages from reservoirs. Geophysical Prospecting 17(1), 36-62.

O'RORKE, G.B., 1972 - A Cutting Failure in Hong Kong Granite. 3rd SE Asian Con. Soil Eng. Hong Kong 1972.

PATERSON, D.W., YEEND, W.E., OLIVER, H.W., & MATTICK, R.E., 1968 - Tertiary Gold Bearing Channel Gravel in Northern Nevada County California. U.S. Geol. Survey Circular. 566. (BMR)

PARTON, I.M., & MELVILLE SMITH, R.W., 1971 - Effects of soil Properties on Earthquake Response. Bull. N.Z. Soc. for Earthquake Eng. 4, 73-81.

PHILLIPS, K.A., 1972 - Some Aspects of the Cross-Harbour Tunnel, Hong Kong. 3rd SE Asian Conf. Soil Eng. Hong Kong.

PIRSON, S.J., 1970 - Geologic Well Logs Analysis. Gulf Publishing Co., Houston.

RAINER, J.H., 1970 - A Review of Dynamic Structure - Ground Interaction Nat. Res. Course Canada Tech. Paper no. 325. (BMR)

RAINER, J.H., 1971 - A Review of Dynamic Structure - Ground Interaction. Nat. Res. Course Canada Tech. Paper no. 325. (BMR)

RAINEY, F., & RALPH, E.F., 1966 - Archeology and its new technology. Science vol. 153, 1481-1491.

REENAN, van E.D., - Subsurface Exploration by Sonar Seismic System. Symposium on Soil Exploration.

RICHARDS, J.W., 1971 - DISCUSSION: Geologic Problems of Urban Growth in Limestone Terrains of Pennsylvania. Bull. Ass. Eng. Geol. 8(2), 195-200.

REEVES, D.R., - In situ Analysis of Coal by borehole logging techniques. Xerox copy in Eng. Geoph. Group.

ROESCHLEIN, E.R., 1960 - Mapping Caves Magnetically. Electronics, Sept. 23, p. 61.

ROFE, B.H., 1971 - Application of Instrumentation to Earth Dams. Jour. of the Inst. of Water Eng. 25, 137-160.

ROSS, N., & HUSTRULID, W., 1972 - Development of a Tunnel Boreability Index U.S. Dept. of Interior, Bureau (BMR) of Reclamation.

ROZENZWEIG, I.E., 1940 - New Method of Depth Determination in East Resistivity Measurements Trans. AIME, 138, 408-412.

RUSSELL, P.L., 1972 - Infrared Detection of Hidden Water Courses near Underground Openings. U.S. Bureau of Mines Progress Report no. 1005.

SANKERNARAYAN, P.V., RAMANUJACHARY, R., 1967 - An Inverse Slope Method of Determining Absolute Resistivity. Geophysics 32, 1036-40.

SAUL, T., & HIGSON, G.R., 1971 - The Detection of Faults in Coal Panels by Seismic Transmission Method. Inst. Jour. Rock Mech. Min. Sec. 8, 483-499.

SCHLUMBERGER, C., & SCHLUMBERGER, M., 1932 - Depth Investigation obtainable by Potential Methods of Electrical Exploration. AIMME Trans. 97, 127-133.

SCHAETZER, I., 1965 - Geophysical Studies of the Continuity of Coal Seams. Inst. Jour. Rock Mech. Min. Sce. 2, 167-196.

SEED, H. BOLTON, 1969 - The influence of Local Soil Conditions on earthquake damage. 7th Int. Con. on Soil Mech. & Found. (BMR) Eng. Mexico City.

SEED, H. BOLTON, 1970 - Soil Problems and Soil Behaviour Earthquake Engineering, Edit. Wiegel, Prentice (BMR) Hall.

SEED, H. BOLTON, IDRISS, I.M., 1970 - Soil Moduli and Damping Factors for Dynamic Response Analysis, (BMR) Univ. of California Report EERC - 70-10.

SEED, H. BOLTON, IDRISS, I.M., & DEZFULIAN, H., 1970 - Relationships between Soil Conditions and Building Damage in the Canacies Earthquake of July 29, 1967. Univ. of California Report EERC-70-2.

SEGGERN, von D., & ADAMS, W.M., 1969 - Electromagnetic Mapping of Hawaiian Lava tubes. Bull. Ass. Eng. Geol. 6, 95-104.

SWEETING, M.M., 1972 - KARST LANDFORMS. Macmillan.

STANLEY, W.D., 1971 - An Integrated Geophysical Study Related to Groundwater Conditions in Cache Valley, Utah and Idaho. University of Utah. Ph.D. thesis. (BMR)

STANLEY, W.D., 1972 - Geophysical study of Unconsolidated sediments and Basin Structure in Cache Valley, Utah & Idaho. Geol. Soc. Am. Bul. 83, 1817-1830.

STEPHENS, E.E., 1972 - Shallow Seismic Techniques. 42 Int. Meeting Soc. Exp. Geoph. Anahaim. (ENG)

TAGG, G.F., 1940 - Interpretation of EARTH RESISTIVITY Curves. Trans. AIME 138, 399-407.

TATE, T.K., & ROBERTSON, A.S., 1971 - Investigation into High Salinity Ground Water of the Woodfield Pumping Station Wellington, Salop. Water Supply Paper. Inst. Geol. Science Report no. 6. (BMR)

TATE, T.K., ROBERTSON, A.S., & GRAY, D.A., 1971 - Borehole Logging Investigations in the Chalk of the Lamboum and Winterbourne Valleys of Berkshire. Water Supply Paper Inst. Geol. Science. Report no. 5.

TAYLOR, D., 1960 - FUNDAMENTALS OF SOIL MECHANICS, New York.

TEISSEYRE, E., 1951 - Metoda Oporu Pozornego w Geoelektry- cznych Pracach Poszukiwawcrych. Pan. Inst. Geol. Bul. 63, Sev. Geoph. 6. (ENG)

THIEL, K., 1966 - An Application of the Cement-Bentonite Grouts to Seal the Dam Foundation on the Carpathian Flysh (in Polish). Osr. Inf. Techn. Econ. Warsaw.

THIEL, K., 1971 - Editor. Badania statecznosci podtoza skalnego zapory betonowej w zlozonych warunkach geologicznych. (Stability Analysis or rock foundation of a concrete dam in complicated geological conditions). Panistwowe Wydawnictwo Naukowe, Poznan.

TRAUTWEIN, W.B., 1970 - Use of water temperature study to define seepage paths. Bull. Ass. Eng. Geol. 7, 11-20.

U.S. ARMY WATERWAYS EXPER. STATION 1969 - Seismic Instrumen- tation Conference on Earth and Concrete Dams. Nov. 1969. (BMR)

WATKINS, J.S., GODSON, R.H., & WATSON, K., 1967 - Seismic Detection of near surface cavities. U.S. Geol. Survey Prof. Paper 599A.

WENNER, F., 1915 - A Method of Measuring Earth Resistivity U.S. Bureau of Standards. Bull. 12. See Pap. no. 258, 469-478.

WIERCHEYKO, E., 1972 - Echo Log - Ein geophysikalisches Meszferfanren zur Bestimmung von Form von Aussolungshohlraumem im Salzgebirge, Geoph. Prospecting 20(3), 649-664.

WILDE, P., 1971 - DATA GATHERING. Univ. of California C.E. 201 C. (ENG)

WITTKE, W., 1964 - Ein rechnerischer Weg zur Ermittlung der Standsicherheit von Boschungen in Fels mit durchgehenden ebenon Absondeningoflachen. Roch. Mech & Eng. Geol. Suppl. 1, 102-129.

WORTHINGTON, P.F., 1971 - The Use of Resistivity Logging to Estimate Borehole Yield from a Matrix Conducting Sandstone. Quart. Jour. Eng. Geol. 4, 263-279.

WORTHINGTON, P.F., & BARKER, R.D., 1972 - A Centrifugal Technique for Rapidly Estimating the Permeability of a Consolidated Sandstone, Geotechnique. 521-524.

WYLLIE, R.J., GREGORY, A.R., & GARDINER, L.W., 1956 - Elastic Wave Velocities in Heterogeneous and Prime Media, Geophysics. 21, 41-70.

VAN NOSTRAND, R.G., & COOK, K.L., 1966 - Interpretation of resistivity data. U.S. Geological Survey Prof. Paper 499.

YOSHIKAWA, S., SHIMA, M., & IRIKURA, K., 1967 - Vibrational characteristics of the Ground Investigated by Several Methods. Bull. Dis. Res. Inst. Kyoto. 16. 1-16.

ZOHDY, A.A.R., 1969 - The Use of Schlumberger and Equatorial soundings in Groundwater Investigation near El Paso, Texas, Geophysics 34, 713-728.

