

CORRESPONDENCE
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Papers Nos. 5164, 5163, and 5165.

“The Galloway Hydro-Electric Development, with Special
Reference to the Constructional Works.” †

By WILLIAM HUDSON, B.Sc. (Eng.), and JOHN KENNETH HUNTER,
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“The Galloway Hydro-Electric Development, with Special
Reference to the Mechanical and Electrical Plant.” *

By WILLIAM HAWTHORNE, B.E., M. Inst. C.E., and FREDERICK
HERBERT WILLIAMS, B.Sc. (Tech.), Assoc. M. Inst. C.E.

and

“The Galloway Hydro-Electric Development, with Special
Reference to its Interconnexion with the Grid.” ‡

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Correspondence.

Mr. H. H. Dare, of Roseville, N.S.W., observed that the explosive used for excavation was stated to have been No. 2 Polar Ammon gelignite. In some of the more recent dams in Australia a different type of explosive, with less shattering effect, had been preferred for dam-foundations. At the Stanley River dam (for a reservoir with a capacity of 725,000 acre-feet) which was at present being constructed on porphyry rock in Queensland, the resident engineer, Mr. Glenister Sheil, stated that Ligdyn, a 40-per-cent. nitro-glycerine explosive containing some 23 per cent. of sodium nitrate, was being used with satisfactory results. He reported that “at first glance this explosive would appear soluble and, therefore, unsuitable for wet holes, but, by leaving the wrappers on, we have not to

† Journal Inst. C.E., vol. 8 (1937-38), p. 323 (April 1938).

* *Ibid.*, p. 376.

‡ *Ibid.*, p. 407.

date lost a hole or had a misfire. It appears economical, and does not knock the ground about."

The scientific methods of grouting adopted in the Galloway scheme represented a distinct advance on earlier practice. In the first place the use of thin 4 : 1 grout was bound to permit greater penetration than the 1 : 1 mixture frequently used in the past. The grouting of the holes in stages, the top 10 feet or so being done first so as to consolidate the upper layers of rock, and the re-grouting of the holes in the manner described in Messrs. Hudson's and Hunter's Paper, should give satisfactory results. Some additional information regarding typical grout-holes would be of interest, stating the quantity of cement injected in the primary and subsequent grouting-operations, exclusive of that required to fill the hole.

The extensive grouting carried out would, no doubt, provide a deep curtain more or less impervious to water below the upstream face of each dam, but, even so, it might be that in time some water would pass the curtain, and in such case it would appear desirable that the water should be led by drains to the downstream face. That matter was not referred to in the Paper.

One most interesting feature was the description of the methods adopted for obtaining a bond between the base of the dams and the foundation-rock, and watertightness in the construction-joints. With reference to the former, it was not clear why the cement grout, originally used with satisfactory results, had been abandoned in favour of $1\frac{1}{2}$ inch of mortar, which seemed somewhat thick ; nor why, under the final method, the rock was not coated with grout before the bonding layer of specially-rich concrete was spread, thus providing, at small cost, an additional factor of security. In the construction-joints it was noted that the skin of the set concrete was entirely removed before placing the layer of special concrete ; also that, to improve the shearing strength along the joints, the top surface of the concrete was rebated, or stepped upwards towards the downstream face. In spite of those wise precautions it was his view that the construction-joints were bound to remain a source of weakness, and that, however carefully the placing of fresh concrete against set concrete were done, there still would be a tendency for water to percolate along the joints.

So far as he was aware, information concerning the internal condition of any of the great dams in the world was very limited, and it was suggested that valuable data regarding the nature of the concrete and the percolation of water into the heart of the dam would be obtained if holes were drilled in some of the structures by means of modern calyx core drills. Those machines, which were being used in America for examining rock-foundations for dams, drilled holes up to 3 feet in diameter, thus allowing visual inspection of the sides of the hole.

At the Stanley River dam, referred to above, a series of percolation-

tests was being carried out under the direction of the chief engineer, Mr. W. H. R. Nimmo, and himself, with the idea of obtaining information concerning the percolation along construction-joints, under various conditions of treatment. Those tests, which were still in progress, were being made under a 100-foot head, and included investigation of the relative percolation along plain and rebated joints; along joints made by wetting only, or by covering with mortar about $\frac{1}{8}$ inch thick, before placing new concrete; and along joints using strips of metal as water-stops near the upstream face. So far, the metal strips appeared to give the best result, and consideration was being given to embodying copper strips, $\frac{3}{8}$ inch thick, and 6 inches or 8 inches wide, in all horizontal joints in the structure, set about 2 feet back from the face, the distance being dependent upon the space required for proper vibration of the face-concrete.

It was stated that the dams were built in bays about 50 feet in length, separated by closing spaces about 5 feet wide, which were subsequently filled with concrete after most of the shrinkage in adjacent monoliths had taken place. Although that method had been used in other dams, it was open to the objection that the shrinkage of the 5-foot closing strips might lead to the formation of two cracks instead of one; why was that method preferred to the more usual one of providing a suitably-shaped copper seal near the upstream face of the joints, without leaving any space between the monoliths? It would be of interest also to learn the results of experience with the grouting of the joints in the arch dams under pressure, after the 5-foot strips had been filled with concrete.

