The Manapouri power project, New Zealand

J. A. LANGBEIN

Mr B. T. Seddon, Binnie & Partners

The Paper is a fascinating record of achievement and a mine of valuable information. The removal by explosives of the rock barrier at the intake within 1·2 m of a reinforced concrete structure as described in § 87 is one of the many imaginative construction techniques described. So far as I am aware, this method has never previously been used so close to a completed structure. Previously I had the feeling that probably one could not go within about 10 m of a completed concrete structure.

96. The layout shown in Figs 5 and 6 indicates a pressure shaft and a cable shaft for each machine, and no turbine inlet valve is provided. Current British and continental European practice would probably require the additional security of an inlet valve in the underground power station designed to close automatically in emergency conditions. This could lead to an increase in power station width of about 1·5–2 m. However, one intake gate and pressure shaft with a concrete bifurcation at the bottom of the shaft would then serve two machines. The transformer galleries could be connected by tunnel leading to two cable shafts serving the whole station. Such a layout appears to offer additional security, and the capital cost might not be higher, although it is perhaps difficult to judge because in this special case I imagine that the costs of excavation in the underground power station are much higher than normal because of the need to bring all the material out through a vertical shaft.

97. In § 36, on the design of the intake structure, the Author states that the screen area was based on an average velocity through the screen bars of 0·52 m/s. This seems low, unless it was dictated by fishery interests. Elsewhere in the absence of such problems average velocities of 1 m/s have been accepted.

98. The ratio of span to rise in the machine hall excavation shown in Fig. 6(b) is about 4. A recent review of about 30 underground stations indicated ratios varying from 1·6 to 6·3, and an average of 3·5. Mathematical analysis confirms that with the shape indicated in the Paper and assuming homogeneous and elastic material, the roof would be in compression if the horizontal in situ rock stresses were equal to or greater than the vertical stress. With the horizontal stress lower than the vertical stress, tension can develop in the arch. The roof arch is in effect supported on the downstream side by a series of pillars of rock 4 m wide between transformer vaults. It would be valuable to have information on the method of stress analysis adopted for this bold design. How would the Author have dealt with a local zone of weak rock revealed during excavation at one of these pillars? I think many would have thought in terms of a separate transformer cavern parallel to the main cavern and far enough away to be out of the stress field.

99. In § 37 the Author gives details of the pattern of grouted rock bolts installed as reinforcement in the penstock shafts. This is an alternative to pressure grouting the rock, in stages up to a pressure in excess of static water pressure. What was the reason for adopting rock bolts for this application? Pressure grouting should serve to seal cracks and to test for watertightness in addition to reinforcing the rock. As an alternative to mechanically anchored rock bolts, resin anchoring has been adopted on some schemes, and the longer effective length of anchor offers advantages in certain types of rock; resin anchoring seems to be more expensive than mechanical anchoring. Resin anchored bolts protected from corrosion by epoxy paint or plastic material have been installed in Eire and Germany and these may become competitive with

Paper published: *Proc. Instn Civ. Engrs*, 1971, **50**, Nov., 311–351.

cement grouted, mechanically anchored bolts although damage to the protective coating during installation seems a strong possibility.

100. In § 61 the Author mentions the use of ammonium nitrate and fuel oil blasting agent in the tunnels. This was abandoned when water-bearing ground was encountered. There appears to be a move away from the use of this explosive agent in underground works because of the problem of fumes. Was it the Author's experience that these fumes could be dealt with satisfactorily?

101. I should like to have more information on the method of continuing excavation of the tunnel while concrete lining is in progress. I understand that the excavation was going on ahead of the concrete lining, and therefore the excavated material must have been brought back through the concrete lining process.

Mr N. S. Long, Bechtel International Ltd

Through circumstances which could be attributed to no one in particular, the cost of this project was increased by industrial relations factors.

103. When it was decided to build the Manapouri project the Ministry of Works in New Zealand, who have an excellent hydro-electric engineering and design and construction team, were fully committed in carrying out their long-range programme for hydro-electric development of the country. The Manapouri project represented an addition to this work load, and the only way it could be accomplished in the time allotted was by bringing in outside consultants and using world-wide tendering for construction.

104. Soon after the project was begun it became obvious that there was an industrial relations jurisdictional problem. The Ministry of Works, who perform with their own forces, used the New Zealand Workers Union, which is an overall coverage union, and on their projects all the employees on the job belong to this union. This covers all the major civil works in the country, and the union also has other assignments which are not relevant here.

