*Discussion on Paper No. 6847**

Skogfoss hydroelectric power station, Norway/U.S.S.R.: civil engineering works

by

B. A. Berdal, M.N.I.F., M.R.I.F.

and

L. G. Kiel, M.N.I.F., M.R.I.F.

Mr E. J. K. Chapman (Partner, James Williamson and Partners) said that, before commenting on the very interesting Paper, he wished to congratulate the two Authors on the very clear way in which it had been presented.

55. One of the main points of interest concerned the unusual international complications arising from a development on a river forming an international boundary and with its principal catchment and storage in a third country. The international negotiations took a period of three years, which did not seem to be unduly long in view of the complications involved. In fact, the time required for obtaining approval to certain of the Scottish hydro-electric schemes had sometimes exceeded that.

56. The final agreements reached for the development of the Pasvik River seemed both sensible and simple, which showed what could be done with good will on both sides. In fact, good will still seemed to be necessary for the operation of Lake Enare where the anti-flood requirements of Finland conflicted with the power requirements of Norway and also to some extent of Russia. It might be too early for the Authors to add anything on that point, but information on how the storage was working out in practice would be of interest.

57. Another unusual feature of the scheme was the very severe winter conditions affecting all surface work. He was impressed by the Authors' statement that concreting could be carried on down to 37° of frost but that when air temperatures fell below that, it became too difficult and the work had to be stopped. This seemed remarkable to him, when comparing the results of winter concreting on Scottish dams, where even with aggregate and water heating, it had only been possible to concrete down to temperatures slightly below freezing point.

58. He wished to ask one or two questions about the technical features of the scheme. According to the drawings, there did not seem to be any provision for the passage of fish past the dams or the power station, nor for the passage of logs, normally a common feature of many Scandinavian schemes. Were those features absent because neither fish nor logs used the river, or was there some other reason?

59. He noticed also that, although the dam had been designed for an ice load, there seemed to be no provision for excluding ice from the headrace canal, and its passage past the dam did not look too easy as the spillway gates were of the undershot type. He would be pleased if the Authors would say how ice was dealt with.

60. He was interested to note that although poor rock was encountered in both the canal excavations and the power station excavations, it was not considered necessary to provide a grout curtain under the dam foundations. In the Paper reference was made to the fact that the river bed had been protected from the severe frost by the water in the river. He wondered whether that was the whole reason or whether there was some change in the geology between the two sites.

* *Proc. Instn civ. Engrs*, 30, 271–290. February 1965.

61. Regarding the cut-off dam at Mãnnika, he was very interested to learn how the difficulties of spreading and consolidating the soft clay blanket were overcome, and in particular how advantage was taken of winter frosts to move consolidating plant over the soft clay. He would like to hear a little more about how this had worked out.

62. He thought the Authors had mentioned that the leakage past the dam was of the order of 3 cusecs, which, although a large leak, was insignificant in relation to the power flow. Were the Authors satisfied that this leakage was now steady and not likely to increase?

63. He also noted that the dam completely cut off the secondary channel, and that there appeared to be no provision for compensation water. However, he noticed that a tributary seemed to join the river about two miles below the dam, and so the extent to which the river bed would be dried up was very limited.

64. The Authors stated that the cost of power from the scheme was high by Norwegian standards, but it certainly seemed low by Scottish standards. In that respect the topography of the scheme was favourable, since the natural Lake Enare provided such an excellent degree of regulation of the river flows. Without cost to the scheme it seemed that the river was regulated so well that the average minimum flow was as much as half the average annual flow. In addition, some degree of daily regulation was provided by the headponds and the plants up river. However, offsetting those natural favourable features were the adverse features of remoteness and severe winter conditions.

65. He thought that the Paper showed that the Authors had been very economical both with their planning and with their design, and they were to be congratulated on keeping the civil engineering costs down to only £1·5 million or £33 per kilowatt installed.

