*Discussion on Paper No. 6767**

Ffestiniog pumped-storage scheme

by

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Mr A. A. Fulton (General Manager, North of Scotland Hydro-Electric Board) said that having read the Paper and listened to the Author's introduction, he was inclined to wonder why, in Gt Britain, it had taken so long for pumped-storage schemes to get the attention they deserved.

95. The principle of pumped storage had, of course, been practised in Germany for many years. The German schemes were large and initially were designed to upgrade the surplus night energy coming from brown coal plants and also from large run-of-river hydro stations on the Rhine and elsewhere. Rather surprisingly, France, which also had a considerable number of run-of-river plants, had not made much use of pumped storage. The idea was, however, catching on in Spain and Portugal, and in the United States more than 4000 MW of new installations was now on the way.

96. That pumped storage might be a useful way of offsetting the irregularities in the delivery of energy from a tidal scheme was aired in this country at the time of the first Severn Barrage report but, like the barriage itself, came to nothing. When the decision to proceed with Ffestiniog was taken in 1953 it caused some surprise but, from the number of Papers which had been written about it since, including the one now under discussion, it was clear that no one had had any regrets and that its performance, apart from providing increased output, had exceeded expectations.

97. In his Paper, the Author did not himself deal in detail with the economics of the scheme but referred to the appraisal in a paper by Booth and Kennedy in 1958.[5] Inevitably, any such examination also involved consideration of the system plant and load conditions which would apply when the actual scheme came into operation. It was on these aspects that he wished to make one or two comments.

98. In Fig. 8, the Author showed how demand on a typical winter day in 1962 compared with that on 24 January, 1963. The load growth shown could be satisfied in two ways. The more usual one was by the introduction of new high-merit thermal plant to meet demand at the base of the load curve, relegating all the older plant to satisfy loads higher up the curve.

99. The other way was to install pumped-storage plant to cope with the increased demand at the peak end of the load curve and leave the existing thermal plants to continue to give the same kind of service as before. This way of dealing with the matter would not be justified unless the cost of all the energy produced with pumped storage in the system was cheaper than without it.

100. Keeping in mind the attempts being made to flatten the top of the load curve, it was essential, of course, that the pumped-storage plant could continue to fill economically the part of the system load curve allocated to it and that there was always sufficient low-priced pumping energy available. In a well-planned generating system, there should always be opportunity to inject enough big thermal plants to ensure a sufficiency of low priced energy at night time and at week-ends. However, the ability to use cheap week-end energy for pumping required the provision of more

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storage and, consequently, placed a further restriction on the number of satisfactory sites.

101. What made the subject even more complex was the difficulty which Clark and Newman referred to in their address to the British Association in Aberdeen in 1963, when they pointed out that owing to the steep fall which had been taking place in the capital cost of conventional thermal power stations, a pumped-storage project had to shoot at what they described as a 'moving target' in any comparison exercise. At that time, their view was that the cost of a pumped-storage project would need to be in the region of £30/kW to be as economic as a new thermal station. This was considerably lower than the figures quoted in Mr Roseveare's Paper.

102. Meanwhile, thermal station costs had tended to become even lower, so that if a pumped-storage scheme was to have any chance of competing it might now need to be somewhat less than £30/kW. At such a cost suitable sites became increasingly difficult to find and even the Cruachan project, which, compared with Ffestiniog, had the advantage of the cheaper reversible plant and the lower excavation costs which went with it, would not be able to compete.

103. Fortunately, there was one site which was now under investigation which looked as if it might come down to the required figure. If it was to do so, it would be necessary, provided that no difficulties were created in matching the load curve, to repeat what was being done with the latest thermal installations and increase the size of plant and the scale of development. Only thus and by taking advantage of every technical advance in design and construction would it be possible to produce a scheme which was economic.

104. It was clear from what the Author, and others, had said, that the installation at Ffestiniog had proved to be effective and valuable. There was room in the national electricity supply system for more, equally well-thought-out, pumped-storage projects.

Mr J. Guthrie Brown (President, International Commission on Large Dams; Partner, Sir Alexander Gibb & Partners) said that as the new President of the International Commission on Large Dams, he had considered that it might be appropriate for him to confine his remarks mainly to the Stwlan dam associated with the Ffestiniog project. Unfortunately, on turning his attention to this major structure, he found that it had been rather summarily disposed of by the Author: one sentence on page 3, and one Figure on Plate 1.

106. However, with one or two straws and some clay, it was always possible to make a few bricks, and he thought it his duty to raise one or two questions which might be of interest to all who were concerned with large dams.

107. From the World Register of Dams—that invaluable record of nearly 10 000 dams, which had been on sale from 1 May—he had noted the number of large dams 100 ft or more in height in Gt Britain which had either been in existence during the last 25 years, were at present being built, or were at the projected stage. The number of these dams totalled 46, the types being as follows:

Rock fill	1
Concrete arch	1
Gravity and earth	2
Earth	13
Gravity	18
Buttress	11

108. Buttress dams, including massive buttress and multiple buttress, represented, therefore, about 25% of the total, while the conventional gravity dam predominated with about 40% of the total.

109. Sloy was the first massive buttress dam to be built in Gt Britain and since then, it was thought, seven of this type had been constructed to the design of the same firm of Consultants. In other words, they had concentrated wholly on this design.

110. He had seen Cruachan dam during May, on one of the study tours following the Large Dams Congress in Edinburgh. It was the latest of the massive buttress types and was still under construction—a most attractive dam and an excellent example of modern British design and construction. There was, therefore, one firm of consultants who obviously found that the massive buttress type had many advantages. During the same period, however, nearly twice as many conventional high gravity dams 100 ft and over were being constructed by other engineers in Britain.

111. Would the Author ascertain from his colleagues, from their extended experience in that type of dam, the average percentage saving in concrete, and the saving in cost, of the massive buttress type as compared with the conventional gravity dam? Also, could they give an indication of the saving in time, if any, with that type? This information would be of the greatest value to engineers in this country, and especially to those who might be considering a conventional gravity dam design.

112. A few changes had been adopted by the engineers in their design of massive buttress dams since Sloy was built in 1951. The batter of the front face at Sloy was 1 in 40, but in the later designs it had been gradually flattened to 1 in 7·4, as at Stwlan. There would appear to be advantages in adopting an even flatter slope.

113. It was noted that there had been changes in the wedge-shaped key-way which closed the arches of the massive buttress. At Sloy, it was a simple key-way with three bitumen-treated slots. At Stwlan, there were still the three key-way slots, but a flexible sealing-strip had been introduced in the upstream key-way. At Cruachan, however, both upstream and downstream flexible water stops were being provided, and in the centre a round bitumen plug, which was capable of being heated by electric wires incorporated in the bitumen.

114. His own firm had fitted that arrangement in the Errochty dam some ten years ago, with excellent results, except that the bitumen was steam-heated by a central pipe. In the Roseires dam now under construction across the Nile, they had fitted two flexible water stops and a central bitumen plug which was heated by circulating hot oil.

115. He was a great believer in belt, braces, and safety pins for sealing these joints in buttress dams. Any leakages through these joints without a bitumen plug capable of being softened by heating were almost impossible to seal off and looked most unsightly.

116. He asked the Author for further details of the final solution to the vortex problem referred to in § 19. The problem of vortex formation had been a major headache to his own firm on the Kariba scheme and was finally cured by a vertical baffle wall. It would be helpful it the Author could give a sketch showing the horizontal wall which he had favoured over the vertical wall suggested by the Research Laboratory.

117. At Errochty, Mr Guthrie Brown's firm held the record for some time for an unreinforced concrete tunnel subjected to very high water pressure. This tunnel, of 15-ft dia. with a 15-in. thickness of concrete, was subjected to a static pressure of 600 ft. It was post-stressed by grouting behind the concrete lining up to 900-ft pressure or 50% of the static load. It was a complete success.

118. The Ffestiniog tunnels were of only 10-ft 8-in. dia., with a thicker concrete lining of 18 in., and they were subjected to a static load of 800 ft. It would be interesting to know whether the rock behind the lining was post-grouted and, if so, to what pressure.

119. Finally, Mr Guthrie Brown greatly admired the Author's courage in omitting the automatic self-closing valves at the tunnel portal.

Mr E. J. K. Chapman (Senior Partner, James Williamson & Partners), who thanked Mr Guthrie Brown for his kind remarks, declared a special interest in the Paper, having been a member of the team concerned with the original planning and subsequent design and construction of the scheme since its inception in 1953. He wished to refer to some of the conditions that existed then and which influenced the layout and design of the scheme and also to developments which had subsequently occurred and would have a major bearing on the layout and capital cost of future plants of this type.

121. The original report discussed the construction of a 200-MW station consisting of four units each of 50 MW capacity, but pointed out that additional storage could be provided at reasonable cost, and it was decided to proceed with a 300-MW installation. There was some doubt at the time as to whether this should consist of six 50-MW units or four units of 75 MW each. There was no doubt about the availability of turbines of the larger capacity, but the pumps for the required head and output were well in advance of what had so far been manufactured. In fact, it might be said that the whole scheme, judged by size and duty, was at that time not only unique in Britain, but also in advance of what had been constructed elsewhere in the world. Since 1953, however, developments in pumped storage had been so great that Ffestiniog already looked rather out-of-date.

122. Undoubtedly, the most important advance had been the development of the high-head reversible pump turbine. With only a small reduction of overall efficiency, the installation of these machines enabled the capital cost of both machinery and civil works to be reduced very considerably.

123. He hoped that others would comment on the machinery, and he would mention only the obvious: that the use of a reversible machine saved both the cost of supplying and the cost of accommodating the following items in the power station:

(*a*) one complete hydraulic machine;
(*b*) the large coupling and associated shafts required for separate machines;
(*c*) one machine valve; and
(*d*) last, but not least, the high-pressure pumping branch and bifurcation from the main power penstock.

124. The reduction in size of machine hall that could be effected by the installation of reversible machines was very significant, as the following figures showed

(*a*) Ffestiniog, with four coupled pumps and turbines and a total uprated capacity of 360 MW, required 8·5 cu. ft of machine hall space per kW of capacity.
(*b*) The Cruachan scheme, at present under construction in Scotland, would contain four reversible machines each of 100-MW capacity operating under a head about 15% higher than Ffestiniog. The size of machine hall required amounted to 4·5 cu. ft/kW.
(*c*) Planning had begun for a future plant in Scotland with a head about 15% less than Ffestiniog. The proposed installation consisted of four reversible machines each of 300-MW capacity and the machine hall size was expected to be about 3·75 cu. ft/kW.

125. The second important development which was likely to affect the layout and cost of future pumped-storage plants, particularly those in the high-head range, concerned the increased use of concrete-lined shafts and tunnels at greater heads and with greater diameters.

126. High-head sites had always been attractive from the point of view that less water was being handled for a given capacity with consequent saving in reservoir and power station costs. Until fairly recently, however, they tended to be expensive in pressure shafts and tunnels owing to the reluctance of designers, probably influenced by Continental practice, to go beyond certain limits without resorting to steel linings.

127. When Ffestiniog was being planned, the combination of head and diameter proposed for the concrete-lined tunnels exceeded Continental practice and, so far as could be ascertained, was matched only by the Bersimmis plant in Canada which was then under construction.

128. As the Author had stated, the experience gained from Ffestiniog, both from the test galleries and from subsequent operating experience, including the 100%

overload, clearly indicated that in suitable rocks concrete-lined tunnels and shafts of larger diameter operating under greater heads could now be contemplated.