105. When private contractors operate in New Zealand they employ the various craft unions. Manapouri was a Ministry of Works project but it was constructed by private contractors so both groups of unions felt it was their own work.

106. In New Zealand, labour relations are governed by an arbitration court, which has the ultimate say in all labour relations questions. The project could not be started until this problem was before the labour relations court. The first major work on the project was the tailrace tunnel, and the court decided that the New Zealand Workers Union should be the union responsible for this portion of the project. Work went on for three years under this arrangement and on that portion of the project there was no industrial work stoppage.

107. However, when the time came for the powerhouse contract to start, the craft unions, feeling that they had a better case because of the greater variety of work in the powerhouse, took their case again to the court. In the mean time, and perhaps unfortunately from the standpoint of the project, the presiding judge of the court had retired and there was a new judge. He decided in favour of the craft unions. The result of this was that in a very remote area there were two groups of several hundred men, camped within 14 miles of each other, belonging to two different union organizations. Although their camps were separate, they used common transportation facilities. The consultants were common to both projects and, although the contracting organizations were different in their make-up, the same contracting firm was the leader in both organizations. The result of this, coupled with the fact that union contracts expired on different dates, was that the contractors, and through them the Government who were ultimately paying the cost, were subject to a whip-sawing action because these unions tried to show their members that they were going to do better by them than the others were by their union. The cost of this project was significantly increased by this circumstance.

108. In New Zealand this arbitration court enjoys great respect of the labour

movement, of Government and of the contracting organizations and because it is absolutely independent, even though the Government saw this problem, they avoided interfering with the court and this problem was not presented to the court. It only heard the union case.

109. Nevertheless the arbitration court works well in New Zealand. Overall, it makes a positive contribution to labour relations, and New Zealanders must accept that occasionally circumstances develop such as this one.

Mr D. Pausch, Weir Pumps Ltd

The turbines and the governing equipment were supplied by the Harland Engineering Co. which is now Weir Pumps Ltd. The contract was placed with Harland in May 1964 by the Ministry of Works, covering the supply and supervision and erection of the water turbines 1–4, with the electro-hydraulic governors, the steel draft tube liners and the draft tube gates. Units 5–7, forming the second part of the contract, were ordered in October 1968, the total value of the contract being about £2 million.

111. The water turbines are the Francis type of Allis Chalmers design, each rated at 144 000 hp at 250 rev/min under the normal net head of 150 m. They have a maximum output of 166 000 hp under the higher heads at which they have to function.

112. From the specification it was realized that efficiency would be a major consideration in the evaluation in view of the high load factor, but the design is nevertheless fairly conventional. It was maximized to give an efficiency which on test proved to match the claim of 95%.

113. The installation of these units in an underground powerhouse with a relatively long tailrace introduced constricting conditions which had to be taken into account in the design. The spiral casing was constructed in two sections with flanged and bolted joints.

114. The spiral casings for the first four units were made in Scotland, but it was found advantageous to manufacture the last three in New Zealand. There were some restrictions in the workshop facilities there for such major fabrications, but resourcefulness came to the fore and the work was completed successfully.

115. The Paper refers to the maximum widths at the penetration through the downstream wall of the machine hall with a limitation of 6·1 m to preserve the adequate thickness of the pillar. This is less than ideal from the turbine point of view, but it had to be taken into account and was overcome successfully in the design of the draft tubes without impairing the hydraulic efficiency.

116. The hinged draft tube gate, which is actuated by an oil-operated cylinder, is relatively novel in the design of these turbines. The gates were manufactured in New Zealand.

117. The friction losses in the long tailrace tunnel resulted in high tailrace pressure under full station conditions, and this came back on the main shaft gland which is a carbon ring mechanical seal type.

118. The performance of the water turbines was accepted contractually on the basis of model tests which were carried out within a few months of the placing of the contract. The prototype power was computed from the model. Prototype turbine efficiency was considered as being equal to the test efficiency of the model plus an efficiency correction as determined by the Moody formula, using a ratio of the diameters to the power of one fifth. Three tests gave the desired results under the contractual guarantees.

119. The governors were supplied by ASEA and were relatively conventional, supplying the pressure oi lthrough a distribution valve to twin turbine hydraulic servo motors in the turbine pit, and were mechanically connected through a regulating ring and a series of links to the wicket gates, separate oil pressure systems being furnished for each turbine.

120. The first unit came into commercial operation in October 1969 and the second was commissioned in 1971. The commissioning procedures required a comprehensive

series of load rejection tests, and these proved the satisfactory functioning of the governing equipment. They were concluded with complete satisfaction for all units.

