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"Burraga Dam and Water-Supply for the Lloyd Copper Company's Mine, New South Wales."

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THE success of mining in Australia depends to a large extent upon the practicability of securing a permanent supply of water; and in many instances the richest mines are situated in the most arid localities, where there are no rivers or creeks, and where the evaporation and the absorption of the soil are so great that the conservation of any large quantity of water is a matter of extreme difficulty. The Lloyd Copper Company's mine at Burraga, in the Bathurst District of New South Wales, is situated in broken and mountainous country at an elevation of 3,000 feet above sea-level, and is reputed to be one of the best low-grade copper-ore mines in Australia. Hitherto the reduction of the ore has been carried out by roasting and the reverberatory furnace, the "matte" being sent 42 miles by road and 53 miles by rail to Lithgow, to be refined, before shipment to London; but now the Company are erecting concentrating machinery and calciners, with a view to doubling or trebling the output, and it is estimated that 180,000 gallons of water per day will be required.

Before determining upon a concentrating plant, the Company instructed the Author to make surveys and investigations of the surrounding country for the purpose of discovering a catchment-area sufficient for the purpose of supplying the requisite water. The valley of Thompson's Creek, a tributary of the Isabella River, was selected as being the only practicable catchment-area available, and a favourable site was selected for the erection of a concrete dam about $3\frac{1}{2}$ miles from the mine. Between this valley and that in which the mine is situated a watershed intervenes, and, in order to discover a route for a pipe-line to connect the reservoir and the mine which should not involve heavy tunnel-works, several trial surveys were made, and eventually a "gap" was found which

admitted of the pipes being laid to the hydraulic gradient, with a comparatively short length of tunnel, about 25 feet below the surface at the deepest part.

Catchment Area.—The catchment-area of the impounding reservoir embraces 5,329 acres of undulating and mountainous country, timbered principally with white gum and stringy bark. The upper portion of the drainage-basin is of granite formation, the hills being rocky and lightly covered with soil. In the valleys the soil is very porous and sandy, but the lower portion of the creek valley in the vicinity of the dam is a slate formation, the overlying soil consisting of a stiff clay mixed with ironstone gravel, whilst the range of hills abutting on the north and east sides of the reservoir site consists of hard diorite.

Rainfall.—The mean annual rainfall is 28·2 inches, and the greatest rainfall ever recorded in one day is 3 inches, the records having been kept for the last 10 years.

Capacity of Reservoir.—In determining the size of the dam and reservoir, and the quantity of water necessary to be impounded for the supply of the works at the mine, the liability to long periods of drought had to be considered. During the six summer months of the preceding year all the rain that fell was either evaporated or absorbed, and there was no flow in the creeks; it was therefore decided to make the storage equivalent to 1 year's supply, so that the continuous running of the machinery might be assured. As already stated, the requirements of the works were 180,000 gallons of water per day, which, for 313 working days, is $56\frac{1}{4}$ million gallons per annum; and to this must be added the quantity likely to be evaporated from the reservoir. The Government Astronomer of New South Wales, Mr. H. C. Russell, C.M.G., has for many years past carried out a series of observations on evaporation at Lake George, about 70 miles south of Burraga, and at an altitude of 2,267 feet above sea-level, the results of which, given in his "Meteorology of New South Wales," show that the mean annual evaporation during the 10 years 1886–1895 was 40 inches. As the climatic conditions at Burraga are similar in every respect to those at Lake George, the Author assumed that Mr. Russell's conclusions would be applicable, and adopted 40 inches as the mean annual evaporation. The area of the reservoir is 31 acres, and 40 inches on that area is equivalent to $28\frac{1}{4}$ million gallons, which, added to the annual requirement of $56\frac{1}{4}$ million gallons, gave the storage required as $84\frac{1}{2}$ million gallons, and the height of the waste weir was fixed accordingly.