129. Although steel linings were usually designed to share the water load with the rock, the fact remained that as the power flow was increased, diameter was increased and it was also necessary to increase the thickness of the lining. The cost of the lining tended to vary directly with the power flow and became a greater proportion of the total cost as tunnel size was increased. This did not apply to concrete linings, where the whole of the water load was taken by the rock and the cost of the lining became a smaller proportion of the total cost as the tunnel size was increased.

130. The savings in cost which could be made were very considerable when high-head sites were developed on a sufficiently large scale. As the total cost of concrete-lined shafts and tunnels tended to vary as the square root of the power flow, it could be seen that if the plant capacity was quadrupled, the cost of the pressure shafts and tunnels might be only doubled.

131. He had mentioned only two significant developments which had occurred since Ffestiniog, the effect of which would be to reduce the cost of future schemes. The combined effect of these, together with other improvements and simplifications which now seemed acceptable, was that future high-head sites using large high-speed reversible machines could be developed at a cost well under the £43/kW required for Ffestiniog.

132. Several good sites existed in Scotland and one in particular, making use of the existing Sloy reservoir and Loch Lomond, had recently been studied in some detail. A total development of 1200 MW was proposed, consisting of four 300-MW reversible units, and the total estimated cost at present-day prices amounted to £25/kW. Good sites were not confined to Scotland alone and some could be found south of the Scottish border. Preliminary studies indicated that the best of these could also be developed for about £25/kW if the development was on a large enough scale.

133. Without taking account of its value for spinning reserve, the original economic assessment showed that Ffestiniog was justified when its capital cost was two-thirds that of equivalent thermal stations which were then costing about £65/kW. As was mentioned in the Paper, the plant is used for spinning reserve for a large proportion of its time, and this added considerably to its value. Although thermal plants could now be built for about £37/kW, future pumped-storage plants could still be constructed for two-thirds of this cost and more efficient spinning reserve capability could now be built in.

134. It was generally accepted in many parts of the world that a basically thermal system would benefit by the addition of a proportion of peak-load hydro plant, and where natural hydro resources were lacking, pumped storage made a very good substitute. The maximum proportion of pumped storage that could beneficially be injected into the thermal system depended upon system characteristics, but several authorities suggested proportions varying from 10% to 25%. When the 1800-MW Cornwall plant of the Consolidated Edison Co., of New York, came into full operation, it would amount to about 24% of their total installed capacity. In Scotland, the 400-MW Cruachan plant with 200 MW of existing natural peak-load hydro plant would together constitute about 13% of the total capacity.

135. Ffestiniog was the only pumped-storage plant south of the Scottish border and at present it amounted to only slightly more than 1% of the system capacity. It was the first of its type in Britain and it was now being followed by Cruachan. Both plants had attracted the interest of engineers from all over the world. The experience gained and lessons learned would undoubtedly influence the development and design of future plants which were being planned in many countries. In several ways, Britain had taken a lead in pumped storage when Ffestiniog was authorized, and it was hoped that it would be possible to maintain this lead by building bigger and more economical plants in the future within her own shores.

Mr J. K. Hunter (Consultant, Sir Alexander Gibb & Partners) said that he found it fascinating to compare the splendour and sophistication of the scheme described by the Author with the rustic simplicity of the nearby power station which was constructed in 1900 by a descendant of the founder of Yale University. That little station, which was only about a mile away from the pumped-storage plant, was probably the first hydroelectric plant to give a public supply in Britain, and after 63 years it was still feeding into the National Grid.

137. The Paper was, of necessity, highly condensed and there was much of interest that one would like to touch upon. It would, for example, be rather tempting to follow in Mr Fulton's footsteps and comment on the economic aspects of pumped-storage plants, but this might not be quite the occasion to do so.

138. As had been stated already, the economic case for Ffestiniog was dealt with fully in a paper presented by Booth and Kennedy[5] to the World Power Conference in 1958. In drawing up a balance sheet to show the financial saving in favour of the Ffestiniog scheme, the authors of that paper took into account the greater availability of hydro plant in comparison with conventional thermal plant. They did this on the basis that pumped-storage plant would have a winter load availability of 100% and an average annual availability of 95%. They compared these figures with those of 88% and 73%, respectively, for the alternative steam plant and by taking account of the difference in the power consumed by the auxiliaries in the two types of plant they reached the conclusion that 100 MW of pumped plant was equivalent to 120 MW of steam plant. Obviously, this was a very important conclusion in making any economic assessment. That estimate had been prepared more than six years previously and it would be interesting to learn whether the Board would wish to modify it in the light of experience since gained.

139. In that connexion, it was, perhaps, worth recording that when the Owen Falls scheme on the Victoria Nile was being discussed at a sister Institution about nine or ten years ago, he had himself quoted some figures relating to hydro power systems in three widely different parts of the world. He suggested at the time that an average figure of 95% was rather pessimistic and that experience in other countries indicated an availability very much closer to 100%. He was referring at that time to straight hydro plant with a turbine and generator only. A pumping plant consisting of three machines represented a more complicated assembly and, perhaps, it would be a little unreasonable to expect from it the very high availabilities commonly obtained from a normal hydro station.

140. As had been pointed out, there were many pumped-storage plants on the Continent, some of which had been in service for more than 30 years. There was therefore ample experience of the availability of such plant, and it would enhance the value of the Paper if actual figures could be quoted.

141. A feature of the Ffestiniog power station which was likely to impress the visitor was the very high degree of watertightness presented by the basement structure. In § 49 the Author had made a brief reference to the use of rubber water-stops to ensure watertightness and had added that certain leakages had to be dealt with by grouting. It would therefore seem that in spite of the very satisfactory appearance of the basement, its watertightness had not been achieved without the need for some remedial work.

142. It might be recalled that about five years ago an informal meeting was held in the Institution on the subject of water-excluding structures. Some of the speakers at that meeting felt that concrete was such an unreliable material that one should start with the assumption that it could not be expected to keep out water unless it was provided with an independent and watertight membrane.

143. At that meeting he had taken a rather different view, because he had in mind the watertight structures which he had seen in other countries; in particular, he was thinking of the Granby pumped-storage station in the Rocky Mountains. The conditions there were, perhaps, even more onerous than at Ffestiniog, because the basement of the structure was more than 130 ft below the level of the Granby Lake;

yet the basement was perfectly dry. It owed its success in this respect to the care taken during design and construction to avoid cracking. As an additional precaution, a comprehensive system of grout pipes was provided in all the construction joints, but the work had proved to be so satisfactory that they never had to be used.

144. To achieve watertightness in a complicated concrete structure, three requirements had to be met. First, it was necessary to produce an inherently impervious concrete, which today presented no special problem. The second requirement was to avoid the percolation of water along construction joints, which was a somewhat more difficult task, while the third was to prevent the development of cracks in the concrete. That last point was really the crux of the matter, because the avoidance of cracks could not be achieved without control of shrinkage and an accurate knowledge of the stress patterns set up in the structure.

145. He was, therefore, a little surprised to read in the Paper that the Author did not consider it practical to use such modern methods of structural analysis as scale models and photo-elastic techniques, because they were the methods which, among others, had been used so successfully in the design of the Granby plant.

146. After the meeting Mr Hunter submitted a further written contribution in which he emphasized that the problem of securing watertightness in complicated concrete structures was one of increasing importance. Since it was clear from the Author's paper that such problems were encountered at Ffestiniog, it might be of interest to describe in greater detail the special precautions which were taken at the Granby pumping station to ensure satisfactory results.

147. The plant formed an essential link in the Colorado–Big Thompson Scheme and its purpose was to divert the headwaters of the Colorado over the Continental Divide formed by the Rocky Mountains. It was completed in 1950 by the U.S. Bureau of Reclamation. The building was a cellular type of structure accommodating three vertical-shaft motor-driven pumps, drawing their water from Granby Lake and utilizing a draw-down of 94 ft. The pumphouse basement was 130 ft below lake level.

148. To make the pumphouse watertight under such arduous conditions, great care was devoted to the structural design in order to eliminate any risk of cracking. The final design was checked by trial-load analysis, and photo-elastic and stress-coat methods were also used to check the calculations.

149. Equal care was given to the measures designed to minimize construction stresses and prevent shrinkage cracks. Among these was the artificial cooling of the concrete for 7–10 days by means of embedded pipes.

150. As regards the concrete itself, the specification provided that:

(*a*) 'Darex' was to be used to produce about 4½% air entrainment;
(*b*) all concrete was to be vibrated within forms and construction joints built up level;
(*c*) construction joints were to be prepared by sand blasting;
(*d*) the maximum rate of placing was to be limited to 3 ft;
(*e*) the slump was to vary between 1 in. and 3 in. according to location;
(*f*) the concrete was to be cured with water sprays for 14 days; and
(*g*) all concrete work was to be carefully protected in freezing weather.

The average cement content was about 440 lb/cu. yd, although richer concrete was used in places.

151. Special care was taken to prevent water leaking at construction joints. For the most part Monel or stainless steel strips with gas-welded seams were used, but rubber waterseals were also used in some places. To make doubly sure that the basement would be completely watertight, a comprehensive system of grouting pipes was provided at all construction joints. So far, however, they had not been used.

152. To sum up, it could be said that the most important factors which had contri-

buted to the watertightness of the Granby sub-structure fell under the following heads:

(*a*) sound basic design and careful stress analysis;
(*b*) attention to the problems of construction, the avoidance of thermal stresses and the preparation of all construction joints; and
(*c*) good concrete control and inspection.

The last-mentioned was particularly important, for, however competent the design, the final result could be spoiled because of incompetent or careless execution.

Mr J. C. Dickinson (Partner, Messrs Preece, Cardew & Rider) said that although the Ffestiniog scheme had been very well documented, the Author's Paper was a most welcome one as opening another forum of discussion.

154. He wished to comment first on the Author's *cri de coeur* on the subject of clients who had extensive technical knowledge. Unfortunately, this was a situation with which practically all consulting engineers throughout the world were now faced. At times, the situation was a little difficult.

155. The Paper was positively pregnant with short paragraphs giving conclusions, any one of which would warrant a pleasant evening's discussion. The Author's conclusions appeared, however, to be backed by an extensive system of model testing and research and, therefore, they ought to be given very great respect. He would like to know whether the very reasonable sum shown for engineering, land, etc, included all the sums spent on research and model testing in connexion with the scheme.

156. Because of the very large number of subjects that could be discussed, he proposed to limit his remarks to two, the first being the matter of protection. In § 62, the Author referred to the use of metal spraying in cases where rubbing action might occur. Everyone knew that metal spraying was not simply a material which was put on the surface, and that there was interpenetration with the base metal, but could some information be given about how effective metal spraying had been against rubbing action? It was a problem that plagued everyone periodically.

157. Obviously, the protection of the pressure conduits had been given a great deal of consideration and a very good answer had been arrived at. Casting one's mind, back, however, to all the old hydro schemes in which ordinary mild steel was used and a coat of bitumen was applied—and a number of those schemes had been

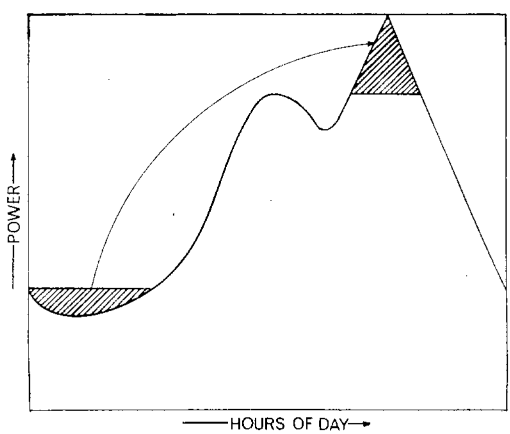


FIG. 26

running with practically no maintenance for a great many years—one wanted to know why so much was being done today. Everybody was spending a lot of money on the preparation of metal and on applying protective coatings of greater and greater virtue. Why? Had the actual constitution of the steels changed, had the makers of detergents been taking something valuable out of the bitumens so that they were no longer as effective or was everyone becoming more and more prudent in this matter? It was difficult to understand.

