*Discussion on Paper No. 6928**

Fish passes and screens at water power works

by

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and

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The following is a report of the oral discussion held in Edinburgh, on 16 November, 1966.

THE FIRST SPEAKER referred to his Paper published by The Institution of Civil Engineers of Ireland in 1956 entitled 'Inland fisheries and the Engineer'[13], which discussed fish pass requirements and made specific reference to the successful application of the Denil fish pass in Ireland. Twelve of these passes had been constructed in the past six years with heights of obstruction ranging from 6 ft to 45 ft, and they appeared to be working satisfactorily.

65. He had originally believed that it was necessary for fish to swim through the fish pass, but in the light of investigations carried out by Mr Stuart[13] at Pitlochry in 1962 he was now quite happy to design fish passes which required fish to jump from pool to pool.

66. He then turned to the Borland fish pass and noted that in certain conditions there was an excessive turbulence in the bottom pool and queried whether the height of the Borland pass should be limited. He mentioned that smolts experienced difficulty in entering a Borland pass in their passage downstream and that at Inniscarra impeller pumps had been installed to produce a current of water leading to the upstream entrance to the pass in conjunction with an arrangement of lights to attract smolts at night.

67. The second Speaker referred to a proposed Borland fish pass in which fish would first have to ascend a 1 mile long tailrace tunnel and asked whether resting pools would be required and also for information about fish reaction to a long dark passage. He also asked about the effect of artificial barriers, such as hecks, on salmon, and whether any change in their habits had been noticed. Information was also requested on the costs of fish passes and on the possibility of rearing all fish artificially, thus eliminating the need for fish hecks and passes.

68. The third Speaker also referred to Mr Stuart's Paper[14] concerning the leaping behaviour of salmon and mentioned its use in the design of natural rock fish passes. He asked for the Authors' comments on the material contained in this Paper. The limit of the head which smolts would withstand was given in the Paper as 100 ft. The Speaker asked what evidence for this limit was available and pointed out the savings which could be made in smolt structures if the limit could be raised.

69. The fourth Speaker asked if the Authors had any experience in the use of artificial light to attract fish to the pass and encourage their passage.

70. The fifth Speaker, in dealing with smolt screens, pointed out that in addition to the required average flow conditions being fulfilled, it was necessary to investigate the actual conditions at different sections of the screen. He described model experiments which were carried out on a screen of about 5000 sq. ft area and asked for comments. He also drew attention to the fine tolerances required for smolt screens

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and asked for the Authors' comments on these in relation to the deflexion of large screens under working conditions.

71. The sixth Speaker asked why the Denil pass had not been used in Scotland. He drew from his experience of the movement of fish through a dark tunnel about 150 yd long and pointed out that the degree of darkness did not seem to be an inhibitory factor in the movement of fish. He asked if any investigation had been made into the movement of fish in passes during darkness.

72. The final Speaker asked if there was any limitation in the height of a Borland pass. He also mentioned that in his experience a dark tunnel did not appear to deter fish when approaching a fish pass.

73. In reply Mr Menzies said that fish would probably go through a tunnel one mile long; resting pools every 100 to 200 yd would be desirable. Experiments in America with artificial lighting were not conclusive. Scottish experience was that fish would use Borland passes by day and by night and no difficulty was experienced in the dark.

74. Artificial obstructions would not change the habits of fish. The rearing of fish artificially was a very expensive process with a poor return, and it would be more economic to provide the fish with facilities at water power structures.

75. With regard to Denil fish passes, Mr Menzies felt that these might have been considered for use in Scotland. However, they were essentially used at low head structures and might prove difficult to adapt to a higher head. They also required a considerable operating flow.

76. Congregations of fish were not seen at the downstream entrance to fish passes unless the temperature of the water was too low. Descending smolts at times tended to be slow to use a fish pass, but until the reason for the natural delay in descent caused by large lochs was known this apparent difference from their natural habits was uncertain.

77. Mr Dickerson, in reply, referred to the first Speaker's criticism of conditions in the bottom chamber of a high head Borland pass. He said that even in high head passes an adequate stilling chamber at the foot of the slope shaft had been found to be effective, and the length of the bottom chamber was also very much a controlling factor.

78. There would appear to be no practical difficulty in extending the lift of the conventional Borland pass to between 200–300 ft, but due to high pressures involved the detail design of the bottom chamber in particular might prove difficult. It would seem that for higher heads there was more scope for the idea shown in Fig. 13.

79. The Board had also used special pumps to induce smolts to enter a Borland pass, but the results had been inconclusive.