Mr J. K. Hunter (Sir Alexander Gibb & Partners) said that he was very glad indeed of the opportunity to discuss before the Institution a Paper which had been submitted by two distinguished consulting engineers from Oslo.

67. On reading the Paper he had been struck by two things. The first was the skilful use which the Authors had made of a language not their own in which to convey their meaning in a minimum of words. The second was the courtesy shown by the Authors in using English units of measurements.

68. To him, the most remarkable feature of the development described by the Authors, was the fact that it had proved possible for a small country to make an equitable bargain with a powerful neighbour over the division of the benefits to be derived from the Pasvik River. That this had been possible was not only a notable diplomatic achievement but a welcome sign that the intransigent attitude previously adopted by the U.S.S.R. in her relations with her weaker neighbours had of late been somewhat abated.

69. International disputes over water rights had long been a source of friction between sovereign states. As the importance of water to the well-being of a community became better appreciated, these disputes tended to become more menacing. Any settlement was almost invariably a matter for negotiation between the countries concerned. There were no rules or principles of international law which were of universal application for the use of river waters.

70. Both the International Law Association and the Institute of International Law had given consideration to international water law, and in 1958 the Association adopted a set of principles which it was suggested should govern the use of international rivers. However, at present there were in fact no principles which could be accepted by any world authority as of universal application.

71. It was very easy to recall examples of disputes over international rivers which had in recent years led to strained relations between sovereign states. One of the most notorious was the dispute over the division of the Indus Waters between

India and Pakistan, which followed the division of India in 1947. The history of the Nile waters on the other hand had been more fortunate. Over the last 40 or 50 years the international nature of the river had been recognized, and within the last few years a negotiated agreement between the Sudan and Egypt over the division of the Nile waters had led to the construction of two dams, one in the Sudan and the other in Egypt.

72. Another example was presented by the Columbia River. Most of the water originated in Canada and flowed into the United States, where it had been vigorously developed for power over the last 30 or 40 years. The stage had been reached where further development was dependent upon the regulation of the Canadian headwaters, necessitating agreement on the engineering works which should be undertaken. The resulting plans for the development of the Canadian section of the river were the result of a hard-fought battle between the two sides, and were incorporated in a treaty drawn up at the end of 1960. The document was signed by President Eisenhower in January 1961 as his last act of state and immediately ratified by the United States Government. However, the response from the Canadian Government was lukewarm and ratification was postponed while further bargaining went on. It was not until four years later that final agreement was reached and a fresh treaty ratified by both parties.

73. These examples made it all the more remarkable that an equitable agreement over the use of the Pasvik should have been reached with such apparent ease between the countries concerned.

Mr H. G. Keefe (Sir Alexander Gibb & Partners) said he was particularly interested to see again the slab and buttress type dam which, while popular some years ago, seemed to have gone out of fashion, reputedly on account of heavy maintenance costs. He noted the Authors had said there had been no serious maintenance problems and no doubt this was largely because they had closed-in the downstream face and kept down the steep temperature gradient which would otherwise occur. The Authors, however, had apparently considered omitting this precaution in order to reduce costs. Frost damage to older, thin slab and buttress dams had been known, and he would like to know what the experience was in Norway of deterioration of any kind. For example, what was the balance between cheap initial cost and maintenance costs over a certain life.

75. No special treatment to the upstream wet/dry face had been mentioned. Presumably this was plain concrete, but it would be interesting to know. Satisfactory watertightness had been achieved using 540 lb/cu. yd concrete. It would be interesting to know what tests were carried out with what results concerning the use of special additives in relation to frost resistance. Apparently concreting had had to be discontinued during extreme winter. How had this affected overall economy?

76. He was puzzled by the fact that the rock foundation under the main dam was apparently so good and yet at the nearby power station they had had considerable trouble. The top surface must have been specially good because only a very shallow cut-off trench and shallow excavation for buttress foundations had been provided.

