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“The Spillways of Burrinjuck Dam.”

By HENRY HARVEY DARE, M.E., M. Inst. C.E.

THE Burrinjuck dam, New South Wales, has been constructed to store the waters of the Murrumbidgee river for the irrigation of an area estimated at about 200,000 acres. The principal dimensions of the structure are: maximum height, 242 feet; maximum depth of water stored, 200 feet (R.L. at full supply, 1,180); length on crest, 765 feet; capacity, 771,641 acre-feet. At the site of the dam the hills rise steeply on either side to a height of 1,800 to 2,100 feet above the bed of the Murrumbidgee river. The formation is red granite, and construction of spillway-weirs even approximately on the axis of the dam was out of the question, on account of the vast quantity of excavation that would have been involved. The design of the spillways adopted, as shown in Fig. 1, Plate 6, includes the provision of ogee concrete weir-walls of gravity section, parallel with the river, over which the flood-waters will fall into excavated channels discharging below the dam.

When the dam was designed, sufficient gauging-data were not available to determine the discharge of the maximum flood to be provided for in the Murrumbidgee river at the site, and recourse was had to the records of the Goulburn river in Victoria, the catchment of which is somewhat similar to, though smaller than, that at Burrinjuck. The highest flood in this stream up to that date had occurred in 1870. Later, during the construction of the Burrinjuck dam, a flood was registered in the Goulburn river with a discharge about 60 per cent. greater than that estimated for the 1870 flood; and this fact, combined with the more accurate knowledge then available of the characteristics of the Burrinjuck catchment, made it evident that the spillway-provision must be increased.

In the early stages of construction one test had been made with a model spillway at Burrinjuck on a scale of $\frac{3}{8}$ inch to 1 foot, from which a record was obtained of the discharge over the weir; but, unfortunately, the model was destroyed by flood before any further investigation could be made. The Author has been unable to trace any literature dealing with the discharge of spillway-channels of the Burrinjuck type, parallel with the river, except for a brief reference in a text-book recently published.¹ It was accordingly decided to construct a model in the river-bed about 10 chains below the dam-wall, the construction of which was then well advanced, with a considerable body of water stored.

SPILLWAY MODEL TESTS.

The general arrangement of the model is shown in Figs. 2, Plate 6. The flow from the reservoir to the river was regulated by the two 10-foot by 6-foot Stoney sluice outlets in the dam, which was within signalling-distance of the model. The scale of the model was one-twenty-fourth of full size.

The component parts of the model are :—

1. Miniature main dam-wall.
2. Miniature spillway weir-wall.
3. Miniature spillway-channel.
4. Wicket regulator in the line of river-flow.
5. Storage-pool, between regulator and dam-wall.
6. Measuring-weir.
7. Stilling-pool, to receive the discharge of the spillway-channel, before passing over the measuring-weir.

In the preliminary tests, which were made about the beginning of 1918, the storage- and stilling-pools were found to be insufficient to prevent surging on the spillway and measuring-weirs. The areas of the pools were consequently extended, and additional baffles were introduced. A hook gauge was used to determine the surface-level of the storage-pool, and velocities of approach to the measuring-weir were determined with a Price current-meter. Photographs were taken showing the conditions in the spillway-channel for successive increases in head on the spillway-weir during the various experiments.

¹ E. S. Bellasis, "River and Canal Engineering," p. 166, 1913.

During the progress of the experiments, Mr. E. M. de Burgh, M. Inst. C.E., Chief Engineer for Water-Supply and Sewerage, and Mr. J. J. C. Bradfield, M. Inst. C.E., Chief Engineer for Metropolitan Railway Construction, were appointed to act with the Author as a committee to report upon the question of increased spillway-provision at Burrinjuck. At the date when the tests were made the northern spillway-weir had been completed, and the floor of the upper portion of the channel had been concreted, so that no alteration was possible in this spillway, except with regard to the gradient of the floor of the channel, then under construction, below the dam. The length of crest of the northern spillway-weir is 564 feet, and, under the original assumption of maximum flood-discharge, it was estimated that there would be a surcharge of 10 feet on the crest. The upper end of the weir is curved to join the rock face. The length of crest in the model was made slightly less—556 feet to scale—due allowance being made in the final computations of discharge for the difference in length. On the southern side the dam-wall had been completed to about R.L. 1140, but the spillway-channel had not been excavated. The length of the crest of the weir and the width and depth of the channel were limited by the precipitous slopes. The length of the crest in the southern spillway model was made to correspond with the 400 feet finally adopted for the spillway-wall as constructed. The weir-wall in the model was constructed of concrete, and the channel was fitted with a carefully-caulked false timber bottom to allow adjustment to suit the different tests.

The information obtained from the model test made some years previously had been of value in designing the spillway-weir. The main object of the present tests was to ascertain what would be the conditions in the spillway-channels and to what extent the original design for the southern spillway, and also the northern spillway-channel below the dam, might be improved.

Although some tests were made with the model to enable the discharges on the actual work, inferred up to a surcharge of 10 feet, the principal object of the experiments was to deduce the discharge at the 10-foot surcharge under varying conditions of level of the bed of the actual spillway-channels. A number of observations were made for each series of tests, at a surcharge equivalent to 10 feet on the full-size weir, and these were corrected in the standard manner for the time interval between observations.