80. As regards costs, a pool type pass might cost between £600 and £2000 per pool, dependent on the flow capacity, while a Borland pass for about 50 ft lift might cost around £60 000. (These prices were for structures completed about ten years ago.) The cost of the screen guides, panels and mesh in the structure at Cruachan outfall (with a gross area of 8000 sq. ft) was about £37 000, while the handling gantry and cleaning equipment cost a further £13 000.

81. Mr Dickerson then referred to the difficulties in maintaining the required clearances with smolt screens. He agreed that inequalities in guides and fabrication could produce unacceptable clearances, but as these screens had to be 100% effective, it was necessary to provide flexible rubber seals to cut down clearances to ¼ in. maximum. He said that correct flow distribution over the whole screen area was essential and the only way this could be ensured was by model experiment.

82. Dealing with the comparison of the cost of electric and conventional screens, Mr Aitken mentioned that it had been the practice up to now to make provision for the fitting of conventional screens in case trouble was experienced with the electric screen. There had therefore been no saving to date in the cost of the supporting structures. With experience and confidence in the operation of electric screens,

however, a lighter and cheaper structure would be acceptable. In addition to the superstructure the electric screen and apparatus at Culligran cost £5500 against the estimated cost of £8900 for mechanical screens and cleaning gear. The value of electricity used at Culligran was only about £30 per year, but on the other hand a 1 in. reduction in head loss would be worth £70 a year. If the problems of using electric screens for the exclusion of smolts could be solved, there would be considerable savings both in capital and operational cost in using them instead of mechanical smolt screens.

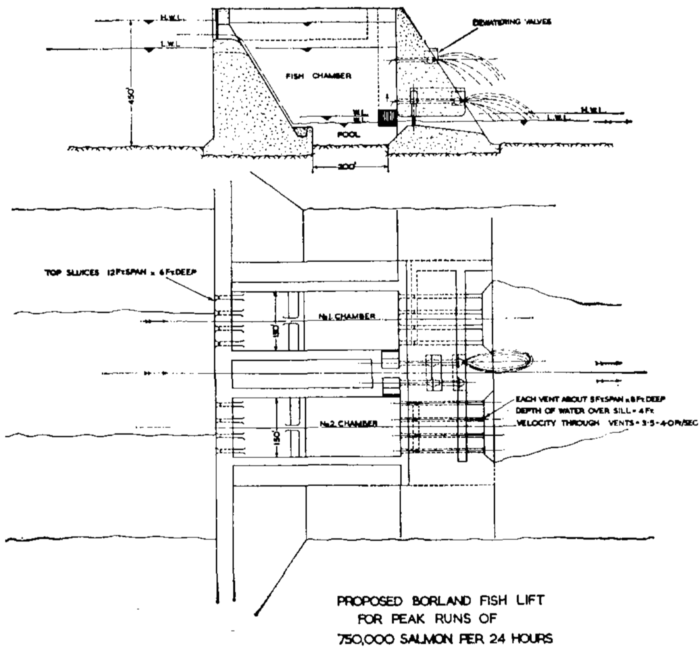
83. Contributors to the discussion included, in order of speaking, Mr J. C. McGrath (Fisheries Engineer, Dept of Agriculture & Fisheries, Dublin), Mr Douglas (Senior Engineer, W. V. Zinn), Mr E. B. Wilson (Partner, Sir William Halcrow & Partners), Mr A. C. Allen (Associate, Sir M. MacDonald & Partners), Mr W. Young (Partner, James Williamson & Partners), Mr L. Stewart (Fishery Officer, Lancashire River Authority), Mr J. D. Kelsall (Fishery Officer, Severn River Authority).

The following contributions were received in writing:

Mr D. A. S. MacLellan (Technical Director, Glenfield & Kennedy Ltd, Kilmarnock) wrote that the provision of means of assisting the passage of migrating fish past barrages and dams had been the subject of increasing attention in recent years and the experience of the North of Scotland Hydro-Electric Board, as recorded in the Paper, was of the greatest interest and importance. He would confine his remarks to the Borland type of fish lock or pass of which 17 had been installed (Table 1) by the Board for widely differing conditions.