77. Regarding the design of the slab and buttress dam, he was interested to note the care which had been taken to prevent damage due to shrinkage of the upstream slab relative to the buttress. He assumed that the shutter bolts were purely temporary and would not provide a permanent tie between slab and buttress.

78. Regarding Mãnnika dam, the main thing that struck him as rather strange was the apparent thinness of the clay blanket. He would be interested to hear a little more about the practical problems of placing and compacting this very thin layer. He would also like to know whether the Authors had in mind any means of re-sealing this blanket in the event of washing away or cracking due to frost action or drying-out, etc, when the reservoir was emptied.

79. It was interesting to hear that the spillway surge basin was not finally required to stabilize the surges in the headrace canal, although it would have been quite cheap to provide.

80. He was not quite clear from the details given for the headrace and tailrace whether they were completely concrete lined. He would like to know whether the lining had had to be tied back into the apparently poor rock.

81. One other point he was not sure about was the question of provision for earthquakes. It might be that this was not a seismic zone, but could the Authors say whether this matter had been considered in the design?

Mr H. Headland (Consultant, Kennedy and Donkin) said that several points seemed to call for some attention. The first was in § 6, where the Authors had stated that construction began in the autumn of 1961 and the station was expected to be in operation by September 1964. He thought this was a remarkable achievement in the climatic conditions which had had to be endured.

83. Another point which had interested him was the relative economics of the project. In §§ 33 and 35 the Authors mentioned a thermal station with an installed capacity of two 7 MW units. This had been replaced by the new scheme, which consisted of two units of 22·5 MW (a total of 45 MW), only one of which was expected to deal with the demand. In view of the reliability of hydro-electric plant, he wondered whether the second unit was justified, and he wished to ask whether, in fact, the costs per kWh quoted included the fixed charges on the thermal plant now held as standby.

84. There was another matter on which he would like further information. The estimated cost of the civil engineering works was £1·5 million, out of a total of £3·75 million. This seemed to him a low ratio of civil engineering to electrical and mechanical plant costs, since the latter apparently amounted to £2·25 million. He wondered whether this figure included the cost of transmission, or whether the high capital cost of mechanical and electrical plant was due to the fact that Kaplan turbines had been used, or if climatic conditions had contributed to the high costs.

85. §§ 37–39 dealt with the instability of the water race, which was interesting in that the electronic computer showed that conditions would be stable whereas the model indicated that they would not; if he had understood Mr Berdal correctly, operating conditions had, in fact, proved stable, but he wondered what was really meant by 'stability' or 'instability'. Was it related to the machines or to the wave action in the headrace under load rejection and acceptance conditions?

86. Finally, he would like information about the design and installation of the air bubbler system used to avoid freezing and icing troubles with the gates, and the Authors' experience with it.

Mr M. J. Kenn (Department of Civil Engineering, Imperial College, University of London) congratulated the Authors on the lucidity of their presentation. It had been mentioned that work stopped when the winter temperatures fell to −5°F. However, Mr Kenn questioned whether it was only the temperature which was of significance. The Authors would be aware that in Canada conditions of temperature were equally severe but that constructional work was continued at such temperatures. However, the latitudes were very different. At Skogfoss (latitude 70° North) there was little or no sunshine during the winter months (at noon on 21 December the sun would be 3½° below the horizon!). The conditions in Norway were possibly even more severe than the Authors had implied and they might perhaps care to comment on the additional influences of latitude, e.g. on radiation effects.

88. It was stimulating to hear of works carried out in difficult conditions in remote geographical locations. The remoteness of location perhaps accounted for the ease of the international negotiations.

89. Mr Kenn had been interested to hear of the differing stability predictions given by the analytical investigation and the model tests and wondered whether the computer had perhaps been supplied with imprecise information.

90. The application of air-bubbling for raising the warm water from the lower regions was also of interest. Were details concerning the air flows and the induced water velocities available?

