Fig. 55. Kariba machine hall under construction in gneiss

Granite

This series of articles discusses the composition and structure of granite, its exploitation as a material, and its occurrence at dam sites, in tunnels and in underground chambers. This final article gives examples of underground power stations excavated in granite

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PART SEVEN

THE underground power stations which have been constructed during recent strenuous years have included a number excavated in granitic rocks, a majority of them in Scandinavian countries where gneissose granites in particular are widespread. Sound though these rocks usually are, original and secondary rock-defects are also not uncommon, and in siting a power station at depth below the surface, exploratory work is always desirable and generally necessary. Defects already referred to in the case of tunnels apply with still greater force to the much more extensive excavations required for power stations and their related chambers.

In regard to the siting of a power house, Dr. Ing. Claudio Marcello—Director of the Hydroelectric Construction Department of the Edison Group—who designed and supervised the construction of the Upper Chiese development (1954–1957) for the Società Idroelettrica Alto Chiese, owner of the projects, of the Società Edison, Milan, has summarised the matter in the following words[21]: "The position of the power house with respect to the intake and tail structures . . . marks the type of development with underground power houses. The power house site can be (a) near the intake; (b) near the return point; (c) halfway between intake and return points." A few examples of these positions in relation to the geology of granitic rocks concerned may be cited in illustration:

(a) For topographic and other reasons the Kariba dam situated near the head of the Kariba gorge on the Zambezi has required an underground power house below the intake point in the bottom of the reservoir and just upstream of the dam, its vaulted roof being 300ft away from the bottom of the reservoir (see Figs. 55 and 56). The double-curvature concrete arch dam, 420ft high, is founded for the most part on granitic gneiss of Archean age, with late Pre-Cambrian beds of highly jointed quartzite with soft partings at the right abutment, the quartzite overlying the gneiss unconformably about 100ft down from the top. The underground power station is excavated entirely in the gneiss. Boring investigations and adits had shown the rock conditions to be reasonable[22].

The gneiss above the vault up to the intake from the reservoir was extensively grouted, and the entire machine hall, 468ft long, 70ft wide, and 132ft high, was lined with concrete throughout. The method of its excavation provides a sample of the sequence of excavations in which an underground chamber of this size is formed.

(b) An example near the return point is the Malga Boazzo underground power house in the upper Chiese valley west of the head of Lake Garda. In this case, again, the position for the power house was suited to the topography coupled with the soundness of the rock at depths not far beneath the surface (Fig. 58). The entire works in the upper Chiese valley already referred to are in tonalite, a variety of quartz-diorite. Except for a system of vertical or steeply inclined joints, it is a good rock throughout in this recently deeply ice-eroded valley with "hanging" tributary valleys well up the mountain sides. The intrusive igneous mass of tonalite extends along the whole upper Chiese valley including the Bissina reservoir down to Malga Ert, a short distance below the Boazzo reservoir, a distance of about 20km. It is understood that no special difficulties were experienced during the excavation of the power house (Fig. 57), but that even in this good rock it was considered desirable by the chief engineer, Dr. Marcello, to excavate the roof vault and strengthen it with concrete lining or rockbolts before proceeding with the deeper excavation. The dimensions of the chamber are 182ft long, 44ft wide, and 39ft high to crown of the vault.

(c) Perhaps the sites of power stations along the Tumut river in the Snowy Mountains scheme, New South Wales, are to be regarded as falling in this category, situated between intake and return points, though much nearer the latter than halfway. These sites are imposed by the geological conditions with deeply weathered granite covering the valley sides for a long way in from the surface. Similarly, soft-rock conditions imposed the same arrangement in the case of the power house for the San Giustina works on the River Noce in Italy. There, as referred to by Dr. Marcello[21], marl occurred downstream of hard limestone in which the power tunnel for the reservoir was excavated, and the steel penstocks and power house were sited in the marl. The Snowy Mountains case here described is the Tumut I (TI) power station in the Upper Tumut river valley about 50 miles NW of Cooma, NSW, which has been dealt with by D. G. Moye, Head of the Engineering Geology Branch of the Snowy Mountains Authority.