85. Theoretically there should perhaps be no limit to the numbers of fish handled, nor the height through which they might be raised or lowered, in a Borland-type lock. In practice, of course, there would be a limit to the civil costs which could reasonably be incurred and the economic importance of the fishing industry to the country concerned might be a very vital consideration. The development of some of the great rivers in British Columbia for hydro power generation had been the subject of much investigation and argument for many years and the fears of the fisheries organization, and Governments, regarding the effect of power dams on the fishing industry (on which the economy sometimes largely depended) had often ruled the day. Nevertheless, it was believed that, for example, a Borland-type pass could deal adequately with the numbers of fish experienced in a river such as the Fraser. Peak runs of up to 750 000 fish in 24 h would have to be accommodated and an arrangement such as that shown in Fig. 24 would be required. With twin chambers sized to allow 4 cu. ft per fish, a cycle time of 4 h, and an arrangement of inlet passages or vents as indicated, it was calculated that migrating salmon could be lifted with a minimum of delay. The provision of large chambers in the main structure of a concrete dam obviously presented practical difficulties, but no doubt these could be overcome. The flow required to operate a pass of such proportions would not be insignificant and could only be provided at the expense of that available for power generation; for example, the rate of flow into each chamber would have to be 250–300 cusecs, in order to give the required velocity through the bottom vents and to fill the vast chambers within the time available. A factor which might mitigate against such a project was the effect of the enormous pondage area into which the fish would be proceeding as there was no doubt that, initially at least, they would be delayed until acclimatized to a radical change in environment. The Authors' views on this aspect would be of interest.

86. An interesting Borland lock which had recently been commissioned was shown in Fig. 25. This was incorporated in the Yla Tuloma Power Plant in the USSR which was designed by the Imatran Power Co. of Helsinki. It was unique in several respects due to the unusual layout and site conditions. In the first place, it was a combination of a conventional pool pass and Borland lift all contained in an



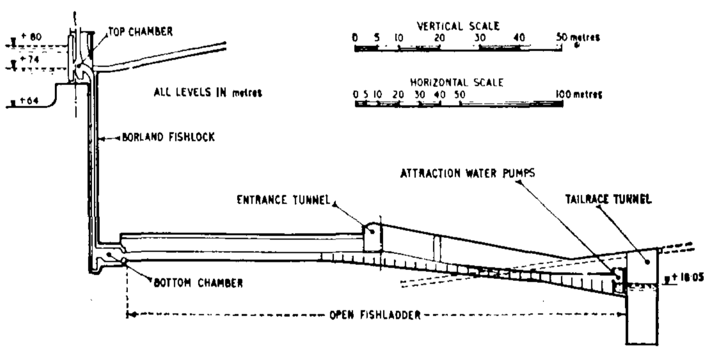
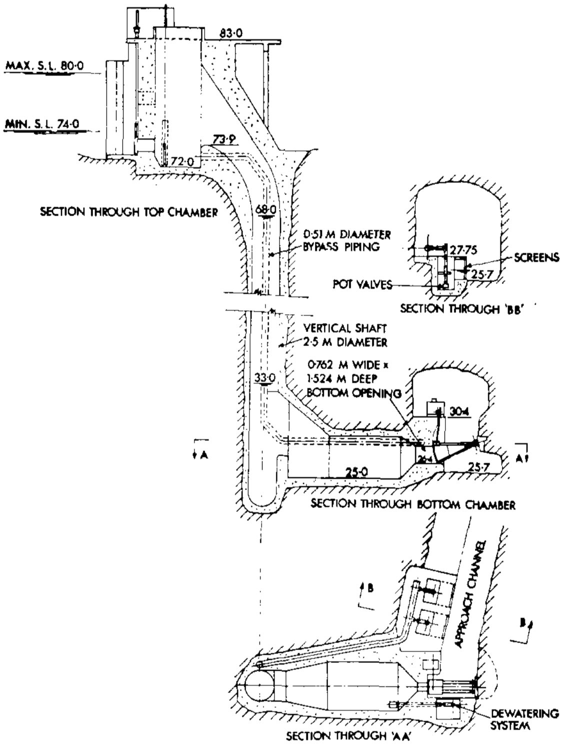


Fig. 24 (top): Arrangement allowing peak of runs up to 750 000 fish in 24 h

Fig. 25 (bottom): The Borland lock incorporated in Yla Tuloma Plant, USSR

Fig. 26 (opposite page): The underground location of Yla Tuloma



underground location (Fig. 26). Having progressed up the approach tunnel, which was illuminated as an extra inducement, the salmon entered the bottom chamber in the normal way.

87. Four main design factors were involved.

(*a*) The provision of sufficient flow from the lift into the approach channel to induce fish to swim up to the bottom chamber opening;

(*b*) the maintenance of flow in the approach channel when the bottom chamber opening was closed;

(*c*) the provision of an emergency safety feature to prevent flooding of the underground workings and power station;

(*d*) the provision of mains to enable fish to pass from the top chamber into the reservoir irrespective of the reservoir water level variation which ranges over 19·6 ft.