APPENDIX - A

(* papers of special interest to BMR Geologists and Geophysicists)

PAPERS ON SITE INVESTIGATION

* BIAREZ, J. AZAMI, C. DESVARREUX, P.	An application of seismic survey to land-slide investigation
* CHAN, S.F. CHIN, F.K.	Engineering characteristics of the soils along the Federal Highway in Kuala Lumpur.
KULKARNI, R.P. KAPRE, B.S.	Shear strength and consolidation characteristics of Bombay Marine Clay.

* NATARAJAN, T.K. TOLIA, D.S.	Interpretation of standard penetration test results.
* PHILLIPS, K.A.	Some aspects of the Cross Harbour tunnel Hong Kong.
* POLAK, E.J.	The application of geophysics in the design of underwater foundation.
* TING, W.H. OOI, T.A.	Some properties of a Malaysian Residual Granite Soil.
* WALKER, L.K. CHANDLER, B.C. LUMB, P.	Site investigation of a deeply weathered soil profile.
YUDHBIR VARADARAJAN, A. VISWANATHAN, K.	Geotechnical characteristics of some Indian marine clays.

PAPERS OF FOUNDATIONS

CHIN, F.K.	The inverse slope on a prediction of ultimate bearing capacity of piles.
DUNCAN, J.D. YEUNG, K.C.	Kowlon North East Corridor Scheme.
ELLIS, H.R. WILLIAMS, A.F.	The capacity of bored piles in dense sand.
* LUMB, P.	Building settlement in Hong Kong.
POOROOSHASB, H.B. MATYAS, E.L. LELIEVRE, B. JURGENS, E.I.	A study of lateral stress distribution acting in flexible quay walls.
POPOULOS, H.G.	Settlement analysis of two buildings on end bearing piles.
PROMBOON, S. BRAND, E.W. BUCHLI, C.	Observations on the deep bored piles for the Tha Chang Bridge, Bangkok.
SAWAGUSHI, M.	Group effect on lateral resistance of a pile group.

PAPERS ON SLOPE STABILITY

BIAREZ, J. BOUCEK, B.	Parameters for stability analysis of a dyke on sensitive clays.
NATARAJAN, T.K. RAO, E.S.	Design of embankment on rubbish fills.
NEISON, J.D.	Pore pressure response beneath embankments.
* O'RORKE, G.B.	A cutting failure in Hong Kong granite.
PANDA, A.P. MATHUR, S.K.	A direct graphical approach of considering inter-slice forces in stability analysis of cohesive slopes.
* RAMIAH, B.K. PURUSHOTHAMA RAH, P. KUMARESAN, V.A.	Stability analysis of slopes subjected to progressive failure.
* WILLIAMS, A.F.	Stabilization of a large moving rock slide with cable anchors.
YAMANOVCHI, T.	Damage features of "Shiraru" and their causes and counter-measures-structurally unstable soil of volcanic product.

PAPERS ON SOIL TESTING

BRAND, E.W. MUKTABHANT, C. AKRAPONGPISAI, S.	Comparative study of undrained strength measurements of a soft clay.
DASH, U. LOVELL, C.W.	Tensile strength of clay.
FANG, H.Y. CHEN, W.F.	Further study of the double-punch test for tensile strength of soils.
* INGLES, O.G. NEIL, R.C.	Some observations of Poisson's ratio in unsaturated clay.
LO, K.Y.	The influence of mechanical disturbances on the consolidation of clays.
MATHUR, S.K. JAIN, K.K.	Saturation of triaxial test specimens with the help of electro-osmosis.

PRAKASH, S. NANDAKUMARAN, P CHANDRASEKARAN, V.	Oscillatory shear tests on a clay.
PRAKASH, S. RANJAN, G.	Effect of rate of strain on strength characteristics of non-cohesive soils.
SATYANARAYAN, B. JAYARAM, H.V.	Tensile stress and strain characteristics of compacted soil.
SUBRAHMANYAM, R.V.	Nuclear-magnetic resonance studies in creep of clays.
TUMAY, M.	Variations in the significance of soil and testing parameters on permeability at different stages of consolidation.

PAPERS ON RESEARCH AND THEORETICAL STUDIES

ANDRAWES, K.Z. EL-SOHBY, M.A.	Measurements of co-efficient of earth pressure at rest.
CHAE, Y.S. CHIANCIA, A.J.	Time effects in primary and secondary consolidation.
FINN, W.D.L. MILLER, R.I.S. EMERY, J.J.	Seismic interaction between foundations and structures.
* KARASUDHI, P. VIWATHANETEPA, S. LEE, S.L.	Vibration of machine frame foundations.
LELIEVRE, B. VIGNESWARAN, K.	Stresses beneath strip raft foundations.
POOROOSBASB, H.B.	A solution to the differential equation governing the mode of consolidation of a sensitive clay.
TAMAKI, O. YAHAGI, K. NAKAGAWA, S.	Earth pressure distribution and designing a braced wall.
TAN, S.B.	A study on secondary consolidation of clays.
YONG, R.N. WONG, C.Y.	Experimental studies of elastic deformation of sand.

PAPERS ON ROADS AND PAVEMENTS

* LEVINSON, R.S. MORIN, W.J.	Suitability of current engineering classification systems for tropically weathered soils.
LIVNEH, M. GREENSTEIN, J. SHKLAVSKY, E.	Influence of the processing method, curing and immersion of cement stabilized loess on its engineering properties.
OBI, B.C.A.	Resilience of soil cement bases under thin bituminous surfacing.
* SHACKEL, B.	Linear and non-linear models of the stress-strain response of a cyclically stressed soil.
SHEN, C.K.	Resilient characteristics of compacted clay-sand mixture.
VASWANI, N.K.	Subgrade evaluation based on theoretical concepts.
WOO, S.M. MOH, Z.C.	Lime stabilization of related lateritic soils.

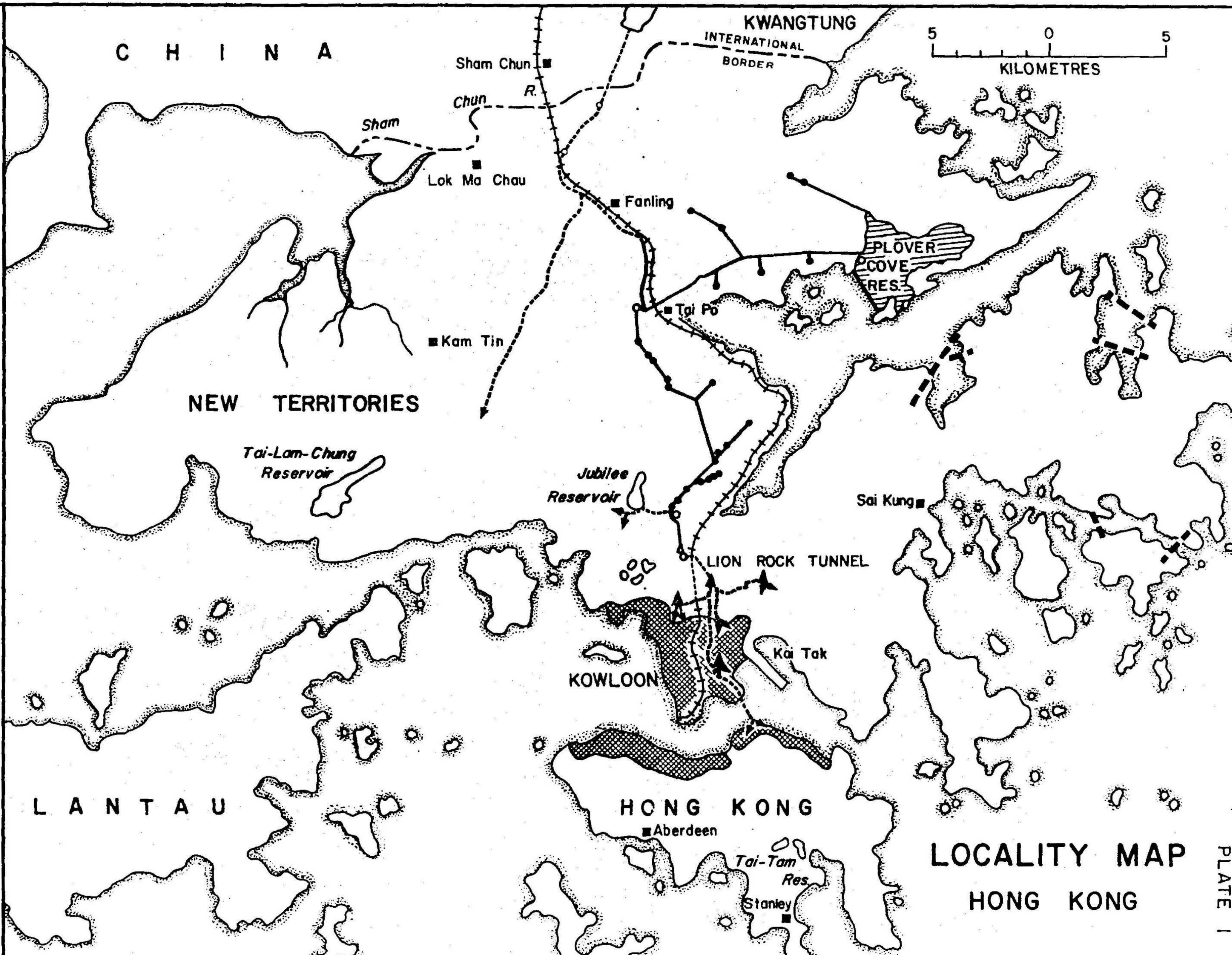
APPENDIX - B

42nd Annual International Meeting,
Society of Exploration Geophysicists,
ANAHEIM, California, Nov. 26-30, 1972.