Mr. M. B. Duff had been especially interested in Messrs. Hudson's and Hunter's Paper, as he had had the privilege of assisting the Promoters when their Bill had been before the Committees of Parliament in 1929, more particularly with regard to the yield of the Loch Doon area and the compensation-water to be sent down the river Doon. Messrs. Hunter and Hudson stated that the amount of compensation which had to be given was equal to one-third of the average rainfall, which, as they said, was certainly a high figure. The circumstances were, however, unusual and complicated. The loch had been already raised and simple arrangements had been made for fish to enter. He remembered being present with the late Mr. R. C. Reid, M. Inst. C.E., to whom he was a pupil, at a meeting with the late Marquis of Ailsa, as far back as about 1885, with regard to alterations of those arrangements. Later, attempts had been made to give a minimum flow to the river Doon of 65 million gallons per day, but it was shown that the storage in the loch above the level of the old sluices could not maintain that flow in a dry season. The opposition of the mill-owners was also based on the supposed flow mentioned above. There was also the plea of the Ayrshire County Council that the diversion of the flood-water from the river Doon to the

Dee would necessitate the provision of sewage-purification works for Dalmellington and other places draining to the river Doon at an earlier date than would otherwise have been necessary. A reasonable money-payment was made towards settlement of that plea. Having regard to all the circumstances, the amount of compensation-water given might not be wondered at, and should not form a precedent in connexion with the ordinary case of taking water from an area not operated upon and not diverting it to another drainage-area.

The figures of rainfall, run-off and loss on p. 330 § were interesting, and showed how difficult it was to fix any definite amount for loss by evaporation. For instance, the loss in 1933 was 11·7 inches on a 49·6-inch rainfall, and 11·3 inches in 1934 on a 69·5-inch rainfall, the difference being no doubt due to the time of year when most of the rain fell. The average loss over the 6 years from 1930 to 1935 was 13·7 inches, confirming that the water engineers of a former generation were not far wrong in assuming a loss of from 12 to 16 inches for lower- and higher-rainfall areas.

He was greatly interested in the experiments made to ascertain the effect on smolts in passing through the turbines at Tongland through a pressure varying from atmospheric up to 45 lb. per square inch and back to atmospheric in less than half a minute, and he was pleased to know that actual experience had been satisfactory. The designs of all the fish-passes appeared to be excellent, and he hoped that they had proved themselves quite satisfactory in practice.

The figures on p. 362 § for the excess concrete for the lining of the Doon tunnel appeared to be very large, and he wondered if that were on account of bringing the finished tunnel to the exact specified size. To have left it larger at certain places would not appear to have mattered, but probably the reason was that the rock was so irregular after blasting that the extra concrete was rendered necessary.

Messrs. H. S. Hvistendahl and G. Gianella, of Baden, Switzerland, observed that, compared with usual Swiss hydro-electric practice, the Galloway plants presented a number of departures.

Referring to the Paper of Messrs. Hudson and Hunter, it was stated in the description of the Glenlee high-pressure pipe-line that electric welding had been adopted for the longitudinal seams, which were welded at the manufacturers' works, but that riveting was employed for the circumferential joints made at the site. In view of the fact that the stress in the circumferential joint was only half that in a longitudinal seam, and was still less when the effect of anchoring was taken into account, it would be interesting to know why welding was not considered suitable for the circumferential joints. Modern Swiss practice tended more and more to the exclusive use of welding, both in the manufacturers'

§ Page numbers so marked refer to the Papers. (Footnotes †, *, and ‡, p. 505.)—
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works and at the site. In certain cases the spiral form of longitudinal seam had been employed for the lower part of high-pressure pipe-lines, to reduce the stress in the weld with a given thickness of plate; as, however, Continental experience, which was confirmed by that at Glenlee, had shown that for that class of work the efficiency of the joint could be taken as practically 100 per cent., the usual straight longitudinal seam was being generally reverted to.

Frequently, where the plate-thickness was 1 inch or more, the weld-portion was stress-relieved by local heating, and as manufacturers were beginning to instal X-ray equipment, there was a tendency to specify X-ray examination of a number of specimen strakes (usually 10 per cent.) selected at random. In other cases, the usual search for leaks by means of hammering during the hydraulic-pressure test was considered sufficient.

In regard to the material, the practice was to specify not only the ultimate and working stresses, but also the elongation, great importance being attached to ensuring a high value, namely about 25 per cent. for steels having an ultimate strength of from 50,000 to 60,000 lb. per square inch, which were usually employed, and about 23 per cent. for the higher-tensile-strength steels having an ultimate strength of from 60,000 to 70,000 lb. per square inch, which were occasionally used for the lower portions of the pipe-line. Frequently, the minimum Izod-test figure was also specified. The corrosion-allowance of $\frac{1}{8}$ inch was twice as much as that admitted on the Continent, but that might be due to the Galloway atmosphere being considered more corrosive than that of the European alpine districts. What was the length of the strakes, was the bifurcating branch-piece of cast or of welded design, and was it stress-relieved?

