Fig. 1. General view of the Pieve di Cadore dam

Recent Dams in the Eastern Alps

A commentary on a paper recently presented to The Institution of Civil Engineers by Dott. Ing. Carlo Semenza on " The Most Recent Dams by the ' Societa Adriatica di Elettricita (S.A.D.E.) ' in the Eastern Alps "

A MOST interesting paper was presented on March 18 to The Institution of Civil Engineers by Dott.Ing. Carlo Semenza, describing the design of the major dams for which he has been responsible in his capacity as Chief of the Construction Department of S.A.D.E. during the past 25 years. All of the dams described are of arched or dome-shaped form, but each presented an individual design problem. Four dams were discussed in detail in the paper: Lumiei, Pieve di Cadore, Val Gallina and Valle di Cadore, and brief notes were given on the projected dams on the rivers Vajont and Maè.

The arched form is favoured by the topographical conditions, for the dam sites are usually in deep narrow gorges, and as these gorges in many cases extend a considerable distance upstream it has been necessary to carry the dams higher than normal in order to impound an adequate quantity of water. Geologically the district is excellent, the prevailing structure being limestone, mainly dolomite. Any defects are obvious on inspection, and water permeability in the direction of the rivers is very low.

The Lumiei Dam

The dam at Maina di Sauris on the river Lumiei, completed in November 1947, was fully described in an article which Dr. Semenza contributed to this journal in 1950*, and Figs. 2 and 3 are taken from that article. It is 134 m. high from the lowest foundation

*"An Underground Station." By Dott.Ing. Carlo Semenza, WATER POWER, July-August 1950, page 144.