The power station is situated 1,100ft underground under the eastern side of the Tumut River gorge, the machine hall being 300ft long, 77ft in greatest width, and 104ft in maximum height. The rock is granite, the variety called tonalite, in steeply inclined sheets up to 300ft thick, which are intrusive in granitic gneiss. Both these rocks are similar in mineralogical and physical properties, except for the planes of foliation in the gneiss and the fact that joints are more closely spaced in this rock than in the granite. As with planes of weakness in all kinds of rocks, in the case both of tunnels and underground chambers, the open-

Fig. 56. Section through Kariba station

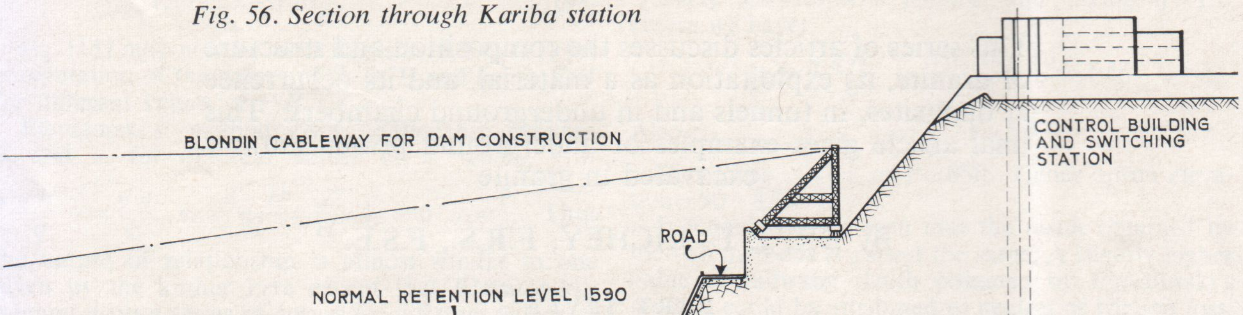

Fig. 57. Malga Boazzo machine hall being excavated in granodiorite

ings at Tumut were oriented so as to avoid main joint directions being parallel with the side walls. As shown in Fig. 60, rockbolting was extensively employed for preventing roof falls along flat-lying joints, the bolts being of mild steel, 1in in diameter, 10 to 15ft long, and stressed to a normal load of 20,000lb. They were spaced 4 or 5ft apart. The machine hall was separated by rock from the transformer hall, these chambers being connected by a short tunnel. An account by D. G. Moye has already appeared in WATER POWER (June 1960) as well as in "Engineering Case Histories" of the Geological Society of America (No. 3, 1959); but a few points concerning the investigations carried out in this notable work may be repeated.

The exact site was decided after a detailed search along the V-shaped valley of the Tumut River by surface mapping, air photo interpretations and diamond-core drilling, a main object being to locate a position free from major faulting. Physical tests were carried out on the granitic rock and the gneiss, including compressive strength, Young's modulus, and tensile strength, with determination of Poisson's ratio, and the triaxial strength. Photoelastic studies were made from models of the power station and other chambers. Natural stresses in the rock mass prior to distortions produced by excavation were also measured. As in other areas, it was found that the stress in the horizontal direction much exceeded the vertical stress. Measurements of sub-audible rock noises in the excavations were made, as one means of assessing rock stability, in addition to instrumental measurements by strain meters and in other ways.

During excavation, only in two places, sound granite failed by rupturing of the type known in tunnels as popping rock. There were no roof falls, the pattern of rockbolts proving effective against falls occurring along the numerous joints.

A final case may be quoted, being of special geological interest because of the occurrence of inclined belts of kaolinised gneiss at intervals, the power house being situated at the bottom of an inclined pressure shaft. These works form part of the Forçacava hydroelectric scheme, situated between

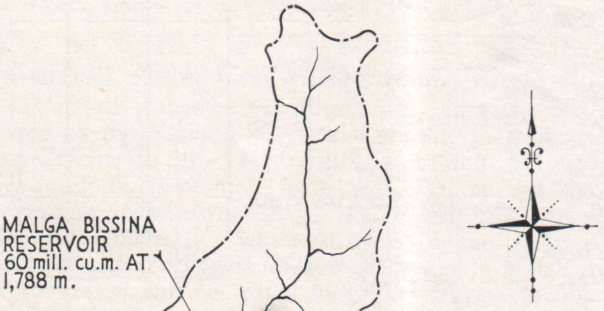

Fig. 58. Map of the upper section of the Alto Chiese scheme

Rio de Janeiro and Sao Paulo, Brazil, and were described in WATER POWER (September 1953, *et seq*) by Prof. Ing. Dr. L. v. Rabcewicz, now in Salzburg.

A plan and section of the works are reproduced from this paper (Fig. 59). It will be noted that parallel kaolinised zones traverse the gneiss, and these are nearly parallel with the foliation of the rock. The selection of the site for the power station appears to have followed upon the favourable orientation of these belts of bad rock at right angles to the inclined power tunnel shaft, which were located by diamond boring. Unfortunately a kaolinised fault-zone traversed the position of the machine hall, crossing this excavation obliquely as well as the adjacent horizontal part of the pressure tunnel. In all, the width of this zone, the central completely decomposed rock 2–4m thick, and margins with slickensides, together with other movement planes carrying water, was about 10m. In addition to this troublesome structure, highly inclined joints extended almost parallel to the length of the machine hall and caused repeated sudden falls of rock in huge blocks.