In the Paper of Messrs. Hawthorne and Williams it was mentioned that the Glenlee alternators were of the usual three-bearing design, but that the machines in the other stations running at lower speed were of the umbrella type. Although common in the United States, the umbrella-type alternator had not found favour on the Continent, partly because there was some doubt as to the tendency to vibration with only two bearings, and partly because of difficulty in performing the overspeed tests at the alternator-maker's works. Would the experience obtained at the Galloway plants cause the Authors to recommend the use of umbrella-type machines for further installations?

The general use of closed-circuit air-cooling for all machines was an innovation, in so far as only in isolated instances, where the noise question was of importance, had closed-circuit cooling-systems been employed in Continental plants.

It might be of interest to mention an ingenious arrangement employed at Tremorgio for damping the sound-waves propagated along the outlet duct of the pelton turbines. The device consisted simply of a water-curtain, sealing the space above the water-surface where the duct changed to an open channel. The water-curtain, for which the outlet water from

the air-cooler was used, had proved very effective. The main difficulty of the closed-circuit cooling-system was the cooling-water supply, especially in the case of high-head stations, where the amount of water taken by the cooler was an appreciable fraction of the total, and represented a serious loss of units; further, that energy had to be dissipated by the reducing valve, entailing a correspondingly high rate of wear of the valve. Had the reducing valves required a large amount of maintenance? Several important Swiss stations, notably Ryburg-Schwörstadt, had been designed with provision for the installation of closed-circuit air-coolers at a later date, having regard to the possibility of trouble caused by occasional swarms of flying insects during the summer season, but the precaution appeared to have been unnecessary.

The surge-towers were stated to be designed with storage-capacity to allow for a 100-per-cent. load being thrown on suddenly, as well as being thrown off. In regard to the condition of load-reduction, it would be interesting to know if the governing gear provided for the momentary diversion of the water-flow, or whether the only compensation was afforded by the surge-tower.

Concerning the devices protecting the sets against over-speed and lubrication-failure, what reserve source of energy was used for operating the governor? Was underspeed protection employed throughout or only at the unattended stations? In view of the relatively frequent starting and stopping, had brakes been provided to bring the machines quickly to rest when the speed had dropped below that at which an adequate lubricating oil-film was maintained in the thrust-bearing? Were the governors driven by belts, gearing, or by electric motors supplied from main or pilot generators?

Test-ponds represented an appreciable cost-item, and for that reason Continental engineers usually thought twice before installing them. They had, however, definite advantages, as they enabled the machines not only to be tested for efficiency on a steady load, but also enabled the sets to be subjected to governing tests without the steadying effect of the system-frequency. Experience had shown that governor-instability was more readily seen when the set was operated independently, and that a unit which governed satisfactorily alone would generally run satisfactorily when tied-in to the system-frequency.

The generating sets at Carsfad and Earlstoun appeared to be identical in all respects, operating under practically identical conditions, and it was, therefore, surprising that the measured efficiencies, according to Table V (p. 336 §) should differ by as much as $3\frac{1}{2}$ per cent. Allowing for the alternator-losses, the overall value of 90.5 per cent. measured for the Earlstoun sets would suggest an efficiency of 94 per cent. for the water-wheel, which was more than would be expected for a machine of the type

and size concerned. The discrepancy appeared to be due to errors of measurement. Could such errors be attributed to the use of the salt-velocity method under conditions for which it was not suitable ?

Mr. Mountain's Paper very rightly stressed the need for re-examining water-power resources in respect of their suitability for economical generation of peak-load power. *Fig. 46* (p. 410 §) showed for the Tongland plant three generating sets coupled to the Grid through two 30,000-kilovolt-ampere transformers. The arrangement of three generating units with two transformers was somewhat unusual, because if conditions justified the splitting-up of the generating capacity into three units, presumably with a view to operating them as nearly as possible at maximum efficiency in spite of varying water-flow, then it was generally considered worth while to follow the same practice for the transformers.

Mr. W. H. R. Nimmo, of Brisbane, agreed with the opinion expressed by Mr. James Williamson (p. 433 §) that in estimating the mean rainfall over the catchment, the area represented by each rain-gauge should be taken into account. In a sparsely-settled country rain-gauges were usually widely distributed and were mostly located in the valleys, and he had found it necessary, in investigating the yield of areas comprising mountains and valleys, where there were steep rainfall-gradients, to modify the results obtained from the rain-gauges to take into account the variation of rainfall with elevation.

The Tables on pp. 330 § and 433 § showed that the average loss deduced by Mr. Williamson was 1·4 inch less than that given by the Authors. The 6-year period of record was insufficient to establish the minimum annual rainfall, and should drier years than those so far experienced occur, then the reduction in the loss might be important. The difference between the loss from the Severn and Dee catchments, referred to on p. 447 §, might be due to the greater area and greater range of rainfall within the former area. A flood of 28,000 cusecs from 144 square miles was rare, but in his opinion considerably larger floods were possible.

