were the tunnels made if a culvert would be sufficient? At the Manchester, Liverpool, and other important reservoirs, where the embankments were of very great height, tunnels were nearly always adopted. Why was this course adopted if their security was not greater than that of culverts? There was always a risk in crossing a puddle trench or under an embankment, but there was none with a tunnel. As to the comparative advantage of cast-iron and masonry valve-towers, last year there was ice all over the reservoir, but round the valve-tower there was hardly any. There was thin ice all round, but no thick ice formed. Mr. Rofe had said he could not understand what he meant by a horizontal as well as a vertical movement. Mr. Bateman had fully explained this, and Mr. Binnie had referred to the example at Leeming, where the culvert had slid 1½ inch. No doubt culverts were every day safely carried through embankments, but there were other culverts which were not safe. He had not heard of any tunnel which was unsafe. If there was a leak in it it did not matter, but if there was a leak in a culvert it was a matter of vital importance. Mr. Wood.

Correspondence.

Mr. Charles H. Beloe agreed with the Author, that, in the majority of cases, a tunnel round the end of the embankment of a reservoir, was preferable to either a pipe or a culvert under the embankment. In the case of small reservoirs, however, for the supply of villages, factories, &c., the cost of a tunnel would be too great, and a pipe or culvert should be adopted. Public attention had been drawn to the danger of a pipe under an embankment by the bursting of the Bradfield reservoir, at Sheffield, which had an outlet of this description; but under favourable circumstances, a pipe could be used with safety. He had employed two 9-inch pipes as the outlet for a reservoir for the North Wales Paper Company Limited, having an embankment 44 feet high. The puddle trench fortunately was extremely shallow, and a trench was excavated for the whole length of the pipes to the same level as the bottom of the puddle trench, which was in rock and filled up with cement concrete to the level of the pipes. These were laid with bored and turned joints with deep sockets, which were also filled with lead and caulked. After the pipes had been laid they were tested to a pressure of 65 lbs. per square inch. A diaphragm was placed round each pipe to prevent the creep of water along it, and the pipes were then embedded in cement concrete 3 feet thick stepped to receive the puddle wall. Owing to the nature of the ground he Mr. Beloe.

Mr. Beloe. was enabled to carry the outlet pipe up the side of the reservoir at an angle of 21°, supporting it on ashlar blocks resting on solid rock. Three valves were fixed to draw the water off at different levels, and the second or emptying pipe had a valve at its termination inside the reservoir. All the valves were of the ordinary sluice pattern, and the spindles were supported by guides bolted to the inclined pipe. The difficulties experienced with the culvert under the embankment of the Vartry reservoir of the Dublin waterworks[1] afforded a good illustration of the objections to this form of outlet. There were several objections to the use of towers of any description, especially in countries where the reservoir was liable to be frozen over, and where large blocks of ice were brought into contact with the tower when the spring floods poured into the reservoir. The Wayoh reservoir of the Bolton waterworks, which had a water area of 95 acres, and a maximum depth of 76 feet, had an outlet formed of a tunnel lined with brickwork 12 feet high and 10 feet wide, and furnished with a brick tower in the reservoir. He thought a preferable mode of construction was that adopted by the late Mr. Duncan, M. Inst. C.E., in the Yarrow reservoir of the Liverpool waterworks, and by himself in the Llannefydd reservoir of the Rhyl waterworks. In both of these reservoirs the shaft was sunk on the centre line of the embankment, but some distance beyond the intersection of the top bank level and the surface of the ground. At Yarrow it had been found necessary to excavate the puddle trench as far as the shaft, which was built of brickwork, surrounding it with puddle. At Llannefydd the shaft was sunk in the rock, and was not lined with brickwork, except a small portion at the top. A brick plug was built in the tunnel on the upstream side of the shaft, in which pipes were inserted and furnished with duplicate valves, worked by gearing from the top of the shaft. The advantages of this plan were the stability of the shaft and the protection of the valves; a subtantial house being erected over the shaft from which the valves were worked. He was now engaged in designing a series of reservoirs for a foreign country, where the winters were very severe, and he was adopting the form of outlet just described. It was intended to erect the dwelling house of the reservoir-keeper over the shaft, to enable him to work the valves without going out of doors; as he was convinced that the valves would be frequently neglected if he had to cross an exposed bridge on to a tower as described in the Paper. In whatever

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxviii., p. 13.