158. The scheme had quite clearly been a success. It had been very well documented and it had brought much credit to Britain throughout the world. There was, however, the fear that as a result, a pumped-storage scheme would become something in the nature of a status symbol which every power undertaking in the world must have if it was not to feel left out.

159. It fell to the Institution to make clear what ends a pumped-storage scheme really achieved so that wildcat schemes would not be propounded. The value of a pumped-storage scheme was threefold: as a spinning reserve, to iron out the top part of the load curve and as a peak lopping device.

160. Taking those three factors separately in the reverse order, he suggested that the original conception, and the one which was obviously applicable where one had spare base load capacity (either run-of-the river or, as conceived in Britain, nuclear) was to convert it into peak as shown in Fig. 26. That was not really the whole story; possibly, in the case of Ffestiniog, it was not the story at all.

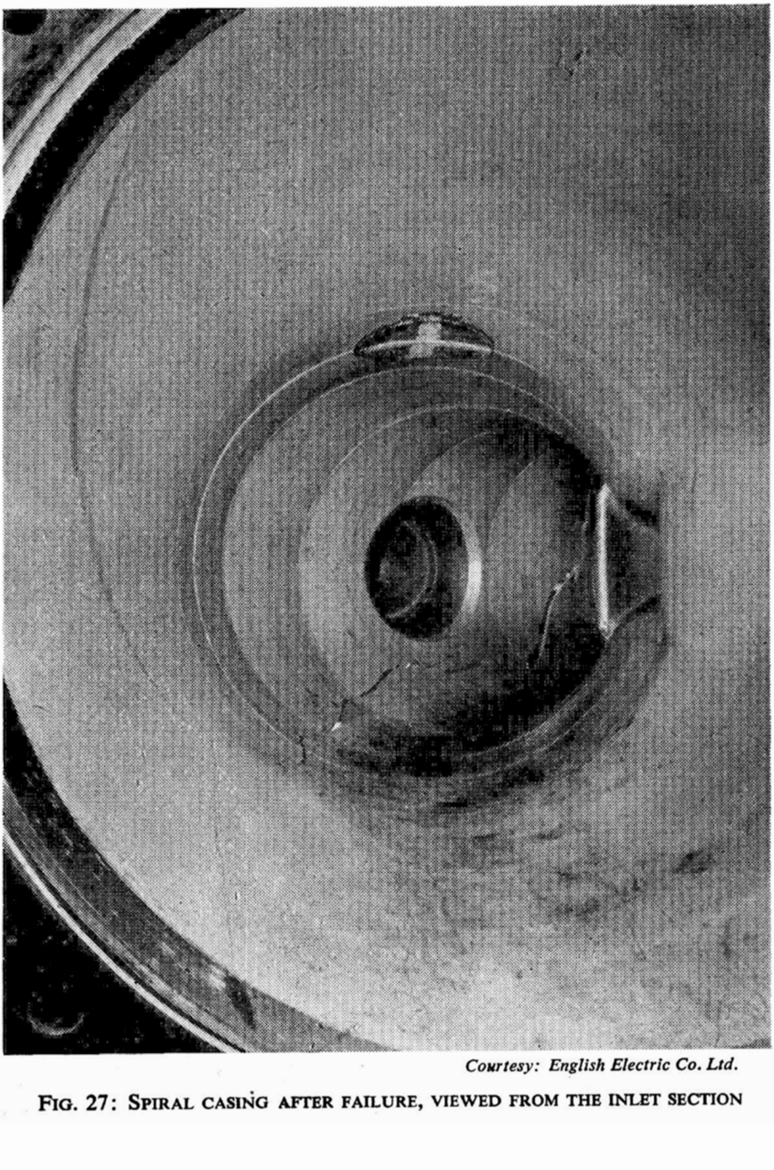
161. Further, in connexion with major peak lopping there were two other conditions to bear in mind: first, whether there were alternative types of peak-lopping plant which could compete, and which had to be given serious consideration; and secondly, whether every system which had a substantial part hydro and a substantial part thermal—where the hydro had material storage and the thermal plant, as was usual, was placed nearer to the load centre—already had a pumped-storage scheme capable of operating, not at 72% efficiency, but at something over 100% efficiency. It did this by simply not using the water and saving the transmission losses from the hydro scheme to the load centre. Given those circumstances, therefore, there appeared to be no case for pumped storage.

162. Considering the other two factors, it was most impressive that for ironing out the load curve and to create spinning reserve, the functions of pumped-storage schemes were practically double their installed capacity. This was a very powerful weapon indeed. Was not the very success of Ffestiniog due, however, in large measure to the fact that the actual installed capacity was, roughly speaking, half of the largest item of the plant on the system and, therefore, it was an ideal spinning reserve to balance the loss of one major unit?

Mr H. Headland (Consultant, Messrs Kennedy & Donkin) said that he wished to fill in some of the highlights in the Author's excellent Paper. The failure of a spiral casing during works pressure testing was referred to in § 29. Fig. 27 was intended to serve as a warning against overconfidence from previous successful experience with high tensile steels. The failure was extensive, and it was associated with the outlet to the pressure relief valve. The photograph was taken from the inlet of the casing. The failure was on the last of four casings and could be attributed to an unfortunate combination of circumstances associated, among other matters, with materials, metallurgy, and welding techniques, which could usefully form the subject of another paper.

164. Fig. 28 was an illustration of the breeches pipes referred to in § 34. The top leg went to the turbine, and the steeply descending pipe went into the pump discharge. The pipes were fabricated in a high-tensile steel, pressure tested in the works and were subsequently welded on site to the legs and to the pipeline upstream. The ultrasonic examination of the site welds was not wholly satisfactory and for field acceptance was supplemented by gamma radiography, using caesium No. 137.

165. Cavitation damage was an important aspect of turbine and pump operation and maintenance. At the last inspection in September 1963 there were no traces of damage on the turbine runners and only slight signs on the upper first stage pump impellers. A typical example, illustrated in Fig. 29, showed how slight it was. The pitting which could be seen in the corner was due partially to blade irregularities and possibly to flow conditions into the impeller rather than an inadequate suction setting. There was no damage on the lower first-stage impellers.



Courtesy: English Electric Co. Ltd.

FIG. 27: SPIRAL CASING AFTER FAILURE, VIEWED FROM THE INLET SECTION

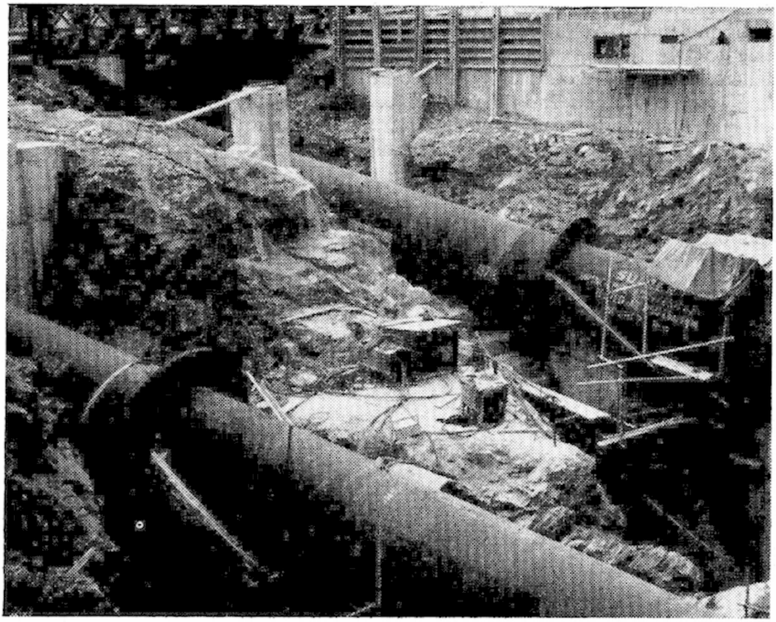


FIG. 28: TURBINE/STORAGE-PUMP BREECHES PIPE AT SITE-WELDING STAGE

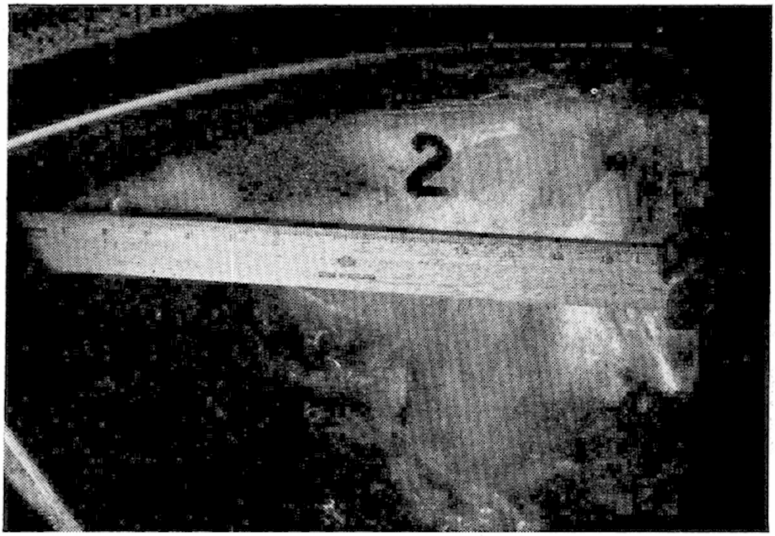


FIG. 29: SLIGHT CAVITATION DAMAGE ON NO. 4 STORAGE PUMP UPPER SUCTION IMPELLER BLADE

166. The estimated rate of metal loss, based on plaster cast measurements since commissioning was worth noting. On No. 1 pump, which had been in operation for 2786 hours, the loss was 0·0009 lb/h. On No. 2, the running hours were 2321 and the estimated loss was 0·0007 lb/h. On No. 4, running time was 1319 hours and the loss 0·0004 lb/h. Blade dressing and weld repairs should in due course reveal interesting comparative results using the undamaged blades as a reference. The electrodes used for these repairs were chromium nickel alloys.

167. Two blades had been repaired with an 18/10 electrode. One blade had been dressed and one blade had been profiled to the reference blade. Two blades had been repaired in 25/20 electrodes and one blade in 17/14 electrodes. Two blades had had the profiles corrected only and four blades had been left untouched. Incidentally, the parent metal was 13% chromium steel.

168. The proposal to embed the pump casings, mentioned in § 43, basically emanated from the Consulting Engineers' experience with high-head Francis turbines. Because pumps introduced flow deceleration, which always tended to instability and vibration as compared with stable acceleration in turbines, it was considered logical to surround the pump casings with concrete.

169. Paragraph 55, dealing with vibration, was, perhaps, a little too generalized. Unless care was taken, vibration could be generated at partial and overloads by draught tube phenomena and turbine-runner and pump-impeller, blade and guide vane combinations. Such disturbances could be transmitted to the water in the system and care was, therefore, taken in the early stages of design to check on these and allied considerations.

170. In § 38 it should, perhaps, be stressed that a characteristic of harmonic resonance and water hammer which could occur with the machine at standstill and isolated was that it was propagated unattenuated through the whole system and was, therefore, particularly dangerous, especially as, broadly speaking, it could not be predicted. The Paper gave the impression that this possibility might have been overlooked, but, in fact, on the basis of experience elsewhere, the problem was under consideration some time before the incident occurred and devices were now provided for the prevention and stopping of such dangerous oscillations.