Mr J. Davie, Sir Alexander Gibb and Partners

There is not a great deal of information on man-made vibrations and their effect on structures. Could the Author give some data on the size of the test shot charges and their measured effect with and without the air bubble barrier? Could he also give details of the size of the charges in the final excavation and the forces produced by them on the intake structure?

122. The ways of developing the power potential between Lake Manapouri and the sea are mentioned in the Paper. Was the reason for the rejection of a layout with the power station at Deep Cove entirely the result of an economic comparison or was the decision influenced by the inaccessibility of the sea end for the carrying out of sub-surface exploration?

123. Heavy water inflow under high groundwater pressure was encountered during the driving of the tailrace tunnel. The pressure grouting ahead of the face must also have been at a high pressure. Did this not merely have the effect of chasing the water around and along the tunnel to reappear elsewhere? Was consideration given to dealing with the water by other means such as by drilling drainage holes in the rock and piping the water away? It seems fortunate that the rock was sufficiently competent to withstand the high pressures.

124. The Author has said that the tunnel lining was provided for economic and hydraulic reasons and was not designed to support unstable rock. A section at the upstream end and the whole of the flat invert were provided with means of relieving unbalanced pressure. Were any other precautionary measures taken to protect the concrete lining at the sections of high groundwater pressure?

125. From the description it appears that there are no gates at the outfall of the tailrace tunnel. Can this tunnel be dewatered for maintenance inspections and how will this be accomplished?

126. Presumably a separate penstock was provided to each machine to reduce the station outage to a minimum if a set or penstock were out of service. The maximum design head on the penstocks is 290 m and the steel lining must therefore be thick. What was the plate thickness? The bending and welding of thick shell plates can pose problems. Were any difficulties encountered in the fabrication of the penstocks? Could the Author give details of the method of handling the penstocks into place in the shafts?

A speaker

In 1970 about 200 000 New Zealanders out of a population of 2¾ million petitioned against the raising of the water level in Lake Manapouri. It was argued that there would be an irreplaceable loss of plant life and fauna on the lakeshore by raising it by 8·2 m. Some considered this loss at shoreline to be serious, but as far as I can judge from the Paper their objections did not carry any weight in the long run and the lake level has been raised.

128. Nearby at Lake Monowai the results of raising the lake level have been that all the trees on the shore stand dead, with their roots and the lower part of their stems under water, and there is a scar wherever the vegetation comes down to the shore. What thought was given and what will be the end result to Lake Manapouri as a tourist attraction when the lake is filled to its final level?

129. No mention has been made of any water being left to flow from Manapouri into the Waiau. What will be the effects on the Waiau of diverting the water over the mountains down to the west side of South Island?

Mr C. L. Clarke, Sir William Halcrow & Partners

When I visited the tailrace tunnel in August 1966 it was about one third of the way through. Water was squirting in at about 1000 lb/sq. in.; the temperature was about

3°C and the Contractor was having to pump out 8000 gal/min. In § 20 the Author states that the roughness of the terrain prevented investigation of rock conditions at tunnel grade and that it was anticipated from the surface geology that the rock would be sufficiently competent. With hindsight, would it have been worth while spending any more on investigations? For every tunnel the decision on how much can be justified on investigations has to be made.

131. By now, engineers should have enough data on completed tunnels to be able to estimate the benefit from spending more money on investigations, although however much is spent there will always be a risk. Most of this risk is finally taken by the Employer, largely due to the clause in the contract covering conditions which cannot reasonably be anticipated—'latent conditions' in the Manapouri contracts. Under these circumstances the Employer, Engineer and Contractor must co-operate as a team to achieve the most economical tunnel. I found this co-operation lacking when I visited Manapouri.

A speaker

In § 24 the Author refers to earthquakes. To what extent was account taken of these in the area between the dam, the lake site and the length of pylons which go over miles of flat country? It is generally considered that the epicentres of earthquakes are in the lower ground rather than in the high ground. Therefore, one might imagine in this scheme that the dam is fairly free from earthquakes but that the pylons, which go for several miles, might be affected by the low ground area of earthquakes.

133. Is that theory true from the Author's point of view, and has he reason to doubt that the low ground, where the pylons are, is susceptible to earthquakes, while the high ground, where the lake is, is comparatively free?

Mr N. Borg, Public Works Department, City of Birmingham

Among the requirements in many engineering departments is one that the design team consults the maintenance agency about the suitability of the design. It may be that as a result of comments received the original and apparently most economical design is not put into practice. Perhaps something more expensive has to be undertaken.