The abstracts of papers delivered at the meeting were published in Geophysics, vol. 38(1), pp. 163-197, Feb. 1973.

Following copies of papers from the meeting are in the Engineering Geophysics Group of the BMR.

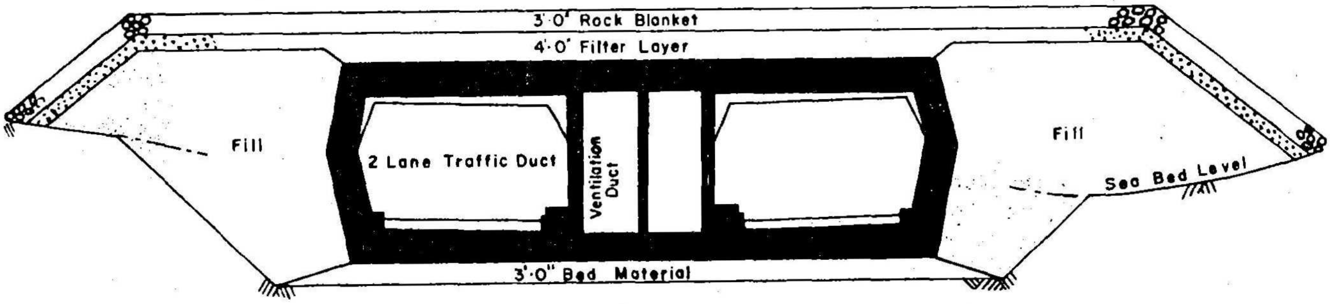
LEE, H.J.	In-Situ Determination of Seafloor Soil Engineering Properties.
LINSSER, H.	Determination of Bouguer Densities by the Preparation of a Vector Field.
NEWMAN, P. MAHONEY, J.T.	Patterns - with a Pinch of Salt.
SUDNIR JAIN. HARTMAN, R.R.	Attenuation of Near-Surface Noise in Aeromagnetic Maps.
STEPHENS, E.E.	Shallow Seismic Techniques.



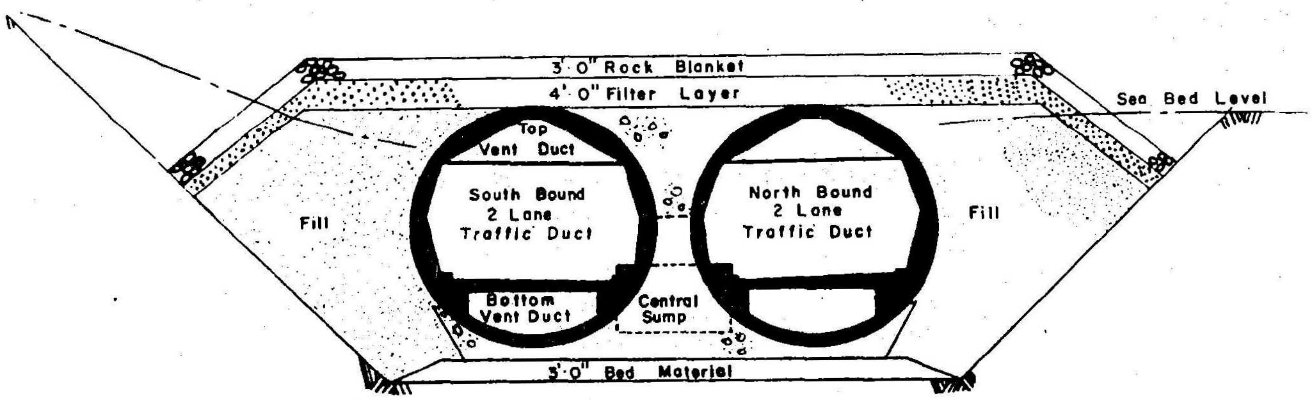
LOCALITY MAP
HONG KONG

PLATE I

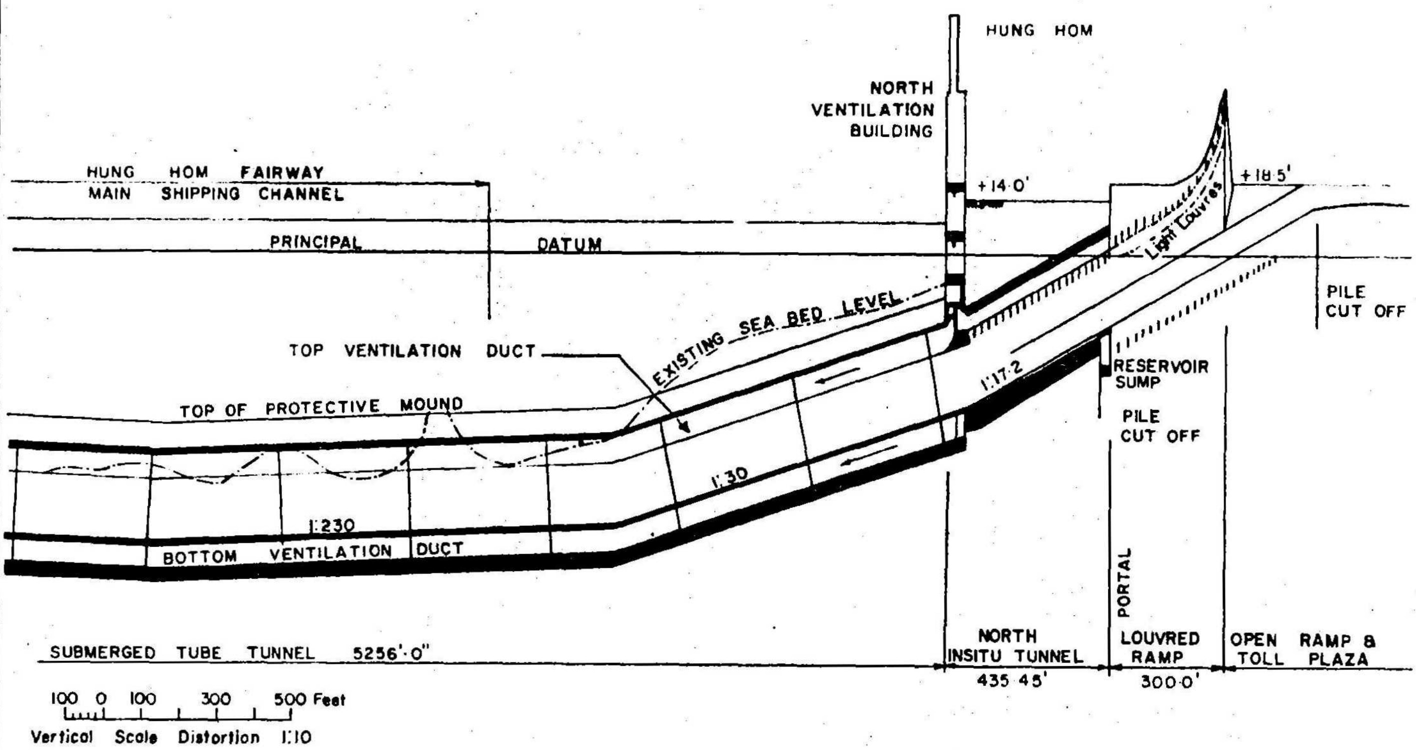
W/B5-1A



Cross-section of Engineer's scheme-
reinforced concrete box type section.