Mr G. A. J. Young (Senior Research Engineer, British Hydromechanics Research Association) said that he wished to speak about the model experiments that were conducted by the British Hydromechanics Research Association at Harlow and to which reference had been made in the Paper.

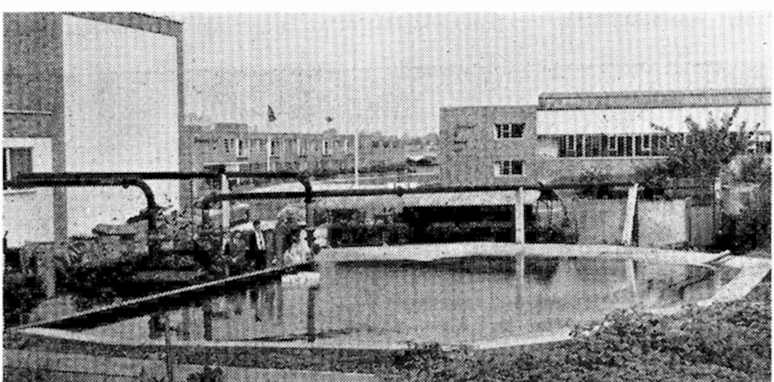


FIG. 30: GENERAL VIEW OF 1/30 SCALE MODEL OF STWLAN RESERVOIR

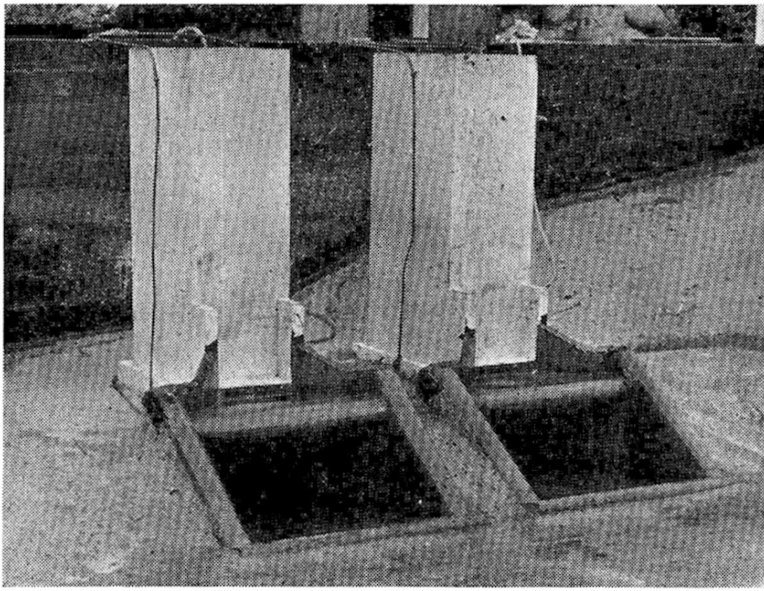


FIG. 31: MODEL OF ORIGINAL DESIGN OF INTAKE

172. Fig. 30 was a general view of the 1/30 scale model of the Stwlan reservoir which was used to study the vortex problem at the two intakes. Fig. 31 showed the model of the original design of intake and Fig. 32 showed an example of the vortex problem which was associated with the design of intake. Examples of the fairly large vortex could be seen. The conditions under which the photograph was taken were a depth of the equivalent of about 10 ft of water above the intake and a velocity through the model intake of 10 ft/s, which corresponded with the full-scale velocity.

173. The basis of scaling the vortex models was still somewhat dubious and the principle adopted at Harlow was to test the model over the full range of velocities from zero up to the equivalent full-scale velocity and over the range of operating water depths. The next step was to plot a diagram of water level against velocity, on which

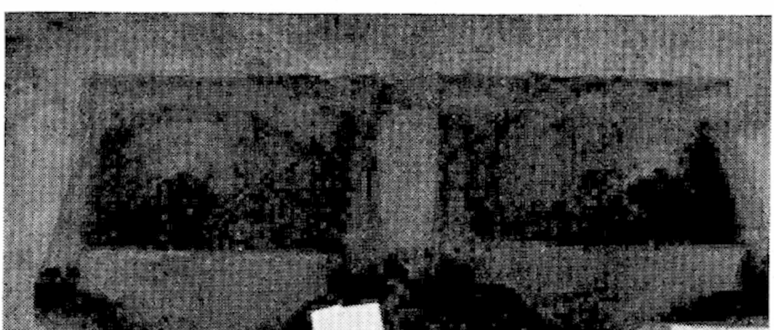


FIG. 32: VORTEX FORMATION WITH ORIGINAL DESIGN

were marked points representing conditions at which vortices either did or did not form. It was then possible to draw a boundary curve between those points of the form shown in Fig. 33. In small scale models the submergence required to prevent air entrainment at the Froude scale velocity would be very much lower than that required at intake velocities in the model equal to the full scale velocities. The true velocity scale relationship was somewhere between these two points and was dependent upon actual model scale.

174. Fig. 34 showed the first remedy recommended, to which Mr Guthrie Brown had referred: a vertical baffle wall above the upper lip of the intake. This was effective, but the wall would have had to be of the order of 70 ft high on the Ffestiniog scheme. This was considered to be rather impractical. Therefore, the alternative remedy which finally was adopted was, as shown in Fig. 35, in the form of a horizontal canopy above the intakes. It was shown also in section in Fig. 11 of the Paper.

175. It was understood from the Author that the prototype flow patterns were very similar to those observed on the model and that no air entrainment had occurred in practice. This was rather encouraging to those who were responsible for the model tests.

176. The second part of the model investigation for which the British Hydromechanics Research Association at Harlow was responsible were the model tests of the intake and the bend and bifurcation at the foot of the shaft. The arrangement of the intake was shown in Fig. 11 of the Paper. The original design did not have the faring which was shown at the top of the shaft just downstream of the stony roller control gate. With that arrangement, the head losses in the intake alone, through the pressure screen and up to the control gate, were very small, less than 5% of the shaft

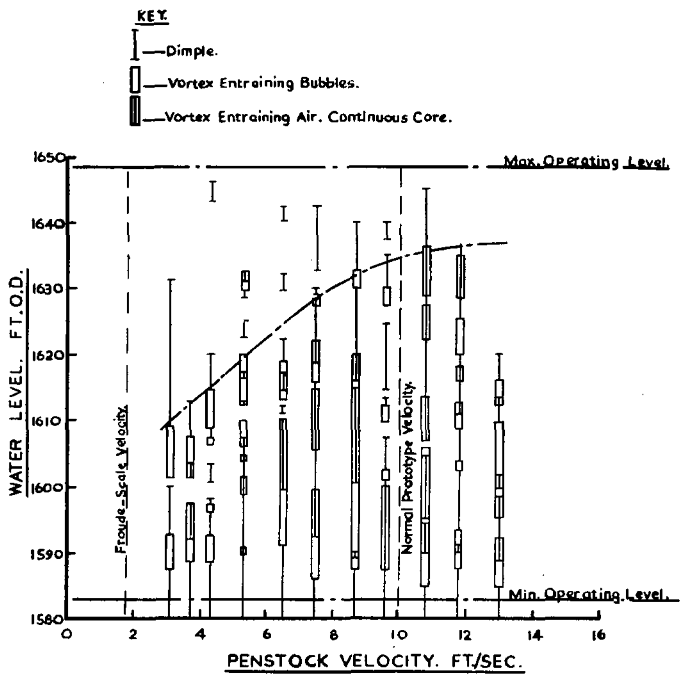


FIG. 33: RELATIONSHIP BETWEEN WATER-LEVEL AND PENSTOCK-VELOCITY

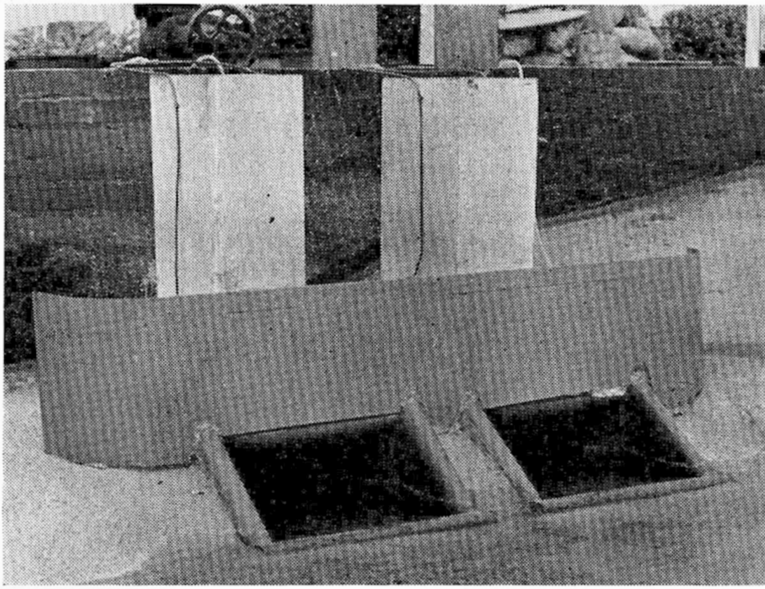


FIG. 34: VERTICAL BAFFLE WALL MODEL

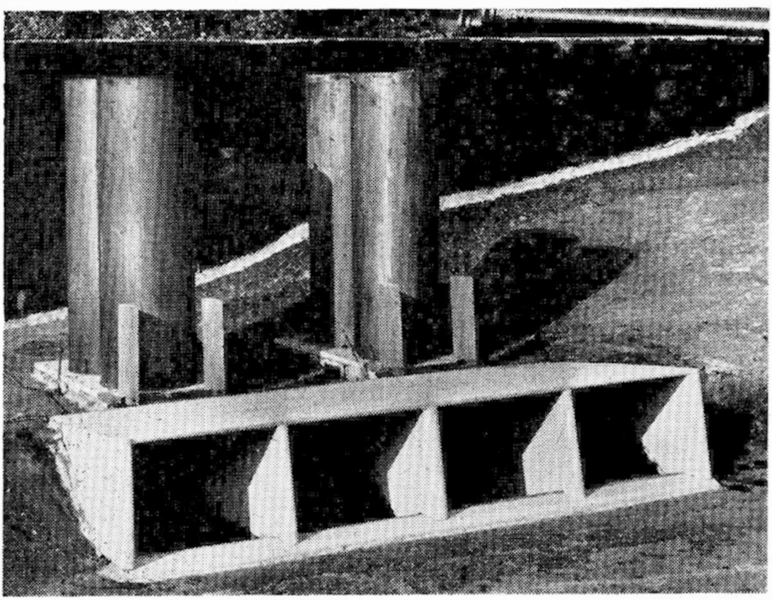


FIG. 35: HORIZONTAL CANOPY ABOVE INTAKES AS FINALLY ADOPTED

velocity head, but the losses in the bend were about 63% of the shaft velocity head, or about 1·6 ft head of water.

177. By introducing the rather simple faring shown in Fig. 11, together with the faring on the wall of the shaft just below the level of the intake, those losses were reduced to 28% of the shaft velocity head, or about 0·7 ft. Although this saving in head loss might sound quite small, it was equivalent to about 400 hp.

178. The model was tested for pump operation as well as for turbine operation with the flow coming up the shaft and out through the intake. This condition was rather bad on the Ffestiniog scheme, because no attempt was made to provide a diffuser after the bend. The losses under that condition were approximately equal to one complete shaft velocity head, which was about 1·3 ft under the maximum load condition.

