

SECT. II.—OTHER SELECTED PAPERS.

(Paper No. 2642.)

“Beetaloo Water-Works, South Australia.”

By CHRISTOPHER JOBSON, Assoc. M. Inst. C.E.

THE district supplied by these works, Fig. 1, Plate 5, forms one of the driest portions of South Australia. The average annual rainfall of the Beetaloo District (Appendix, Table I) does not exceed 13 inches and in some parts even this amount is not reached. Attempts to supply water from deep bore-holes and from small impounding-reservoirs constructed in the district having proved abortive, it was decided in 1885, after due investigation of other available sources of supply, to adopt the “Beetaloo” scheme. The Author, having been appointed Resident Engineer, proceeded to the site of the works in December, 1885, and at once began operations. Owing to the urgency of the demand for relief to unemployed labourers, contract drawings and specifications were dispensed with and the work was almost entirely carried on by day-labour.

The first operation was to construct the accommodation-roads, of which there were no less than 21 miles. All trees within the basin of the reservoir were felled and used for firewood, and all refuse and rubbish were burned. In order to afford a supply of water during the construction of the main dam, two small temporary earthen embankments were formed in the reservoir-basin, and a temporary main was laid from them to Bute, 50 miles distant, the water being supplied there by temporary works in January, 1887.

There are 20 creeks emptying into the basin of the reservoir. In order to intercept the detritus brought down by floods, small catch-dams of dry rubble masonry were constructed across these creeks, at such levels as to make the bottom of each dam about 5 feet above top-water level of the main reservoir. Four years' experience has shown that they answer their purpose admirably. When the basin behind the dam becomes filled up, it is cleaned out and the spoil is stacked on some adjacent flat place. This spoil is rapidly overgrown by grass, which checks further erosion. In order to prevent the rush of water down the steep hill-sides

of the reservoir-basin from carrying débris into it, catch-water drains were made round the basin, at about 10 feet above top-water level. These drains deliver into the catch-dams, and are also cleaned out from time to time as required.

When the question of the outlet from the main reservoir was under consideration, it was deemed prudent, in view of the height of the dam and the fact that it would be built of concrete, not to carry pipes through the dam but in a tunnel cut through the solid rock round its eastern end. The position of this tunnel is shown in Fig. 2, Plate 5. It was 7 feet 6 inches in height by 7 feet in breadth. Three shifts of men were employed, working 8 hours each. No trouble was experienced in driving, timbering being unnecessary. Provision had been made in fixing the size of the tunnel for lining it if required, but when the work was completed this was found to be not requisite. Nothing was done after driving beyond turning a concrete arch and forming a face at the southern end, the rock there being inclined to perish when exposed to the atmosphere. An iron gate is fixed at the south end to protect the valves, meters and other apparatus in the tunnel.

MAIN DAM.

One of the first works undertaken on arrival at Beetaloo was to finally select a site for the dam. Trial holes were put down, and comparative estimates were prepared for different sites, the result being that the present site (Fig. 2, Plate 5) was chosen. In order that there might be no doubt as to the foundation, eight shafts were sunk on this site, varying in depth between 43 and 135 feet. These all showed a uniformly satisfactory rock foundation. The shafts were filled with concrete before the building of the dam was commenced. The foundation consisted of bands of quartzite alternating with shale. The shale was excavated until the overhanging quartzite hung plumb over the bottom edge of the excavation; the latter being then filled in with concrete up to the level of the top of the quartzite.

In preparing the foundation, all excavation in rock was effected by plugs and feathers, moils and gads. All loose stone was thus removed and the excavation carried well down into the solid rock. After each portion had been completed, the surface was carefully scraped and was then washed by a jet of water under a head of 150 feet and scoured at the same time. In the foundation of the lowest portion of the dam two approximately parallel