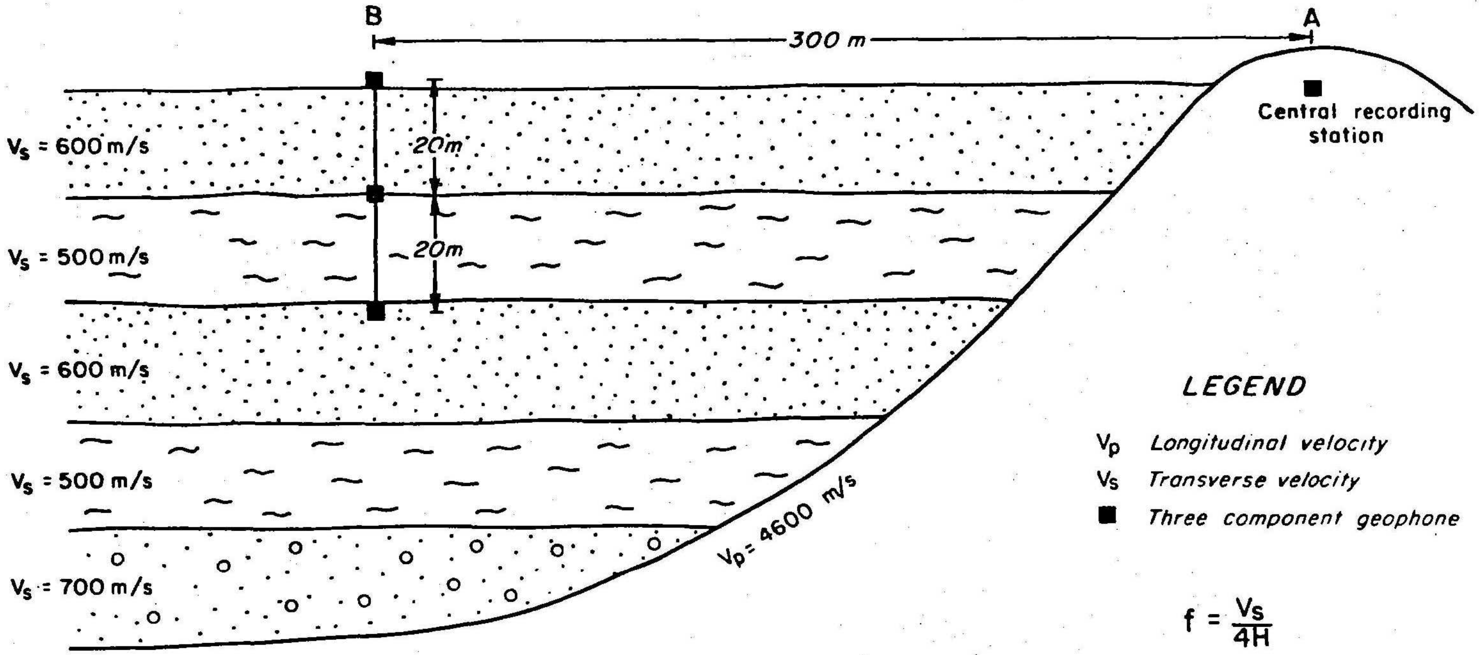
Cross-section of Contractor's alternative proposal-
steel tube design.