135. To what extent was this practice followed in the preparation of this scheme? To what extent did it make any difference to designs, and, in the main, what are the techniques of maintenance which are foreseen, particularly in winter conditions or in the event of unexpected conditions developing in a tunnel which appears to have been heavily perforated?

Mr J. C. A. Roseveare, Freeman Fox & Partners

It is interesting that the turbine inlet valves have been omitted. Could the Author comment on his philosophy in approaching this feature of the design?

137. At Ffestiniog it was thought advanced to omit the automatic self-closing valves at the portal on the penstocks leading down to the power station, but the inlet/outlet valves at the turbines and pumps were retained. A complicated piece of apparatus can itself constitute a hazard and, in some circumstances, simplicity and safety go hand in hand.

138. Large forces are exerted on a machine of this size and head. Where were those forces absorbed in the structure? In this case there is no inlet valve and the hydraulic thrust will always be on the spiral casing, irrespective of the operating condition. How did the Author allow for absorbing those forces?

139. In a large machine with a high head and comparatively thin plates, there are sizeable expansions in the spiral casing. The casing was concreted while it was under pressure, and there was a thin coating of compressible material on the top of the spiral.

140. What was that material? When a spiral casing is completely confined, if the material is going to be effective it must be compressible as well as flexible. At Ffestiniog, where concreting was not done under pressure, the material was nitrogen filled microcellular rubber which was genuinely compressible.

Mr V. F. Lindsey, M

The visitors to Manapouri in April 1971 were faced with posters denouncing a proposal to raise the level of the lake. Lines were painted on the walls of buildings to show the proposed new water level.

142. Does this indicate that it is already proposed to extend the project by implementing the High Manapouri scheme as mentioned in § 19?

Mr D. J. D. Reid, Fluor Australia Pty Ltd

The construction of the West Arm powerhouse involved the use of several temporary plant installations and adaptations of equipment. Almost without exception these were designed by the Contractor's site staff which proved an advantage because they were on hand to monitor modifications during installation and initial operation of the plant.

144. During the excavation phase there were 45 headings of different sizes, shapes and inclinations and so the drill jumbos and work platforms had to be adaptable and mobile. Two pieces of equipment proved outstanding: 10 ton forklifts with a work platform containing four drifter drills mounted on the forks were used for drilling headings up to 5 m square with the ability to reach tight or high corners, and a two-man work platform on the boom of a 12 ton hydraulic crane gave access to tunnel arches for rock bolt installation, grouting, guniting and rock inspection. The main sidewall drilling jumbos contained seven Drifter drills at three levels mounted on the chassis of a 30 ton rear dump truck.

145. The 1130 hp mine hoist (§ 72) was manufactured by Metropolitan-Vickers in 1927 but had not been used until brought to West Arm in 1967. A few parts were replaced but otherwise it gave excellent uninterrupted service and hoisted over 150 000 m^3 of muck. The payloads were $10\frac{1}{2}$ t, the height of lift 260 m and the cycle time $3\frac{1}{4}$ minutes.

146. Water disposal posed a problem before the tailrace tunnel was holed through, because of grout and other fines suspended in the water and because of the static head of 230 m against which the water had to be pumped to the surface. The water was passed through a settling tank designed to settle particles above 0·067 mm and into a sump drained by a battery of 4 two-stage electric pump units each rated at 4554 litre/min, together with an emergency diesel pump. As only a flow of 5500 litre/min was experienced, the particle size probably did not exceed 0·042 mm, which is less than one third of the clearance between the pump impeller and casing. No major wear or down-time was experienced. Disposal of the fines and spillage from the mine hoist was a continuing problem which involved much labour.

147. In the construction phase the most pressing problem was that of material distribution and storage in the restricted space of the machine hall and access tunnel. This was mainly solved by separating the concrete supply system from the vehicular access required by the other materials, as described in § 77, using a vertical dropline and conveyor belt system. As a result there was little delay to trucks unloading at the end of the access tunnel.

148. The concrete was dropped in 6 cu. yd batches down the 254 mm dia. dropline through a quick-acting valve to minimize segregation, into a 458 mm dia. circular boot 30 m high. The increase in diameter was sufficient to allow the momentum of the falling slug of concrete to be destroyed in time rather than sustain the full force of an impact load. In the last month the concrete was dropped as it was delivered from the transit mixer, and no segregation was apparent; however, these trials could not be considered conclusive, and with time there would undoubtedly have been problems from grout build-up in the pipe. The boot opened on to a 6 cu. yd holding hopper which fed a conveyor that ran the full length of the machine hall.