Mr W. E. Blackmore (Sir William Halcrow and Partners) had queries concerning the hydrology dealt with in § 7. In the Table, the Authors had listed various data, some of which were listed as runoff and others as river flow. He was not sure what the difference was, and it would be helpful if this could be explained.

92. In this connexion he noted that the average runoff was given as 6300 cusec, i.e. about 1 cusec per square mile or about 13 in. per annum. This seemed low compared with 60–70 in. per annum in Scotland. He wondered whether it was due to a high evaporation, or whether the rainfall was as low as 20–30 in., which would be rather surprising in such a climate.

93. Secondly, he took it that the figure of 255 500 cusec for maximum river flow was the design flood for the scheme. This was about four times the average, which compared with about twenty times the average in Scotland. Presumably it was low because of the great regulating effect of the lake a little further upstream.

94. In connexion with floods, he saw that the method of discharging flood was by bottom-opening radial gates. He had seen no provision for a free overfall form of spillway, even for the small day-to-day variations, and it seemed that the gates would have to be opened each time there was a variation in the demand from the turbines, which would make the day-to-day operation difficult. What were the reasons for adopting this system?

Mr D. A. Brown (Sir Murdoch MacDonald & Partners) asked for more information about the method of regulating the water level in the lake upstream of the power station. The Mãnnika dam had a crest level of 178·5 ft and the top of the buttress dam was rather lower at 174 ft. Attention had already been drawn to the lack of an overfall spillway. It appeared to him that the buttress dam might possibly have been designed to withstand overtopping: was this assumption correct?

96. The Mãnnika dam had stone protection on the upper portion of the upstream face but the clay blanket on the lower part of the face appeared to be entirely unprotected. Reference to the levels of the control gates suggested that it was possible to draw the reservoir level down and so expose the unprotected clay to wave action. The Authors' comment on this would be appreciated.

Mr R. Freer (Hawker Siddeley Dynamics Ltd.) said this was a very interesting Paper about a power scheme built under unusual conditions, and he would like to ask the Authors a question about the measures taken in the design of the power station to reduce possible hydrostatic uplift under the intake and power station.

98. In this area the Authors had said the excavation had been in rock which was very cracked and weathered, and from that description one would expect there might be some seepage through the rock. The cross-section of the intake in Fig. 12 showed a drainage gallery formed against the rock with no cut-off trench under the intake invert, only a shallow trench under the tail-race outlet, and there was no mention of the rock having been grouted. Would the Authors say whether there had been much seepage into the drainage gallery when the head-race canal was filled and whether they thought a deep cut-off trench at the intake or grouting of the rock would have made any significant difference.

Mr J. C. A. Roseveare (Engineer, Freeman, Fox & Partners), who congratulated the Authors on their excellent Paper, said that the question of winter working in the

United Kingdom was never really tackled because this country so seldom suffered a long period of icy weather. However the Paper had shown what could be done.

100. The international aspects of the scheme were of interest to him because he had recently been to Aswan where he had seen what could be done when people agreed to agree. On the other hand there were other problems to which one could see no solution because the people concerned were determined not to agree, as was the case with the Arabs and the Jews over the headwaters of the Jordan.

101. The design of the dam was of course of great interest. He would be glad to have a little more detail on how the joints had been made watertight.

102. The use of the rising shutter for the face of the dam was certainly very interesting. He wondered whether there had been conflict in the concrete mix design between the watertightness requirements and the requirements from the point of view of the shutter being used. It would be interesting to know at what rate the shutter moved and whether there were any particular problems with this system during construction.

103. He could not help remarking on the size of the undershot gates at the bottom of the dam. The sections in the dam were light compared with more conventional designs and he wondered whether there had been any model tests for vibration in the dam structure under heavy discharge conditions, or whether there had been any difficulties of this kind with the operation of the gates.

The following contributions were received in writing:

Mr D. C. Willett (Project Engineer, H. G. Acres and Co. Ltd) wrote that the Authors were to be congratulated on their most interesting Paper. While he realized that space limitation prevented the Authors discussing the many unusual features of the development more fully, it would be of value to have a little more information on one or two points.