179. Talking after the event and with the benefit of more recent experience, Mr Young was now able to suggest a design for the intake which would have the same sort of loss for turbine operation and which could well have a loss of about 30% of the shaft velocity head for pump operation. This would save approximately 0·8 ft under pump operation, corresponding to about 150 hp.

180. Mr Dickinson had mentioned the cost of model tests. Speaking offhand and subject to later confirmation, the cost of the hydraulic model tests for which the Research Association was responsible was about 1/2000 of the £15 million total cost of the scheme. The part concerned with the reduction of head losses in the system was, possibly, one-half of that amount, or about 1/4000. The increase in output resulting from these tests was greater than 1/1000. It was, therefore, clear that the expenditure on the model tests was well justified.

Mr V. G. Newman (Hydro, Industrial and District Heating Engineer, Central Electricity Generating Board) said that he proposed to confine his comments to one point made by the Author concerning the economics of the scheme. First, however, he wished to say that since the first machine was commissioned in December 1961, Ffestiniog had more than fulfilled expectations on the score of performance, reliability, and versatility for purposes of system control. The Author and his colleagues in the three firms of consultants concerned in the engineering of the project were to be congratulated on having produced an outstandingly successful power station for the C.E.G.B.

182. The Author had referred to the changed operational regime of the station since the scheme was originally planned, notably the increased plant utilization factors. This change was accounted for by two main factors. The first was that operating experience had demonstrated the usefulness of the plant for following variations in system demand so that extended part-load running outside peak periods had been found to be operationally expedient even when this was not strictly in accordance with the economic merit-order plant loading.

183. The second factor was that the growth of system load in recent years had exceeded earlier predictions and had necessitated the increased use of old thermal plant for peak load duty. As a result there were more days in the year when Ffestiniog could be used to replace higher-cost thermal generation.

184. A rough estimate showed that because of the changed conditions of operation, Ffestiniog was currently making a net saving of about £½ million per annum compared with the earlier estimate of only £200 000. The figure might be expected further to increase as more efficient conventional plant became available for supplying energy for pumping. Eventually, when sufficient nuclear plant had been installed, the pumping energy would become available at much cheaper cost and the savings effected by pumped storage would again increase substantially.

185. The reference in the Paper to the favourable siting of Ffestiniog in relation to Trawsfynydd was somewhat misleading. Ffestiniog was planned before the Trawsfynydd nuclear power station was thought of and was in no way dependent

upon it economically or operationally. It was only when the aggregate nuclear capacity on the system exceeded the minimum night load that nuclear stations would be able to operate directly in association with pumped storage.

186. As a result of its experience with Ffestiniog, the C.E.G.B. was now fully convinced of the value of pumped storage in a predominantly thermal system, and it would be reassuring to Mr Chapman to know that the Board was thinking about embarking on a further project in the fairly near future.

Mr J. G. Warnock (Manager, Hydroelectric Division, English Electric Co. Ltd, Netherton) said that the Paper recorded an excellent collection of engineering facts covering design, installation and operation of the first major pumped-storage scheme in Gt Britain. As a plant manufacturer, he would like to endorse the Author's view regarding the happy co-operation which existed on the project throughout the engineering and construction. The additional value of Ffestiniog's contribution to the C.E.G.B. system over and above that foreseen at the time the scheme was planned was particularly interesting.

188. The Author had referred to the hot standby duty on which it was envisaged that Ffestiniog would be operated largely in the months of March to November. In the design stage it was established that with automatic sequence control, full output could be obtained from rest in under five minutes. The additional value of spinning reserve was, however, very significant from the early days of commissioning of the station. By ingenious modifications to the controls and the operating sequences of the turbine and its valve, spinning reserve losses for the whole station had been later reduced by about 16 MW to 5·25 MW and full output of 360 MW could now be obtained in about 50 seconds at the expense of only a very moderate energy loss while the units were spinning and available for this duty.

189. It now appeared, however, that future pumped-storage plants or conventional hydroelectric plants used in the same manner as Ffestiniog on spinning reserve might have to achieve loading time substantially shorter than that achieved at Ffestiniog. The demand for very rapid loading arose from the critical needs of the system should a major generating unit or transmission line drop out of service.

190. His company had been studying possible means of accelerating the speed of loading and had found that with a water conduit system laid out with that prime object in mind, a 15–20 s loading might be feasible. It remained now to evaluate the contribution to the system of, say, 1000 MW of spinning reserve at this rate which would have a very high degree of reliability, as Ffestiniog was at present demonstrating.

191. The alternative source of the spinning reserve capacity was partially load thermal sets of, say, perhaps, 4000-MW total capacity operating at only 3000-MW load and able to contribute the remaining 1000 MW of capacity within 5–10 s of demand. It might be that timings of this sort were of little more benefit to the systems than the 15–20 s from alternative hydroelectric sources. The hydroelectric sources did not suffer from the thermal inertia of the boilers which might make it difficult to sustain the increased output from the steam turbine generating plant.

192. Pumped-storage installations under a head of the order of 600 ft, operating without inlet valves, might give the optimum rate of loading. If rapid loading was recognized as a principle of design from the outset, designs of 1000-ft head, such as Ffestiniog, could accommodate these requirements.

193. Mr Headland had presented the somewhat alarming illustration (Fig. 27) of a Ffestiniog turbine spiral casing with a serious fracture in the shell plate. This spiral casing had failed on hydrostatic pressure test at about 800 lb/sq. in. Following the failure a most exhaustive investigation was carried out. The extensive failure was due to a brittle fracture which occurred in plates which suffered from centre-line segregation and low ductility. The fracture was initiated by an undetected crack in a weld in one of these plates in an area of relatively high stress. The other units,

which by that time had been successfully fabricated, pressure tested, and installed, were all very thoroughly re-examined to make sure that no similar failure could take place.

194. It had to be accepted that the failure had brought into prominence the vital importance of plate quality and tests to prove this, the need for scrupulous examination of fabrications for cracks and the necessity for adequate hydrostatic pressure tests in the shop.

Mr C. D. Crosthwaite (Messrs Freeman, Fox & Partners) remarked that the one person to whom the Paper could not make acknowledgment for the work done on the project was the Author. Mr Crosthwaite did not know how the work could have been successfully carried out and the project commissioned in time without Mr Roseveare's invaluable help from the very outset. Throughout, they had been faced with tremendous difficulties and the need for improvization. Since the scheme was a new one, there were changes in plant design and layout, which meant that the civil engineering design could not be finalized as early as it should have been. This entailed a continuous process of rethinking, both in London and on the site, to ensure that there was no falling behind. The fact that substantially dates were met could be attributed very largely to the Author.

196. The Author had stated that a new scheme could probably be commissioned and put into effect within five or six years from its inception, and this was probably true. It might therefore be asked how it was that the Ffestiniog scheme was first thought about in 1953 but was not commissioned until 1963. There were a number of reasons for such a long time-scale. One was that it was the first project of its kind. Secondly, the Author had left out of his time sequence the long period that was taken up by Parliamentary procedure. Until a Bill had passed through Parliament, a client was reluctant to spend much money or to ask anyone to do so on genuine design. Furthermore, there had been a period of retrenchment when, for a whole year after a start had been made, the Government decided that nothing should be done, as a result of which it was necessary to restart virtually from scratch. Thus, although a five or six-year time scale was correct, there were sound reasons why Ffestiniog took longer.

The following contributions were received in writing:

Dr J. Allen (Lecturer in Civil Engineering, Queen Mary College, University of London) was interested in Mr Young's remarks concerning the scale-model investigations into the development of vortices, and particularly in his references to the appropriate scale of velocities to adopt in such tests.

198. Recent experiments at Queen Mary College had proved to be rather inconclusive, but seemed to indicate that, as regards the effects of vortex motion in orifice flow, there was no clear-cut velocity scale such as was provided by the use of the Reynolds Number or the Froude Number in other types of model investigation.

199. On the occasions when a fully-developed vortex core was formed above the horizontal orifice, the head, and therefore the velocity, varied irregularly with the diameter of orifice; in the case of orifices of very small diameter, of the order of 0·5 in., it was extremely difficult to initiate any vortex motion unless preliminary stirring had taken place. Certainly the head at which a vortex core extended from the water surface to the orifice was not proportional to the diameter of the orifice.

200. As Mr Young had stated, the problem of choosing the correct corresponding velocity was by no means well understood, and it seemed that that was yet another illustration of the need for fresh research into the scale-effects associated with models of various types.

Mr C. A. Gillott (Manager, Civil Engineering Division (Home), The Cementation Co. Ltd) observed that Mr Roseveare has succeeded in covering all aspects of the

Ffestiniog pumped-storage scheme in a most precise and interesting manner. He was to be complimented on his courage in presenting, in a single Paper, such a broad description of a relatively new approach to the control of power supply. Mr Gillott's company was proud to have been associated with the project.

202. It is noted that the Pumped Storage Scheme developed from a proposal to construct a conventional hydroelectric station. Because of the very small catchment area of the upper reservoir—some 160 acres—it would be interesting to know what size and type of scheme had been intended originally?

203. In view of the benefits offered to power supply by pumped-storage schemes, which were, in effect, very large accumulators, one began to ask whether there were many sites in Britain suitable for such schemes? The essential requirement would seem to be the fairly close siting of an upper and lower reservoir. An adequate rainfall, required for a conventional hydro scheme, did not appear to be necessary, except perhaps for the initial filling of the reservoir. Possibly some Scottish schemes offered the most likely prospects, although the installation of pumps in existing power stations might not be possible. It was believed that provision was to have been made for pumping on the Lawers Scheme, with which his Company was closely associated, but this was not incorporated in the completed scheme.

204. The Ffestiniog pumped-storage scheme was like most large power-supply projects, in that early completion was most desirable. With this objective in mind from the very start of the design stage, it was inevitable that certain conflicts would arise between the need to spend time and money seeking full information for design purposes and the wish to start construction work as soon as possible. Additional knowledge of the detailed geological structure of the site might have persuaded the designers to resite the Stwlan Dam and so eliminate the need to construct a substantial toe trench to connect the buttresses. Greater knowledge of ground conditions might have avoided amendments to the intake towers during construction and might have suggested alternative routes for the tunnels with a resultant saving in tunnel supports.

205. On the other hand, opportunities to save time were taken during the planning of the various phases of the project. The construction of the access roads to the upper works prior to the letting of the contract for these works was an excellent example of such savings. The excavation of the foundations of the power station was included in the contract awarded to the main contractor for the Stwlan Dam to enable work to proceed whilst the design of the station was being completed. The drawings supplied for the excavation were of a preliminary nature and were amended frequently during the course of the work. The completion of this excavation was carried out by the power station Contractor simultaneously with the establishment of his site offices.

206. Since the scheme was sited in the Snowdonia National Park particular attention had to be paid to preserving the amenities of the area. Although the need was appreciated, it was considered that sometimes there was a tendency to go too far in favour of such preservation. Certainly it did not take long for local interests to realize their advantageous position and to seek benefits not necessarily connected with the power scheme. Very often engineering decisions were influenced by consideration for the amenity value and Mr Gillott wondered whether it was necessary to reduce the length of steel pipelines visible on the mountain side, so altering the level of the tunnels. The subject of amenities was discussed in the House of Commons but, when discussing it, had the Honourable Members taken account of the innumerable slate bings, derelict farms and abandoned property in the area?