chases were cut in the rock so as to ensure a bond between the rock and the concrete. These chases were carried up the ends of the dam and any smooth surfaces of the rock were roughened, to give the cement a good grip. It was originally intended to construct the dam of masonry in cement, but owing to the impossibility of obtaining suitable stone, it was decided to substitute cement-concrete. The stone used was a hard quartzite, coming from the quarry in 9-inch to 12-inch cubes. It was broken by hand to 2-inch gauge until stone-breaking plant was procured. The machine-broken metal gave better results for concrete-making and was found to mix better in the machine than the hand-broken. The bulk of the sand used was pit-sand obtained from the banks of the creek and the adjacent flats. It was very dirty, containing between 30 and 60 per cent. of loam, and was cleaned in sand-washing machines of the revolving type. An attempt was made to produce sand artificially by crushing the quartzite in a mortar-mill; but the experiment proved a failure, the rollers reducing the stone to powder. It was found, however, that excellent sand could be obtained from the screenings of the machine-broken metal; and as soon as the stone-breakers were got to work, the screenings were passed through the sand-washers and used with the other sand. The cement for the works was supplied by the Alsen Portland Cement Company of Hamburg. It was not artificially aerated before being used, the long sea voyage and the length of time the bulk of it remained in store being considered to be quite sufficient for the purpose. On arrival at Beetaloo it was stored in a galvanized-iron shed. The casks were kept about 12 inches off the ground by wooden sleepers and were nearly two years in store before being used. The tests made showed that the cement suffered no deterioration through being stored. In weight the several consignments varied between $93\frac{1}{2}$ lbs. and $112\frac{1}{2}$ lbs. per bushel; and in tensile strength between 394 lbs. and 573 lbs. per square inch, when 7 days old. The stone-washing machinery was of similar type to that used for sand-washing. The concrete was mixed by machinery in two operations; the sand and cement being first incorporated together by being passed through one revolving drum, and subsequently added to the washed stone and mixed in a second drum. All the drums except the last, which was carried on a spindle, were slung from pulleys in chains, by which they were at once supported and caused to rotate.

In preparing the concrete, the addition of the water to the dry materials was regulated for each mixing. The man in charge soon

learned to judge from the appearance of the concrete as it dropped into the truck whether the proper quantity of water had been added or not.

PROFILES.

After examination of different types of dams proposed or actually carried out, it was decided to adopt the profiles suggested by Professor Rankine.¹ A number of sections derived from his equations were plotted with different top-breadths of dam. A comparison of the sections resulted in a top-breadth of 14 feet being adopted, as giving the best results combined with the most graceful appearance.

The pressure at the inner toe, reservoir empty, is 6·3 tons per square foot; reservoir full, 1·87 ton per square foot. The pressure at the outer toe is 0·34 ton, reservoir empty, per square foot; reservoir full, 4·19 tons per square foot. The maximum intensity of pressure being 5·122 tons per square foot at 82·8 feet below the top of the dam. In order to strengthen the outer toe, so as to enable it to transmit stress to the foundation without failure, it was decided to modify the outer profile, as given by Professor Rankine's method, by the addition of a block of concrete, the dimensions of which were purely arbitrary. This addition to the toe of the dam was gradually diminished up to 58 feet from the top, when it vanished. The pressure at the inner toe, according to Rankine's type section, being deemed rather high, it was decided to extend that toe 10 feet further up stream, stepping this extra width back to the dam in steps, each 2 feet 6 inches wide and 5 feet high. The inner profile of the dam, as calculated, did not therefore commence until a height of 20 feet from the bottom had been reached. The actual profiles are illustrated in Figs. 3A, 3B, 3C, Plate 5.

The dam is curved in plan as shown in Fig. 2, the radius of a vertical plane, one foot outside its crest, being 1,414 feet. The principal dimensions are as follows:—

Greatest height of dam	118·5 feet.
„ height of dam above ground-level	107·7 „
„ depth of water impounded	102·7 „
„ available depth of water	85·0 „
„ width of dam at foundation	115·0 „
„ „ at top	14·0 „

¹ "Miscellaneous Scientific Papers." By W. J. M. Rankine, p. 550. *Engineer*, vol. xxxiii. p. 1.

Length along crest, including the waste-weir . . .	567·0 feet.
Total width of waste-weir.	200·0 „
Height of centre of outlet-pipe above lowest ground- line at dam	18·4 „
Diameter of outlet-pipe	18 inches.
Concrete used	56,722 cubic yards.
Actual working time occupied in depositing concrete in dam	24 months.