88. As was the case at Ardnacrusha (Fig. 14) the height of the vertical shaft, 177 ft, necessitated the provision of bypass piping which discharged into the approach channel through special 'Pot' type regulating valves to control the flow and dissipate the energy of the discharge under a possible head of 184 ft. It was of interest to record that the counter installed for this installation was designed and supplied by the North of Scotland Hydro-Electric Board.

89. Two modifications were incorporated in this installation at a later date and he would be interested to have the Authors' opinion as to whether they should be

incorporated in all future projects. Firstly, it was reported that when the vertical shaft was emptied and some fish still remained in the top chamber, there was a tendency for them to jump backwards and fall down the shaft to their death. A simple 'fence' had now been erected to prevent this happening and it would be interesting to know whether the Board had experienced the same problem. Secondly, a special conical 'non-return valve', comprising a structure of elastic splints, had been fitted to the counter flume to prevent fish falling back through the flume. He believed the same idea had been applied to the Board's counter on the Lochay lift, but again he would welcome the Authors' views as to whether this device should be applied to all counter arrangements.

90. Finally, he briefly mentioned a Borland-type lift which was under construction in Europe for a new application. The pass was designed primarily to handle shad and lamprey which varied in size from 0·1 in. to 0·2 in. and 0·2 in. to 3·9 in. in length respectively. These species had radically different habits to that of the salmon—the shad travelled at 1·8–2·4 miles/h but did not jump and preferred to swim close to the bed of a river. They were, however, migratory and the Borland lock had been selected as the best means of assisting the passage of these and other breeds (mullet and possibly eels) over the large dam in question. An interesting feature of this particular installation was the provision of a number of bottom gates at different levels which were necessary to accommodate a downstream level variation of 33 ft. It would be noted also that a great deal of thought had been given to the siting of the entrance to the pass—a factor which the Authors had also stressed as important. Due to the narrow width of the pass and the fact that it had to be operational when flood water spilt over the adjacent spillway, the entrance vents had been located at an angle to the main stream but in such a way that they faced the natural approach channel to the dam. This Borland lock will be fully automatic in operation and it was planned to incorporate a special counter which was being designed and constructed by the North of Scotland Hydro-Electric Board. Provision was being made for extensive lighting in the bottom chamber and at the bottom end of the inclined shaft. It would be of value to know whether the provision of lighting had definitely resulted in improved performance in any specific fish lock. One was inclined to make provision for illumination, possibly more than was necessary, in case it proved to be of assistance.

91. While figures were available for the numbers of fish successfully lifted over dams in Scotland, Mr MacLellan wondered whether much detailed research has been carried out to determine the mortality rate resulting from the various hazards to migrating fish, for example:

(*a*) the hydraulic turbines;
(*b*) the possible prolonged delay due to the change of environment when fish reach the upstream pond;
(*c*) failure to find the fish pass entrance.

The possibility of fish being killed as a result of falling down the shaft of the fish lift had been mentioned, but he understood that there was evidence that the mortality rate from this cause might be quite small.

92. In connexion with the designing of the fish pass entrance, it had been usual to provide for a flow velocity of 4–5 ft/s through the inlet gate aperture. This flow, together with the additional flow often passed through bypass arrangements or 'attraction' jets, had been found adequate to attract the fish to the entrance and then to enter the bottom chamber with the minimum of difficulty.

93. All these were points for consideration by the designer and any improvement in knowledge of the habits of fish in relation to existing fish locks or artificial barriers of any type should be published as widely as possible so that commensurate improvements in design may also be achieved.

Mr D. A. Brown (Associate, Sir Murdoch MacDonald & Partners) welcomed this authoritative Paper on a subject which required for its handling a great deal of practical experience.

95. One great difficulty in regard to satisfactory design and construction of efficient fish passes and screens was that man had not observed the habits of salmon in sufficient detail or for long enough to fully understand their habits. However, when the money value of salmon fishing rights was appreciated, together with the fact that the balance of nature could not be upset with impunity, the reasons for the expenditure of large sums in the preservation of fish life by passes and screens was easily understood.

96. When the level of the headwater varied considerably, as at a dam, it became difficult to employ the pool or overfall type of pass and some mechanical device such as the Borland pass became necessary. Any mechanical device depended on the use of power but more on the watchfulness of human attendants. Mr Brown always had at the back of his mind the suspicion that a strike of labour or a power failure might cause such a mechanical device to fail to operate. It was presumed that this was a risk which could be accepted. The simple overfall type of pass was much more akin to natural river conditions and was not subject to mechanical failure.

97. The observations of Stuart[14] threw a great deal of light on the conditions applicable to the pool type of pass and they appeared to confirm the virtue of the spoon-shaped depression in the Craigo Pass.