207. On the project, located in one of the remoter parts of the United Kingdom, the recruitment and retention of good labour was never satisfactory, and, as pointed out by the Author in § 71 there were numerous problems. The nearness of the Trawsfynydd nuclear power project exacerbated the labour difficulties and also encouraged the labour organizations to take advantage of the situation to further their own ends in seeking, among other things, enhanced wages and a guaranteed bonus.

Although the contract conditions required the Contractor to give priority to the employment of local labour, most of the men available for work in that part of Wales were slate quarrymen who were not used to the techniques of modern civil engineering construction.

208. Finally, Mr Gillott wished to mention the excellence of the supervision and control exercised on the project by the Consulting Engineers employed by the Central Electricity Generating Board. Relationships on site between the representatives of the Contractors and the Engineers were very good throughout the period of the contracts.

Mr D. A. Brown (Sir Murdoch MacDonald & Partners) was particularly interested in the penstock system and he welcomed the publication of Fig. 12. He observed that sections of the penstock had been brought to the site whole in order to avoid longitudinal site welds; perhaps this might have added to the cost. He had had experience of a larger steel penstock where the cost of bringing whole sections some 250 miles to the site would have been high. In that case the specification for the work stated that the pipe sections were to be hydraulically pressure-tested before being taken into the tunnel.

210. The steelwork contractor brought curved plates to the site and then welded them into pipes. The completed pipes were then successfully hydraulically pressure-tested on a core shaped rather like a straw hat. This enabled the test to be carried out with a small fraction of the volume of water required to fill a completed pipe section: it had the further advantage that the axial loads to be resisted during the test were substantially reduced.

211. The Author indicated that Coltuf 32 had been used: was this steel used throughout the penstock? Had any stress-relieving of the penstock been done on those sections where the outside of the pipe was exposed, i.e. at the portal access chamber and adjacent to the pump and turbine valves?

212. Condensation always made the application of the protective coating to the inside of the pipework a difficult operation and it would be interesting to know what, if any, special measures were adopted in view of the long curing period for the protective coating.

Mr P. L. Maloy (Sir Alexander Gibb & Partners) remarked that on the Tan-y-Grisian Dam free discharge regulators of the Howell-Bunger or Sleeve type had been adopted. It would be interesting to know why this type of valve was used and whether model tests were carried out to determine the angle and spacing of these valves. It was appreciated that hollow jet or needle-type valves would be an expensive solution, but was consideration given to a jet-flow type gate and, if not, did any consideration other than cost determine the adoption of sleeve-type valves? The section shown in Fig. 7 suggested that there could be problems of spray on the operating house, taking into account the wide angle of dispersion of the jet. Mr Malay wondered whether any such problem had arisen during operation and whether any vibration had been experienced when the valves were discharging fully open.

214. Although the names of manufacturers were listed for the main items of plant in the power house, similar information was not included for the valves, pipework, gates, screens, etc. Perhaps the Author could publish this additional information.

Mr F. W. Coates (Resident Engineer, Trawsfynydd Nuclear Power Station Site) remarked that Fig. 21 demonstrated very clearly the time scale involved in the pioneering project at Ffestiniog, once the decision had been taken to proceed, but, as the Author had mentioned, the initial conception went back to December 1963. Some 9½ years were involved from start to finish, including about 1½ years before the authorizing Bill received the Royal Assent and construction could proceed.

216. Fig. 21 showed that capital expenditure was incurred on a considerable scale for some 8 years before there was any return from the commissioning of the first set. A reduction of 5 to 6 years overall as suggested by the Author in his conclusion would be well worth while and of great financial value to the client.

217. It seemed to Mr Coates, however, that such a reduction would have to come largely in the period of construction rather than in the initial development stage, and pumped storage, with its larger proportion of civil engineering site work than was involved in a conventional power station of a similar capacity, would seem to offer great scope for a reduction in construction time. Mention of hydroelectricity or pumped storage stirred strong feelings throughout the length and breadth of the British Isles, and although objections to the Ffestiniog scheme on amenity grounds were limited, nevertheless the negotiations with the many interested parties at the development stage were prolonged. Having regard to the rigid procedures involved in the promotion of a private Bill and its passage through Parliament, it was difficult to see how the 18 months required at Ffestiniog could be reduced to any great extent on a future project. It would also be hazardous to proceed with the detailed design of the project and the preparation of detailed specifications concurrently with this approval stage, for conditions involving quite radical changes could be imposed on the project almost at the very last moment. For example, Ffestiniog was opposed at the second reading stage in the House of Commons as late as July 1955.

218. The natural advantages of the site at Ffestiniog, with suitable reservoir sites less than one mile apart in plan, but with 1000-ft head difference between them, and suitable foundations for the power station alongside the lower reservoir, were obvious, but the limited effect of the project on the amenities of the area also played a part in its selection as the first pumped-storage project to be developed in the CEGB system. On the experience gained on the small extensions of the existing hydro stations in North Wales which were in progress at the time, the Board included an amenity clause in the Parliamentary Bill for Ffestiniog. Among other things, it required the Board to have regard to 'the preservation for the public of the natural beauty of the district' and 'to the enjoyment thereof by the public', and also to appoint a landscape consultant.

219. Although it had now become almost standard practice to appoint a specialist adviser on landscaping on power stations and other large industrial projects, Ffestiniog was probably the first to include such an appointment from the outset. It might be of interest to note that in 1963 the CEGB was awarded a Certificate of Merit by the Welsh Tourist Board for its contribution to tourism in Wales arising out of the works at Ffestiniog and the facilities afforded to visit the Stwlan Dam.

220. That the final result should have proved so satisfactory was in large measure due to the very close collaboration between Engineer, Architect, and Landscape Consultant which prevailed throughout the job. Mr Coates wished to add a word in defence of landscape and amenity advisers, not that they really needed his support, but far too many engineers still took the view that they knew all that needed to be known about amenity and landscaping. In his experience those who expressed this view most strongly tended to be those most in need of a landscape consultant's advice.

221. With regard to costs, it was of interest to note that the final cost per kilowatt, excluding transformation and transmission costs, was approximately £39 when the bonus of 60 MW of uprating was taken into account, i.e. the same as the original estimate made in 1953. It was a rare example of uprating of plant keeping pace with inflation!

Mr C. W. Wolley (Messrs Freeman, Fox & Partners) said he had been closely associated with this scheme from the initial survey until a late stage of construction and appreciated the problem of condensing all that might have been written into one paper. He congratulated the Author on covering most aspects of the scheme but would like to contribute one or two details.

223. The use of Colcrete for the embedment for the turbine and pump spiral casings had been very successful. The colloidal grout was mixed in the following proportion:

Cement	112 lb.
Pulverized fuel ash	28 lb.
Leighton Buzzard sand	220 lb.
Colplast W.E.	5·32 oz.

Typical strengths obtained from grouted 8-in. test cubes were as follows:

7 days	3500 lb/sq. in.
28 days	3850 lb/sq. in.
42 days	5200 lb/sq. in.
200 days	7125 lb/sq. in.

A cube test at 24 h, cured at 140°F, gave 4050 lb/sq. in.

224. During the post-tensioning of the strands surrounding the penstocks, strain gauge tests on the steel linings showed that the maximum amount of prestress induced in the steel was about 0·5 ton/sq. in. This was not uniform, however, owing to the considerable loss of tension in the strand, which tests prior to construction showed to be of the order of 45% at the bottom of the loop.

225. Mr Wolley said that the short period available for construction had been referred to in the Paper and another factor which had added to the Contractor's difficulties was the very compact dimensions of the station. Although the dimensions might be adequate to house the plant on completion, the difficulty of access during construction with such a complicated structure could be underestimated. It had been necessary to complete the substructure perimeter walls and superstructure steelwork very early to enable the roof to be placed to allow plant erection to start. Work in progress on adjacent units might be separated in elevation by as much as 60 to 80 ft, and as both the turbine and the pump foundations were suspended structures, shutter fixing was a complicated task.

226. Would the Author say how the original construction period for the station compared with that actually available? Could he give an estimate of the saving in cost of the work if the commissioning dates had been put back, compared with the loss in revenue which the Board would have incurred by not having the station in commission?

Mr V. B. Chandorkar (Engineer, Bombay Sub-Office, Messrs Bertlin, Wildon and Bell, Consulting Engineers) was proud to say that he had been closely connected with the construction of the tunnels and the buttress dam at Stwlan, as he was Assistant Engineer for 2½ years on the staff of the Resident Civil Engineer.

228. In congratulating the Author on his comprehensive account of the Ffestiniog scheme, Mr Chandorkar was, however, surprised to read that he had not mentioned the installation of strain gauges in one of the buttresses of the Stwlan Dam. There were 35 Maihak-type vibrating-wire transmitters concreted into the buttress at various points to find out the stress distribution and temperatures. Periodically, the measurements of these strain gauges were taken, both during the construction of the dam and after its completion, at various water levels in the lake during operation cycles of the station. The results of those measurements had been analysed and a paper entitled 'Measurements of strain and temperatures in the Nant-y-Moch and Stwlan buttress dams' was presented by Crosthwaite, Lonergan and Campbell at the Eighth Congress of the International Commission on Large Dams held at Edinburgh. Would the Author care to make any comments on the stress distribution in the dam in the light of the information now available?

229. Referring to Fig. 10, Mr Chandorkar would like to know why it was necessary to provide two horizontal bends at the tunnel portal at ch. 811.46 and at ch. 720.0. Those bends naturally created problems as regards their fabrication and

setting out on site. It was also necessary to construct massive prestressed-concrete anchor blocks with 200-ton special cables to withstand the forces at the bends. Why was not the alignment of the tunnel pipeline and the penstocks simplified?

230. Secondly, why was the access chamber situated so far away from the power station and at such a high level? Would the Author say whether the possibility was ever considered of increasing the depth of shafts and increasing the length of tunnels (thereby reducing the lengths of the prestressed-concrete penstocks) and locating the access chamber near the power station at a lower level.

231. Mr Chandorkar agreed with the Author that excellent relations were maintained between the Consulting Engineers and the Contractors all the time; the credit should go mainly to Mr J. A. Baines and also to Mr A. P. Shrimpton, the Resident Civil Engineer.

Mr H. W. Golding (Station Superintendent, Ffestiniog Power Station) observed that when it was first proposed, not a great deal of support was received for a pumped-storage power station. There was little doubt that the remarkable availability, dependability, and flexibility that had been achieved since the commissioning of the first unit had greatly influenced and won over a great number of the more practical engineers associated with power generation.

233. For that reason it might be helpful to summarize some of the operating statistics that had become available in the last financial year.

234. *Availability.* Since commissioning, the hours the unit had been available (expressed as a percentage of the possible hours) were as follows:—

No. 1 Unit	*No. 2 Unit*	*No. 3 Unit*	*No. 4 Unit*
88·90	89·98	89·73	88·36

Those figures compared extremely favourably with equivalent figures for conventional plant; it should be noted that those availability percentages include the outages for uprating the plant from 75 to 90 MW, and also the outages necessary to modify the plant for spinning reserve operation.

235. *Spinning reserve.* As mentioned by the Author, the Control Scheme was modified in order to enable the plant to pick up full load from the motoring condition in under 60 s; that feature, coupled with the fact that the plant could be run up from standstill and synchronized in 2 min 30 s, had been the principal asset of the scheme in providing cover for the national network. The alternative cover to pumped storage for standby was obtained from conventional steam plant, but the beauty of an automatic control scheme associated with hydro plant was that the advertised times could always be met. With steam plant, unless the standby was carried on modern boiler plant with automatic boiler control, the rate of response times would be unreliable and even with modern plant the hazards associated with starting were much greater than in hydro plant. There was little doubt that the regular monotony with which the automatic starting sequence had run through had greatly enhanced the usefulness of Ffestiniog.