149. Distribution within the machine hall was effected by a transverse conveyor that hung by variable length ropes from trolleys on temporary monorails attached to the permanent crane columns. This same monorail supported two gantry cranes

with 5 ton hoists, also suspended from ropes of variable length, which transported reinforcing steel and other construction materials. Thus both concrete and material distribution could be effected to any part of the machine hall, at varying heights to suit the stage of construction, while still allowing the main permanent bridge cranes to traverse with loads overhead.

150. The 4·9 m dia. penstocks required special plant for construction as they were 164 m deep and had vertical curves of over 12 m radius at top and bottom, so that direct hoisting was not possible. A rail system of 6 in. × 4 in. I beams was installed in the shafts, serviced by mobile hoist units comprising two 150 hp hoists with line speed 100 m/min, and a 50 hp hoist with line speed 10 m/min. The hoist ropes were guided round the upper vertical curve by idlers adapted from used dozer track idlers. The hoists successively lowered a man car for the miners to complete excavation, the 14 ton steel liners, the backfill concrete and a holding hopper and work platform for concreting. All were designed to accommodate the rotation inherent in operations in the upper horizontal and vertical sections of the penstocks.

151. The 3·66 m dia. 2·44 m high slipform for lining the vertical penstocks was raised by eight 3 ton jacks climbing on 25 mm bright steel rods embedded in the concrete. It was kept from rotating by guides in contact with the rails and line was checked by a laser beam set in the top of the shaft. The form surface was heated by a steam jacket, and ½% of calcium chloride was added to the concrete. The maximum daily advance was at a rate of 0·86 m/h and 0·58 m/h was the average for the 760 m of shaft lined.

152. The final operation that required specialized equipment was the removal of the underwater spoil from the cofferdam (§ 90). Three hoists were stationed on the far shore 300 m distant, each with a drag bucket and a return line which went to a tail pulley mounted on a monorail on the trashracks. Many sizes and shapes of bucket were experimented with, but the most successful was a standard 2½ cu. yd dragline bucket, and it was necessary to weight heavily the back of the ripper and to fit a bridle to prevent sidesway. Of paramount importance was the skill of the operator in avoiding tangled ropelines, and continuous sounding to monitor progress, as it was possible to operate for long periods with the lines at normal tension and afterwards find that no spoil had been effectively moved.

153. There was a slow start due to delayed hirings of labour and an unexpectedly large grouting programme to cut off free water, and there developed an increased work commitment through design changes. Despite these hindrances the units were commissioned only slightly behind schedule and the Contract was, with minor exceptions, completed on the due date.

Mr Langbein

The variations of the general arrangement of the station referred to by **Mr Seddon** were seriously considered and carefully studied, together with other versions during the earlier planning stages. Cost comparisons showed that differences in total construction cost were relatively minor and the unitization concept was a particularly desired feature. With this arrangement, one generating unit and associated equipment can be shut down for inspection or major overhaul, without affecting any of the other six remaining units, and this is important in a high load factor station.

155. The possibility of one or a pair of cable shafts serving the entire station would appear to offer a cost advantage over the seven cable shaft arrangement adopted, but detailed comparisons did not support this. The estimated cost of constructing the horizontal tunnels needed at the power station level to bring the power cables to the single shaft or pair of shafts, plus the cable trenches required at the switchyard level to spread the cables to the unit bays in the switchyard, plus the cost of the additional lengths of 220 kV oil filled cables, outweighed the cost of the individual shafts and cables provided.

156. Lake Manapouri and surrounding rivers are popular sport fishing waters,

being well stocked with trout and salmon. It was particularly desired to hold water velocities sufficiently low at the intakes to avoid drawing young fish into the penstocks, although economic considerations justified the cost of the rack area provided.

157. Stress analysis of the underground chambers was based on the results of photo-elastic model studies and a finite element analysis of a similar underground chamber, supplemented by observations of the rock behaviour during the exploratory investigations. During excavation, heavy jointing inclined at about 60° was exposed in one of the rock pillars between a pair of transformer vaults. When this pillar began to show symptoms of distress, it was monitored by deformeters, flat jacks and sub audible rock noise (SARN) equipment. Excavation proceeded with care, and supplementary rock bolting was installed perpendicular to the planes of the joints to assure stability of the pillar.