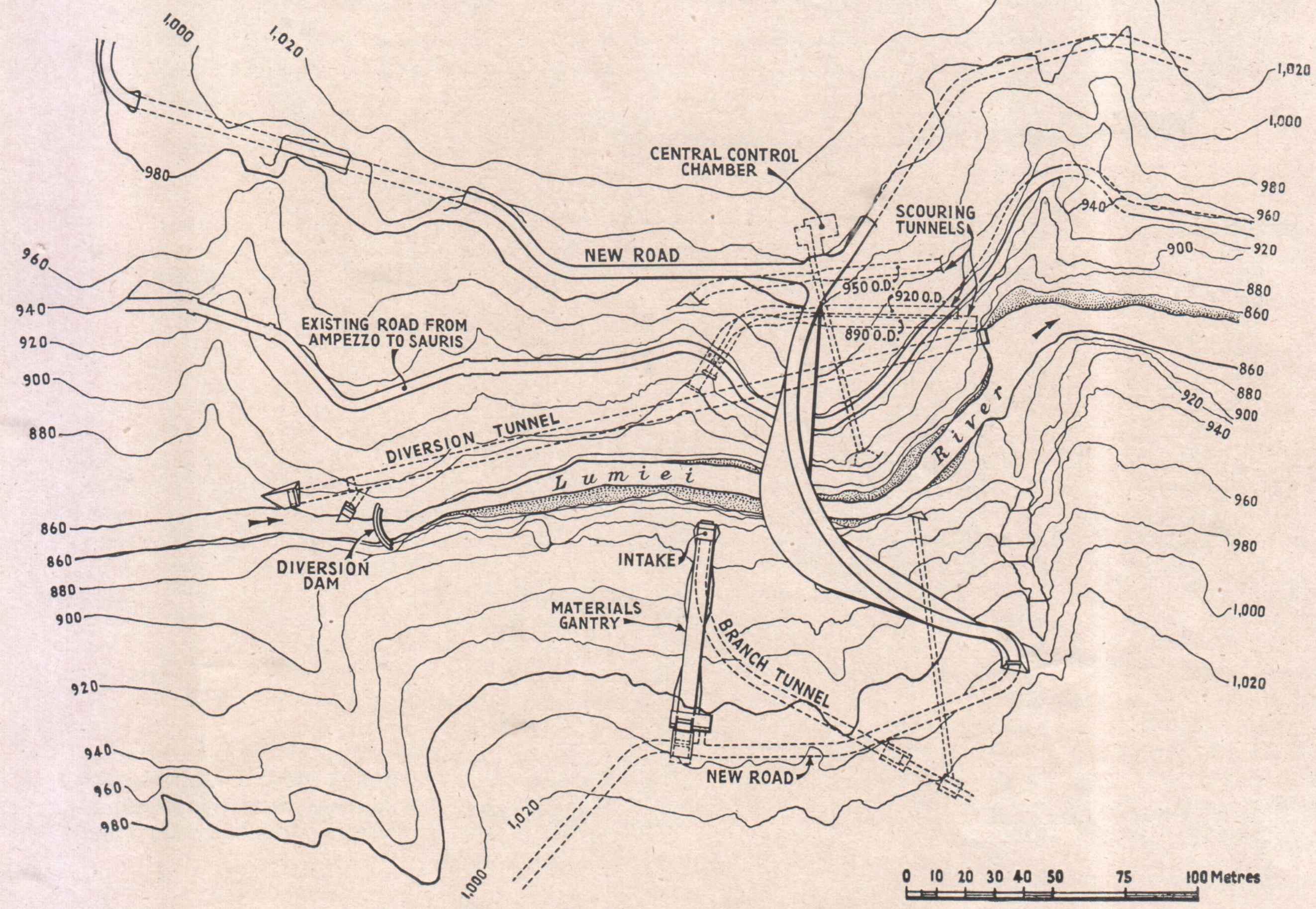

Fig. 2. Plan of the Lumiei dam and associated works

to high-water level, and the top chord is 130 m. The crown thickness is 16 m. at the base and 3·15 m. at the top, the increase of thickness at the abutments being from 20 to 30 per cent. The dam is a triangular dome-shaped shell which has been made absolutely symmetrical by an excavation in the right bank. The greater volume due to the increase of space was balanced by the reduction of thickness due to the absence of abnormal twisting stresses, and it was evident from Dr. Semenza's remarks that he attached considerable importance to symmetrical construction.

The thrust from the dome perimeter is transmitted to the rock faces by a reinforced-concrete saddle through a perimeter joint made watertight by several layers of asphaltic sheet and a copper sealing strip. The joints within the dam are at intervals of 15 m. and are mainly vertical and radial except when approaching the perimeter joint, where their direction changes gradually to meet the perimeter joint at right angles. Upstream and downstream faces are lightly reinforced.

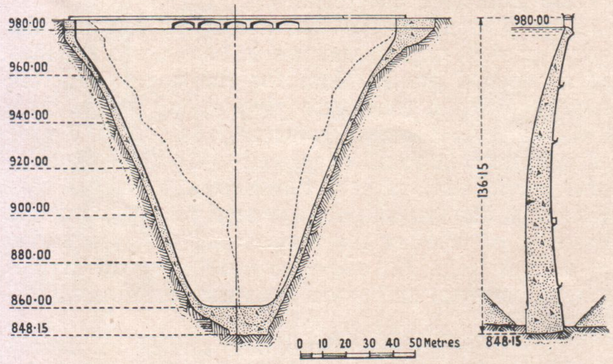

Fig. 3. Lumiei dam: elevation and cross-section

Design computations and model tests were undertaken by Prof Guido Oberti of Milan Polytechnic. The mathematical analysis was based on the Italian regulations of 1931, the dam being divided into independent horizontal arches at intervals of 10 m. starting from the crest, which were considered to be subjected to hydraulic pressure and thermal stress. The theory of the hyperstatic elastic arch fixed into the abutments was applied, allowance being made for shear in the case of arches having a high thickness/length ratio. Arches below + 900·00 m. (see Fig. 3) were calculated by the theory of thick rings.

A ferro-pozzolanic cement of high resistance was chosen for the concrete, the normal 1 : 3 mortar giving a 28 day compressive strength of 709·5 kg. per sq. cm. The composition of the concrete was as given in Table I, and cubes of concrete cut from the dam itself had compressive strengths ranging from 528 to 691 kg. per sq. cm.

Pieve di Cadore Dam

An outline of the Piave-Boite-Vajont scheme has just been given in this journal by Dr. Mainardis