98. Mr Brown considered that screens which were effective were simple to design, but screens which combined effectiveness with ease of maintenance in use required a considerable amount of thought and were expensive.

99. The gantry for handling screens at Cruachan intake (shown in Fig. 18) appeared to embody the most up to date ideas for large screen installations and he imagined that its cost was well justified. The smolt and kelt panels shown in Fig. 20 appeared admirable for smaller installations but reference to Fig. 19 did not indicate the method of fixing the panels in the screen frame. Would the Authors give some detail on this point?

100. A high degree of accuracy was required in the side guides in which screen frames were held. Long pieces of rolled steel sections were rarely straight and free from twists when delivered. For this reason, if the guides are of any height it was undesirable to fix them in position concurrently with the raising of the concrete walls or piers: it was far more satisfactory to set rag bolts in boxed out chases. These bolts could then be used to constrain the guides into correct alignment and spacing in the chases during the grouting-in operation.

101. With large areas of steelwork immersed in water there were problems of corrosion. Was it correct to assume that cathodic protection of steelwork was not used owing to the risk of the electrical currents adversely affecting the fish?

102. He had been associated with the design and construction of a large electric fish heck of the Lethlean type and he had been surprised at the capacity of the electrical equipment installed. Would the Authors give some idea of the power consumption of an electric heck?

The Authors were grateful to Mr MacLellan for the very interesting points raised in his contribution. Regarding the Fraser River proposal, such vast works could only be economical on a very large development and one in which the concrete works were of sufficient magnitude to allow for the considerable chambers necessary. A flow of 300 cusecs for the fish pass should not be a handicap as the average flows in such rivers are large. The Authors did not envisage any serious effect on fish entering a large impoundment, as there always remained a very strong urge to ascend to the headwaters for spawning. There was no evidence of any harmful holdups in the large reservoirs created in the Columbia River in the United States. If, however, the impoundment submerged some of the former spawning grounds then there might be some adverse effect with overcrowding on the remaining spawning grounds.

104. On the modifications suggested to the Yla Tuloma pass, the 'fence' or screen at the top of the vertical shaft had been installed in some of the Board's passes. This was not to prevent the fish from damaging themselves, but for the purpose of trapping fish for stripping and artificial hatching. In this instance the screen was pivoted on a horizontal axis so that when the pass was 'locking up' the screen was swung clear, and only at the start of the 'emptying' phase was it swung into position to stop fish descending again, holding them in the top chamber. The North of Scotland Hydro-Electric Board had also used a 'non-return' grid made out of fibreglass rods with the narrow end of the taper upstream, and while this was successful in preventing fish falling back through a fish counter, it sometimes acted as a slight deterrent to fish making a direct ascent.

105. In reply to Mr MacLellan's query about losses of fish due to hydro-electric works, considerable research had been done in Sweden, USA and Scotland on the passage of smolts through turbines.[15-17] The Scottish work showed that on the larger machines of up to about 100 ft head the losses were of the order of 2% to 10%, the mortality being least when the turbine was operating at best efficiency. At about 180 ft head on a Kaplan turbine of 20 000 kW capacity the loss was of the order of 15% to 20%, dependent on the load on the machine. At the other end of the scale, through a Francis turbine at 450 ft head there was found to be a loss of 50%. In a larger turbine at Cushman in USA[14] operating under about 450 ft head, the loss was shown under best conditions to be about 30%. Smolt losses up to about 100 ft head were generally considered acceptable in Scotland and only above that figure was the provision of smolt screens insisted on, although no doubt this figure might be safely exceeded if the turbine clearances were ample.

106. Referring to Mr Brown's comment about operation of the Borland Pass if a power failure occurred, provision was always made for manual operation of the sluices and valves, while the risk of labour in some form not being available for this was so remote that the risk could be accepted. The same risk applied to pool passes where upstream sluice adjustment had to be made with a change of reservoir level. As Mr Brown rightly said, an effective screen could be expensive, but if, at the design stage, full consideration was given to the problems arising in cleaning, then the additional expenditure could be fully justified by the saving in labour in attendance. The panels shown in Fig. 20 were each fixed by 4 in. × ½ in. bolts on to the horizontal members of the frame: there were also two locating studs per frame to facilitate fixing.

107. Reference had already been made in reply to another question about the alignment of screen guides and Mr Brown's suggestions for box-outs had in some cases been followed. The possibility of cathodic protection had been considered. The earlier electric fish heck with which Mr Brown had been associated certainly had extensive electrical equipment, but with the advent of more compact means of producing the required impulses, the gear had been very much reduced in size. The average power consumption for an electric heck was approximately 1 W/sq. ft of screen.

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