The method of setting out the profiles was as follows:—Two stone piers built at the ends of the dam, out of reach of the works, were surmounted by 6-inch theodolites. The instruments were carefully ranged upon the line shown in Figs. 3A, 3B, 3C, as the “theodolite line,” so as to intersect vertical cuts on each stone pillar. The profiles of the dam were then set out by off-sets, measured from the intersection of the vertical plane swept by the “theodolite line” with successive horizontal planes 10 feet apart. The ordinates from which the off-sets were measured were spaced at intervals of 10 feet along the theodolite-line; the zero point being given by the intersection upon that line of the vertical plane swept by a third theodolite mounted on a pillar situated some distance from the outer toe of the structure.

The timber moulds for the concrete were carried by a framing secured to the faces of the work by $\frac{3}{8}$ -inch bolts and nuts which were built in about 12 inches at vertical distances of 3 feet 3 inches—the bolts being subsequently unscrewed out of the nuts, leaving the latter in the work when the framing was removed. This was carried up in 10-foot stages. The proportions of cement, sand and stone adopted at first, were 1 measure of cement to 2 of sand to 4 of stone (2-inch gauge); but, after a height of 50 feet had been reached, the cement was reduced to $\frac{3}{4}$ measure and this was continued until the completion of the work. For the reception of fresh concrete, all surfaces of concrete more than 24 hours old were picked over with short heavy picks, weighing $5\frac{1}{2}$ lbs. each; the surface was then washed with water under a pressure of 150 feet head and all loose chippings were carefully brushed off.

Over the surface of the rock in the foundations a layer of cement, mortar and sand was spread and carefully worked into all corners and recesses. Upon this mortar the concrete was tipped out of trucks containing $\frac{1}{2}$ cubic yard each, running on an 18-inch tramway, and was spread with forks. There was thus no possibility of any of the metal of the concrete coming into contact with the rock; and the same precaution was observed when depositing concrete on any of the already set work. The concrete

was deposited 9 inches deep in long strips about 4 feet wide, but each day's work formed one continuous layer, as the freshly deposited concrete united perfectly with the concrete of the strip last deposited, which was not more than half-an-hour old. In order to ensure a good jointing of each day's work, the edge of the previous day's work was picked and rendered with cement-mortar. The work proceeded thus until a 9-inch layer had been completed over the whole surface of the dam. The tram-lines were then so altered as to run the next layer in a series of strips at right-angles to the direction of those forming the preceding layer.

The system of completing one 9-inch layer before commencing another was continued until a height of 69 feet had been reached, when it was decided not to move the tram-lines until three 9-inch courses in one layer had been completed. The reason for this alteration was that, as the walls had become much narrower, three courses could in one day be brought forward for the full width of the dam, in such lengths as would not make the joints unduly numerous. When this method was practised, care was taken not to bring the joints of two consecutive days' work over one another. The system of crossing the courses at right-angles to each other was continued as previously; but, instead of each 9-inch course being crossed, the crossing only took place every third course alternately, *i.e.*, three 9-inch courses were completed all over the dam; then the tram-lines were reversed and three courses were put on at right-angles to the direction of the strips of the lower courses. This continued until a further height of 20 feet was reached, when the dam narrowed sufficiently to allow of the whole width being brought along at once. The vertical joints in this case were all across the dam; and, if permitted, the joints would have run in straight lines from the inner to the outer face of the dam. This was prevented by making the lines of vertical joints broken instead of straight. The concrete was therefore left just in the condition it was in when the boards were taken away.

After being rammed, the surface of the concrete was covered with wet bags, which were kept damp by being sprinkled occasionally with water. At each 10-feet level, when the framing was removed, a small ridge was disclosed, due to the impossibility of getting the new framing as close to the old concrete as the old framing had been; consequently the new concrete showed at the joint a horizontal overhanging line. This slight projection was clipped off and the place flushed over with cement mortar. Nothing else was done to the face of the dam.

