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ENGINEERING GEOLOGY IN AUSTRALIA

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THE ROLE OF GEOLOGY IN ENGINEERING.

Engineering geology is a comparatively new branch of the Science which is growing up as a link between two disciplines - engineering and geology - in response to an increasing awareness of the value of geology to engineers. Although the value of geology was clearly seen by a few workers early this century, it was not until the 1930's that the geologist was conceded a recognised role in engineering projects. The position of the engineering geologist was further consolidated during World War II and has now progressed to the point where most engineering organisations, dealing with rocks or rock materials, use engineering geologists as a matter of course. The progress of this branch of geology has been in the past, and will continue to be in the future, largely dependent on the ability of the geologist to appreciate what the engineer requires and to provide this information in such a way as to be readily understood and used.

With the widening of knowledge and specialization within both disciplines, it is patent that the engineer cannot become a geologist any more than the geologist can do the work of an engineer, but the engineer needs sufficient geological knowledge to understand the geologist and to appreciate where geology can help and the geologist must learn sufficient engineering to talk the engineer's language and to anticipate many of his requirements.

Our experience clearly shows that the efficient practice of engineering geology depends on team work between geologists and engineers, based on regular contacts in field, laboratory and office.

ENGINEERING GEOLOGY IN AUSTRALIA.

Engineering geology in Australia has received its greatest encouragement in the fields of hydro-electric power and surface water supply, particularly in the eastern states of the Commonwealth. The demand for geological work on roads, on the supply of rock materials and on foundation investigations is less marked but is steadily growing.

The services of the engineering geologist are provided in three main ways in Australia: - by small engineering geology sections within major engineering organisations: by small sections within State Geological Surveys and the Bureau of Mineral Resources which function as consultants to other Government Departments or to private organisations, or by private consultants usually drawn from University staffs.

The total number of geologists actively engaged on engineering projects in Australia varies with the demand, particularly on the Government surveys, but the number at present would probably lie between 30 and 40; the two major employers of engineering geologists are the Snowy Mountains Hydro-Electric Authority and the Bureau of Mineral Resources. Most of the geophysical work on engineering projects is carried out by a group within the Geophysical Section of the Bureau of Mineral Resources which functions as a consultant to government organisations, but small geophysical sections have been built up in the Snowy Mountains Hydro-Electric Authority and in the Geological Survey of South Australia.

Public organisations in Australia, apart from State Geological Surveys and the Bureau of Mineral Resources, who employ engineering geologists are as follows:-

Organisation	Type of Work.
Snowy Mountains Hydro-Electric Authority.	Hydro-Electric Projects.
Hydro-Electric Commission of Tasmania.	Hydro-Electric Projects.
Water Conservation and Irrigation Commission of New South Wales.	Surface Water Supply.
The Main Roads Board, N.S.W.	Construction and maintenance of Highways and Trunk roads.
State Rivers and Water Supply Commission, Victoria.	Surface Water Supplies.
State Electricity Commission, Victoria.	Hydro-Electric Projects.
Irrigation and Water Supply Commission, Queensland.	Surface and Underground Water Supplies.
Co-ordinator General's Department, Queensland.	Co-ordination of Public Works,

THE WORK OF THE ENGINEERING GEOLOGIST.

This short paper cannot provide a comprehensive account of engineering geology in Australia, but the principal activities will be mentioned and some current techniques discussed.

HYDRO-ELECTRIC AND WATER SUPPLY PROJECTS.

The engineering geologist's main concern is the investigation of dam sites, tunnel lines, canals and power houses, either on the surface or underground. In general, his work falls into three stages; the first is the preliminary investigation of sites, including alternative sites, to provide sufficient geological information to enable engineers to appreciate difficulties and prepare preliminary costs; the second is the very detailed investigation, commonly associated with the design of projects on selected sites, and the third is the inspection and mapping of excavations during the construction period.