Field of Gathering Ground.—As the flow in the creeks had never

been gauged, it was impossible to calculate exactly how much water the catchment area contributed to the streams and what proportion of the rainfall was lost by absorption and evaporation, but for a preliminary estimation it was assumed, after careful examination of the surface, that 65 per cent. was lost by those agencies. The average rainfall of 28·2 inches on the catchment-area of 5,329 acres, less 65 per cent., amounts to 1,193 $\frac{1}{4}$ million gallons, or sufficient to fill the reservoir fourteen times every year, leaving 1,108 $\frac{3}{4}$ million gallons to pass away down the creek to the settlers below the dam. Just before the dam was completed an opportunity occurred of actually measuring the amount of rainfall contributed to the reservoir, which proved that 72·8 per cent. of the rainfall was lost by evaporation and absorption on the catchment.

Rain commenced to fall on 19 September (the ground surface being fairly moistened with the winter rains and snows, but not by any means saturated) and terminated on 26 October, and during that period the rainfall was 4·78 inches, of which 2·65 inches was contributed in one day; this rainfall was measured by the Government Astronomer's deputy on the spot and recorded daily, and represents a fall of 577 million gallons on the catchment. The reservoir was empty when the rain commenced, and was full on 10 December, after which date the streams leading to it had ceased to flow. During the period of contribution, 35 million gallons were run off by the contractor (this quantity being measured through the sluice-pipe), 4 $\frac{1}{4}$ million gallons were evaporated from the reservoir, and 85 million gallons remained in the reservoir, so that in all, the catchment contributed 124 $\frac{1}{4}$ million gallons to the reservoir. The percentage of the rainfall actually conserved is therefore $\frac{124\cdot25}{577} \times 100 = 21\frac{1}{2}$ per cent. It may

readily be conceived that after a prolonged drought, and during the heat of summer, the percentage would be considerably less, as the absorptive and evaporative agencies would be more active; but as the bulk of the rainfall occurs in the winter months, the assumed percentage of contribution may be considered fairly accurate.

Trial Pits.—Trial pits and trenches were sunk right across the site of the dam, and what was supposed at the time to be sound rock was located as shown upon the sections (*Figs. 1*), but when excavation for the foundations of the dam was commenced, and the whole site was laid bare, it was discovered that the rock was so laminated with nearly horizontal fissures, containing clay,

gravel and wash, through which water was flowing, that it was found necessary to remove a much larger body of rock than was

Figs. 1.

at first deemed sufficient, in order to secure a solid rock seat for the dam.

Design of Dam for the Impounding Reservoir.—The dam is curved in plan, the inner face of the wall having a radius of 539·83 feet. The length of the crest measured on the curve is 425·58 feet, and subtends an angle at the centre of $45^{\circ} 10' 10''$, the versine being 41·40 feet. The dam is designed with a gravity section, and no

Figs. 2.

reliance is placed upon any strength that may accrue on account of its curved form, as it was thought that the southern bank of the creek was not sufficiently abrupt to act as an abutment, the curved form being introduced only to minimise the effects of expansion and contraction. The centre of gravity and centre of pressure were determined graphically, as shown in *Figs. 2* and *3*. The limit of pressure was assumed to be 10 tons per square foot and the density 170 lbs. per cubic foot for concrete masonry. In cross-section the inner face of the dam is vertical, the outer face of the upper part being curved to a radius of 40 feet, and on the lower part battered to a slope of 1 horizontal to $1\frac{1}{2}$ vertical. The greatest height of the dam is 41 feet, the width at the crest being 2 feet, and at the base 25·32 feet. The waste weir was designed as an overfall, and was placed at about the centre of the dam, being calculated to provide for a rainfall of $3\frac{1}{2}$ inches in 24 hours from a full reservoir with three-fifths flowing off. The Author has found during a long experience of flood investigation in New South

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Fig. 3.