The most rigid supervision was exercised over the depositing of the concrete. A clerk of works had charge of the material from the time it was delivered upon the dam and had nothing else to attend to—all the setting-out, erection of framing, &c., being supervised by others. No care or trouble was spared to make everything as perfect as possible and, with two exceptions mentioned below, the result bore witness to the pains taken. From time to time test-holes were put down in different portions of the dam to ascertain the condition of the concrete; and in every case the result of such examination was most satisfactory, the concrete setting hard and compact. No perceptible difference could be detected at the horizontal joints of each layer or the vertical joints of each strip, except, perhaps, a greater thickness of mortar at some of the joints than would appear in the body of the concrete; but this mortar was as hard as any other portion of the mass.

The first of the two exceptions to the generally satisfactory nature of the work was noticed in October 1888, eight months after the dam had been commenced. The defect lay in the non-adhesion of two horizontal layers of the concrete. This was the first time such a thing had been observed and was, next to the disintegration of the concrete itself, the most serious defect which could possibly exist. Careful attention was at once given to the matter. The surfaces of the non-adhesive layers were examined when taken up; and samples taken from these defective layers, from sound layers, and from scrapings taken off the surface of the newly-deposited concrete, were forwarded to Professor Rennie of Adelaide University, for analysis. He did not, however, attribute the failure to want of homogeneity of the concrete at the joints of the layers. Meanwhile, examination of the under surface of the defective layer and the upper surface of the layer upon which it rested, showed them to be covered with a thin coating of clean sand, which appeared to have been spread over the surface of the bottom layer before the top layer was deposited. In such samples as could be obtained of sound joints, no such sand was discovered, nor was any sand shown at a fracture of the body of the concrete. The defective portions did not occur continuously over any one layer, but in patches. They could easily be detected by the peculiar hollow sound emitted when they were picked over in the preparation of the surface for the next layer. In every case the layers presented the same sandy appearance when removed; and in every case it was noticed that there were one or more small depressions in the

surface upon which the defective layer had rested. The Author thereupon came to the conclusion that the cause of the failure was the presence of the sand and that it had occurred owing to the presence of too much water on the surface of the old concrete, when the mortar was being spread, washing the cement away from the sand. Upon this, special care was taken to revert to the methods adopted at the commencement of the work, viz., not to allow any water to remain on the prepared surface of the bottom layer whilst mortar was being spread thereon. Thenceforward no more failures of this kind were observed.

THE CRACK IN THE DAM.

The second of the exceptions before alluded to relates to a crack which appeared in the western end of the dam. It was first noticed as a fine hair-crack on June 30, 1890—eighteen months after the commencement of the dam—and three days afterwards it had opened out to a bare $\frac{1}{8}$ inch wide. It was 145 feet 3 inches from the centre-line of the dam and extended vertically from the then surface (1,295·2 feet above datum) down to 1,274 feet; then turned at a right-angle and ran westwards horizontally for 12 feet; then turned again and ran vertically downwards to the foundation. It extended in a nearly straight line across the then top of the wall and continued down the inner face in a direction corresponding to that pursued on the outer face. The edges of the crack were parallel, that is, the opening was of the same width at the top of the dam as at the bottom.

From daily examinations it was ascertained that no movement occurred after the first three days; nor was any movement perceptible at different periods of the day, which might have been attributed to changes of temperature. The concrete along both edges of the crack was tested and appeared to be of first-class quality. A peculiar feature was that the opening of the horizontal portion was of exactly the same width as any portion of the vertical crack, as if the portion of the dam on the eastern side of the crack had settled bodily and at the same time drawn away from the portion on the western side; but the most careful examination failed to show that such was the case.

The external forces which might occasion such a crack are:—(1) settlement of the foundation; (2) contraction due to variation of temperature, say, 30° Fahrenheit; (3) earthquakes.

The Author has given the matter earnest attention, but is

quite unable to come to any conclusion as to which of the above forces caused the crack. His theory—put forward with much hesitation—is that the shale-bands, which are wider at the higher levels of the western end of the dam than at any other point, became saturated with water, swelled and lifted the western end of the dam upwards and outwards at the same time. Exactly one week from the first appearance of the crack, water made its appearance on the outer side. The quantity coming through at first was small, but it gradually increased until it reached 1.66 gallon per minute—at which rate of discharge it remained. The level of the water behind the dam at that time was 1,296.7 feet above datum. The water did not come through the whole length of the crack on the outer side, the highest point of discharge there being 1,276 feet above datum.