105. In § 18 the Authors stated that radial gates were installed in the main spillway. From a study of this and other developments, it would appear that the radial type of gate was in general use in Scandinavia. Was this due solely to economic considerations, or was it considered that radial gates had operational advantages over flat gates which outweighed any disadvantages in cost? Was provision made for heating the trunnion arms to prevent buildup of ice from spray during discharge? In Section BB (Fig. 6) it would appear that there was no provision for stoplogging the spillway gates: was this the case? In a recent competitive tender calling for radial or vertical lift gates (45 ft wide by 50 ft high) for a job in Canada, marginally lower prices were submitted for the flat gates. These prices, in conjunction with the higher civil costs associated with the radial gates, resulted in the selection of the flat gates. One reason for the continued competitiveness of the flat gate would appear to be the stressed skin design now being used.

106. In describing the compaction of the clay seal on the Männika Dam, it was stated that the top crust was allowed to freeze sufficiently to allow compaction by crawler tractor. The thickness of the seal seemed rather light. Was the seal allowed to remain exposed during the winter following this treatment, or did impounding follow immediately after? How satisfactory had this seal been? Had any leakage occurred?

107. Turning to the intake (Figs 12 and 13) these appeared to be somewhat unconventional by Canadian standards. It would be interesting to learn of the design philosophy involved: what sort of drainage and grout curtain was provided? How much reliance was placed on the drainage and grout curtains, in particular under conditions when the intake was unwatered? Did the poor rock conditions encountered require any changes in the intake design to handle shear sliding problems? There would again appear to be no provision for stoplogs or sectional gates: how would servicing of the gates be accomplished?

108. The Authors' remarks on the problems of winter work in building con-

struction in Norway were very revelant to Canada where, of course, a similar problem existed. In general, every effort was made there to maintain construction work in operation throughout the winter in order to minimize the amount of seasonal unemployment. It was also important, of course, that once a capital commitment had been made every effort should be made to ensure the earliest possible return on that capital and to this end it sometimes proved more economical to make appreciable additional expenditure to provide heating for winter concreting rather than to delay the completion date by perhaps a year or more. As the Authors stated it was difficult to quote figures for the cost of winter work; from \$2·00 to \$16·00 additional per yard of concrete had been quoted for heating and enclosing, depending upon the type and scale of the operation involved. On large scale hydro-electric projects, careful design and planning could keep additional costs to a minimum, allowing the scheduling of concrete pours to enable the maximum use of large temporary enclosures. At the Manicouagan II development of Quebec-Hydro, for instance, pouring rates of over 15 000 cubic yards per week were maintained during the winter months of January and February 1964, when temperatures dropped as low as $-20°$F. Most of this was placed in the intake structure, a hollow joint gravity section which lent itself to the construction of large covered enclosures.

Mr F. Johansen (River and Harbour Research Laboratory, Technical University of Norway) wrote that as the project leader for the model tests, he would like to put forward a few supplementary remarks on the model tests, with particular reference to §§ 37–39.

110. The main purpose of the model tests being a study of the stability of the plant against surges in the head race canal, the turbine governor action had to be taken into consideration. This was done by using specially designed electronic equipment, which controlled the discharge through the turbines according to the equation $Q.H=\text{const.}$ Changes in efficiency during load variations were consequently not taken into account.

111. The test results proved the plant to be stable for all load conditions, with damping coefficients (defined as the ratio of two consecutive amplitudes of the surge in the head race canal) ranging between 1·3 and 2·0, with a mean value of 1·66. The stability was also studied by means of an electronic analogue computer, this study indicating unstable conditions for loads over 50–75%, as mentioned in § 37.

112. The contradiction between model and computer results was the reason for preparing the construction of a damping pool with a slotted wall connexion to the head race canal. Pools of this kind had previously been developed for a couple of other power plants, and had proved effective. However, their proper functioning required that the slot width and the pool area be precisely adjusted to each other.