His experience confirmed that of Messrs. Hudson and Hunter that too little attention was given to the shape of the particles of concrete aggregate (p. 365 §). Flaky stone produced a less workable mix, which required more water, with consequent reduction in strength. The concrete aggregate for a dam which was now being constructed under Mr. Nimmo's direction was derived from a porphyrite which was of a flaky nature, but by the use of vibrators it was found practicable to consolidate concrete having a slump of $\frac{3}{4}$ inch. Although the inclusion of stone dust decreased the strength of concrete, it might perhaps be found also to decrease the permeability ; in regions where the water might be aggressive to cement, that advantage might outweigh some reduction in strength.

Mr. Guy Richards thought that it might be of interest to give some details of the steel pipe-line at Glenlee. Pipes were delivered to the site by road in 24-foot lengths, fabricated from three 8-foot strakes with plain butt-welded circumferential joints; all field-joints were riveted butt-joints with cover-plates. The pipe-lengths were transported into position by bogies on a 3-foot-gauge railway running parallel to the pipe-line, were rolled off the bogies, and were manoeuvred into line. The general procedure of erection was to set, in turn, the vertical bends at the anchor-blocks (Figs. 31, Plate 3, facing p. 454 §) accurately for line and level, and partially to concrete them in, after which the pipes were erected to the next bend, and, as soon as that was set, the intervening pipes were jacked into line and riveted. It was interesting to note that the two circumferential welds in each length of pipe caused a shrinkage of approximately $\frac{1}{8}$ inch in the 24-foot length. Insignificant as that might appear, it necessitated some adjustment at the anchor-blocks and expansion-joints to counteract it.

Whilst each length of pipe was hydraulically tested in the shops, the Contractor decided to test the field-joints before testing the completed pipe-line, by drilling small holes in the cover-straps and injecting paraffin under pressure. In that way any defect in the internal sealing-weld at those joints could be detected and rectified with a minimum of delay and trouble. The final test on the completed pipe-line showed all shop-welds to be absolutely tight; the only leakage which gave trouble occurred at the crutch of the bifurcation, which was rectified by additional welding.

The connexion of the bifurcation to the two 6-foot-diameter butterfly valves immediately downstream presented an interesting problem. The design allowed for a $2\frac{3}{8}$ -inch gap between the valve- and bifurcation-flanges, which was to be filled by a special packing made to a template after erection, as a metal-to-metal contact was required. Whilst it was realized that those packings would in all probability require to be slightly tapered, since the valves had to take their setting from the 6-foot-diameter pipes, it was found that the heavy bifurcation-flanges had warped during welding to a maximum of $\frac{3}{16}$ inch out of a true plane. The Contractors ingeniously overcame that difficulty by making the packing of two rings spot-welded together to give the correct taper; after insertion, small wedges were driven between the rings until perfect contact was obtained on both flanges, and then the gap in the packing was welded solid all round.

Some difficulty was experienced in setting the base-plates for the sliding saddles which supported the pipe-line between the anchor-blocks. In order to obtain a perfect bearing, the design allowed for those base-plates to be temporarily bolted up to the saddle bearing-plates while they were grouted in to the concrete pier, the pipe-line, although completed,

still being supported on packing. It was found, however, that the expansion and contraction of the pipe-line during the setting period of the grout dragged the base-plates and loosened the grout. The method finally adopted was to wedge the base-plates off the piers up to the saddles so that sliding could take place. The base-plates were surfaced with phosphor-bronze and coated with graphite grease.

From experience gained on that pipe-line it was evident that shop-welded strakes in conjunction with riveted field-joints gave a most satisfactory and economical result. It was considered that welded field-joints would not be practicable with pipes of the diameter and plate-thickness employed, due to the difficulty which would be experienced in holding the ends of pipes to a true circle during welding, together with the fact that it would be impossible to line the pipes and at the same time to maintain a constant butt-gap. It was also apparent that welding introduced minor distortions which were difficult to anticipate in the shop; the Contractor, however, had maintained a high standard of workmanship throughout.

Dr. E. G. Ritchie observed that the peak-load problem in power-generating stations was one of growing importance. In 1925 the aggregate maximum demand in Great Britain was about $2\frac{1}{2}$ million kilowatts, whilst by 1935 it had grown to nearly 5 million kilowatts. Over the same period the gross capacity of reserve plant, expressed as a percentage of the aggregate maximum demand, fell from about 80 per cent. to about 33 per cent., with a further drop to 25 per cent. in 1936 and to 20 per cent. by the end of 1937. As the demand was at present increasing at the rate of approximately 1 million kilowatt per annum, the percentage of available standby was obviously approaching the lowest permissible level.

Having regard to the fact that development of the base-load stations was nearing completion, attention would have to be directed to the development of the lower-load-factor stations. An important consideration was that, although the load-factor on the system as a whole had improved, and was likely to continue to improve, there was some evidence to show that the load-factor of at least the top 10 per cent. of the aggregate-load curve tended to diminish. The problem of the low-load-factor stations (embracing, as it did, the peak-load problem itself), was, therefore, assuming an importance that it did not have 3 or 4 years ago, when semi-obsolete plant in abundance was available for short-period service.