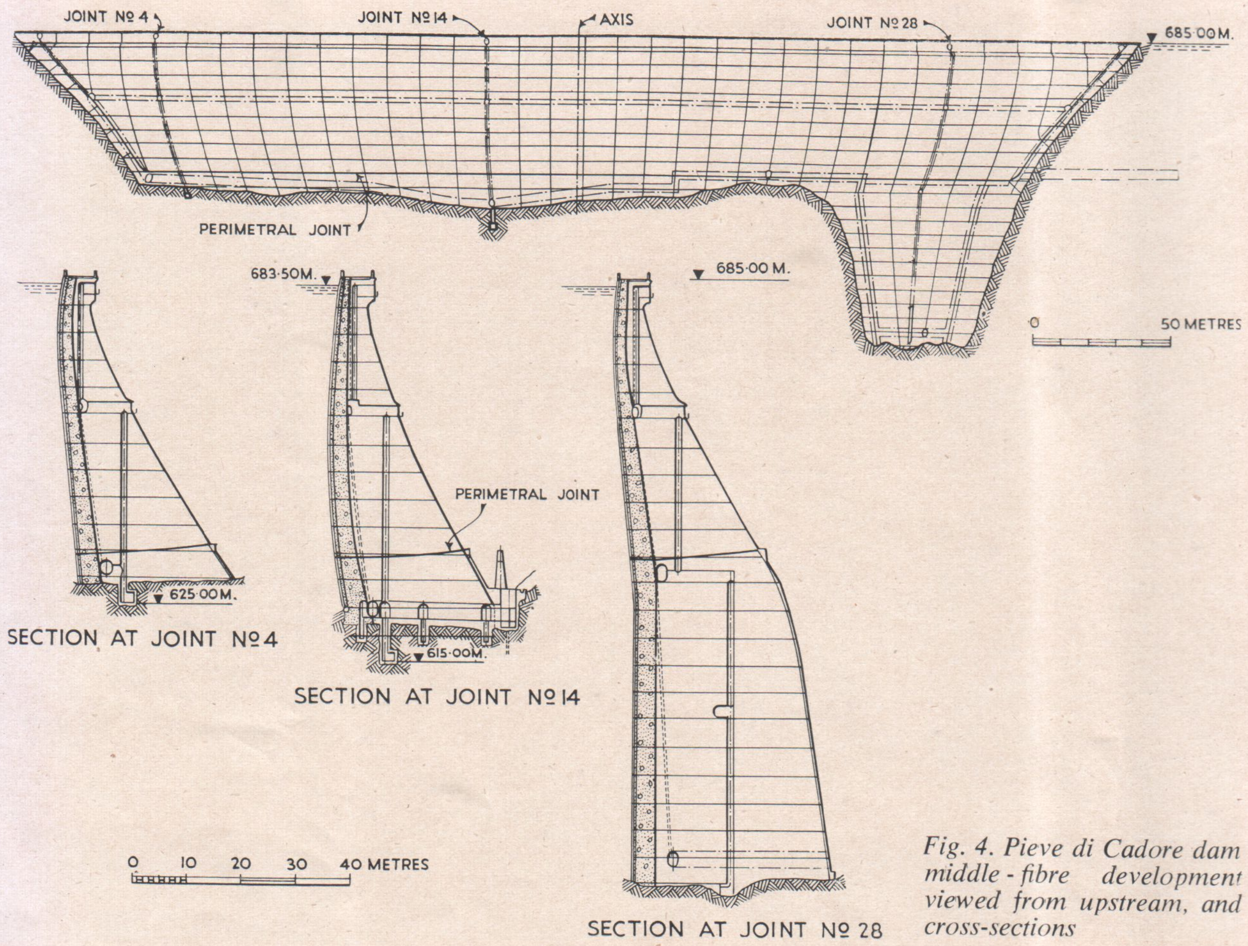

Fig. 4. Pieve di Cadore dam middle-fibre development viewed from upstream, and cross-sections

TABLE I

	Per cent.
Ferro-pozzolanic cement	10·8
Very fine sand	1·2
Sand 0-4 mm. (0-5/32 in.)	22·5
4-10 mm. (5/53-$\frac{3}{8}$ in.)	7·5
Aggregate 10-40 mm. ($\frac{3}{8}$-$1^{9}/_{16}$ in.)	28·0
40-80 mm. ($1^{9}/_{16}$-$3^{5}/_{32}$ in.)	30·0
	100·0

Water/cement ratio: 0·53.

and a view of the Pieve di Cadore dam is reproduced from that article in Fig. 1.† Sections through the dam are given in Fig. 4 reproduced from Dr. Semenza's paper.

The site chosen was not entirely favourable although it was the most suitable one from topographical and geological standpoints. It is cut out in the dolomitic limestone in the form of a trapezium about 300 m. wide and 55 m. high, the floor of the valley forming a rocky plateau. On the right the river Piave flows in a narrow gorge, 55 m. deep, the sides of which diverge downstream and which cuts the plateau in a direction converging towards the axis of the plateau.