113. For various reasons, a pool area of about 4300 sq. ft was found desirable, leaving the optimal slot width to be determined by the model tests. This was found to be 20 in. (The pool area of 3200 sq. ft (§ 38) seemed to be a slip, caused by the fact that several pool sizes were discussed). A computer analysis proved the damping effect of the pool, but indicated an optimal slot 13 times as wide as that found by the model tests. Prototype tests had later been carried out for conditions roughly corresponding to the model conditions, and damping coefficients were found to range between 1·1 and 2·2, with a mean value of 1·45.

114. On these results it was decided not to construct the damping pool. No tests designed to evaluate the optimum slot width were therefore possible in the prototype, thus leaving unanswered whether the model or the computer had given the better prediction.

The Authors wished to thank all contributors for the interest shown in the Skogfoss Power Plant, and for the kind words regarding the presentation of the Paper.

Hydrology

116. Mr Blackmore had asked for information on the difference between runoff and river flow. Runoff was the total yearly runoff from the catchment area given in the first column of Table 1 (the heading for which should read 'acre-ft × 10^6', 'acre-ft 10^3' being a printing error). In column 2 the corresponding river flow was given (divided by 31·5 million secs). By 'average' was meant the yearly average throughout the observation period (the gauging station had been in operation since 1911). Annual maximum was the highest and minimum the lowest yearly runoff recorded. The regulation at Enare would only influence the runoff figures if water was transferred from one year to another. The river flow was recorded in cusecs and was, of course, influenced by regulation.

117. The average runoff was very low in this area, due to low precipitation. The west coast of Norway was more like Scotland and a precipitation of more than 80 in. per year had been recorded.

118. The ratio between the design flood and the average was low due to the regulation in Enare, and probably due to the storage capacity of the marshland in the area.

Main dam

119. Mr Chapman had asked how the operation of storage was working out in view of the conflict of interests between Finland and Russia/Norway. It was too early to add anything. As long as the load on Skogfoss was relatively low the problem would not arise.

120. There were no provisions for fish passage because the salmon had never been able to pass the waterfall at Boris Gleb (now developed in the Russian plant). It was also assumed that neither Russia nor Norway was interested in an extension of fishing in a river which formed the border between the two countries. In the head race channel provisions had been made to facilitate a future installation of a log chute from the headrace to the tailrace channel. This was specified in the treaty between Russia and Norway. There had so far been no timber floating in the river as the timber produced along the river was transported by trucks.

121. In rivers of the type found in Norway there were seldom any problems with drifting ice. There was, however, a timber boom across the entrance to the head race channel preventing ice sheets from entering. Otherwise no provisions had been made for passing ice. The ice cover had normally melted so much and the remaining ice was so soft before the spillway gates were opened in the spring that the remaining ice could pass without damaging the gates.

122. The rock difficulties in the power station were mainly due to an unstable rock zone. Such bad rock was not encountered in the dam foundations. Shorter sections, where water pressure tests indicated leakage, were grouted. Altogether 300 ft of the dam foundation were grouted through holes 20 to 30 ft deep and approximately 11 metric tons of cement was consumed.

123. Mr Keefe asked about the slab and buttress type dam. If low dams were included, there were more than 100 slab and buttress dams in Norway, spread all over the country. One dam built in 1918 had recently been replaced, and one dam built in 1916 (the first of this type in Norway) had been extensively repaired. In both these cases the damage was in part due to the lack of experience at that time. Apart from these cases maintenance had been practically non-existent. There had, however, been several cases of damage in gravity dams, in some cases occurring only a few years after commissioning.

124. The upstream face was of plain concrete with no treatment. Air-entraining and plasticizing agents were added and an air content of 5% was aimed at. Some tests regarding the quantity of additives were done at the construction site.