In peak-load plant, perhaps the most important consideration was availability. In the Galloway scheme 33 per cent. of the total capacity could be developed within 5 minutes, and 77 per cent. within 15 minutes, whilst the full capacity of the system was not available under 25 minutes. That did not compare favourably with the performance of modern boiler-plant, which could be brought up from a nominal rating to full rating in from 6 to 8 minutes. With specially-designed steam-raising equipment the time taken to get the boilers fully under way was even less, and steam

plants were in regular operation in which a full head of steam was attained from a live banked condition in from 3 to 4 minutes. Where steam-accumulators were installed, a change in load over the full range of capacity of the plant could be met in less than 5 seconds with generating units as large as 25,000 kilowatts. If, therefore, the time taken to bring the Galloway plant up to full load was characteristic of peak-load hydro-electric plant, the lower availability as compared with specially-designed steam generating plant was a definite disadvantage.

In considering peak-load plant, low capital cost was of fundamental importance, and in that connexion the Galloway scheme was bound to be regarded as costly, the price being about £31 per kilowatt of operating capacity, including the cost of interconnexion to the Grid. The total cost per unit generated by the Galloway plant compared favourably with the corresponding figure for a modern steam-station operating with the same load-factor. A load-factor of 20 per cent. could not, however, be regarded as representing true peak-load conditions, and, moreover, steam generating plant specially designed for peak-load service would be much less costly than that proper to a high-load-factor station. With load-factors of the order of from 5 to 10 per cent. a comparison should definitely favour steam generating plant specially designed for that duty. In that connexion, steam-accumulation offered important possibilities.

In the Papers no indication was given of how either the total cost per kilowatt-hour on the Galloway scheme was computed, nor was the method of calculating the capital charges shown. A statement by the Authors on that point would be of very great value.

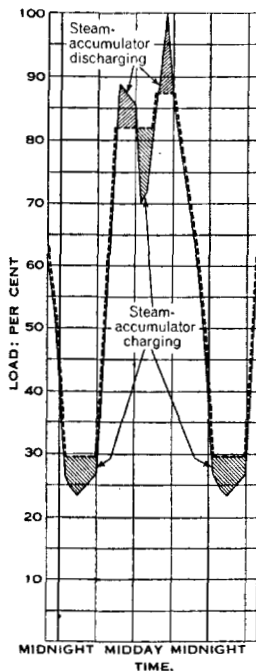
Fig. 57 showed the approximate shape of the aggregate-load curve throughout Great Britain during a mid-winter day, the load-factor for the whole system during that day being about 60 per cent. The top 30 per cent. of that in effect represented the peak-load problem, as the rapid drop in the demand during the mid-day break was as disconcerting to the system as were the peaks themselves.

If steam-accumulators were installed, an analysis of the diagram showed that the economical sub-division of the load would be to carry about the top $12\frac{1}{2}$ per cent. of the load on stored steam. That would mean in effect that in an area where the demand totalled 500,000 kilowatts, about 62,500 kilowatts would be met by accumulated steam on a time-base of about $2\frac{1}{2}$ hours. As the major peak was of triangular form, the steam-storage capacity to be provided per discharge would be equivalent to approximately 78,000 kilowatt-hours.

With steam-storage capacity installed to the extent of $12\frac{1}{2}$ per cent. of the maximum demand, the equivalent boiler-firing line would be as shown dotted in *Fig. 57*, the accumulator-battery being charged during the night and during the mid-day break, and discharged to meet the morning and afternoon peak loads, as shown by the respective shaded areas. That would mean that, with the load-curve indicated, the boiler-capacity engaged

would be constant for about 5 hours during the night and about 10 hours during the day, with an increase from normal rating to about 7 per cent. overload rating over a period of about 4 hours in the afternoon, to cover the lower part of the major peak. All variations in load above and below the night and day firing-rate would be covered by the automatic charging and discharging of the steam-storage system. That would raise the boiler-house load-factor of the whole generating system from 60 per cent. to 70 per cent. Alternatively, if all load above the 50-per-cent.

Fig. 57.



level were allocated to a two-shift station, the boiler-house load-factor of that station would be increased from 35 per cent. to 50 per cent. by the installation of steam-accumulators.

In many stations which during the past few years had been developed into high-load-factor stations, semi-obsolete turbine plant was available. In such stations, steam-accumulators for peak-load service could profitably be installed, using the old turbines, modified, if necessary, to enable them to operate on accumulated steam. That would provide useful fly-wheel effect for the base-load boiler-plant, and would at the same time profitably absorb existing turbine equipment. Alternatively, existing two-shift stations might be equipped with steam-accumulator batteries to enable

them to deal with the peak-load demand for energy and to permit stations to be shut down which would otherwise be required only for short periods of time throughout the year.