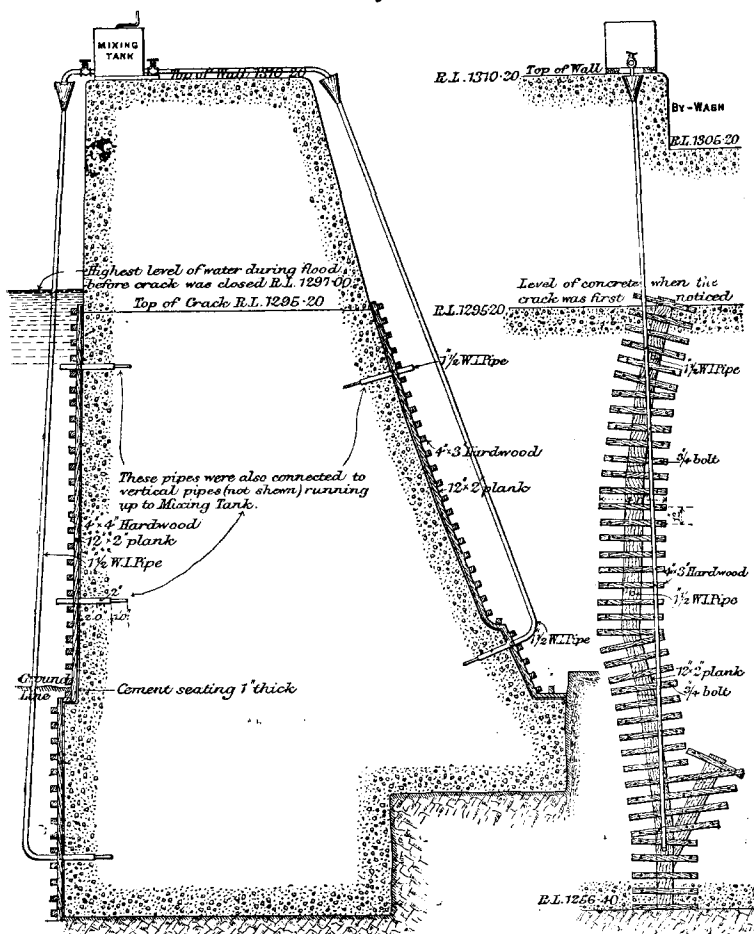
Five weeks after the crack was first noticed, a heavy flood came down the creek and flowed over the western portion of the dam, where the concrete happened to be hardest. After it had subsided and the water-level behind the dam had been somewhat reduced by means of the scours, the crack was carefully examined, but no trace of movement could be detected. On the inner side of the dam, a shaft, 8 feet by 7 feet, was sunk in the line of the crack down to the foundation. The crack was then left until October 15, 1890, when preparations were made to close it up by forcing in cement-grout under pressure.

CLOSING THE CRACK.

The arrangements for forcing the grout into the crack are illustrated in *Figs. 4*. A row of holes, 24 inches deep, was first drilled on each side of the crack. These holes were 12 inches apart vertically, and 3 feet horizontally; $\frac{3}{4}$ -inch bolts, with double nuts, as used in the framing of the dam, were cemented into them. On each side of the crack a seating of neat cement, 6 inches wide, was rendered over the face of the dam. Upon this seating, when dry, a 12-inch by 3-inch plank, truly planed on the surface, was placed, and held in position by cross-pieces of hard wood, 4 feet long, which were attached to the wall by the bolts on each side of the crack. Previous to the seating being finished, 3 holes to take $1\frac{1}{2}$ -inch wrought-iron pipe were drilled into the concrete to a depth of 3 feet on the line of the crack. Into each of these holes a $1\frac{1}{2}$ -inch wrought-iron pipe was introduced for a distance of 2 feet. The pipes passed through

the planks, and a joint was there made by leather washers and jamb-nuts screwed on the pipes. The other ends of the pipes were connected by a bend with vertical pipes of the same size, carried

Figs. 4.