The geologist makes his main contribution in the investigation stages before construction starts. His aim should be to provide sufficient geological information at the least possible cost, but with the full knowledge that mistakes or mis-interpretations will probably affect costs, and his reputation, if construction follows. With current engineering knowledge and techniques, most natural difficulties can be surmounted; the question which geologists and engineers have to answer on investigation is not so much whether a project can or cannot be built at a site but what are the difficulties and what is their effect on the probable cost.

A fairly typical pattern of engineering geology investigation of dam sites in Australia is provided by the Upper Cotter Project which is now under construction on the Upper Cotter River near Canberra. Five possible sites, A, B, C, D and E, were originally selected from air photographs by an examination of the topography only. In the preliminary geological investigation which followed, the valley was geologically mapped, at a scale of half a mile to one inch, to provide a regional geologic setting for the investigation of individual sites and information on storage areas and the supply of rock materials. Each possible site was then inspected; preliminary plans showing outcrop geology were produced for four sites; the fifth, site D, was rejected on field inspection because of an obviously weak left abutment. One of the four sites, site E, was subsequently rejected by engineers on the grounds of access and the remaining sites listed in order of geological suitability - B, C, and A. The possible weaknesses at these sites were listed; the tightness of the storage areas and the supply of rock materials were investigated.

In the second stage of the investigations, sites were examined in detail to establish the most suitable type of dam in each case and the approximate cost involved. In this and in succeeding stages, geologists and engineers kept in close contact. Although site A appeared to have more geological hazards than the other two, detailed investigation started at Site A because it had the cheapest access and would entail the shortest pipe line on completion. The site was cleared of undergrowth with flame throwers, and outcrop geology checked and extended by plane table on a scale of twenty feet to an inch. Additional information between outcrops was obtained by trenches, auger holes and pits and a programme of diamond drilling, water pressure testing and seismic work designed first to check apparent weaknesses and eventually to prove the site fully. This programme was stopped when half completed because information on the site was then sufficient to indicate that it was unsuitable for a thin arch or rock fill dam but could be used for a gravity structure costing 1½ to 2 million pounds.

Attention turned to sites B and C farther up the valley; 'B' was eliminated without any additional geological work, when seismic transverses proved abnormal depths of weathering in granite on one abutment. Detailed work on site C followed the pattern of that of site A and the completed programme of mapping, trenching and exploration diamond drilling proved that the site was suitable for a thin arch dam costing about £1,000,000. Site 'C' was finally chosen because a thin arch dam there, despite the cost of additional roads and pipe lines, was less expensive than a gravity dam at the more accessible site 'A'.

The design stage followed immediately on the detailed investigation of Site C; a programme of design drilling was prepared mainly to determine the best position for the arch and thrust blocks and the leakage characteristics of the abutments beyond the wings of the dam. Geological reports on the site and on numerous sources of aggregate and sand were compiled for inclusion in the documents prepared for those contracting firms who wished to tender a price for the construction of the dam.

In the construction stage, which is now proceeding, geological work consists mainly of determining, with the resident engineer, the final level of the foundations, laying out (with the engineer) the blanket and curtain grouting programmes,* in relation to joint patterns and other rock structures, mapping completed excavations at a scale of ten feet to the inch, guiding the development of the aggregate quarry for the contractor, and the detailed mapping of the storage as clearing proceeds.

ROAD CONSTRUCTION

The geologist is mainly concerned with the supply of rock material for base courses and for the aggregate bitumen seal (blacktop); he also advises on the geology of new road locations and on special problems such as landslips. He works closely with engineering colleagues associated with both construction and laboratory testing.