The installations of steam-accumulators as suggested would reduce the operating costs on the system as a whole, as labour charges on the peak-load plant would be confined almost entirely to additional turbine-room attendance, and, whilst the heat-consumption per kilowatt-hour would be somewhat greater on accumulated steam than on live steam, that would only affect a negligible percentage of the total yearly demand ; further, in any case improvement in the boiler-house load-factor and stabilization of the live-steam pressure and temperature due to the elimination of peak-load firing should more than offset the slight increase in the heat-consumption for the generation of the peak-loads. On the basis of a triangular peak load lasting $2\frac{1}{2}$ hours, the total capital cost of steam-accumulators, including foundations and all building work, and including also a reasonable sum as representing possible modifications to the turbines used for peak-load service, worked out at approximately £4 10s per kilowatt of operating capacity. That was bound to compare favourably with the cost of meeting peak loads by any other means, especially having regard to the fact that a steam-accumulator came into contact only with distilled water and saturated steam. There was nothing to cause its deterioration, and its useful life was much longer than in any other item of power-station equipment. In addition, when charged, steam-storage plant offered the advantage of providing a reserve of energy almost instantly available.

Dr. R. A. Sutherland, of Hastings, Nebraska, was particularly interested in the relatively high specific speed obtained at the Tongland plant. The range of head was from 95 to 114 feet and the specific speed was 84 revolutions per minute. That was considerably above the commonly-used American curve, which would give a specific speed of about 59 revolutions per minute for a head of 95 feet. In deciding on suitable speeds for turbines for three plants at present being built in Nebraska, two of which had a gross head of 113 feet, he had had occasion to consult a number of turbine-manufacturers, and he had been advised that a specific speed of about 55 revolutions per minute was as high as the manufacturers would care to bid on. The machines were of 13,000-h.p. capacity, and a specific speed such as had been used at the Tongland plant would have enabled the speed of the machines to have been raised probably to 225 revolutions per minute (60 cycles per second) instead of 180 revolutions per minute, with a consequent considerable saving in the cost of electrical machinery. He would be glad if the Authors could give some more details of those interesting turbines.

He was also glad to see the use of six arch dams on the one development. Those dams were amongst the first of their type in the British Isles.

Had the Authors considered the use of the differential surge-tank as

an alternative to the simple surge-tanks used, and if so why had they been discarded? The differential tank had become almost general in the United States for installations of any size requiring a surge-tank, and it seemed to him that a considerable saving in size of tank could have been made at the Tongland plant by the use of that type of tank.

Mr. Ronald Walker would like to refer to two aspects in connexion with the concrete-production, namely the gradation of aggregates, and controlled batching.

With regard to gradation of aggregates, he had no doubt that the importance of gradation of aggregates in relation to workability, density, and strength, of the concrete, had been fully appreciated. He held the view that the gradation of aggregates for concrete should be controlled within comparatively narrow limits¹, so as to ensure optimum workability, density, and strength, with minimum cement-content (and therefore minimum liability to temperature-effects). Further, he had been partly responsible for the evolution of plant for the automatic control of gradation. He would, therefore, be interested to learn what variations obtained in the sieve-analyses of the aggregates, and whether any information was available regarding the effects of such variations on the workability, density, and strength of the concrete.

He would welcome the Authors' observations regarding the contention that, with regard to the construction of large concrete structures for the retention of water, requirements could best be met by the use of aggregates conforming to such gradation-curves as would, in conjunction with the minimum content of cement (preferably coarsely ground), result in concretes of maximum workability and density, with minimum liability to be adversely affected by temperature-effects.

Applied in practice, the foregoing would mean, so far as gradation of aggregates was concerned, that the ideal gradation-curve would be found by experiments, and plant (which was now available) would be employed to ensure that all aggregates used would constantly and reliably conform thereto.

In regard to controlled batching, he would be interested to learn what steps were taken to ensure that the manual control of batching resulted constantly in the concrete produced being strictly in accordance with specification, and to learn, approximately, the cost of taking such steps. Batching-plant which operated automatically, and in which the proportions were guaranteed by mechanical interlock, being now available, he would like to have the Authors' views regarding the desirability of employing such plant.

Mr. Hunter, in reply, observed that he was interested to hear of the

¹ See Prof. H. N. Walsh, "Aggregate Grading and Concrete Quality." Trans. Inst. C.E. Ireland, vol. lix (1932-33), p. 275.

— "Aggregate Grading in Relation to Concrete Mix Design". *Ibid.*, vol. lxii (1935-36), p. 197.

favourable experience which had been obtained at the Stanley River dam from the use of the explosive Ligdyn. In Galloway, although the various works had been carried out by a number of different contractors, No. 2 Polar Ammon gelignite had been used almost exclusively, and, so far as he knew, no serious attempt had been made to experiment with any other explosive.

Mr. H. H. Dare had asked for additional information with regard to the grouting operations. At Tongland arch dam, alternate holes 30 feet deep had been drilled and grouted, after which the intermediate holes had been drilled and grouted. In the initial stages of the injection, the grout consisted of 8 per cent. of cement by weight, thickened to a 60-per-cent. mixture for finishing-off. Seventy-two holes took an average of 48 cwt. of cement, each, the maximum for one hole (two groutings) being 218 cwt. It should be mentioned that the figures given for the quantity of cement used included the grout required finally to seal the tubes.