In Figs. 3-9, Plate 6, are shown the effects on the full-size spillways deduced from the model experiments where the levels

of the spillway-channel floors were altered for each series of tests ; the results of observations are given in Table I, Appendix A.

It will be noticed with regard to Series Nos. 1, 2, and 3 that the effect of lowering the floor of the channel opposite the axis of the dam has been to increase the discharge only slightly in the case of Series No. 2, but by 9·2 per cent. in the case of Series No. 3. The deepening of the channel in the latter series caused a marked improvement in the overfall conditions on the spillway-weir, which in Series No. 1 had been partially drowned towards the upper end.

In Series 4, 5, and 6, the floor of the channel below the dam was stepped and made comparatively flat in gradient only for convenience in the construction of the model. It was thought that these gradients, apart from the fact that they did not represent the actual conditions of the full-size structure, might prejudice the depth of water in the lower channel, and, incidentally, affect the height of the training-wall. Whereas it was impracticable at the site of the model to reproduce exactly the long steep gradient of the full-size structure, yet a compromise could be made as shown in Figs. 9. In addition to the steeper slope of the lower channel as compared with Series 4-6, further slight amendments to the model were introduced whereby the vertical face of the spillway-weir adjacent to the abutment of the dam was carried back a little farther into the storage-pool, and the comparatively abrupt change of spillway into training-wall at the axis of the dam was replaced by a transition. A test was then made which showed that, while the discharge was not increased, these modifications appreciably stabilized the flow in the lower portion of the channel, the depth of flow being likewise generally eased. The increase in discharge between Series Nos. 4 and 6 represents about 9·0 per cent.

Further tests were made, from which inferences were drawn as to the conditions on the actual work with surcharges up to an equivalent of 16 feet, at which height the concrete parapet on the dam would be topped. Observations of discharge were made showing large increases over the discharge at the 10-foot surcharge, but since the large volume of water passed at the higher surcharges caused considerable surging on the measuring-weir, the results obtained were approximate only, and the figures for these latter tests have not been included in Table I.

Generally speaking, considerable eddying occurred in the spillway-channel, due partly to the overfalling water striking the back wall and being reflected therefrom, and partly to interference where

the water flowing down from the upper end of the channel met the water falling over the weir lower down. Near the upper end a heap-ing-up of the water took place in the channel, especially in the case of Series No. 1. Except for a small space at the top end of the channel, a strong forward movement was everywhere apparent, even at the foot of the spillway-weir, the general direction being diagonal to that of the channel.

The values of C shown in the Table should be read with caution. The purpose of the experiments was not primarily to ascertain the values for C in the weir-formula, but rather to ascertain the dis-charging-capacity of the spillways. With a surcharge equivalent to 10 feet the crest of the weir was more or less submerged for a portion of its length, whilst in the remainder of the crest more closely adjacent to the axis of the dam no submergence was evident. No differentiation could, however, be made, since these relative conditions existed simultaneously on the crest of the weir, and thus the deduced values of C are average values. For this reason it was to be expected that the values for C would be appreciably less than values deduced from other experiments, notably those by Mr. R. E. Horton¹ and Professor G. S. Williams,² for weirs with the general type of crest used at Burrinjuck, since in these latter tests the direction of flow was not changed after discharge over the weir, while uniform conditions, with a clear overfall, prevailed throughout the length of the crest.

Following upon the model tests, it was decided, upon the recom-mendation of the committee, that the spillways should be completed to the design shown in Fig. 1, Plate 6.

ESTIMATED BEHAVIOUR OF SPILLWAY IN 1916 FLOOD.

The area of the water-surface at full-supply level in large reser-voirs, such as those constructed for irrigation purposes, is generally extensive, and the rate at which the inflowing flood-waters reach the spillway may be modified considerably by the storage provided by the reservoir above the crest of the spillway. Assuming that the reservoir is full to the crest-level of the spillway at the

¹ Robert E. Horton, "Weir Experiments, Coefficients and Formulas." Water Supply and Irrigation Paper, No. 200, U.S. Geological Survey.

² Gardner S. Williams, "The Flow of Water over Dams." *Engineering News*, 12 January, 1911.

commencement of the flood, the proposition may then be stated as follows :—

(1) Total inflow during any period = total outflow plus increase in quantity stored. (All measurements in acre-feet, where not otherwise mentioned.)

(2) For any small interval of time T seconds,

Q denotes the rate of inflow in cusecs (i.e. cubic feet per sec.),

L „ length of crest of the spillway in feet,

H_1 „ depth over crest in feet at the commencement of period T ,

H_2 „ depth over crest in feet at the end of period T ,

C „ coefficient used in weir-discharge formula,

D „ rate of discharge through sluices, if any, in cusecs,

A „ mean area of reservoir-surface during period in square feet.

$$\text{Then } Q = \frac{CL}{2} (H_1^{\frac{3}{2}} + H_2^{\frac{3}{2}}) + \frac{A (H_2 - H_1)}{T} + D.$$

The problem to be solved may be stated in two ways :—

(1) For a given length of spillway-crest, what will be the maximum surcharge due to flood ?