GROUTING APPARATUS FOR STOPPING THE CRACK IN THE DAM.

Scale, $\frac{3}{4}$ inch = 1 foot.

to the top of the dam, 1,310.2 feet above datum. The top of the pipe was provided with a large funnel into which the cement-grout was run from a mixing-tank.

Vent-holes bored in the planks permitted the escape of air and any water which might have been in the crack previous to the admission of the grout. The joints of the pipes were first tested with water; the water was then allowed to escape, and, while the surfaces were still wet, the grout was run in through the lowest pipe on the inner side and rose nearly to the top of each of the remaining four pipes, passing through the crack to the outer side of the dam. In order to make certain that the crack was completely filled, the other pipes were then charged to the top with grout. Two days were allowed to elapse before the planks were removed; the crack was then found to be perfectly filled from bottom to top, the neat cement showing like a thin inlaid strip, $\frac{1}{8}$ inch wide, along the face of the dam. The pieces of pipe were then removed, the seatings were cut off the faces of the dam and the place was flushed over with cement rendering. The operation effectually stopped the crack.

Since then, up to March, 1891, no trace of further movement has been observed, either in the neighbourhood of the crack or in any other portion of the dam.

OUTLET WORKS.

These are shown in Fig. 5, Plate 5. The idea of the design was to save the expense of a valve-tower, by laying the outlet-pipe on the surface of the hill-side over the tunnel. An 18-inch pipe is laid through the concrete, which closes the mouth of the tunnel, and is bent by a special casting into a nearly vertical direction, rising parallel to the face of the hill for a distance of 33 feet, where another bend is introduced to cause the pipe to follow the contour of the hill-side. From this last bend it runs straight to the upper outlet-valve, where it terminates. The pipe is supported on concrete pillars.

The valves are of a common flap pattern, and are worked by rods, $1\frac{1}{2}$ inch in diameter, running up to the valve-house. The rods are connected with long screws, working into female screws formed in the bosses of hand-wheels, 2 feet 3 inches in diameter. Three cast-iron brackets carry the bearings of the hand-wheels. The rods running to the valve-lids are supported by pulleys carried by cast-iron brackets, bolted to concrete blocks spaced 15 feet to 18 feet apart. At the sharp angle in the profile of the hill-side, the change of direction is made in the rod working the lowest valve by means of a cast-iron bracket-lever. Another cast-

iron lever is fixed to prevent bending of the rod when closing the valve, in the event of it sticking.

Over each valve a galvanized wire-gauze strainer, 5 feet in diameter by 3 feet 6 inches high, is fixed. These strainers were covered by $\frac{1}{8}$ -inch galvanized-iron plate, and the sides by galvanized wire-gauze, $\frac{1}{8}$ -inch mesh; but the usefulness of this apparatus in excluding foreign bodies from the pipe is somewhat reduced by the long slotted apertures in the cover-plates through which the valve-rods pass. The strainers are bolted to the concrete blocks upon which the valves rest, and can only be reached for cleaning or repairs by either running the water off or sending a diver down. This part of the works was thus designed and adopted by the engineer-in-chief for the sake of cheapness.

The mouth of the outlet-tunnel is closed with a block of concrete, 35 feet long, through which the 18-inch outlet-pipe is laid, as before mentioned. A chase, 18 inches deep and 7 feet long, was cut round the tunnel. Framings were then put across the tunnel, one at the further end of this chase, 35 feet from the mouth, and the other 15 feet from the mouth. The bottom of the space between the framings was filled with concrete, rammed round a template approximately of the dimensions of the outlet-pipe. After the concrete had set, the template was removed and the pipes were laid in position, neat cement-grout being run into the 1-inch space between the pipe and the concrete, and well worked with hoop-iron swords. Concrete was then deposited until there was only sufficient space left between the top of the concrete and the roof of the tunnel for a man to work in. This space was then hand-packed, partly with concrete and partly with dry rubble, and grouted under pressure at four operations, in a manner similar to that employed in filling the crack in the dam, special care being taken to afford a means of exit for air contained in the cavities of the roof. The space from the stopping-block to the mouth of the tunnel was filled with inferior concrete and was not grouted.