158. The grouted rock bolts installed in the penstock excavations were not regarded as an alternative to pressure grouting the rock. The bolts were installed close to and concurrently with the advancing excavation face, primarily to minimize relaxation of the rock.

159. All rock bolt grouting was performed with a Portland cement grout mixture. This was deemed prudent at the time, due to lack of experience with resin grouted bolts. Expansion shell type anchorages performed satisfactorily in the type of rock encountered in the underground excavations.

160. The choice of blasting agent used in all excavations was open to the construction contractors. The permissible limits of contamination of the underground atmosphere by toxic gases and particulate matter were specified according to accepted standards and were monitored by underground safety inspection. The tailrace tunnel contractor initially used a 60% gelignite, but converted to an ammonium nitrate and fuel oil mixture (ANFO). Improvements in rock fragmentation and fume dispersal were noted with this change, but when groundwater was encountered in the heading, the use of ANFO had to be discontinued, and gelignite was used throughout the remaining tunnel excavation. Details of the average excavation cycles for the typical rock bolted tunnel section are:

Drill tunnel face	63 min/m
Complete rock bolting	3 min/m
Load explosives	20 min/m
Ventilate	10 min/m
Muck out	63 min/m
Move sliding floor	23 min/m
Total	182 min/m

Rock bolts were installed during the face drilling cycle, but required 3 min/m more time than the drilling cycle itself. When steel arch supports were installed, the average total cycle time increased to 250 min/m of advance.

161. Tunnel excavation and concrete lining both proceeded in an upstream direction. Concrete arch lining began when the heading excavation had advanced about 3000 m from the downstream portal. The toes of the steel arch forms were anchored by bolts embedded in the previously placed concrete kerbs, thus eliminating the need for transverse strutting across the tunnel invert. In the design of the forms, sufficient space was provided to permit the passage of muck trains and concrete trains through the forms, the pneumatic concrete placing equipment being located upstream of the 30 m length of forms. Usually about 65 cars of 10 m^3 capacity were required to remove the fractured rock from one 4 m round. The cars were made up into trains of ten cars each. The mucking cycle averaged about 252 min per round, so the muck trains were spaced about 40 min apart. This interferes with efficiency of concrete placement, but the effects of traffic congestion can be minimized

by judicious location of rail slidings and passing switches. Concrete trains consisted of three 4·6 m^3 rail mounted mixers hauled by a 22 t locomotive.

162. In reply to **Mr Davie**, published data show that an effective air bubble curtain can reduce underwater blasting pressures to about 10% of the pressures measured without the air bubbles. To attain this degree of attenuation it is necessary to discharge not less than 0·024 m^3/s per lineal metre across the length of the air curtain. Total air flow across the primary curtain in front of the trash rack structure and the secondary curtains in front of the intake gates was 3 m^3/s. In production blasting, the size of charge varied according to the cross-section of the rock barrier, and ranged up to about 1350 kg with an explosive factor of about 0·95 kg/m^3.

163. Pressure transducers were suspended in the water immediately in front of the Unit 4 and Unit 5 intake gates. Two velocity meters were attached to the reinforced concrete sill beam cast on the rock across the toes of the trashrack structure piers between Unit 4 and Unit 5 intakes. Typical measurements recorded from these instruments are shown in Table 3.

164. As may be seen from the figures in Table 3, there is reasonable correlation at Gate 4 between the pressure change measured by pressure transducer, and the pressure change calculated from the observed dynamic gate strain during the presplit blast which severed the base of the rock barrier from the bedrock below.

165. The reason for adoption of the layout with the powerhouse located at West Arm, rather than at Deep Cove, was not based entirely on economic considerations. The economic differences between the two layouts were not great in relation to the total construction cost, but several intangible considerations greatly favoured the West Arm location.

166. As Mr Davie's query surmises, there was positive evidence to support the postulation that high pressure grouting ahead of the tailrace tunnel face 'chased the water around'. Adjacent portions of the tunnel which had yielded little groundwater inflow when first penetrated, subsequently exhibited water inflows after grouting the face ahead. Consideration was given to collecting the water by pipes caulked and grouted into interceptive holes drilled in the rock, and manifolding these pipes into a header pipe through which the water would be conveyed to the downstream portal under its own pressure. Several other alternatives were weighed, not the least of which was the substitution of two smaller diameter parallel tunnels for the single 9·2 m dia. bore. The faces of the two smaller tunnels would be driven ahead alternately, the one acting as a large drain while the face of the other was being advanced. This of course would have been a last resort.