Mr. Beloe.

position the shaft and valves were placed, he thought it would be advisable to dispense with pipes in the tunnel; by doing so several valves might be inserted in the plugging or in the tower, as described in the Paper; and all of them could be opened simultaneously, should it be desired to lower the water-level in the reservoir quickly in the case of sudden floods, or of accident to the embankment or by-wash, the whole area of the tunnel being available for the passage of water; a pipe could also be led from the tunnel into a supply tank, to which the main pipe was connected, the surplus water passing away into the old stream course. In this way the supply to the town would always be at the same pressure instead of varying with the level of water in the reservoir. The Paper confirmed the opinion published by him seven years ago, that a tunnel outlet was the best that could be adopted for the majority of large reservoirs.

Mr. Duncanson.

Mr. A. Duncanson furnished the following particulars of the tunnels of the Liverpool Corporation waterworks at Rivington. These tunnels had been in work for twenty-three years; and when examined in the summer of 1879 they were as sound as when first used in 1857. There were in all nine tunnels. Seven of them formed part of the original works, and were built from the designs of Mr. Hawksley. The Upper Roddlesworth tunnel had been constructed in 1863 from the designs of the late Mr. Duncan, and also the Yarrow tunnel, which had been built in 1869. The original seven tunnels, and the tunnel at Upper Roddlesworth, passed through the banks of the reservoirs; but the tunnel of the Yarrow reservoir was cut through a solid hill of shale. This arrangement, he thought, was preferable to the plan of laying the tunnel through the bank, because, in the latter case, where the puddle trench was deep, the ground which was excavated had to be strongly timbered. In filling up with clay this timber had to be withdrawn; the ground gave way more or less, and to some extent injured the ground on which the tunnel rested, and tended to crack the work. The tunnels designed by Mr. Hawksley were of blue Staffordshire bricks, built with wing walls at the entrance and at the outlet, and finished with stone coping. The thickness of the work varied from 18 inches to 27 inches, according to the depth of the bank resting on the tunnel. The Upper Roddlesworth tunnel was built of flat-bedded stone quarried in the neighbourhood. The stones were set radially in rubble work, and were carried up to about half the diameter of the tunnel. On this was built a circular lining of $4\frac{1}{2}$-inch blue Staffordshire brick. The rubble work was carried round the outside of the brickwork to give it strength. The

Mr. Duncanson. valve-shaft was in the centre of the bank, just outside the puddle gutter. It stood on a mass of concrete carried up from the bottom of the puddle trench. The bottom of the shaft was formed of flag stones soundly bedded on the concrete; the flags being sufficiently large to have the walls of the shaft built on their ends. The puddle gutter was continued on the water side of the shaft and its foundation. The shaft was lined with parpoints backed with rubble masonry; and the inlet and outlet ends of the tunnel were faced with rockwork. The Yarrow tunnel, driven through the solid shale, was lined with parpoint work, and was finished at the inlet and outlet ends in rock-faced masonry. In constructing the tunnels and shafts, provision was made, and toothings were left out, to give support to the stoppings in building in the valves. In this part of the work great care was taken to have all the bricks cut to fit their particular places, and to soundly bed them in cement. In each of the shafts there were four valves, and two lines of pipes—two valves being on each pipe for facility in case of repair. In all cases the size of the outlet tunnel was determined by the area draining into the stream, and the maximum rainfall; and the tunnel was of such a size as to take the water in floods, during the construction of the works.