The roof arch was first excavated, in stages, with temporary wooden framing supports, followed by concreting. It was found that rock without joints in a span of 24m by 8m would remain stable for at least a few days. A dry season appeared to have favoured the stability of the kaolinised zones. The rock above the concrete arch was finally grouted, and the rock was drained by means of deep holes driven through the arch.

Thus, in conclusion, this series of articles concerning the economics of granite in engineering practice emphasises the dictum of that great elucidator of the Alps and of many dam sites, Maurice Lugeon of Lausanne: "Combien il faut se méfier au granite."

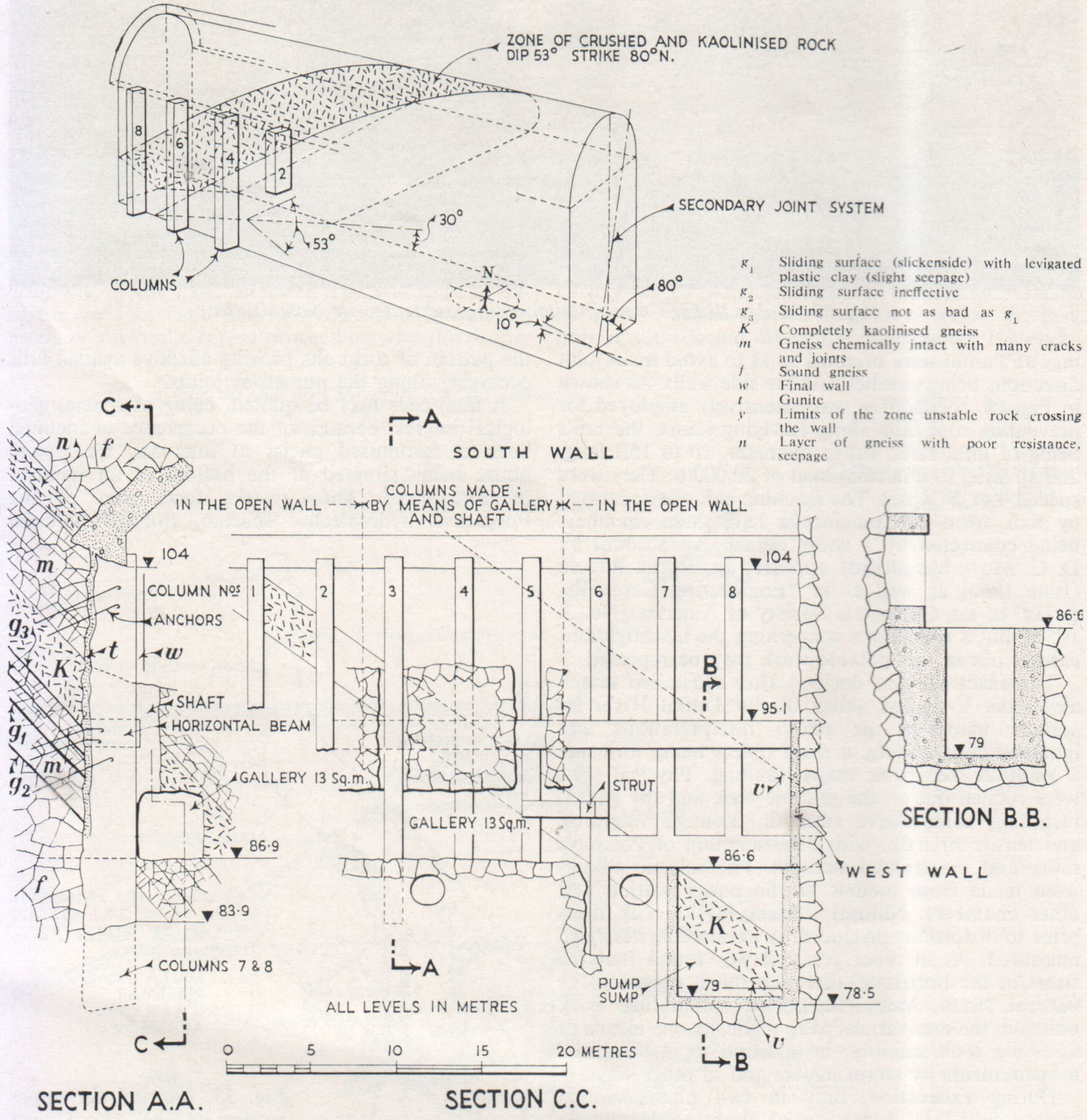

Fig. 59. Geological situation and methods of construction of Forçacava machine hall