167. As stated in the Paper, the upper reaches of the tailrace tunnel lining are provided with pressure relief holes on a 1·2 m grid pattern. Throughout the remaining length of the tunnel, pressure relief holes are provided approximately on a 2·4 m grid pattern except that in locations where high groundwater pressure occurred, the spacing is reduced to 1·2 m. During placement of concrete in the tunnel lining at locations where high groundwater inflows occurred, the fresh concrete was protected by embedding pipe elbow drains in the concrete kerbs. Sheet metal flashing was installed adjacent to the rock surface and outside the steel supports, when these were used. The water falling on to the outside surface of the flashing was diverted into the kerb drains. After removal of the tunnel lining forms, the drain holes were drilled through the concrete lining into the rock.

168. With the adopted powerhouse and tunnel layout, a simple means of draining the railrace tunnel cannot be provided, and consequently there are no gates at the tunnel outfall. Any planned dewatering of the tunnel would be a task of major proportions requiring about three months pumping time with practically-sized pumping equipment. Before dewatering was started, a cofferdam would have to be constructed in the outlet channel, but this would be a comparatively small item in relation to the total scope of the work involved in a dewatering operation.

169. The maximum penstock plate thickness satisfying the design criteria is

Table 3

		Pre-split blast	Production blast
Vertical velocity	Frequency, Hz	42·8	40
	Velocity (pen recorder), cm/s	7·44	7·07
	Velocity (oscilloscope), cm/s	9·84	9·19
	Time lag of peak after detonation, ms	450	0·001 positive peak 15 negative peak
Horizontal velocity	Frequency, Hz	42	40
	Velocity (pen recorder) cm/s	13·46	24·49
	Time lag of peak after detonation, ms	450	0·001 positive peak 15 negative peak
Pressure change, Gate 4	Frequency, Hz	7·1	9
	Positive, N/mm²	0·0265	0·0266
	Negative, N/mm²	0·0496	0·0254
	Time lag of peak after detonation, ms	665	170
Pressure change, Gate 5	Frequency, Hz	7·1	8
	Positive, N/mm²	0·0380	0·0316
	Negative, N/mm²	0·0487	0·0411
	Time lag of peak after detonation, ms	650	70
Strain gauge observations, Gate 4	Dynamic strain		
	Max positive, horizontal, microstrain	+19·2	
	Max positive, vertical, microstrain	−8·0	
	Max negative, horizontal, microstrain	−18·5	
	Max negative, vertical, microstrain	+6·0	
	Calculated gate stress change		
	Max positive, N/mm²	3·75	
	Max negative, N/mm²	3·74	
	Calculated change in water pressure		
	Max positive, N/mm²	0·035	
	Max negative, N/mm²	0·034	

41·4 mm. The last three cylinders at the bottom of each penstock are increased in thickness to 44·5 mm, 50·8 mm and 57·2 mm, respectively, the last to match the plate thickness at the flexible coupling at the turbine inlet erection joint. No particular difficulties were experienced in rolling and welding these thick plates though some laminar defects were discovered in a few plates which were replaced by the plate supplier.

170. The question raised regarding the method of handling the penstock liner sections into place in the shafts is described in the written discussion submitted by **Mr Reid.**

171. As mentioned by a speaker, a petition of restraint against raising Lake Manapouri was submitted to the New Zealand Government in 1970. At that time, no decision had been reached regarding any raising of the lake level, nor has it been raised at the time of this discussion. In acknowledging the points of public concern, the Government appointed a Commission of Inquiry which held public hearings over a period of several months in New Zealand, so that all interested persons would have adequate opportunity to express their views. From the inception of the project, the effects of raising the lake had been a matter of prime concern, and liberal allowances were made in the project cost estimates for clearing, and for shoreline restoration to minimize disturbance of the flora and fauna.

172. Obviously the flow in the Waiau River would be reduced, and this is in accordance with the provisions of the Te Anau–Manapouri Development Act but, as noted by the speaker, there are many other downstream tributaries.

173. Much thought was given to the effects of the project on Lake Manapouri's attraction to tourists. In 1959–60, before commencement of construction of the project, 7100 tourists travelled in launches on the lake. In 1969–70 the figure was 30 796. Similarly, the number visiting Deep Cove before the impact of the project was felt was about 500 per year. After completion of the Wilmot Pass Road, and the inauguration of a tourist bus service, that number increased to over 5000 per year. Since completion of the powerhouse, a further attraction has been created by provision of a bus service down the access tunnel, thus permitting visitors to view the underground chambers and power generating equipment. Ultimately, on completion of the final stages of the development of the project, I believe that the reduced fluctuations in the lake level, effected by regulation of water inflow to match the diversion of water for power generation, will enhance the natural beauty of the lake.