Longitudinal Profile of Tunnel

CROSS—SECTION
HONG KONG

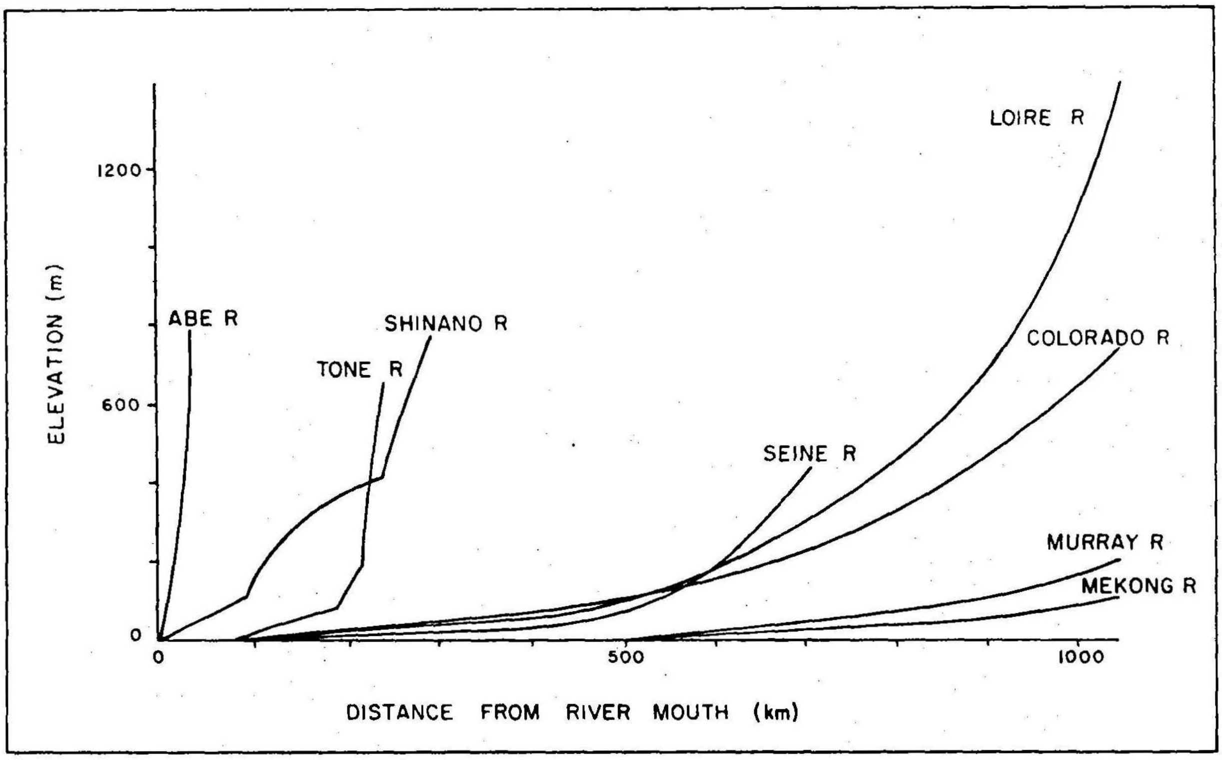
Record No 1975/133

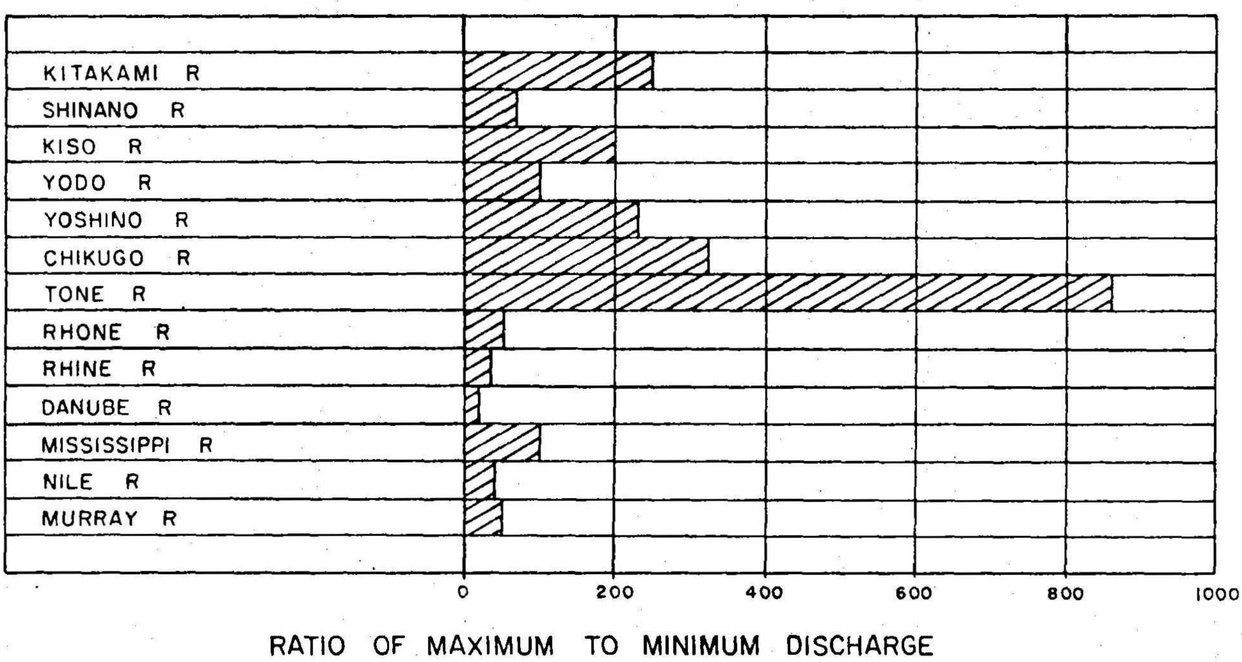


DISASTER PREVENTION RESEARCH INSTITUTE
TEST STATION AT UJI CITY

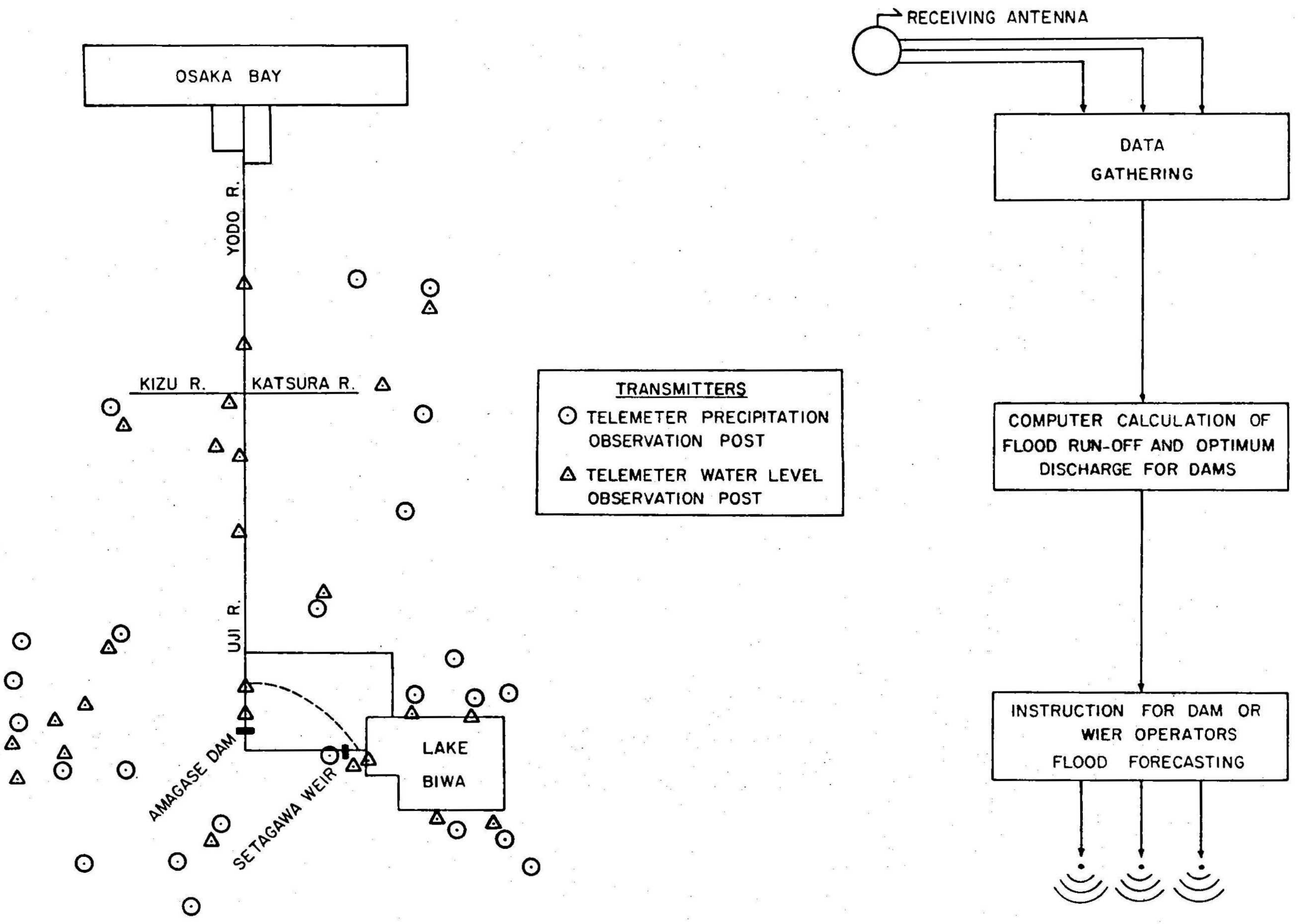
W/B5-9A

PLATE 3



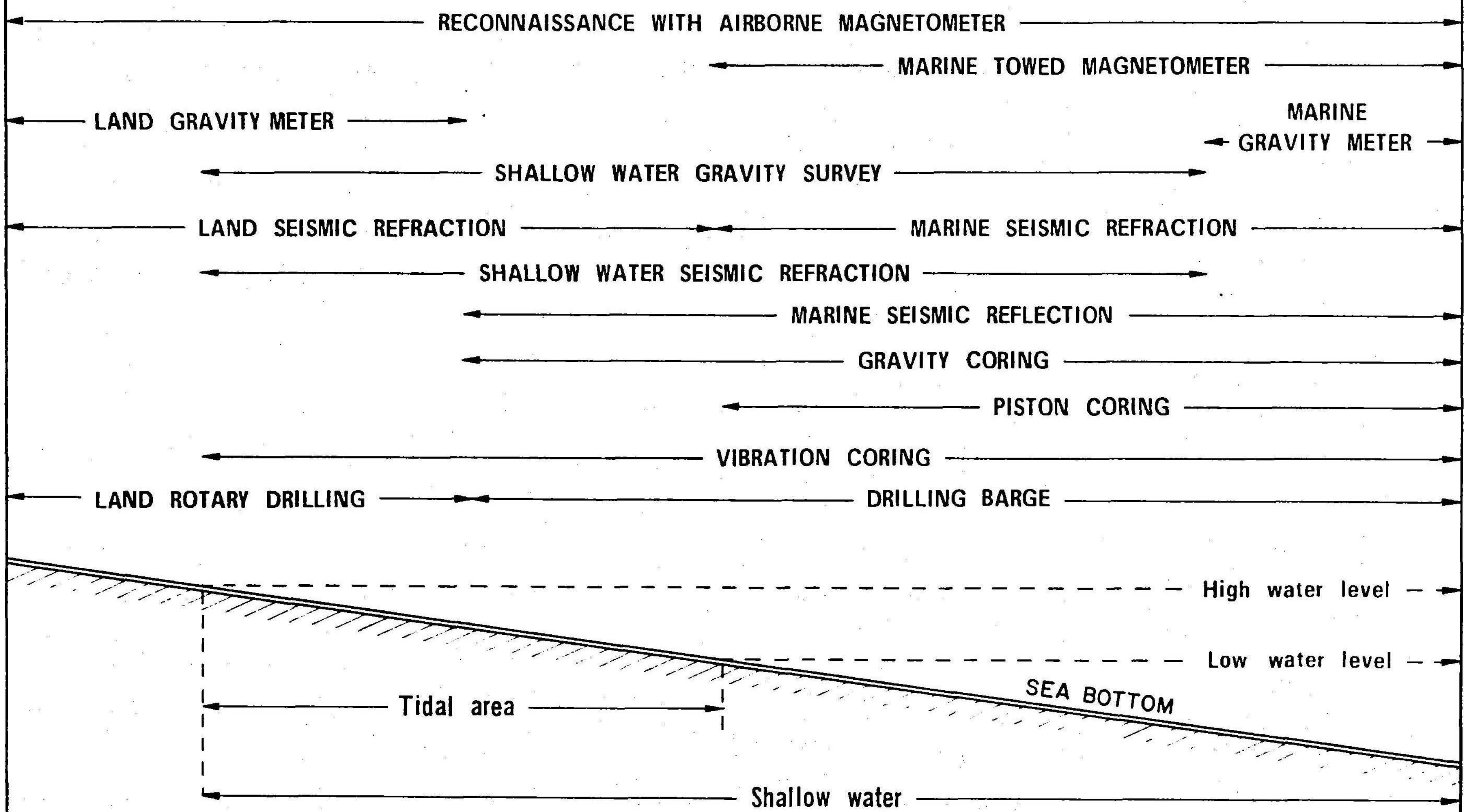


CHARACTERISTICS OF SOME RIVERS OF THE WORLD



THE YODO RIVER MANAGEMENT

PLATE 5

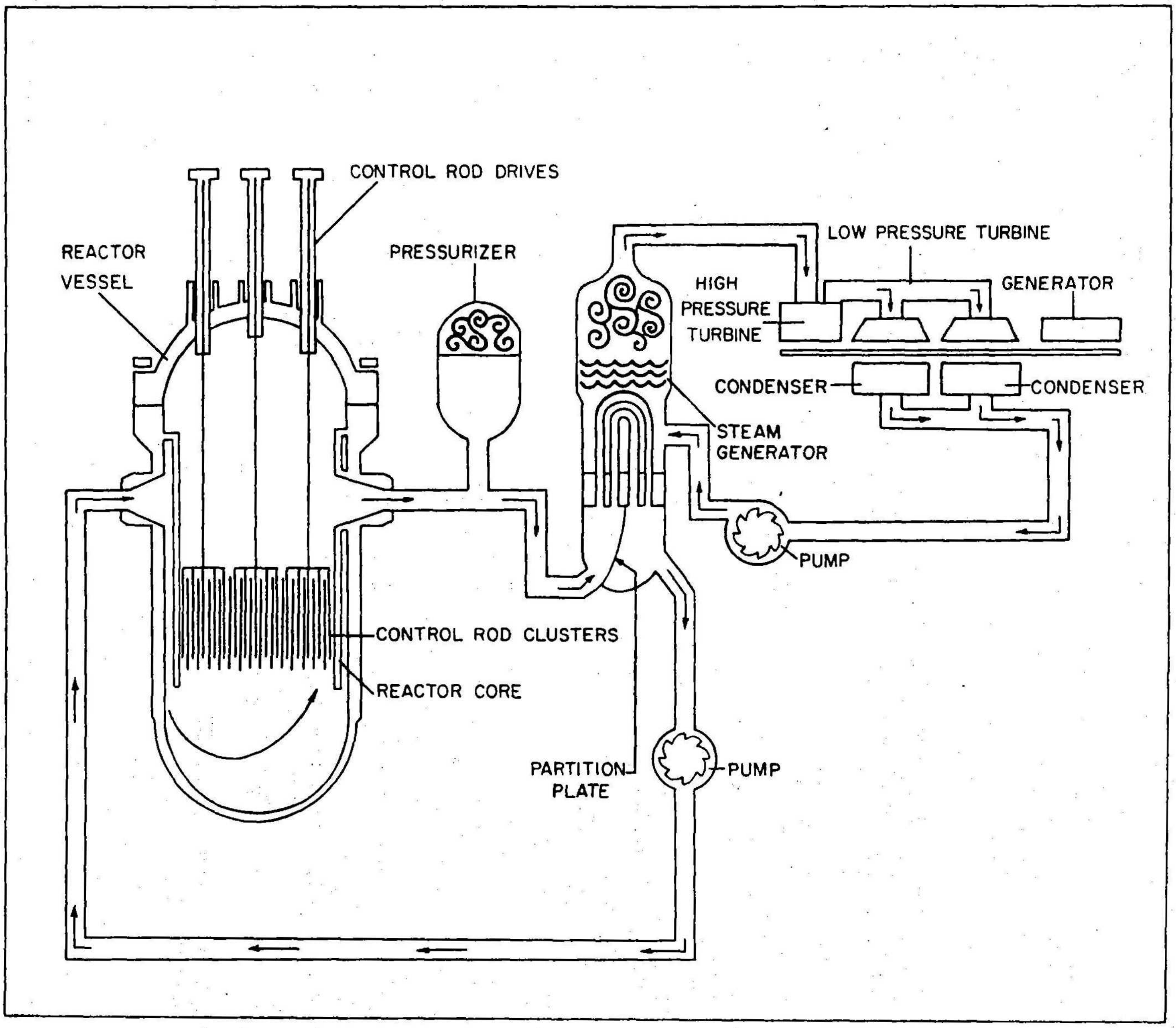


TECHNIQUES APPLICABLE IN SHALLOW WATER

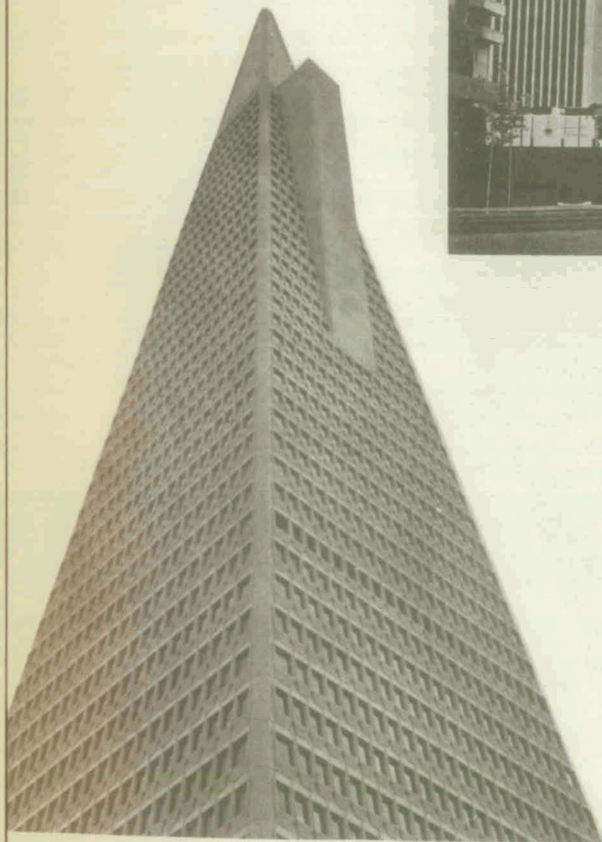
From: de Bosset (1970)

PLATE 6

W/B5-5A

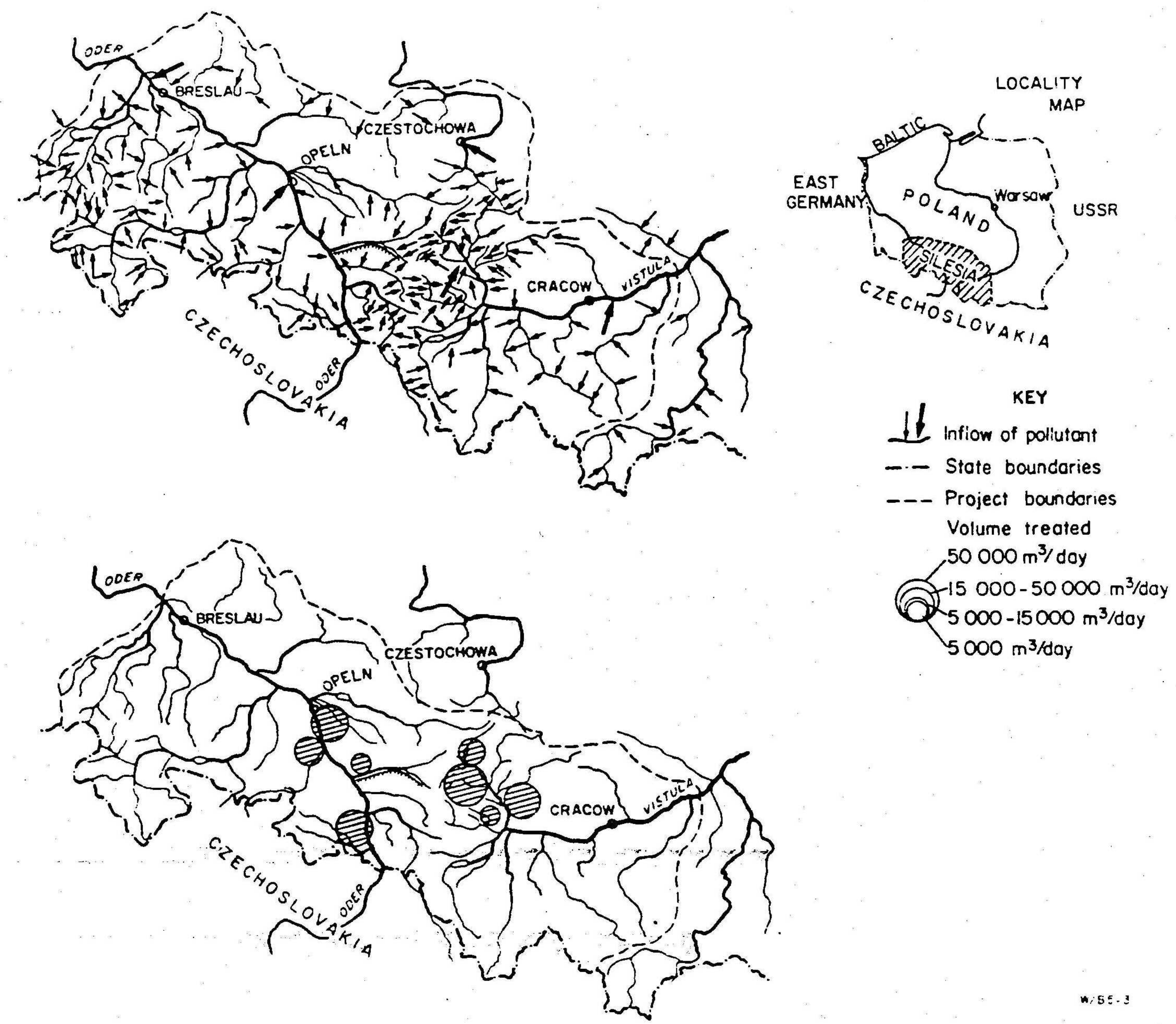


SAN ONOFRE NUCLEAR GENERATING STATION LAYOUT