WASTE-WEIR AND BY-WASH (Figs. 6, Plate 5).

The total width of the weir is 200 feet, of which 130 feet are over the dam and 70 feet through excavation in the hill-side. It is divided into four bays, separated by walls; the idea being to make it conform to the natural slope of the ground and discharge the flood-waters at different levels. The walls are also intended to prevent the waters of the upper bays from coming

down across the weir into the lower bays. The excavated portion of the by-wash, being in rock, has not been pitched or protected in any way.

MAIN PIPE-LINE.

Briefly described, there is one trunk main running from the storage-reservoir to Paskeville service-reservoir, $80\frac{1}{4}$ miles distant, measured along the main. The first portion of this main consists of $7\frac{3}{4}$ miles of 8-inch pipe from the tunnel at Beetaloo to Hughes' Gap, where it connects with No. 1 of the three relief-tanks erected there. Thence a 12-inch pipe runs westward for 5 miles, a 10-inch main runs west and south for 15 miles, and, finally, an 8-inch main runs southwards for $52\frac{1}{2}$ miles, emptying into Paskeville service-reservoir. At 40 miles from Hughes' Gap an 8-inch main branches eastwards for a distance of 5 miles, emptying into Barunga reservoir. A plan of the mains is given in Fig. 1, Plate 5.

The stop-valves are of the ordinary screw-down pattern and are placed in the mains 2 miles apart. Each valve is protected by a concrete chamber and iron cover.

SCOUR- AND AIR-VALVES.

Scour-valves were provided between each pair of stop-valves. The Author's experience of automatic air-valves led him to recommend that they should not be used on the Beetaloo mains and that an ordinary bib-tap should be substituted in their place. The arrangement consists of a $\frac{3}{4}$ -inch stop-cock, tapped into the main as though for a service. From this a short length of ordinary service-pipe rises, fitted at the top with an ordinary screw-down service bib-tap. These were protected by concrete fire-plug chambers and covers. The bib-taps were set so as to allow of the water weeping through; though in some cases they were shut down altogether, being only required when the main was being charged. The maintenance men, when going over their districts, were supposed to open the air-cocks (or as many as they deemed necessary at the time), allow them to run for a short time and then close them down as before. Owing to the cocks being set so as to weep, air was seldom found in the main when they were opened.

It was at first intended to put relief-valves on the mains, but

this idea was abandoned, the Author's experience of such valves being that they soon stick unless constantly attended to.

The pipes were all manufactured in the colony by Messrs. G. E. Fulton and Co. of Adelaide. Before leaving the foundry they were tested, in the presence of an inspector, by hydraulic pressure to 800 feet head of water. The pipes cracked or otherwise damaged in transit from the foundry to the pipe-line amounted to between 2 and 7 per cent. of the total number, the larger figure being amongst the 10-inch and 12-inch pipes. The loss was mainly due to the rough handling the pipes received when being moved from one truck to another, at the change from the broad-gauge to the narrow-gauge lines.

The pipes were jointed on the bank, and lowered into the trench in sets of five, six or seven. Ordinary lead joints were used. No recess was cast in the faucet to keep the lead from being forced out by the pressure of the water, and the joints stood well under the highest pressure to which they were subjected. Strip-lead was used instead of spun yarn in the joints. This improvement in South Australian water-works practice was due to Mr. Oswald Brown, M. Inst. C.E. The caulking was done with ordinary "setting-up" tools and 2 $\frac{3}{4}$ -lb. hammers. In filling the trenches, the earth was carefully packed round, under and over the pipes, until they were covered to a depth of 6 inches. After that the earth was shovelled in without further ramming and allowed to consolidate naturally.

RELIEF-TANKS.