236. *Costs.* The costing of a pumped-storage system was complex but it would appear that in the dearer-fuel areas the unit sent-out cost could compare very favourably with that obtained from conventional stations. That was greatly assisted by the fact that works costs and other costs, besides the fuel cost, were so much greater in conventional stations.

237. It was interesting perhaps to note that to start the Ffestiniog plant generating cost 17*s*. 3*d*. and to run it up as a pump cost £5 15*s*. 0*d*. The equivalent cost in conventional stations varied with the fuel cost and the time shut down, but the real savings, as compared with thermal stations, occurred in the increased maintenance costs associated with starting and stopping, and also the much more expensive outage costs which starting and stopping entailed.

238. *Efficiency.* The overall efficiency based on the units imported and exported

for the last financial year was 72·10% but to a large extent the success of the scheme had been largely responsible for drastically reducing the overall efficiency.

239. Because the spinning reserve feature was so desirable nearly 5000 machine-hours were spent on that type of running. Although the motoring losses were low they had had the effect of reducing the exported units to the detriment of the overall efficiency.

240. During the previous twelve months to July 1964 the plant had been run up from standstill over 4000 times. Although from the national point of view it was cheaper and more convenient to start the pumped-storage plant, so great a number of starts also had the effect of reducing the allover efficiency.

241. *Loading*. It was interesting to note that the station had a running time factor of 79%, while original estimates had indicated that the plant might only run for the three winter months. That factor, however, was influenced greatly by the national plant shortage and the fact that the system contained a certain amount of high-cost plant; the high differential between the best and worst plant helped the economics of pumped storage.

The Author, in reply, expressed his gratitude at the reception of the Paper. He thanked Mr Fulton and Mr Chapman for their valuable contributions dealing with the operation and economics of pumped storage schemes generally. He agreed entirely with their remarks and hoped that the Generating Board would give further thought to these matters in relation to their system.

243. Mr Guthrie Brown had raised some very interesting matters on dam construction. The Author's firm and their Associates, Messrs James Williamson & Partners, were convinced of the merits of the massive buttress design, originated by the late Mr James Williamson, for certain site conditions. This design compared favourably with other buttress designs in that the shutter-forms were simple and the concreting techniques required were the same as for a conventional gravity dam.

244. Technically, the massive buttress design compared very favourably with the conventional solid gravity design, in the reduction in the amount of uplift which had to be allowed for, and the advantage of having ready access from the back face to within easy drilling distance of the front face of the dam. Galleries, troublesome to construct, expensive in shuttering, and technically undesirable as stress raisers, were avoided.

245. To illustrate the relative cost of shuttering, Table 2 gave the ratio of shuttering costs on four dams recently completed. The ratios showed clearly that the unit shuttering costs differed very little for the two designs.

TABLE 2

Description	*Massive buttress type*		*Solid gravity section*	
Straight vertical face	1·0	1·0	1·0	1·0
Contraction joint face	1·14	1·21	1·0	1·57
Straight sloping face	1·25	1·39	1·0	1·33
Buttress sides	1·44	1·41	—	—
Buttress ellipse	1·30	1·15	—	—

246. The massive buttress design allowed normal concrete placing and consolidation methods to be used and the unit concrete rates did not therefore greatly differ from those of a conventional gravity dam. The total volume of concrete would be a large factor in the unit price and it was difficult to compare one site with another.

247. The figures in Table 3 for Tan-y-Grisiau, Stwlan and Nant-y-Moch may be of interest in this context.

TABLE 3

	Tan-y-Grisiau	*Stwlan*	*Nant-y-Moch*
Design	Solid gravity	Massive buttress	Massive buttress
Elevation	625 ft	1650 ft	1125 ft
Volume ratio	1·0	2·25	8·25
Adjusted unit cost mass concrete/cu. yd	115*s*. 6*d*.	137*s*. 6*d*.	98*s*. 0*d*.

248. The saving in concrete depended upon the height of the section, but for a dam 120 ft high, amounted to 43% on the gravity sectional area. In comparing shutter costs, the policy regarding contraction joints or contraction slots in the gravity dam would have a marked effect. Mr Guthrie Brown's firm, judging from the paper on the Orrin Dam, evidently preferred contraction slots through the dam. In that case the increase in shutter costs for a massive buttress would be of the order of 7½%. If contraction joints with block and space construction were adopted for the gravity section, then the increase in shuttering was of the order of 35%. One could not generalize on savings in cost but there was no doubt that on suitable sites a massive buttress gravity design could show a marked saving in cost compared with a solid gravity section.

249. The design was very suitable in the case of a broad flat valley, but difficulties could occur in establishing satisfactory buttress foundations when the valley sides were steep. Unless one was prepared to adopt the swallow-hole type of spillway, complications could arise in providing satisfactory arrangements if a large spillway capacity was required.

250. The Author's firm, after investigating other types, had no hesitation in choosing the massive buttress design for the Nant-y-Moch Dam, which was about 175 ft high. In that case, the front face batter was 1 in 6. A factor to be considered in further flattening the slope of the front face was the degree of overhang which could be accommodated without running into difficulties over shuttering inside the ellipse. In that case, the overhang was 1 in 8. Sliding factors become of increasing importance in that design and shear blocks were provided between all lifts of concrete, and in the buttress stems the concrete lifts were finished with a slope of 1 in 6 towards the upstream face.

251. On the question of water stops, the Author agreed that in high dams the provision of more than one system was wise, but he felt that sometimes insufficient attention was given to the workmanship on horizontal construction joints. It could allow seepage past the most efficient water stop arrangements and would show as leakage at a construction joint on the downstream face. Seepage on horizontal construction joints was a more obvious defect that could be seen in many dams.

252. The solution of the vortex problem had been dealt with by Mr Young during the discussion.

253. Mr Guthrie Brown had enquired as to whether the concrete-lined tunnels had been pressure grouted. This was the case, and the work had been done very thoroughly with complete success. Cavity grouting at 30 lb/sq. in. in the crown of the tunnel was carried out at 10 ft centres with a 2:1 sand cement grout. Cement used averaged 1 cwt of cement per ft run of tunnel. Pressure grouting with cement only using 80 g of water per cwt was carried out in four stages. Four primary holes on the circle were drilled, 5 ft into rock at 10 ft centres and grouted at 50 lb/sq. in., four secondary holes at 10 ft centres mid-way between the primary holes and 45° off centres were drilled 10 ft into rock and grouted at 150 lb/sq. in. These holes were

then extended a further 5 ft and regrouted at 500 lb/sq. in. The final stage involved deepening the primary holes to 10 ft and grouting these at 500 lb/sq. ft. Cement used averaged 2½ cwt per ft run of tunnel.

254. Finally, Mr Guthrie Brown had commented on the omission of the automatic self closing valves at the tunnel portal. The Author considered this a sound decision based on good modern practice and economics. The penstocks were designed as first class pressure vessels and fabricated under shop conditions with full radiography. The risks did not appear to be greater than those accepted in thermal power stations throughout the country. From information given at the World Power Conference in Lausanne, the Americans were going even further in this direction by the omission of head-gates as well as portal valves on the Cornwall plant referred to by Mr Chapman.

255. In reply to Mr Hunter, the Yale Power Station was unfortunately closed recently by the Generating Board. Consideration had been given to renewing the plant but the Station was so small that this did not prove economic. Mr Hunter had raised the question of availability and Mr Golding had quoted actual figures for the last financial year. Bearing in mind that the figures given included an outage of one month for each machine for uprating, the true availability under normal circumstances of this plant was of the order of 97·5%. This bore out the point made by Mr Hunter and stressed the fact that it was correct to take into account the inherent reliability of hydro-plant in any economic assessment vis-à-vis thermal plant. The Author regretted that he had not had the opportunity of collecting data on the annual availability of plant on the Continent but he agreed that the information would be interesting if it could be obtained.

256. Mr Hunter had dealt at some length with the question of watertightness and had been surprised that scale models and photo-elastic technique were not used in the design of the sub-structure. He had cited the Granby plant of the U.S. Bureau of Reclamation as being a case where these techniques had been employed successfully.

257. The problem was one with which the Author personally had been closely involved throughout the design of the Station, and he would have been delighted to have found an engineering laboratory in Britain which would have been willing and able to have carried out the type of analysis to which Mr Hunter had referred. Unfortunately, on the best advice, it was not thought possible to obtain useful results by these methods in this instance.

258. Granby Station had three 6000 hp pumps with a head of 186 ft. The cellular sub-structure was of symmetrical form and the pumps were mounted on the basement floor with no problems on the disposal of the hydraulic thrusts. The station was therefore hardly comparable with Ffestiniog.

259. Considerable thought had been given in the case of Ffestiniog to the design of the sub-structure, and its behaviour under transient load conditions had proved to be very close to that predicted.

260. Fig. 36 showed the sub-structure movements measured recently during a plant outage when the shaft and tunnel system was drained and refilled. The effect of lower reservoir water level was clearly shown and the difference in movement under penstock pressure at the turbine floor between the north and south sides was because the south side was adjacent to the turbine inlet thrust flange.

261. There had been no signs of structural cracking and the performance of the station since commissioning had, in the Author's opinion, confirmed the validity of the structural design. Mr Hunter's prescription for waterproof concrete structures was very sound but, without doubt, success in the end depended upon site constructional methods and supervision.

262. In reply to Mr Dickinson, the total cost of model testing on the project was approximately £15 000, and that sum was included in the cost of the various items of work.

263. On the subject of corrosion, metal spraying had been used in cases where occasional rubbing action took place, such as screen guides. It was unlikely that metal spraying would be effective as a corrosion protection under constant rubbing action. The Author did not agree with Mr Dickinson's views on the protection of the tunnel linings and penstocks that a coat of bitumen was all that was necessary or that the state of some of the old conduits was satisfactory with this type of treatment. The type of water had naturally to be taken into account. An inspection of the test plates or a sight of a small strip of steel left unpainted at a manhole branch for a year would have convinced Mr Dickinson of the need for a first-class protective system at Ffestiniog.

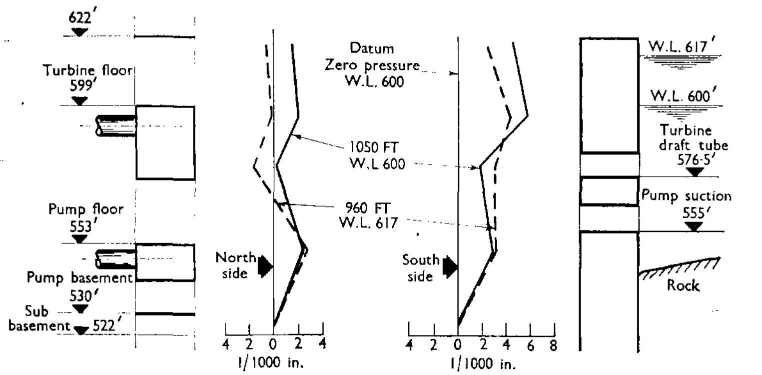


FIG. 36: FFESTINIOG POWER STATION: SUB-STRUCTURE MOVEMENT DUE TO PENSTOCK PRESSURE AND RESERVOIR LEVEL AT ACCESS HATCHWAY MACHINES 1 AND 2 (October 1963)

264. A low coefficient of friction was also very important, especially as for every unit sent out friction losses were incurred both pumping and generating. The gain in efficiency due to the very smooth pipe finish had been taken into account in assessing the economics of the painting system employed.