DIAGRAM FOR POLYGON OF FORCES

Wales, and by the comparison of many observations compiled by the Government Astronomer, that the maximum rainfall for 1 day in this district is very nearly one-eighth of the mean annual rainfall, and that the maximum rainfall for 1 hour is nearly one-fourth of the greatest daily rainfall; in a period of 8 hours the maximum rainfall is double that for 1 hour; in a period of 16 hours it is treble, and in 24 hours four times as great as the rainfall for 1 hour; it was therefore assumed, for the purposes of calculation of the discharge over the weir, that the maximum rainfall for 1 day would be $3\frac{1}{2}$ inches, for 1 hour 0.87 inch, for 8 hours 1.76 inch, and for 16 hours 2.64 inches. Assuming that the rain is general over the whole area, and of sufficient duration to allow the flood-waters from all parts of the drainage-area to reach the dam at the same time, it was determined, after a careful examination of the creeks and gullies, and the slopes of the ground on the catchment-area, that at least 8 hours would be required, after the rain commenced, to reach the moment of maximum discharge at the dam; and, allowing the ratio of diminution of discharge due to area to be $\frac{M^{\frac{3}{2}}}{M}$, the quantity in cubic feet to be discharged was calculated by the Chamier formula,

$$Q = 640 \times R \times C \times M^{\frac{3}{2}},$$

in which—

R = average rate of rainfall in inches per hour = $\frac{1.76}{8} = 0.22$
for a duration of 8 hours,

C = coefficient of surface discharge, determined by inspection on the ground = 0.60,

M = catchment area in square miles = 8.3,

Q = quantity of water reaching outlet in cubic feet per second =
 $640 \times 0.22 \times 0.60 \times 8.3^{\frac{3}{2}} = 413$ cubic feet per second.

The length of waste weir required to discharge this rainfall with a depth on the crest of 1 foot 3 inches was found from the formula,

$$L = \frac{Q}{m \times d \times \sqrt{2gd}}, \text{ in which } m = 0.30, \text{ to be 123 feet,}$$

but as the inlet-well for the supply-valves projects above the crest of the dam and divides the waste weir into two separate parts, the clear combined width was made 125 feet in order to allow for diminution of discharge due to the contraction at the ends. The outlet-works consist of a semicircular well or valve-chamber with two cast-iron outlet-pipes, 9 inches in diameter, laid side by side,

leading therefrom through the wall of the dam and provided with stop-valves on their outer ends, one pipe being a reserve in case of emergency. The well is supplied from the reservoir by three 12-inch inlet-pipes, set at different levels in the semicircular wall of the well and controlled by valves supported on brackets and worked by spindles from the platform on top of the well, so that water can be drawn at any desired level. A sluice-pipe 18 inches in diameter is laid through the base of the wall for the purposes of cleaning out and regulating the discharge of the creek waters during construction. A light steel girder-bridge on top of the dam connects the valve-chamber with the shore. The impounding reservoir has an area of 31 acres, and contains, when full to the level of the overflow-weir, 85 million gallons of water; a rainfall of 1 inch on the watershed is sufficient to fill the reservoir.

Construction.—After all laminated and decayed rock had been removed from the foundations, the surface was cleaned off by means of a jet of water at a pressure of 60 lbs. or 70 lbs. per square inch, supplied by a pump, and all crevices and fissures were cleaned out and filled with cement grout, mixed in the proportion of 1 of sand to 1 of cement; a layer of cement mortar in the proportion of 2 of sand to 1 of cement was spread over the surface of the rock to a thickness of $\frac{1}{2}$ inch before any concrete was placed in position. The concrete was laid in courses, 2 feet in depth, extending from one end of the dam to the other, and was of two qualities, the inner face of the dam, for a thickness of 18 inches, consisting of concrete composed of 1 of cement, $2\frac{1}{2}$ of sand, and $3\frac{1}{2}$ of crushed stone to pass through a ring $\frac{1}{2}$ inch in diameter, and the outer face of the dam, for a thickness of 6 inches, being of concrete composed of 1 of cement, 3 of sand, and 5 of crushed stone to pass through a ring $1\frac{1}{2}$ inch in diameter. The heart of the dam was built of blocks of stone set in concrete, locally known as plum concrete, each stone having 6 inches of concrete all round, and no stone being laid nearer than 18 inches to the inner face of the dam, or nearer than 6 inches to the outer face, or within 2 feet of the foundations; the stones were not larger than 16 cubic feet nor smaller than $2\frac{1}{2}$ cubic feet, and were roughly squared and placed with their longest dimensions at right angles to the axis of the dam. All the stones were scrubbed and hosed clean before being laid in the work.