The shape and direction of this gorge presented a difficult design problem, and several solutions were considered. The first was to close the gorge with a thin arch and to provide its left abutment on the plateau by means of a big gravity structure; from this point to the left the barrage would have been completed by a solid or hollow gravity dam. Model tests, however, showed that the tension stresses at the base of the structure were high, and to eliminate them it would have been necessary to increase the volume to such an extent that the structure would have been unduly expensive.

Another, and a simple solution would have been a straight gravity dam supported by the plateau and a plug to close the gorge, but owing to the angularity in the direction of the gorge this would have involved considerable excavation of the gorge wall and a large and expensive plug; furthermore, the static conditions at the joint between the plug and the foot of the dam were uncertain.

This pointed to the desirability of crossing the gorge at right-angles, and this in turn led to the idea of an arched gravity dam for the upper structure together with a transverse plug in the gorge. This involved several unknown factors, such as the degree of reliance that could be placed upon the behaviour of a gravity arch of such dimensions, the stress conditions at the transition from arch to plug, and the problem of whether the plug would act as a wedge or a thick arch. An extensive programme of mathematical analyses and model tests was therefore undertaken.

The mathematical analyses were carried out mainly by Prof. Filippo Arredi of Rome University, who

†"Soverzene Generating Station." by Dr.Ing. Mario Mainardis, WATER POWER, March 1952, page 95; April 1952, page 124.

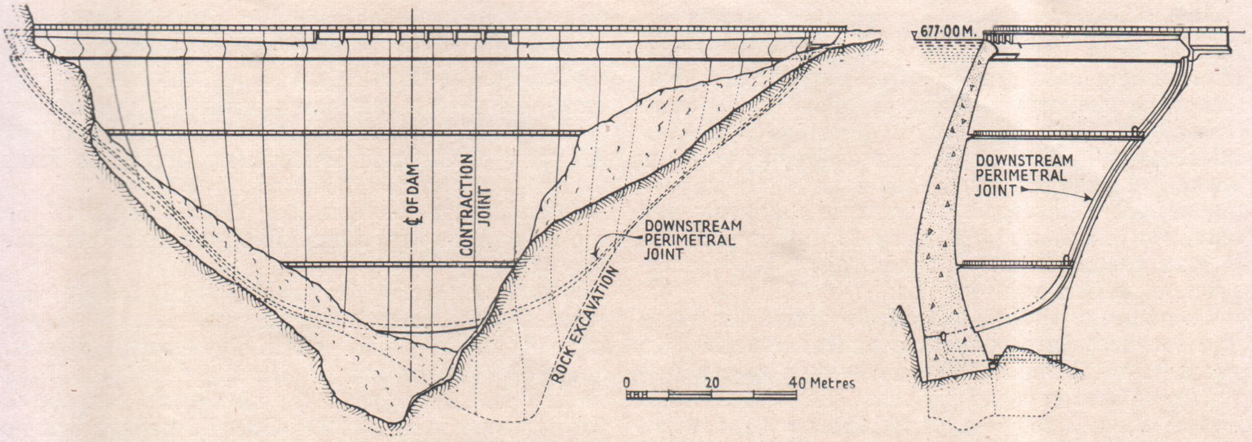

Fig. 5. Val Gallina dam: elevation and cross-section

starting with the studies of Smith, Conté and Tölke, followed mostly original methods. Other studies, based on Tölke's method, were carried out by Prof. Oberti with Prof. Danusso as consultant. Their results were checked by experiments on two-dimensional photo-elastic models, and deflections so obtained embodied in the system of equations covering the imaginary network of arches and cantilevers. In addition, the trial-load method of the American Bureau of Reclamation was carried out by Prof. Tonini.

Finally, a one-fortieth scale model was built in concrete, loaded by a system of hydraulic jacks to represent both deadweight and water pressure, and the resulting movements, which were of the order of 0·01 m., measured. In the light of all these studies a second model was built to a slightly modified shape, and convincing agreement obtained between analytical and model-test results. The percentage of the load absorbed by the arches was much greater than had at first been expected, because the modulus of elasticity of the rock foundation was much inferior to that of the concrete. Further, the structure was found not to conform to the theory of horizontal arches but to behave as a set of arches lying in inclined planes with their crowns high and their abutments low.