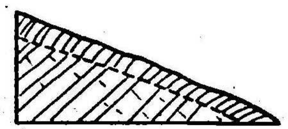
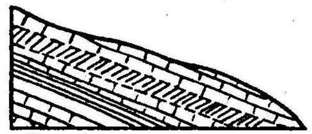
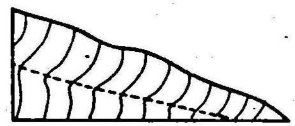
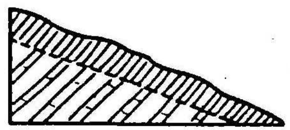
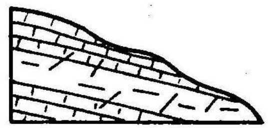
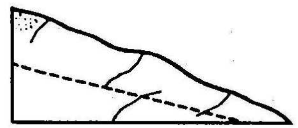
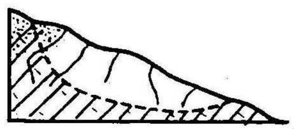
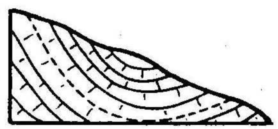
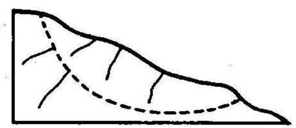
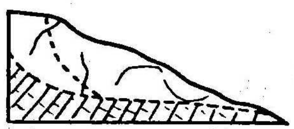
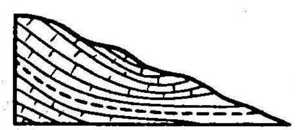
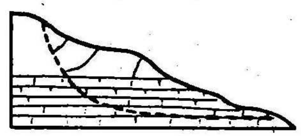
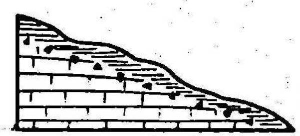
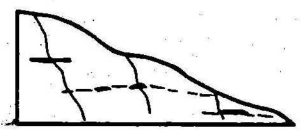
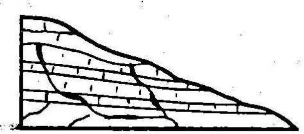
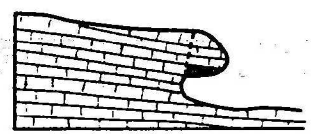
TRANS—AMERICA BUILDING
SAN FRANCISCO