Mr. Hassard. Mr. R. HASSARD stated that where the ground was dislocated, or where it was found necessary to sink the puddle trench to a great depth for the whole width of the valley, it would no doubt be preferable to draw off water from a reservoir by a tunnel, removed as far as possible from the embankment; but where the ground was good, he would certainly give the preference to an outlet culvert, which could be constructed by cutting a deep trench in the hill-side, the culvert being placed on solid ground entirely beneath the bottom of the puddle trench, the space above it being filled in with Portland cement concrete, and the puddle trench for some distance longitudinally on both sides of the culvert protected by cross walls. In this way the embankment would be left practically as intact as by a tunnel, and the whole work could be seen and inspected in progress. He knew by experience the difficulty in tunnelling, in ground which required timbering, of getting the excavated space between the extrados of the arch and the roof made up solid, and he believed it would be scarcely possible in practice to get the upper part of the annular space round the cast-iron plates in the tunnels, under Mr. Binnie's supervision, made up perfectly solid with concrete. He would also much prefer brickwork in cement to cast-iron plates as the lining for an outlet tunnel. It must, however, be borne in mind that immunity from leakage depended, not only on the material through which the outlet was constructed, but also in the design and arrangement of the work itself—the failure of the embankment of the Roundwood reservoir of Dublin being a case in point. Here nothing could be sounder than the ground through which the outlet was constructed, and the materials and workmanship were of excellent quality. Yet as soon as the reservoir was nearly filled an alarming leak appeared in the culvert, rendering it necessary to empty the reservoir and cut down the embankment; it was then found that the water had penetrated between the puddle and the brickwork of the culvert in which the stopping was built. Under Mr. Bateman's directions, he having been called in by the Corporation, remedial works, consisting of cross walls of brickwork in cement, and the substitution of concrete for puddle where in contact with masonry, were undertaken. If this mode of construction had been adopted in the first instance great delay in supplying the city with water, and an expenditure of about £15,000 in making good the defective work, would have been avoided. Mr. Hassard.

Mr. A. JERVIS observed that in deciding whether the outlet from a storage reservoir should be by way of a tunnel distinct from the embankment, or by a culvert built in a trench under it, no precise rules could apply, as it rarely happened that any two sites for an embankment were alike, and each case had to be considered on its own merits and natural advantages. In present practice, tunnelling had the preference, but it was questionable if this might not be carried too far. The position for an embankment might be selected suitable for a tunnel, but the stratification of the rock through which it was to be driven ought to have an important bearing in the matter, and on this point the Paper was somewhat deficient. If the rock was of a solid and compact nature, an outlet by tunnelling might be the best, but should the rock be shattered and intersected by fissures or faults, a culvert built in an open trench along the side of the valley under the embankment might be the most judicious way of dealing with it. A tunnel would seldom stand without being timbered, and a fissured rock would almost certainly be loosened, and cavities formed, by the operation of blasting or otherwise, so that it would be difficult, if not impossible, to pack the space watertight between the top of the arch and the roof. Where the rock was of a doubtful character, outlet tunnels had been successfully carried out by laying bare a considerable portion at the inner end, and filling up with puddle the space at the side and over the arch. One of the most favourable conditions for a culvert was, Mr. Jervis.

Mr. Jervis. where the point of intersection with the puddle trench was on solid rock, or where the trench had been filled to a moderate depth with strong Portland cement concrete. In such a case a properly prepared trench for a culvert under the embankment, as the Author justly remarked, was constructed in the light of day, and the culvert could be thoroughly inspected, and any scamping be readily detected, either of material or of workmanship. With reference to the material to be used, brickwork in cement had advantages which the best ashlar did not possess, in being more readily handled; additional rings could also be added to resist the increased pressure under the centre of the embankment; and the whole arch, cased in a thick body of Portland cement concrete, would form a piece of rigid work, as it undoubtedly should be; and any risk from the settlement of the embankment might be reduced to a minimum, if the banking was carefully executed in thin layers 6 inches in thickness, tipped from and thoroughly consolidated by dobbin carts. The possibility of the culvert being fractured by the movement of the puddle in the trench longitudinally and transversely was a contingency which could, in most instances, be averted, by having the puddle properly soured and worked before being put in place, and when tipped brought up regularly and in level layers. Pipe outlets laid under embankments had in some instances given cause for serious apprehension, but it was a question, where opinions differed, if they deserved all the reprobation they had received. Failures might have been caused in certain circumstances through defective workmanship, or by placing the valves on the outer ends, thereby subjecting the pipes to shocks and strains, endangering not only themselves but the embankments, and it was an arrangement which could not be too severely disapproved of. Many extensive reservoirs, which had pipe outlets under the embankments with double sluice valves placed at the inner end, and worked from an upstand, had served their purpose satisfactorily, and experience showed that in particular situations they might be adopted with safety.

---

25 November, 1879.

JOHN FREDERIC BATEMAN, F.R.SS.L. & E., President, in the Chair.

The discussion upon Mr. Wood's Paper on "Tunnel Outlets from Storage Reservoirs" occupied the whole evening.