The resulting structure has an average height (excluding the plug) of 55 m., a length at the upper arch of 390 m. and a chord of 305 m. The average radius of the arch is 160·9 m., the upper arch being poly-

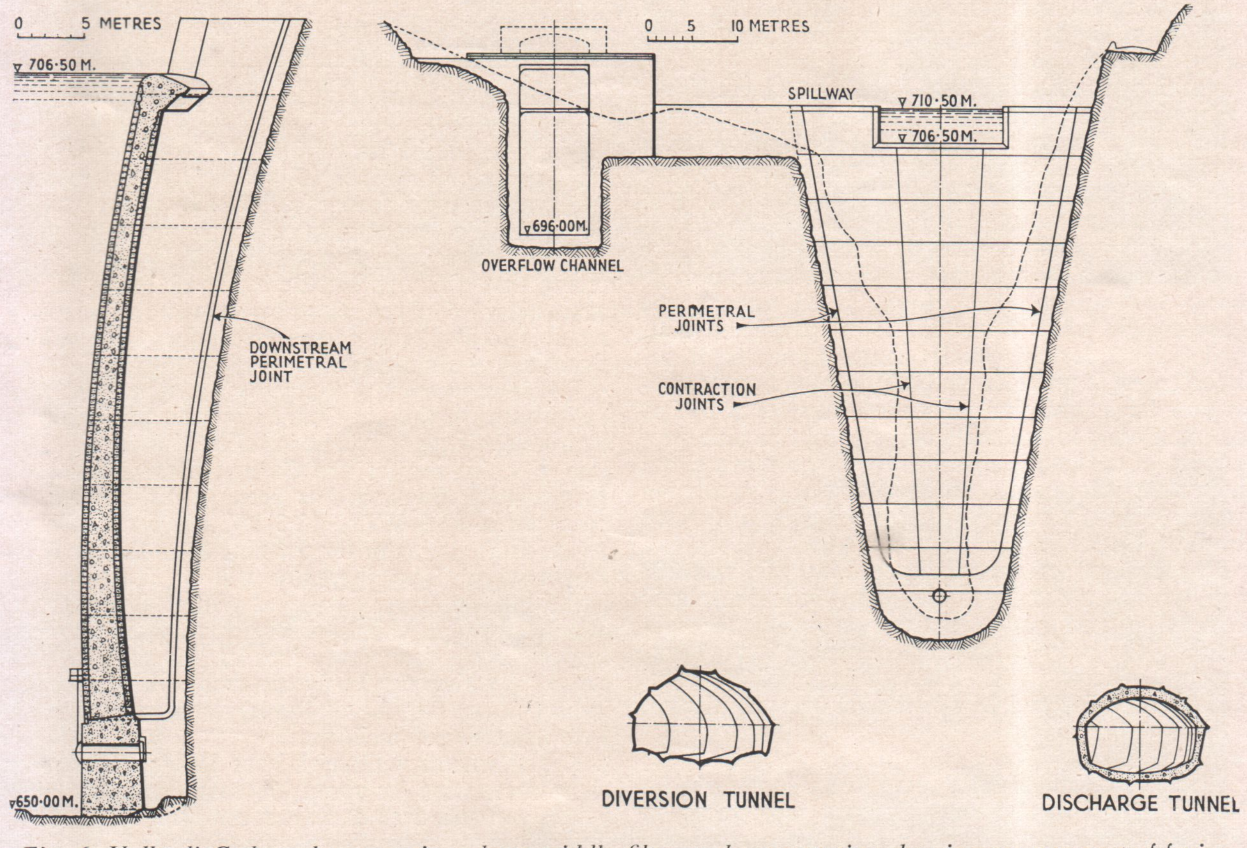

Fig. 6. Valle di Cadore dam: section along middle fibre, and cross-section showing arrangement of facing blocks

centric and the base circular. The thickness at the base is 26 m., which is about 65 per cent. of that of a straight solid gravity dam. Towards the abutments the thickness increases by about 20 per cent. The plug is 53 m. long, and its thickness in the axis of the gorge is 36 m. at the base decreasing to 26 m. where it matches the foot of the dam. A curved perimeter joint is incorporated in both abutments and base. No allowance was made for uplift pressure, and an adequate system of drainage pipes and inspection tunnels was provided.

To minimise temperature effects, resort was made to a low-heat ferro-pozzolanic cement containing 25 per cent. of Roman pozzolana, with a tri-calcium-silicate content of 40-45 per cent., and with an addition of about 1 per cent. of Plastiment. As a result, the maximum temperature rise was no more than 15°C. as against the usual 30-35°C. The concrete mixes used for face and core are given in Table II.

The dam was completed in November, 1949.