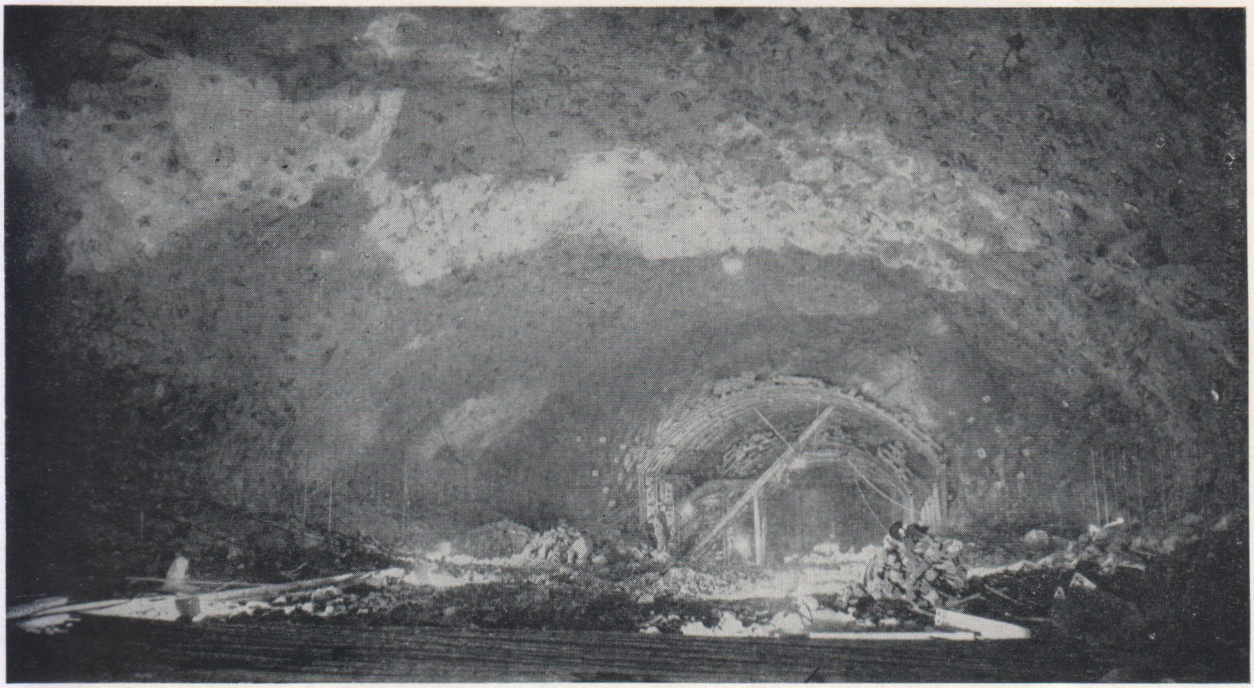

Fig. 60. Excavation for Tumut transformer hall showing complete rockbolt support

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BEAMA Power Generation Division

A further stage in the gradual introduction of a divisional structure within the BEAMA (British Electrical & Allied Manufacturers' Association) organisation is reached with the announcement of the formation of a Power Generation Division under the chairmanship of Mr. E. B. Banks (English Electric Co. Ltd.), who is also Deputy President of the BEAMA. This is in accordance with the BEAMA Council's policy of bringing together within a Division the sections concerned with similar or related products. Each Division will have its own Divisional Board which, under the authority of the Council, will formulate policy and guide its sector of the industry and act for the Council in negotiations on behalf of the members whose interests they represent. There are already four Divisional Boards covering Domestic Appliances, Electric Traction, Industrial Electronics, and Industrial Electrical Machinery. The new Power Generation Division will link together the BEAMA sections covering large steam turbines, turbine-driven alternators, condensers and feed heaters, gas and water turbines, cooling water apparatus, and nuclear reactors for power generation.

Current Meter Calibration at Wallingford

The current meter calibration service formerly provided by the National Physical Laboratory has been transferred to the Hydraulics Research Station, Wallingford, Berkshire, from where details of the service are now available. All meters that give an indication above the water surface of the relative motion between the meter and the water in which it is immersed can be tested in the 330ft-long towing tank at the Station. Individual consideration will be given to self-contained meters which cannot be tested in the tank but whose operation might be compared with that of a calibrated meter. Major overhauls of meters will not be undertaken, but cleaning, lubrication and adjustment of the meter and the replacement of worn or damaged simple components such as pivots, spindles, bearings, and contacts will be carried out upon request.

Welding Data Book. A welding data book has been published by Eutectic Welding Alloys Co. Ltd., Feltham. This company manufactures over 150 products based on the low heat input concept, and used for forming and overlaying all industrial metals.