265. The Author agreed with Mr Dickinson's general remarks on pumped storage, and the success of the scheme was well illustrated by the intensive use to which the station had been put since it was commissioned. This was shown in Table 4. The actual operation period was equivalent to only 11 months due to the outages of each machine referred to above.

266. The Author thanked Mr Headland, with whom he had had such pleasant companionship on the scheme for so many years, for his interesting contribution on the turbines and storage pumps. The spiral casing failure under works test had been instructive, and experience with the various welded fabrications on the plant and pipework both in the works and at site showed that no one method of weld examination was necessarily the answer. Each case had to be dealt with on its own merits and a combination of methods gave one increased confidence.

267. The data given on the pump cavitation was a most useful addition to the Paper and having seen the pump impellers, he could confirm the very high standard of the welding repairs. Whilst it was true that there was no real damage on the lower first stage impellers, there was a light marking of a similar pattern to that on the upper impellers, which indicated that the increased submergence was beneficial. The Author regretted that, due to space considerations, the question of vibration had not been dealt with more fully. He well remembered that the case of harmonic resonance

referred to occurred only one week after the details of the anti-flutter device had been agreed with the English Electric Company.

268. The Author thanked Mr Young for his remarks on the upper reservoir model test which answered Mr Guthrie Brown's point on the vortex problem. He hoped Dr Allen would continue with his tests on this problem. At present the need to test at prototype velocity meant that model testing was more expensive than might otherwise be the case if lower velocity ratios could be acceptable.

TABLE 4: FFESTINIOG POWER STATION OPERATING DATA 1963–64

Design		*Actual*
300 MW	Maximum output capacity	360 MW
500	Number of generating periods	872
250	Number of pumping periods	646
1000 h	Station time: generating	3593 h
1500 h	Station time: pumping	3174 h
28·5%	Operating time factor	77·2%
	Electricity used:	*kWh* × 10^6
	Pumping	527·971
	On works while pumping	1·433
	Shut down	0·687
	Total import	530·091
	Electricity generated	383·380
	Used on works while generating	0·619
300·000	Total units sent out	382·761
72·5%	Overall efficiency	72·2%
11·4%	Average load percentage of average output capacity	13·46%

269. All those concerned with the scheme would be very gratified with Mr Newman's kind remarks on its success. Mr Newman had acted as Chairman of all the technical meetings held at Central Electricity Generating Board headquarters during the long preparatory technical investigation into the scheme. The figure given for the annual net saving was encouraging and all who were interested in hydro-electric power would be glad to hear that the merits of pumped storage were now appreciated by the Central Electricity Generating Board.

270. Mr Warnock's contribution enabled the Author to recall the very pleasant relations which existed with the English Electric Company and all the plant contractors on the scheme. His remarks on future developments, in particular the matter of rapid loading, were most interesting; those developments would further enhance the future of pumped storage.

271. The Author thanked Mr Crosthwaite, who had been closely associated with every hydroelectric station built in Wales in recent years, for his very kind remarks about the Author's contribution to the scheme. In introducing the Paper, the Author had referred to the lengthy list of acknowledgements and had tried to stress that the work had been a co-operative effort by many engineers from the Clients, Consultants, and Contractors, all of whom contributed to the successful completion of the project.

272. Mr Gillot had made a stimulating contribution. His firm was one of the two who had borne the brunt of the civil engineering work. The original conventional hydroelectric development utilized a total catchment area of 16·3 sq. miles in the

vicinity of Blaenau Ffestiniog. Power was to have been developed in three stages—an upper stage with three small reservoirs, an intermediate stage with a reservoir formed by raising Llyn-Cwmorthin, and a lower stage with the reservoir at Tan-y-Grisiau, as in the current scheme. The total amount of energy that would have been generated in the three stages was 49 m units for an average year and 34 m in a dry year. There were two alternative proposals for plant with an installed capacity of 29·5 MW or 35·5 MW. The estimated costs for the two schemes were £109 and £93 per kW.

273. Mr Gillott had raised the question of the adequacy of the site investigation. The conflict inherent between the need to start work and the time required for a full site investigation will always be with us until long term planning for future schemes was. accepted. In the case of the dam there was little scope for any alteration to the siting. With the benefit of hindsight it might have been better to have made the dam radial in plan with the same abutment areas. This would have given a more favourable shape for the foundation rock at the toe of the buttresses but would not necessarily have improved its character. The toe trench would probably still have been ordered. The additional work did not affect the programme for first commissioning as it was possible to reduce the initial impounding level by 14 ft and still have sufficient storage for the operation of one set.

274. The design of the intakes was altered, and the foundation rock levels were lower than anticipated. The towers, however, were altered to a circular section, at the contractors' request, to facilitate the use of a sliding shutter. As to the shaft and tunnel system, it was difficult to visualize how further drilling—a long and expensive task at the depths involved—could have led to a redesign of the system. The truth was that shaft sinking was one of the most difficult civil engineering operations. It was significant that firms with experience of a vertical or a sloping shaft tended to extol the merits of the other types, until they had experience of it.

275. The contract documents allowed for arch supports for 12·2% of the tunnel length, the actual amount placed being just under 11%. Extensive use was made of rock bolting.

276. On the question of amenity, during proceedings in the House of Lords the height of the tunnel portal was considerably lowered and but for this the difficult conditions encountered at the foot of the shafts might have been avoided.

277. Mr Brown had raised some points in connexion with the penstock and tunnel linings. It was difficult to see how, on a scheme like Ffestiniog, shop fabrication of the penstocks and tunnel linings could have added to the cost of the scheme. On the other hand, it might be well worth while to incur a cost penalty in order to obtain the advantages of shop fabrication when work to first class pressure vessel standard was specified. Coltuf 32 had been used for the penstocks and tunnel linings nos 1 and 2; for tunnels 3 and 4 mild steel had been used. The reason for the difference was that at the time of going to tender great difficulty had been experienced in obtaining any steel supplies for the scheme. For the first two tunnels it had not been possible to obtain truly competitive tenders on this account. The only stress relieving carried out at site was on a closure section in one of the mild steel tunnel linings. The improvement in notch ductility over mild steel is one of the good reasons for using Coltuf 32 on work of this nature.

278. No satisfactory method of dealing with the condensation difficulties could be achieved due to the very high heat input required. This was a factor in making the change in the painting specification.

279. Mr Maloy had referred to the free discharge regulators which were of Glenfield & Kennedy manufacture. This type of valve was chosen on account of its technical suitability for the work and its low cost. No model tests were carried out and the wide angle of dispersion caused no difficulty at site. At Stwlan dam the scour pipe was fitted with the same type of valve with a hood since the wide dispersion in this case could not be tolerated. There was no vibration at full discharge.

Full details of manufacturers and sub-contractors would be found in references 1 and 2 of the Paper.

280. Mr Coates, who had been Northern Project Group's Resident Engineer at site during construction, had made an interesting contribution to the discussion and the Author would like to take the opportunity of thanking him for the valuable work he had done on the scheme and the way in which he had helped to maintain the friendly relations which existed between Client and Consultant.

281. Mr Wolley had submitted details of the Colcrete process used for plant embedment, which provided a valuable record. The system had been most successful, but in this case prices had had to be negotiated with the Contractor and the work was costly. This was largely due to standing time and the natural difficulties which occurred in phasing the work with a tight erection programme.

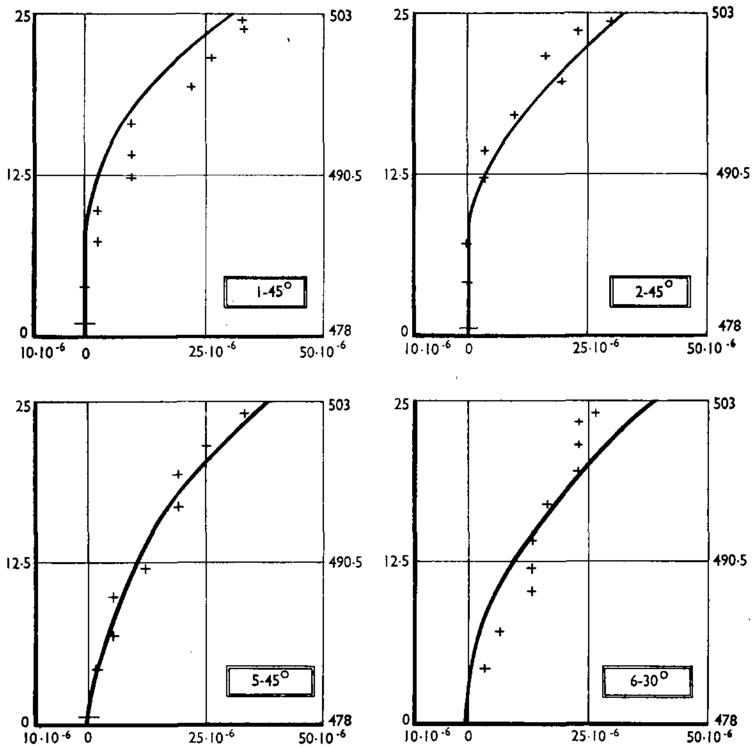


FIG. 37: STWLAN DAM: SURFACE STRAINS IN MICROSTRAINS
(March 1963 and remeasurement April 1964)

282. He had raised some interesting points regarding the construction programme. There was no doubt that the decision to place the power station excavation in the upper works contract saved a whole year on initial commissioning. A draft construction programme dated July 1957 showed foundation slab concrete starting in July 1958. In fact, the contract starting date was 9 February, 1959 and concreting of the foundations did not start until May of that year. It was a notable achievement, therefore, on the part of the Civil Engineering Contractor and the Resident

Engineer's staff to have carried out work of a high standard, originally programmed to take 38 months, in 32 months, and thus achieve commissioning of the first machine only four months later than originally programmed. On a basis of cost alone a case could no doubt be made for delaying the start of the work and for allowing a longer contract period. The better planning and more orderly construction would avoid extras and contractors' claims. In practice the value of the kilowatts in a hard winter was so high that the extra expense would usually be accepted to commission a set for the winter load.

283. In reply to Mr Chandorkar, the Author had referred to strain gauge measurements in introducing the Paper. Fig. 37 showed the satisfactory repeatability which the surface strains gave during a remeasurement recently.

284. Regarding the layout of the tunnel and penstock system the original scheme included automatic self-closing valves at the portal and these were to be housed in pairs in two valve chambers. That was one reason for the plan bends in the system. But a second reason was the topography of the hillside on the line of the penstocks. The actual line chosen gave the minimum excavation for burying the penstocks. For that reason, although the valves were omitted, the plan arrangement of the system remained unaltered.

285 Mr Chandorkar was not correct in his statement regarding the prestressed anchor blocks. They were mainly required to restrain the pipework at the portal when a blank flange was fitted in the portal access chamber.

286. The natural point for access to the tunnel system was at the tunnel portal and at the head of the penstock section, which had a steep gradient. The point chosen on the hillside was a natural one from the point of view of topography and there was a good access road so that the disadvantages of the arrangement were not obvious to the Author. To eliminate the penstocks altogether and bring the tunnel portal to a point immediately behind the station would have had a disastrous effect upon completion dates. As it was, there was sufficient confusion and turmoil at the junction of the two main contracts at the head of the penstocks under the existing design.

287. The Author thanked Mr Golding for the data he had given on operating results. Mr Golding had come to the station from a thermal plant and it was very satisfactory to note that he was now an enthusiast for hydroelectric plant. Due to the very nature of the C.E.G.B. system there was little knowledge of hydroelectric plant within the organization but it was interesting that practical experience soon resulted in conversion to the view that there were merits in that form of generation.