174. **Mr Clarke** commented very pertinently on the difficult tunnel excavation conditions when high pressure–low temperature groundwater was encountered. A minimum programme of additional exploratory drilling conducted from the surface along the tunnel alignment would have delayed the start of tunnel construction by at least a year. In retrospect, I think that the true nature of the worst groundwater conditions that were encountered would most probably have escaped detection, for they were confined to about 10% of the total length of the tunnel lying about 1000 m below the most inaccessible portion of the ground surface over the tunnel alignment. Apart from the need to import drilling crews and equipment capable of drilling to these depths, the extreme difficulty of access and the time required, coupled with the unreliability of extrapolating drill hole data, were the overriding factors in deciding not to conduct a comprehensive drilling programme from the surface along the tunnel alignment.

175. When difficult working conditions occur, such as the worst that were encountered in the railrace tunnel, it is natural to expect that divergent views will be put forward by all concerned parties as to what procedures are best suited for the continuance of the work. Presumably Mr Clarke would have visited the tunnel at this critical stage. In summary, an amendment to the contract, completely revising the completion dates and the terms of payment, was negotiated for the successful completion of the tunnel. I believe that such major revisions to the contract must reflect

that complete understanding and co-operation between the Employer, Engineer and Contractor that was finally attained.

176. Replying to **Mr Walter**'s questions regarding aseismic design, all structures were designed to withstand earthquake effects. The extent varied according to the nature of the structure or equipment. The designs of the supports of some vital items such as current transformers and potential transformers which were mounted on pipe columns in the switchyard, were modified to withstand lateral forces due to $0 \cdot 75\,g$ acceleration. The fixings of the main power transformers were designed to withstand lateral forces of the same magnitude. These pieces of equipment have a large mass with little ability to absorb energy by elastic deflexion. Transmission towers, on the other hand, have a large damping factor and have a good capacity to absorb the effects of lateral forces by elastic deflexion. Although the effects of seismic loadings were checked, wind forces, ice loadings and the unbalanced line pulls resulting from conductor failure were the overriding factors governing transmission tower design. There was no evidence to support the adoption of a higher seismic design factor for that portion of the line which lay outside the mountainous terrain.

177. **Mr Borg**'s comments are well taken. It is commendable when the requirements of the operating authority can be properly incorporated in the final design. The Designers of the project were most fortunate in that the New Zealand Electricity Department appointed one of its senior representatives, resident in the Designer's office for several weeks, while the general arrangement of the project and major design features were finalized. This accelerated the elimination of many alternative arrangements and systems, all of which possessed features of merit, and permitted the rapid resolution of a layout with mechanical and electrical systems schematics consistent with the established operating procedures of the Electricity Department. The unitized plant layout enables any one unit of the power plant to be removed from service without disturbance to any of the remaining six units. Every tower on the transmission line is accessible by four-wheel drive vehicle preceded if necessary in winter by snow-clearing equipment. Questions relating to dewatering the tunnel and perforation of the concrete lining are discussed in the reply to Mr Davie's comments.

178. Many excellent discussions have been published on criteria to determine whether and when shutoff valves should be provided at the turbine inlets. Such valves are commonly omitted in low head plants and Manapouri is among the higher head plants not so equipped. The high plant load factor, the high cost of increasing the powerhouse width to accommodate turbine inlet valves and the high cost of the valves, which in themselves are complicated pieces of equipment, were principal factors influencing their omission. As noted by **Mr Roseveare,** a complicated piece of equipment can itself constitute a hazard and many instances of valve failure have been recorded with dire consequences, as witness the recent calamitous flooding of a very large underground pumped storage station in the USA, reportedly due to the failure of an inlet valve operating cylinder.

179. The large forces exerted by penstock hydraulic thrust were absorbed in the powerhouse substructure according to normal design procedures. Although not considered an essential feature, due to embedment of the spiral case under pressure, a layer of bituminous impregnated fibre was placed over the upper half of the spiral case. This material does not have the compressibility of nitrogen filled microcellular rubber. However, vinyl sheeting, which is even less compressible, has been used for this application in a number of recently constructed plants.

180. In reply to **Mr Lindsey**, at the time of this writing no decision has been announced regarding the ultimate regulated water level in Lake Manapouri.