Whilst the grouting which had been carried out on all the dam-foundations had apparently been very successful, it had been recognized that those operations could not be entirely depended upon to seal off all leakage through the rock or along the plane of contact between the dam and the rock. In the case of the arch dams any uplift arising from such leakage would have no appreciable effect on the stability of the structure. In the case of the gravity dams, provision for counteracting the effect of a reasonable amount of uplift had been made in the designs of the dam-profile, and no under-drainage had in any case been provided.

Mr. Dare's references to the experiments being carried out at the Stanley River dam on the percolation of water along construction-joints were interesting. Messrs. Hudson and Hunter had found that, provided the contractors were conscientious in carrying out the precautions laid down by the engineers when depositing a fresh lift of concrete, a perfectly watertight joint could be relied upon even in the thin arch dams. The production of a watertight joint by ordinary methods called for unremitting care, however, and it occasionally happened as a result of carelessness that a defective joint would be revealed when the reservoir was filled.

Mr. Dare also referred to the grouting of the vertical construction-joints between the bays of the arch dams. The result of the methods adopted and described on pp. 358 § *et seq.* had been entirely satisfactory, and no percolation of water along any of the closing-space joints had been observed in any of the arch dams. In the case of the gravity dams the upstream key in the face of the closing spaces had been painted, before filling-in with concrete, with a thick bitumastic compound, and that method had proved equally successful in sealing the vertical joints between bays.

With regard to the figures given in their Paper for the overbreak in the Doon-Deugh tunnels, to which Mr. Duff drew attention, they were mainly

to be attributed to the contractor's desire to cut down trimming expenses to a minimum. In the case of the Glenlee tunnel, which was carried out by another contractor, the main heading was driven "tight," resulting in relatively little overbreak but consequently increased trimming. It was a matter for argument which of the two methods resulted in the greatest overall speed and minimum expense.

Messrs. Hudson and Hunter were indebted to Messrs. Hvistendahl and Gianella for their contribution in connexion with high-pressure pipe-lines. It would be found that their queries in connexion with the welded pipe-line were answered by Mr. Guy Richards, who was the member of the Consulting Engineers' staff responsible for the field-work, and whose contribution formed a valuable addition to the subject of the Papers.

Messrs. Hawthorne and Williams, in reply to Messrs. Hvistendahl and Gianella, observed that there was so far no indication that the umbrella type of design caused vibration of the machines, and Messrs. Hawthorne and Williams would have no hesitation in using that design if the Galloway plant had to be repeated. The question of vibration with only two bearings was chiefly a matter of exact static and dynamic balance. The alternators had been over-speeded in the works, with the shaft vertical. A short stump shaft had been bolted to the coupling and a small steady-bearing had been provided. The distance between the two guide-bearings under test was less than between the two guide-bearings on site, so that the overspeed test had been carried out under much more severe conditions than in normal running. The closed air-circuit for the alternators and exciters had been adopted to prevent moisture condensing from the humid atmosphere on the windings of machines, which would frequently be standing for hours between periods of peak load. There was also no risk of a muddy deposit forming on the end windings from any dust that might be present in the atmosphere. Noise had been reduced by closing in the machines, and particular attention had been given to the stiffening and supporting of the cover-plates to prevent drumming. With regard to the reducing valves for the cooling water, maintenance on them had been negligible.

At Glenlee and Kendoon, where the pipe-line conditions demanded it, automatic pressure-relief valves operated by the turbine-governor were provided to divert the water-flow momentarily. Surge-towers were necessary at those two stations and also at Tongland. Three alternative drives were available for the governor-pendulums: belt-drive, direct mechanical drive from the turbine-shaft, and electrical drive by a synchronous motor fed from a potential transformer connected to the main generator-leads. The last-mentioned method was used for turbines of such dimensions that direct drive would be heavy and awkward to arrange. The main Galloway machines, however, were of a size that permitted simple and effective mechanical drive to be employed, whilst belt-drive

was adopted for the small auxiliary sets in Tongland and Glenlee stations. The mechanical drive comprised a vertical shaft driven by spur gears from the turbine-shaft, and driving through bevel gears a horizontal shaft carried in bearings to the actuator. A gap in that shaft was spanned by a shrouded stainless steel strip held in slots, which eliminated vibration and was self-aligning.

The operating oil was supplied to each servo-motor by a geared rotary pump with an idler-valve. The oil was fed into a pressure-receiver in which was a cushion of air, replenished either by an air snifting-valve on the suction-pipe of the pump, or from an air-compressor set. Bus-pipes interconnected the pumping sets which were of such capacity that, even if one set were out of action, there would be sufficient remaining capacity to operate all the servo-motors in the station. It was common practice to depend on the snifting-valve for replenishing the air, but the process was too slow for the frequent starting and stopping of peak-load operation. Air-compressors with automatic control-gear had accordingly been installed in duplicate at Tongland and singly at the other stations, where provision was also made for connecting in a portable compressor when the station compressor was being overhauled.