125. The overall economy was, of course, affected by the discontinuity of the construction, but as the slab and buttress dam was divided in many separate parts the

discontinuity had no harmful consequences for the watertightness and the quality in general.

126. As previously stated the trouble with the rock quality at the power station was mainly due to a zone of bad rock. The rock in the dam foundation was less cracked by the frost action. For Skogfoss Dam only relatively small quantities of surface rock had to be stripped to get down to rock of an adequate quality. In many other cases it had, however, been necessary to remove 1 to 2 metres of rock in the dam foundation. It was found more practical to remove the rock over the whole area covered by the dam, than to excavate a deep cutoff trench and trenches at the buttress foundation.

127. Experience showed that if the slab was monolithically concreted to the buttresses, horizontal crack easily occurred in the slab due to shrinkage. Parts of the shutterbolts were screwed out from the upstream side before the concrete was fully cured. The rest remained in the concrete, but movement of the slab relative to the buttresses was allowed as the outer part of the bolt embedded in the buttress was wrapped with fibreglass as shown on Fig. 6.

128. The area was not a seismic zone and seismic forces had not been considered.

129. Mr Headland had enquired about the air bubble system. The system was very simple. It consisted of a plastic tube resting on the bottom as close to the upstream face as possible. Compressed air supplied from a 10 HP compressor, was forced out through approx. 1/32 in. holes drilled at a spacing of 10 to 15 ft along the tube. Care had to be taken to prevent freezing in the tube where it passed the water-surface. This might be done by passing the tube inside the buttress and by some electrical heating. The system at Skogfoss cost approximately £500 and had proved to be satisfactory.

130. Mr Blackmore had asked a question concerning the radial spillway gates. The gates were operated from the control room where the position of the gates and water level could also be read. The surface area of the pondage was approximately 20 square miles and demand variations did not call for immediate operation of the gates. The gates could be opened partially without any vibrations.

131. Mr Brown had asked if the main dam had been designed for overtopping. It had not, but the question was related to the reply in § 130.

132. Mr Roseveare asked about the joints in the dam. The joints were sealed by copper seals of approximately 1 mm copper sheets given a u-bend in the middle. Today when plastic seals of 'arctic' quality could be obtained this type was usually preferred, since jointing was easier.

133. The concrete used for the heavily reinforced dam structures met the requirements for the use of sliding forms. The forms were raised approximately one foot per hour. There were no problems in connexion with the use of sliding forms and the quality of the surface had improved.

134. No model tests had been made for the bottom outlet gates to investigate the danger of vibration. However, from more or less identical structures, the Authors had found that as long as the bottom edge of the gate was properly designed, with a sharp edge no vibrations would occur.

135. Mr Willet had a few questions about the spillway radial gates. This type of gate was chosen mainly for economic reasons. Radial gates were, however, normally regarded as preferable in a cold climate because flat roller gates could be blocked by ice collecting around wheels and rails due to leakages in the sealings. Provisions had been made for stoplogging of the spillway gates. Recesses had been left in the piers, to fit a hollow floating beam which was floated in position and lowered into the recesses by temporarily lowering the water level. The beam formed the upper support for needles. There was no provision for heating of the trunnion arms. Experience had, however, shown that ice collected on the arms during discharging in the winter period, causing some inconvenience for its removal.

Männika Dam

136. Mr Chapman, Mr Keefe, and Mr Willet had all asked questions regarding the Männika Dam. The clay used for the upstream sealing was so soft that even light vehicles fitted with belts could not drive on the clay because the belts dug through the clay and down to the gravel. The clay blanket was therefore spread and evened-out by using a bulldozer which travelled on the gravel and worked upwards from the upstream toe. When the frost started and a crust of frozen clay had developed it was possible to compact the clay using a light vehicle fitted with belts. From the time the clay was placed until the time it was finally compacted it had probably also dried up to some extent. Before the water level was raised the next summer the clay blanket was compacted again by a heavier vehicle.