TABLE II

		Face-concrete	Core-concrete
		%	%
Cement	... ...	9·5	7·6
Sand 0-4 mm.	... ...	35·5	26·4
Coarse sand	4-16 mm. ..	23·0	20·0
	16-40 mm. ...	16·0	17·0
Aggregate	40-75 mm. ...	16·0	15·0
	75-120 mm. ...	—	14·0
		100·0	100·0
Approx. water/cement ratio		0·5	0·55

Val Gallina Dam

The Val Gallina dam, completed at the end of 1951, is of the dome type, and was constructed only after exhaustive investigations, including drilling, tunnelling and grouting tests, since the rock, an Upper Trias limestone, was rather cracked on the surface. The original cross section of the site was far from symmetrical, and symmetry was obtained by blocking the deepest part of the gorge by a plug. Drawings of the dam are reproduced in Fig. 5.

The longitudinal section is shell shaped and the vertical section dome shaped with a pronounced overhang downstream. The height is 85 m. and the chord/height ratios 2·7 : 1 inside the perimeter joints and 2·15 : 1 for the whole construction. Steel reinforcement is provided on both upstream and downstream faces, and the volume of concrete is 98,000 cu. m. Owing to the shell shape a considerable proportion of the load is absorbed by the cantilevers, and important information on this type of construction was obtained from model tests designed and directed by Prof. Oberti.

The cement content of the concrete mix was 250 kg. per cu. m., and was the same ferro-pozzolanic cement as used for the Piave dam during the cold months. Grouting assumed considerable importance, and up to March 31, 1951, a total length of 32,301 m. had been drilled and 25·085 tons of cement injected.

Valle di Cadore Dam

The Valle di Cadore dam was completed in November 1950, and drawings are reproduced in Fig. 6. It is an arch dam, 58 m. high, spanning a narrow gorge, and has two centres, one relating to the upstream face and one to the downstream face. The chord/height ratio is 0·425. Both upstream and downstream faces are protected by precast concrete blocks, the object being to insulate the internal concrete against frost and thaw stresses. It is this internal concrete that is relied upon for design strength. The thickness of the arch immediately above the base, excluding the protection blocks, is 2·77 m.

In conclusion Dr. Semenza referred briefly to the Vajont and the Maè dams, which are in the preparatory stage.

A most interesting discussion ensued, and we only regret that the author's written reply must be awaited to many of the points raised. Dr. Oberti, however, dealt with one or two of the major queries. Great interest was displayed in the nature and purpose of the perimeter joint, and Dr. Oberti explained that its objects were to prevent cracking due to shrinkage and thermal stresses, especially on the upstream side, and to obtain a symmetrical main structure.

On the question of models Dr. Oberti stated that plaster of paris was a difficult material for large structures because it took a long time to dry out and tended to be non-uniform. He had been using a concrete made with volcanic rock, an advantage of which was that the modulus of elasticity could be adjusted to requirements. It was possible to make a model having a modulus of elasticity only one tenth of that of the final structure, with a corresponding advantage in taking measurements.

Dr. Semenza's paper also gave particulars of a comprehensive system of measuring devices incorporated in the actual dams to enable their behaviour in service to be watched. Prof. Tonini reported that good agreement had been found between analytical results, model-test results, and results on the actual dams.

Hydro-Electric Plant for Norway

Norway, in the past widely known for farming, forestry and fishing, is rapidly becoming an industrialised country. This change has been brought about by the increasing development of the country's resources of water power since the war, and it is interesting to record that, although bauxite has to be imported, the availability of cheap electrical power has made it possible to export at competitive prices considerable quantities of aluminium.

It is in connection with a new aluminium plant now under construction at Sunndalsora, that additional hydro-electric plant is to be installed at Aura Kraftonlegg. For this project The General Electric Co. Ltd., Birmingham, England, has been entrusted with the order for a 62·5 MVA, 12·3 kV, 428·6 r.p.m. horizontal-shaft alternator for coupling to an Escher Wyss Pelton wheel. The alternator will be designed and built in the company's works at Witton, Birmingham, and although machines of bigger output have been made, the physical dimensions of this machine will exceed anything previously constructed in the works; in fact, it will be one of the largest horizontal-shaft hydro-electric sets in Europe.

The alternator will weigh over 310 tons, the rotor alone accounting for about 170 tons. Transport difficulties are such that no part must exceed 55 tons in weight and for this reason the machine will be specially designed and constructed so that it can be shipped in sections and erected on site.