In the construction of principal roads, suitably graded crushed rock is normally used for base courses but in many places uncrushed rock material is sought for base courses to save costs on minor roads. The search for rock material of suitable grading as it stands, washed or when blasted, tests the geologist's ingenuity and experience of road material. The products are rarely ideal, but materials can be found to provide a reasonable road base without crushing. Apart from a knowledge of the local geology, the geologist learns to recognise likely material such as scree gravels, weathered or closely fractured rock. The sampling and testing of possibly suitable material is often critical and methods may have to be devised to suit individual cases; for example, one volcanic rock which produced fairly well graded fragments, including fines on blasting, was tested by building a section of road pavement; after rolling and exposure to traffic for a week or so, holes were dug in the pavement and samples taken for laboratory tests from which the main deficiency of the pavement (low plasticity) was noted; the addition of fines made the material a satisfactory and economic road base. Testing of materials in the soil mechanics laboratory plays a vital part in road construction because bonding characteristics and reaction to moisture cannot be accurately determined in the field; preferred specifications vary between organisations but are based on the grading of the material and on the plastic index and linear shrinkage of the fine components.

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* In grouting, a thin slurry of cement and water is forced under pressure from a pattern of drill holes into cracks and cavities in the foundation rocks. Blanket grouting is normally done over the whole area of foundations to a depth of some thirty feet for the main purpose of stabilization; curtain grouting is done later from a line of deep holes, roughly following the upstream toe of the dam, to provide a narrow grout screen beneath the foundations to minimize leakage.

Much research has gone into the quality of aggregate for use in blacktop. Many Australian rocks, particularly basalt and acid intrusives are liable to strip from the bitumen unless hydro-carbon additives are used; these have to be imported and virtually double the cost of the bitumen. As a result of research carried out by the Main Roads Board, New South Wales, aggregate prone to strip is now sprayed with creosote before using, or used with bitumen containing dehydrated tar; both methods have so far proved successful and economical.

The polishing by traffic of particles of aggregate embedded in the bitumen, resulting in a slippery surface, has caused concern in recent years and aggregate consisting of softer material like limestone or coarser rocks liable to mechanical disintegration like granite are rejected for bitumen seal on main highways.

FOUNDATIONS AND ROCK MATERIALS

Increasing emphasis is being placed on the geological and geophysical investigations of foundations for bridges and buildings. The work ranges from the simple determinations of the depth of overburden and weathered rock to major geological and geophysical investigations for large bridges and buildings for which the detailed geological section must be determined and the various materials laboratory-tested. One practical application of geology in some projects has been the classification of rock material to be removed into various grades, depending on hardness and ease of excavation; contractors quote prices for each grade in compiling a tender for the complete excavation and, providing the geological work is sound, this method has resulted in economies and greater efficiency.

With the increased use of concrete, the services of engineering geologists are increasingly sought in the search for, and development of aggregate. The main task is to sample the material adequately for laboratory tests, and to establish reserves and disposition so that development can be properly planned. New sources of aggregate are tested for expansive reactions with cement, commonly by use of the Meilenz test ** rather than the lengthy mortar-bar tests in which samples of the aggregate are tried with cement of varying alkaline content.

The building stone industry in Australia has declined markedly over the last twenty years although a few quarries still supply ornamental stones such as granite, marble or sandstone when required. However, small current demand for building stone should not discourage the geologist from indicating likely deposits because even roughly-shaped stone can be used to effect in mortar and stone foundations to replace brick or for architectural reasons.

ENGINEERING GEOLOGY MAPS

Regional or local maps showing the location of major and minor deposits of rock materials, printed over the geology of the area, are most sought after by engineers and town planners, particularly in rapidly developing areas. Such maps anticipate many of the engineer's demands by showing on one plan the location of deposits such as aggregate, sand and clay of various types, brick shale and building stone; as much information as available on reserves and quality can be shown by symbol and annotation.

** A comparative quick chemical test in which the level of likely reaction with cement is determined by the amount of silica leached from the aggregate.

METHODS AND TECHNIQUES

GEOLOGICAL MAPPING

The instrument most useful to the engineering geologist in detailed mapping is still the plane table which allows him to map contours and topographic outcrop features with accuracy in the field. In general, Australian surveyors are reluctant to use the plane table in mapping contours at dam sites; in many cases, the contours shown on survey plans, compiled by draftsmen from the surveyor's tachiometer surveys, are not sufficiently accurate in detail for compiling geological sections. The geologist commonly establishes the contours by plane table over critical portions of the sites and uses the survey plans to extend these upstream and downstream. The photo theodolite, which combines photography and tachiometry, provided accurate contour plans of a site suitable to the geologist but these instruments are costly and are not as yet in general use.