137. To date the dam had been in operation for a little more than one year. The leakage had been observed and proved to be constant at a level of 2·6 to 3·0 cusecs. The greater part of the leakage was assumed to be passing through the ground below and at the sides of the dam. The leakage would, of course, be watched for some years, but it was not expected to increase.

138. There was no provision for compensation water in the Männika branch. This had not been demanded by Russia possibly because a strip of some kilometers width along the border on the Russian side was uninhabited and a dry river bed would probably not be of any inconvenience.

139. Mr Keefe had asked if the clay blanket could be repaired, which was of course possible by emptying the reservoir. As the intake pond was not a regulation reservoir except for some daily regulations, the variations in water level would be small, and the lower part of the clay blanket would not need protection (a point about which Mr Brown had expressed concern).

Headrace and intakes

140. Mr Keefe wondered if the headrace and tailrace canals were lined. The ground level on both sides of the headrace canal was somewhat lower than the water level, and low training walls had had to be constructed along the canal on both sides. The wet face of the training walls was extended down to the canal bottom to form a complete lining of the canal sides. The invert was unlined. The lining was tied back by a couple of rows of rock bolts. Even if the rock was cracked in places the strength was good enough for grouted bolts to be effective. The tailrace canal was unlined except for a short section close to the power station.

141. Mr Freer and Mr Willet had asked about the water sealing and stability of the intake. The seepage through the rock and between the concrete and the rock into the drainage gallery was small. There was, however, a leakage through the rock on the west side of the intake draining into the gallery. The leakage amounted to less than a gallon per second. The rock was grouted with a curtain just upstream of the drainage gallery and along the canal sides, approximately 200 ft on the west side and 270 ft on the east side reckoned from the intake. About 12 metric tons of cement were consumed. A deeper cutoff trench would probably not have made much difference.

142. The stability of the intake and the strength of the invert was computed assuming an upward pressure of roughly 3/4 of the static head at the intake cutoff trench. Shear sliding was no problem as the spiral case and the draft tubes were concreted directly against the rock. The shear stress therefore was very small.

143. When the intake gates were serviced the intake was closed by planking directly against the trash rack. The trash rack and the supporting beams were calculated for the full water pressure. The closing of the trash rack would, of course, be under-water work.

Costs

144. Mr Chapman, Mr Headland, and Mr Willet had dealt with the cost of the project, especially in relation to the remote location and the severe climate. The

figures for the cost given in the Paper were quoted before the actual construction costs were known. More correct figures were:

	£ *million*
Civil works	1·6
Mechanical (turbines, crane, gates, etc.)	0·5
Electrical (not including transmission lines)	0·5
Field investigations, administration, fees, interest during construction period, electric power, housing for operational personnel, office, damages including inundation of land, miscellaneous	0·9
Total	3·5

Assuming the annual cost to be 9% of the total investment, the price per kWh would be from 0·35*d* to 0·44*d* depending upon whether 230 million kWh or 180 million kWh was taken as the annual production. No charges for the thermal plant were included in this figure.

145. The second unit was regarded as a necessary stand-by. The thermal plant was too small to be adequate in case of maintenance or repair to the main plant.

146. The Authors wished to make the following acknowledgements. The Skogfoss plant is jointly owned by the Varanger Power Board (which is municipally owned) and by A/S Sydvaranger, a large mining company in Kirkenes. The contractor for civil works was Pasvikkraft, a company also owned jointly by two Norwegian contractors Thor Furuholmen and Astrup and Aubert. The turbines were supplied by K.M.W., Karlstad, Sweden, and the generators by Siemens, Norway. The gates were jointly supplied by A/S Kvaerner Brug, Oslo and Akerselvens Maskinverksted, Oslo. The main consultants were Ing. A. B. Berdal, Oslo, and Professor Faanes of Trondheim for the electrical engineering, and Messrs Thoresen and Nybro-Hansen, Oslo, for the mechanical engineering. The resident engineer during construction was Mr O. T. Rønning.