PLATE 9



Record No 1975/133

Record No. 1975/133

TYPE OF LANDSLIDE	SLIDE SURFACE	UNCONSOLIDATED	STRUCTURAL	
			CONSEQUENTIAL	INSEQUENTIAL
		SHAPE OF LANDSLIDE		
		in weathered zone	parallel to structure	across the structure
CREEP	LACK OF SLIDE SURFACE			
SLIDE	PLANAR			
	ROTATIONAL			
	COMPLEX (combination)			
	IRREGULAR			
FALL	FREE FALL			

THE PROPOSED CLASSIFICATION OF LANDSLIDES

G16-132A

PLATE 10

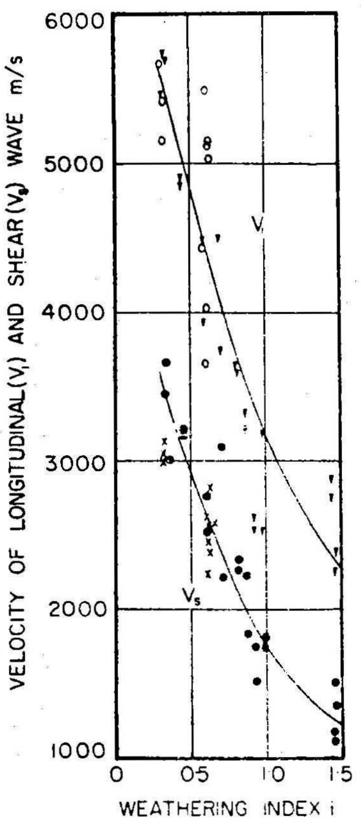


Fig. 1 Relationship between weathering index and velocity of ultrasonic wave.

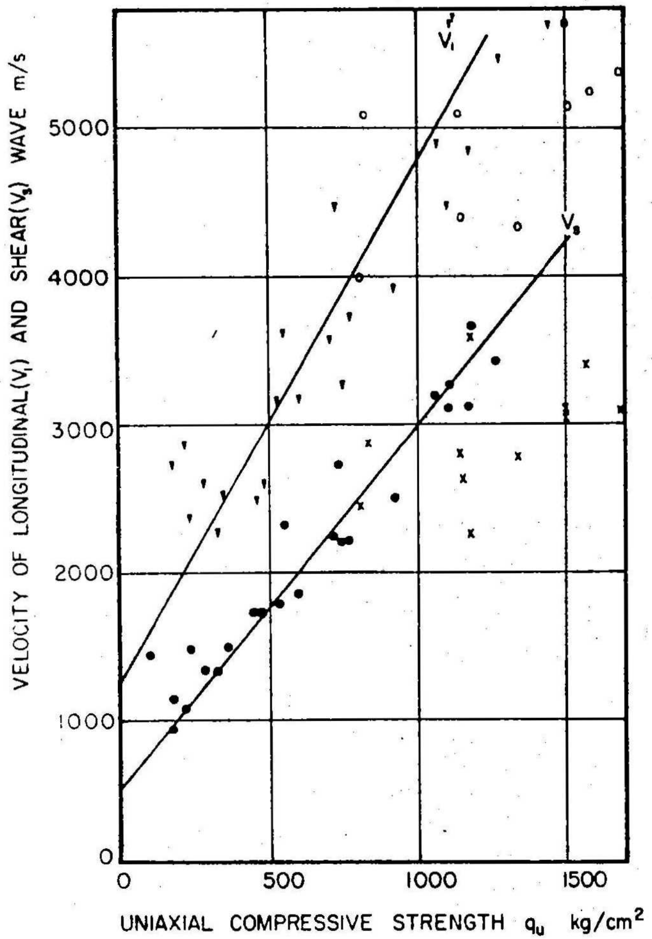


Fig 2. Relationship between uniaxial compressive strength and velocity of ultrasonic wave.

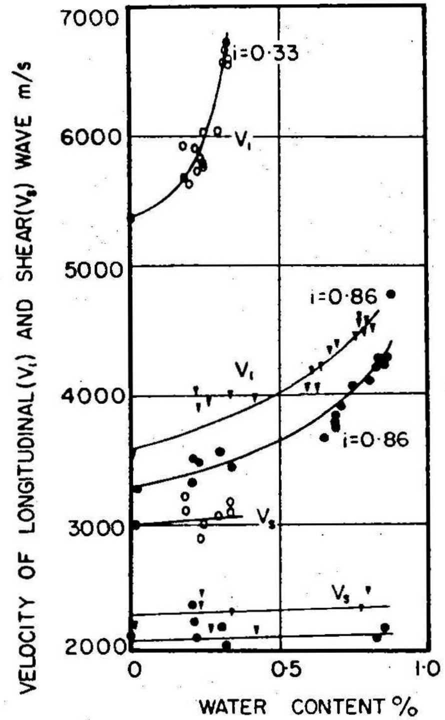


Fig. 3 Variation of velocity of ultrasonic wave versus water content.

A sample — ▾ — ●

B sample — o — x

(After Murayama, Yagi & Ishii)

STRENGTH CHARACTERISTIC OF WEATHERED GRANITE

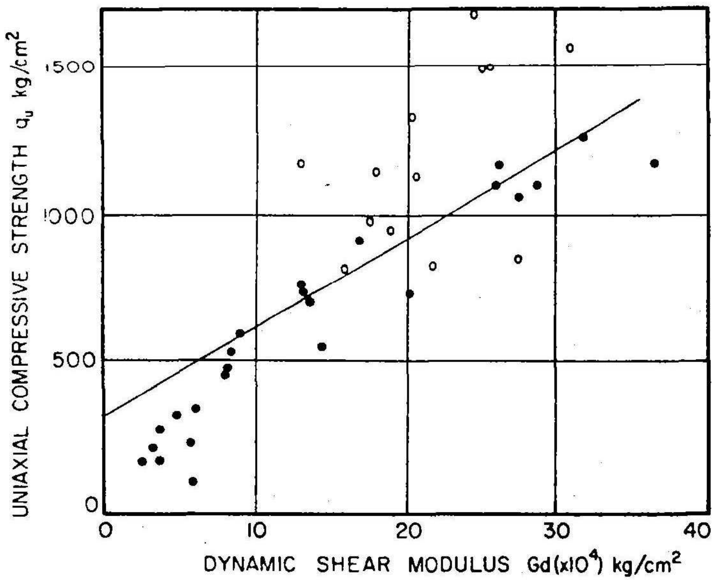


Fig 4 Relationship between dynamic shear modulus and uniaxial compressive strength