Clearing of sites before detailed mapping, results in greater efficiency but the undergrowth must be removed and not merely cut and left on the ground; flame throwers can be efficiently used where undergrowth is largely dry. Where vegetation cannot be removed and is too thick for efficient plane tabling, preliminary geological mapping is commonly done by a "plot as you go" compass, abney and chain survey, controlled by a series of stations established by the surveyor or geologist by theodolite or plane table. The geologist plots his data, including contours, directly on to a small board which serves the same purpose as a plane table.

DRILLING

A hundred percent core recovery from diamond drilling holes is important in engineering geology investigations for two main reasons: (1) it minimizes geological interpretations, (2) core recovery can influence a contractor's tender price; if some of the core is missing, whatever the stated reason, the contractor will tend to make the worst possible interpretation and adjust his tender price accordingly.

Core recovery, with modern techniques, mainly depends on the equipment, (particularly the type of core barrels) and the ability of the driller; however, the geologist with insufficient experience of drills and drilling can decrease efficiency by planning holes at too low an angle, or in the wrong direction, for the rock types or structures involved.

The invention of the split inner-tube core barrel and the development of water-pressure testing have brought about notable advances in investigation techniques; together they have greatly increased the geologist's knowledge of foundation and leakage conditions. The older, stationery inner tube barrel provided nearly 100% recovery, even in fractured rocks, but the core had to be shaken out of the barrel and fragmented core became a jumble of deoriented fragments in the core box. With the split inner tube, the core can be inspected and photographed _in situ_ in the barrel; the pattern of fracturing is preserved and even fine clay bands have in many cases remained in place.

The practice of photographing all drill cores to provide records, apart from the cores themselves, is well established but is essential with the split core barrel as the photograph is the vital record of what the core looked like before removal from the barrel. Practically all drilling for engineering geology investigations is now done with the split barrel which is readily available in the NX and BX sizes; a number of split inner barrels are made available at the drill so that the photographing and inspection of cores do not hold up drilling.

Water-pressure testing is also standard practice in dam site investigations; it is usually carried out over successive 20-foot sections, as the hole is deepened, by using a packer (mechanical or pneumatic) placed some 20 feet above the bottom of the hole. Water under pressure is applied and leakage read at three or more pressures. Major leakages can be isolated and pin-pointed by using two packers on either end of a perforated five or ten foot pipe which is connected to water pipes from the surface. The tests show the relative leakage in different rocks and in different sections of the holes and are of considerable use in determining the leakage characteristics of foundations and the optimum position and depth of grout screens.

TRAINING.

The principal training in engineering geology in Australia is carried out 'on the job' within these organizations using engineering geology. Courses on the subject are given to students studying economic geology in their degree courses in the Universities but there is, as yet, no comprehensive course on engineering geology either at the under-graduate or post-graduate level. The problems of specialized training are now receiving more attention but the pattern of future training is not yet clear.

The problem of the level at which specialized training should be given is a vital one for the engineering geologist. Although he is a specialist, his work calls for a sound practical knowledge of most aspects of his science - stratigraphy, petrology, structural geology, including sedimentary structures, regional mapping, hydrology and geomorphology. This establishes two inportant points:

(1) specialized training in engineering geology should not be given in under-graduate courses at the expense of basic geological training.

(2) the engineering geologist will be better equipped if he is given some general field experience, say in regional mapping, before specializing in engineering geology.

The ideal training would therefore appear to be basic geologic training up to graduation, general geological mapping experience for two or three years and then specialized training in engineering geology carried out, on the job, in an engineering organization or geological survey in association with a special course of post-graduate studying arranged through the Universities.

The training of engineering geologists from south-eastern Asian countries might well follow a similar pattern in that graduates with some field experience might be selected for specialized training of one to two years with engineering geologists of other countries, including some post-graduate study where suitable courses are available.