To guard against the effects of frost, which was very severe at night during the winter months, work was suspended before sundown, and all new concrete was covered over with tarpaulins; before resuming work in the morning, the surface of the concrete

was hosed down with boiling water before the next course was placed in position. Diorite stone of excellent quality was obtained within $\frac{1}{2}$ mile of the dam, its only fault being that it was too hard for the stone-breaker, the jaws of which frequently failed. The following is an analysis of the stone : —

Silica	67.44
Ferric oxide	3.20
Alumina	22.40
Lime	1.12
Magnesia	2.20
	<hr/>
	96.36
	<hr/>
Specific gravity	2.60

It will be seen that the two essential hydraulic constituents of cement, viz., silica and alumina, are present in this stone, but in much larger proportions than in cement. The stone in passing through the crusher produced comparatively little sand or dust, and it was found that the admixture of a small proportion of the dust with the concrete produced a very beneficial effect both upon the setting of the concrete and upon its strength. The sand used in the concrete was of a very coarse character and quite unsuitable for making a water-tight dam, but the admixture of the dust from the crusher greatly improved the quality of the concrete in that respect. Portland cement was employed, and was specified to bear a tensile stress of not less than 300 lbs. per square inch after 3 days (2 days in water), 450 lbs. per square inch after 7 days (6 days in water), and 550 lbs. per square inch after 28 days (27 days in water); it was required to be so finely ground that the residue on a sieve of 6,400 meshes per square inch, without rubbing, should not exceed 20 per cent., and on a sieve of 14,500 meshes per square inch should not exceed 30 per cent. It was also specified that the cement when gauged with three times its weight of standard sand, crushed from the sand-stone, washed, dried, sifted through a sieve of 400 meshes per square inch, and retained upon one of 900 meshes to the square inch, mixed with 10 per cent. of water, made into briquettes, and placed in water for 24 hours, should stand a tensile stress of not less than 100 lbs. per square inch after 7 days, and 200 lbs. per square inch after 28 days. The actual tests of the neat cement showed a tensile strength of 529 lbs. per square inch after 3 days, 607 lbs. per square inch after 7 days, and 664 lbs. per square inch after 28 days. The tests of cement mixed with three times its

weight of sand showed a tensile strength, after 7 days, of 229 lbs. per square inch, and after 28 days 284 lbs. per square inch. The specific gravity of the concrete in the dam was found to be 2.724. Stout timber centres were erected the full height of the dam, and the casing was erected as the work proceeded. Great care was observed in bedding the stones in the concrete to avoid cavities, and the concrete was thoroughly punned around them; the concrete on the faces was well worked with spades to get a smooth surface when the timbers were struck. It was found that the proportion of "plums" was 33 per cent. of the whole wall.