A sample —— •

B sample —— o

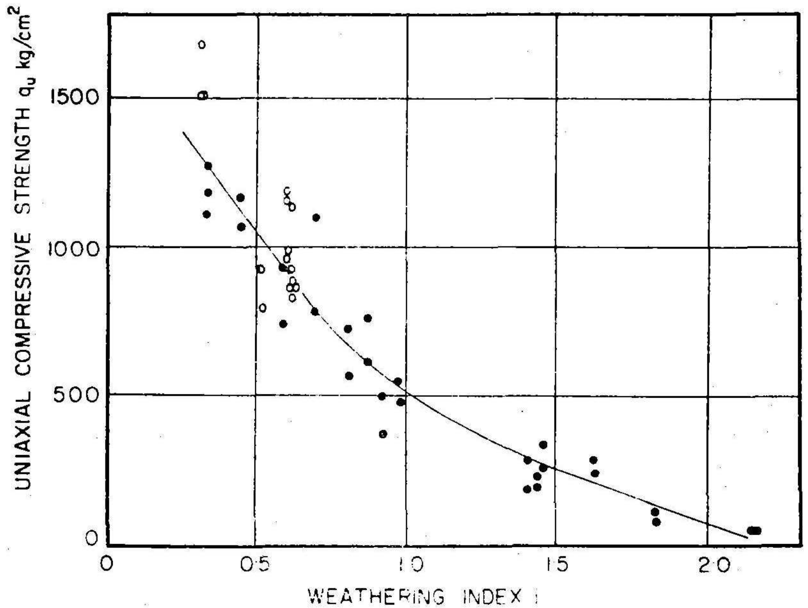


Fig 5 Relationship between weathering index and uniaxial compressive strength

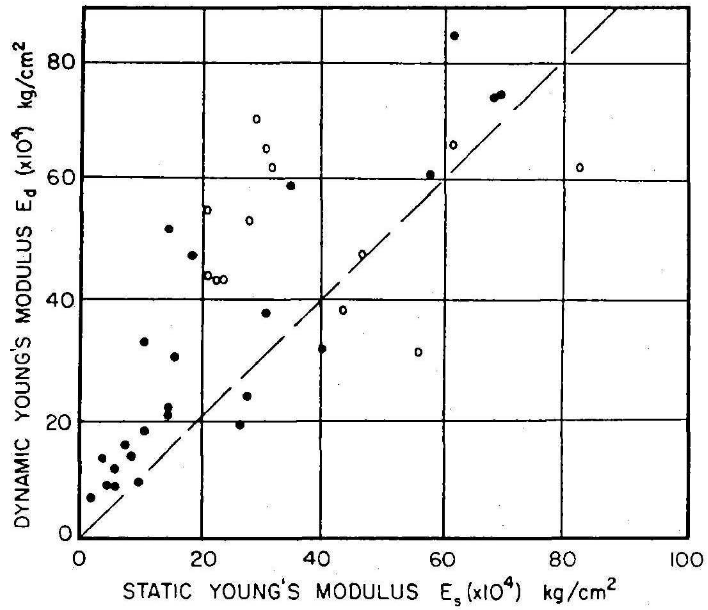
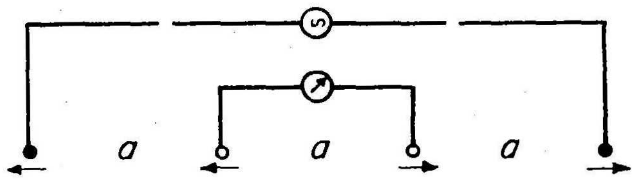


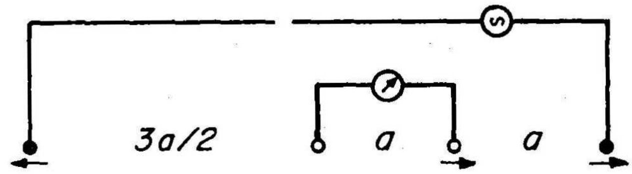
Fig 8 Relationship between static Young's modulus and dynamic one

(After Murayama, Yagi, & Ishii)

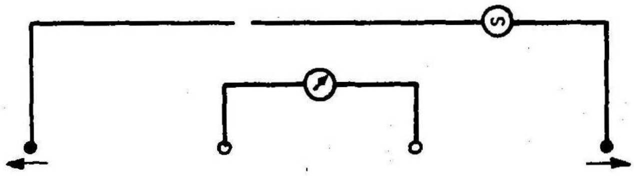
G16 131A



WENNER
Fig. 1

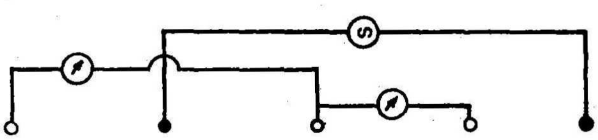


LEE
Fig. 2

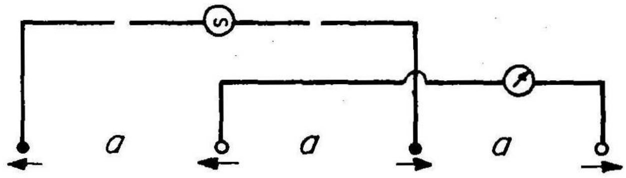


SCHLUMBERGER
Fig. 3

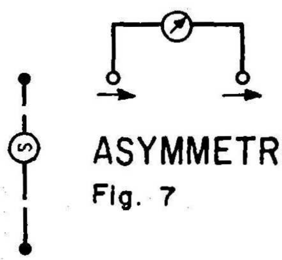
DIPOLE-DIPOLE (polar)
Fig. 4



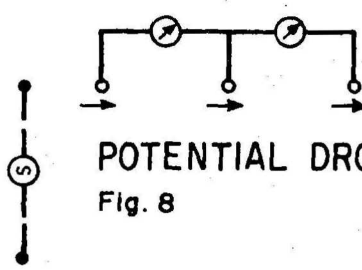
TEISSEYRE
Fig. 5



TRIPOTENTIAL
Fig. 6



ASYMMETRICAL
Fig. 7



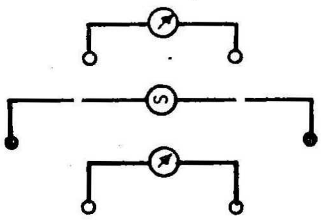
POTENTIAL DROP-RATIO
Fig. 8

● Current electrode
○ Potential electrode
Ⓢ Current source
↗ Voltmeter

ELECTRODE ARRANGEMENT

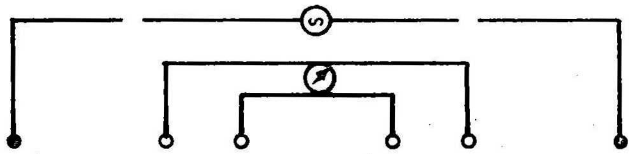
BILATERAL BIPOLE DIPOLE EQUATORIAL

Fig. 9



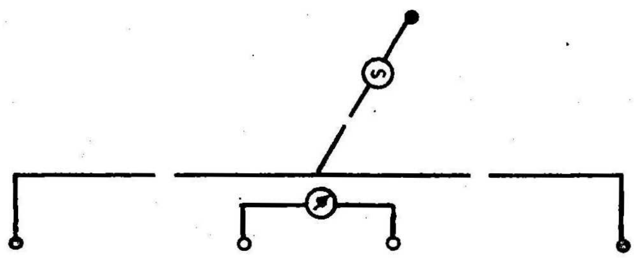
LATEROLOG

Fig. 10



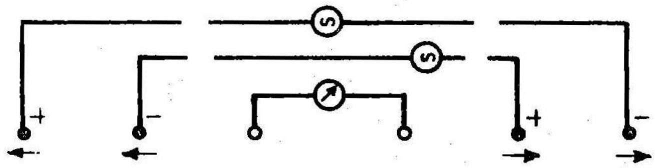
COMBINATION

Fig. 11



SUBTRACTION OF FIELDS

Fig. 12



CROSSED FIELDS

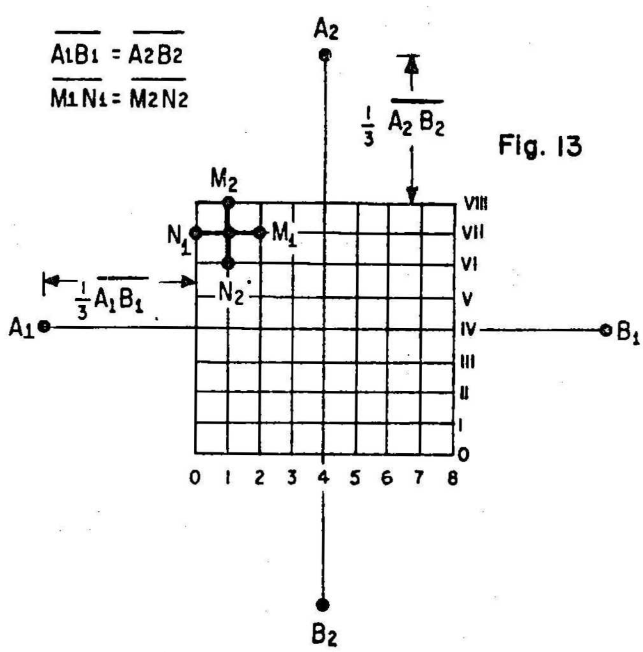


Fig. 13

SECOND DERIVATIVE

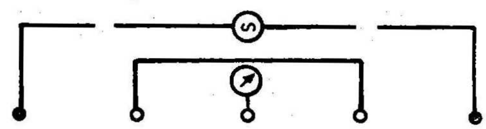


Fig. 14a

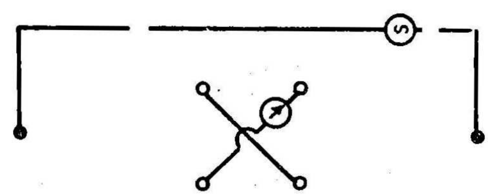


Fig. 14 b

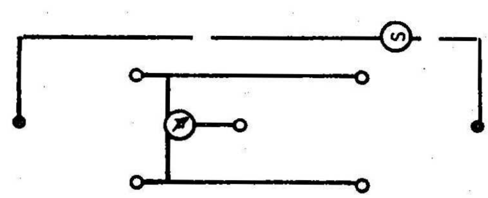


Fig. 14 c

ELECTRODE ARRANGEMENT