The governor-actuator contained emergency gear which closed the turbine in case of failure of the pendulum drive or the oil-pump drive, or if the speed dropped to half normal. An overspeed safety governor mounted on the turbine shaft was adjusted to trip at 32 per cent. above normal speed. It operated twin valves on the governor servo-motor through an oil-pressure relay, and caused the servo-motor to close the turbine-gates; at the same time the trip-gear, through an electrical relay, operated the control-valve of the main valve or gate.

A set of brakes bearing on the underside of each alternator-rotor, and operated by air-pressure at from 40 to 50 lb. per square inch through a solenoid-operated valve controlled from the machine indicator-panel on the turbine-room floor, could bring the machine to rest from full speed in 5 minutes. Safety switches were inserted in circuit with the solenoid to prevent the brakes from being applied until the governor had closed the turbine-gates and the main circuit-breaker of the machine had been opened. The brakes might be applied with the machines running at full speed, and the brake-blocks were of material such that the friction did not produce metallic dust which, by settling on the windings, might cause short circuits. The brake-cylinders could also be used with oil at high pressure to jack up the alternator-rotor. The brake-system was tested to a pressure of 3,000 lb. per square inch.

The three test-ponds had been installed in view of the inconvenience which would be caused to the Central Electricity Board by frequently throwing on and off load at the middle of a long transmission-line when governor-tests were made. They also enabled a set to be tested while the others were supplying power to the Grid.

The Earlstoun and Carsfad runners were of the same general design and dimensions. When they were designed a difference of head of from 6 to 8 per cent. had been expected between the two stations ; that, together with the results of experiments carried out on models in their hydraulic testing station, had led the manufacturers to make slight differences in the shape and arrangement of the runner-blades for the two stations. The difference in efficiency determined on site was accounted for partly by that and partly by the fact that, the normal head at Earlstoun being slightly greater than that at Carsfad, there was a displacement of the gate-load curve. During the efficiency tests, for each loading of the machines the readings of electrical output were taken from four, five, and six electric meters, and those for waterflow from several "shots" of the salt-velocity method. Those readings were consistent among themselves, and since the test-conditions at Earlstoun and Carsfad were so nearly the same, the test-results at the two stations should be equally accurate. Taking the salt-velocity tests on all the stations, it could be said that the percentage deviation of the maximum from the mean of the readings of water-flow velocities with each quantity of water flowing was comparable with (and in the case of the longer conduits, less than) the percentage of the maximum deviation from the mean readings of the electric meters.

It was intended that the Galloway stations should run usually at full output. Estimates of the overall costs, taking into account excavation, buildings, plant, switchgear, generating and transformer losses, had come out less when the generating capacity was split up between two or three generating units and the transformer capacity was concentrated in one unit, than with one machine and transformer in each station.

Dr. Sutherland referred to the adoption of a specific speed of only 55 revolutions per minute for 13,000-h.p. machines under a head of 113 feet. That might be due either to a desire to flatten the efficiency-curve, to special conditions affecting the regain of head in the draught-tube, to the loading being partial for much of the time, or to the quality of the material used for the runners. The specific speed of 84 revolutions per minute adopted for Tongland had been used for similar machines that had been in satisfactory service for several years.

Differential surge-tanks had not been adopted because any saving in cost would not have compensated for the increase in the size of pipe-lines, the greater momentary speed-rise (WR^2) of alternators, etc., required to balance the choking effect of the stand-pipe on the governing of sets.

Dr. E. G. Ritchie's remarks were a contribution to the literature of another subject, and Messrs. Hawthorne and Williams felt that they could not deal adequately with the relative merits of hydro-electric stations and steam-accumulators for peak-load supply in a reply to the discussion on the present Papers. With regard to capital costs, however, they would point out that the Galloway system, with an annual load-factor of over 20 per cent., did not deal exclusively with the finer peaks of the load-curve of the

Grid ; for that purpose sites were available where the capital and operating costs per kilowatt would be much less than at Galloway.

Mr. Mountain, in reply, wished to thank Messrs. Hvistendahl and Gianella for their support of his suggestion that a re-examination of water-power resources would be of value.

Dr. E. G. Ritchie asked for a statement of the way in which the total cost per kilowatt-hour of electricity generated in the Galloway scheme was computed. The total capital charges and working costs of the scheme were stated to be a little under £240,000 per annum, which, with an output of 180,000,000 units per annum, corresponded to a total cost of generation of electricity of 0.32*d.* per unit. It was stated that that did not allow for the cost of any additional equipment required for the interconnexion with the remainder of the Grid system.

The amount of £240,000 could be divided roughly in the following way : interest and sinking-fund payments, £185,000 ; rates, £15,000 ; maintenance, including a reserve for machine-renewals, £28,000 ; and operating expenses, £12,000. The operating and maintenance costs were an estimate of the average annual costs to be expected, and the costs to the present time had been below those estimates.