Stopping a Leak.—When the dam had reached a height of about 20 feet above the bed of the creek, a heavy fall of rain occurred on the drainage area, causing a freshet in the creek, which the sluice-pipe was insufficient to deal with, and the water rose behind the wall to some height. Owing to the immaturity of the concrete masonry, the water forced a passage through a joint, causing a leak just above the root of the apron. In order to plug the hole in the face of the dam and such interstitial voids as might exist in the heart of the masonry, liquid cement was injected under hydraulic pressure. An iron tank holding 400 gallons was placed on the hill-side 50 feet above the leak; a 2-inch wrought-iron pipe was laid from the tank down the slope of the hill to the leak at the foot of the dam, and was connected at one end to the tank, the other end being provided with a valve and a short length of flexible pipe terminating in a nozzle, which was inserted into the orifice of the leak in the face of the dam. The face of the dam for 6 feet above and below the hole and on either side was then planked over with 2-inch hardwood planks, tongued and grooved, with insertion laid between the face of the wall and the planking, a hole being bored through the plank over the leak to allow the nozzle to pass through; the planking was strengthened with hardwood stringers, 4 inches by 4 inches, which were strutted back to the rock and wedged up to hold the planking against the face of the dam and make it water-tight under pressure; the nozzle was then inserted and made perfectly secure and tight by driving home and wedging. The tank on the hill was filled with liquid cement kept in a thoroughly mixed state by men with shovels, and when everything was in readiness the valve was opened and about one-third of the mixing passed down the pipe into the hole. After an interval of 3 days the shores and planking were removed, and it was seen that the hole had been most effectually filled with the cement grout, which, when the water rose behind the dam to

its full height, was found to be quite water-tight. Although the greatest care was observed in the mixing and laying of the concrete to secure a water-tight wall, it was recognised that the coarseness of the sand would greatly militate against success in spite of the inner face of richer concrete, and it was found as the dam progressed and the water rose in the reservoir that a considerable leakage occurred, which appeared on the down-stream face of the dam like water coming from a very fine rose. To render the inner face with cement mortar made from such coarse sand would not improve matters; it was therefore decided to paint the inner face with neat cement mixed to a slurry, applied with stiff brushes, and well rubbed into the pores in three successive coats; this proved most effective, for when the water rose again in the reservoir the wall was found to be perfectly water-tight.

The expansion and contraction in concrete dams when the reservoir is low is very great, and when the reservoir is full it is very unequal in different parts of the cross-section; this is especially the case in some parts of Australia, where hot days and cold nights are of frequent occurrence, giving a range of temperature of about 90° F., and on that account many of the concrete dams in this country are badly cracked. In order to obviate this tendency to some extent, and to assist the closing of the cracks as the reservoir filled, the curved form of dam was adopted. It has been observed that the curved form does not render the structure altogether immune from cracking, and the cracks occur generally at about one-third of the length of the dam from the wings, commencing at the crest, first as a very fine crack and afterwards opening out and extending down the wall a distance of one-third to one-half of its height, and opening and closing as the reservoir empties or fills. It was thought that the introduction of an iron tie-bar in the crest of the dam, to take the tensile stress due to the contraction, would completely preserve the dam from cracking. It has been proved in other works that the temperature in the heart of the dam, say 3 feet from the surface, is constant, from which it may be argued that in order to ensure safety from cracking it is only necessary to protect from tensile stress the upper or thinner part of the dam where the cracks invariably originate. To find the cross-sectional area of such an iron or steel tie-bar to resist tensile stresses due to a range of temperature of 90° F., the unital stress in the upper part of the wall due to that range of temperature was determined by the formula—

$$\text{Unital stress} = c \times t \times E,$$

in which—

c = the coefficient of expansion or contraction for concrete for 1° F. = 0.0000076 ;

t = the range of temperature above or below the average temperature = $\frac{90^{\circ} \text{ F.}}{2} = 45^{\circ} \text{ F.}$;

E = modulus of elasticity for concrete = 750,000 lbs. per square inch.

Hence the unital stress = $0.0000076 \times 45 \times 750,000 = 256.5$ lbs. per square inch, which is greater than the usual maximum tensile stress allowed in concrete—about 200 lbs. per square inch. The coefficient of elasticity of concrete bears to that of iron the ratio of 1 to 40, and the stresses required to produce the same strain in the two materials are directly proportional to these coefficients, so that assuming that it is undesirable to allow a greater stress than 200 lbs. per square inch in the concrete, and that the cross-sectional area of that part of the wall subject to the effects of temperature is 1,930 square inches, the total tensile stress = $256.5 \text{ lbs.} \times 1,930 \text{ square inches} = 200 \text{ lbs.} (1930 - x) + 200 (40 x)$, in which x is the cross-sectional area of the iron required ; i.e., $495,045 = 386,000 - 200 x + 8,000 x$, $7,800 x = 109,045$ and $x = 14$ square inches. Hence two 70-lb. rails would be theoretically sufficient, but in order to provide a margin of safety three 70-lb. double-headed rails were laid, 6 inches below the level of the weir-overflow, and were jointed with fish-plates and embedded in the concrete.