These are constructed of concrete, 14 feet in diameter by 6 feet deep, and covered with a galvanized-iron and timber roof. The inlet-pipe enters at the bottom of the tank, terminating in a flanged vertical bend. On the top of the flange is bolted a four-way flanged branch. To each flange is bolted a 4-inch equilibrium ball-valve. Three of the balls have been halved and are found sufficient to close the valve when the half-ball is immersed in water. These three half-balls were so arranged on their respective rods as to close in succession as the water in the tank rose. The fourth ball was left intact and was so arranged as to close the fourth valve when the water rose to T. W. L. The outlet- and overflow-pipes were of the ordinary type and need no description.

SERVICE-RESERVOIRS.

Two earthen service-reservoirs were constructed at the southern end of the district, in case of accident to the trunk main. One of these is situated at Paskeville, at the extreme end of the trunk main; the other at Barunga, about halfway between Hughes' Gap and Paskeville. Both reservoirs are of the same type. The depth of water is 16 feet 6 inches and the capacity is 10,000,000 gallons. At Paskeville the water-level is 7 feet above the ground-line, the spoil from the excavation being used to form the embankment round the reservoir. This embankment is faced with puddle formed from the best of the clay obtained from the excavation. The puddle was covered with 9 inches of stone broken to 3-inch gauge. The metal was spread in two layers, the first layer being 4 inches thick, and well rammed into the puddle. The remaining 5-inch layer was then spread loosely over these rammed stones. The inlet-pipe, 8 inches in diameter, which also acts as the outlet-pipe, was of ordinary spigot and faucet type, carefully jointed, and brought into the reservoir in a deep trench. The pipe was surrounded by puddle for its entire length. No "stops" to prevent water from creeping along the pipe were used, as it was considered that the faucets afforded ample security against this. The overflow pipes were of the ordinary description. The embankments were soiled and sown with grass as usual.

The Author acted as Resident Engineer from the commencement of the works in 1886 and presents this account with the permission of Mr. R. L. Mestayer, M. Inst. C.E., late Hydraulic Engineer to the South Australian Government, and of Mr. A. B. Moncrieff, M. Inst. C.E., Engineer-in-Chief, under whose control the works have been carried on during the last two years—the department of the Hydraulic Engineer having been amalgamated with that of the Engineer-in-Chief in May, 1888.

The Paper is accompanied by thirty-two sheets of tracings and six photographs, from a selection of which the figures in Plate 5 have been engraved.

APPENDIX.

TABLE I.—RAINFALL IN THE BEETALOO DISTRICT.

Locality.	Rainfall.	Remarks.
Pirie	Inches. 11·66	Average of 12 years.
Wandearah	12·47	„ 8 „
Crystal Brook	12·68	„ 8 „
Gladstone	13·77	„ 13 „
Red Hill	14·74	„ 10 „
Snowtown	12·81	„ 8 „
Wallaroo	13·18	„ 25 „
Kadina	14·52	„ 13 „
Moonta	14·02	„ 17 „
Beetaloo Watershed	24·24	„ 10 „

TABLE II.—DETAILS OF COST TO 30TH OCTOBER, 1891.

Description.	Amount.	Total.
	£ s. d.	£ s. d.
<i>Head Works.</i>		
General expenses—		
Survey, engineering and superintendence . . . . .	..	14,321 14 6
Land and compensation . . . . .	..	514 19 0
Dam, outlet-works, waste-weir, catch-dams and drains, bye-wash, &c. . . . .	..	127,680 3 10
Machinery and plant . . . . .	..	12,632 2 6
Temporary works . . . . .	..	10,464 13 8
Total . . . . .	..	165,613 13 6
<i>Distribution Works.</i>		
General expenses—		
Survey, engineering and superintendence	10,591 1 3	..
Land and compensation	78 1 11	..
Mains—		
Trunk mains	133,576 11 3	..
Branch mains	151,401 15 4	..
Services	1,955 5 4	..
Service-reservoirs	10,051 19 5	..
Relief-tanks	733 19 5	..
Houses and offices	3,118 6 11	..
Machinery and plant	1,187 7 11	..
Temporary mains	3,998 15 6	..
Reticulation of pipes	12,282 1 8	..
Total . . . . .	..	328,975 5 11
General account—		
Roads . . . . .	..	4,484 0 1
Interest during construction . . . . .	..	19,157 5 5
Total net cost . . . . .	..	518,230 4 11