Pipe-Line.—The pipe-line is 16,890 feet in length and conforms to the principal contours of the intervening hills, crossing a low-lying gap in the dividing-range, through a tunnel 1,100 feet in length, *Fig. 4*. The pipe is 9 inches in internal diameter and is constructed of mild wrought steel $\frac{1}{8}$ inch in thickness. It is constructed in lengths of 24 feet and multiples of 24 feet, the plates being 4 feet in length. The longitudinal joints are $1\frac{3}{4}$ inch and the transverse joints $1\frac{1}{8}$ inch in width ; the rivets are $\frac{5}{16}$ inch diameter and $\frac{7}{8}$ inch pitch ; the longitudinal joints are double-riveted, the pitch-lines being $\frac{3}{4}$ inch apart, and the cylindrical joints are single-riveted. Each pipe is fitted with a welded and rolled socket shrunk on, riveted and caulked, the sockets being $3\frac{1}{2}$ inches in depth. Spigots are formed by welding the pipe-end to make it seamless, a welded ring 5 inches in width and $\frac{1}{8}$ inch in thickness being then shrunk on and secured by counter-sunk rivets. All seams have a tarred canvas insertion and were

the pipe-line passed through private lands, special arrangements had to be made with the proprietors for way-leave. In all cases, however, the conditions under which the land was obtained were very satisfactory. The following are the costs of the materials per cubic yard used in the concrete:—

Rubble Stone.

	s.	d.
Quarrying and explosives	4	6
Cartage (1 mile)	2	0
Total	6	6

Broken Stone ($1\frac{1}{2}$ inch and $\frac{1}{2}$ inch).

	s.	d.
Quarrying and explosives	4	6
Cartage (1 mile)	2	0
Crushing	1	6
Total	8	0

Sand.

	s.	d.
Getting and carting 2 miles (no washing necessary)	4	0

Cement.

	£	s.	d.
Cost per cask weighing 3 cwt. 2 qr. 7 lbs.	0	11	6
Freight by rail 149 miles from port of Sydney	0	4	4½
„ „ road 42	0	5	4
Storage and handling	0	0	4½
Commission	0	0	1½
Total	1	1	8½

The work was carried out under contract by Mr. John Ahearn, of Sydney, from whose accounts the following particulars of net cost for the two classes of concrete have been compiled:—

	Per Cubic Yard.		
	£	s.	d.
Cement	1	5	1½
Sand	0	2	3½
Broken stone ($\frac{1}{2}$ -inch gauge)	0	5	4¾
Timber and labour in fixing	0	2	6
Labour in mixing and laying	0	3	6
Net cost of plant, including erection, removal, and freight, after deducting proceeds of sale . . . }	0	0	11
Total	1	19	8½

1:2½:3½ concrete.

for which the contractor was paid £2 per cubic yard.

	Per Cubic Yard.
	£ s. d.
Cement	0 14 8
Sand	0 1 7
Broken stone ($\frac{1}{2}$ -inch gauge)	0 4 6
Rubble plums	0 1 1 $\frac{1}{2}$
Timber and labour in fixing	0 2 6
Labour in mixing and laying	0 3 6
Nett cost of plant, including erection, removal, and freight, after deducting proceeds of sale }	0 0 11
Total	<u>1 8 9$\frac{1}{2}$</u>

1:3:5 concrete and rubble plums.

for which the contractor was paid £1 14s. 4 $\frac{1}{2}$ d. per cubic yard.

The Paper is accompanied by two drawings, from which the Figures in the text have been prepared.