(2) For a given surcharge, what will be the length of spillway-crest required ?

Various mathematical investigations, to which references are given in Appendix B, have been made of phases of this problem. Some of them are based upon the assumption of a constant inflow, which for large floods must involve elements of considerable error. In no case, so far as the Author is aware, has a purely mathematical solution been arrived at.

A simple graphic solution¹ by successive approximations has been propounded ; and this is shown in *Figs. 10* and *11*, used in connection with a flood which occurred during the construction of Burrinjuck dam, and for which complete records are available. This method is applicable to any case where a flood-characteristic can be drawn. It is desirable that the time-intervals adopted in calculations shall be as short as possible ; in this case the interval is 2 hours. The data upon which the curves are based are shown in Table II, Appendix A.

¹ C. C. Jacobs, *Engineering News*, 13 June, 1912.

The Table is generally self-explanatory, but it may be added that ordinarily a spillway rating-curve would be made to include rates of discharge as ordinates, with corresponding heights of surcharge as abscissas. In the present case, however, it is desirable to know what will be the rate of discharge of the spillway when the volume of storage above the crest of the spillway-weir is of any particular value. Accordingly in curve C, *Fig. 10*, the abscissa axis is marked out for volumes of storage above the level of the crest of the weir, and the ordinates indicate corresponding rates of discharge. The ordinates intercepted between curves B and D, *Fig. 11*, represent the net volume of flood-water stored in the reservoir above the crest of the spillway-weir at any stage, and from these curve E is plotted. The point X, where this curve commences to descend, represents

Fig. 10.

the maximum level reached in the reservoir. Thereafter, though the inflow will continue for some time, the discharge of the spillway will predominate, and the level of the reservoir will be reduced gradually until it falls again to the level of the spillway-crest or full storage-level.

Subsequent to the date of investigation on the foregoing lines, details of an alternative method of treating such a problem were published by Mr. R. E. Horton,¹ who has deduced function curves covering both variable rates of inflow and also variations in the area of the water-surface of the reservoir corresponding with the depth on the spillway-weir. A graphical treatment based on these curves

¹ *Engineering News-Record*, 5 September, 1918.

is used. Since the principles and assumptions are exactly similar to those adopted in the method of investigation already described, the two methods should give results very much in agreement, with no relative advantage in the degree of accuracy; but Mr. Horton's method has a decided advantage, in that there is not the necessity

for successive approximations in ascertaining the water running over the spillway during any time-interval, and there is consequently an appreciable saving of time in treating a problem by his method. For comparative purposes the results obtained by Mr. Horton's method are included in Table II.

In conclusion, the Author desires to thank the Officers of the Water Conservation and Irrigation Commission, and especially Mr. H. M. Larkins, B.E., for assistance rendered in the preparation of the Paper.

The Paper is accompanied by four tracings, from some of which Plate 6 and the Figures in the text have been prepared, and by a book of photographs.

APPENDIX A.—TABLE I.—RESULTS OF

MODEL.								
Series Number.	Number of Observations.	Simultaneous Readings : Model Structure.					Calculated.	
		Spillway-Weir.		Measuring-Weir.			Measuring-Weir. Q.	Spillway-Weir. C.
		Length. <i>l</i> .	Depth on Crest. <i>h</i> .	Depth on Lip. Average.		Velocity of Approach.		
		Inches.	Inches.	Inches.	Inches.	Foot per Second.	Cusecs.	
1	207	278	5.0	8.47	8.68	0.74	20.45	3.28
2	14	278	5.0	8.55	8.76	0.67	20.67	3.32
3	15	278	5.0	8.84	9.29	0.80	22.33	3.59
4	14	200	5.00	6.58	6.84	0.54	14.09	3.14
5	15	200	5.00	6.64	6.85	0.53	14.18	3.17
6	20	200	5.00	6.97	7.24	0.55	15.35	3.42

Measuring-Weir, $Q = 3.33 \sqrt{h^3}$ where $l = 10.0$ feet,

MODEL TESTS AT BURRINJUCK DAM.

FULL SIZE.												
Water Line in Spillway-Channel. Reduced Level, referred to Full-Size Structure.										Spillway-Weir. (Full-Size Structure.)		Remarks referred to Full-Size Structure.
Gauges on Back Wall. (Figs. 2, Plate 6.)										Depth on Crest.	Discharge.	
A	B	C	D	E	F	G	H	J	K			
1185	1187	1183	1179	1173	1169	1162	1156	1146	1135	Feet.	Cusecs.	Northern spillway, 10 feet surcharge, floor as constructed.
1182	1185	1181	1176	1171	1166	1160	1155	1146	1135	10.0	57,706	
1172	1182	1174	1170	1165	1162	1156	1153	1149	1135	10.0	58,313	
1172	1182	1174	1170	1165	1162	1156	1153	1149	1135	10.0	63,011	Northern spillway, 10 feet surcharge, floor lowered 15 feet at axis of dam.
..	1188	1185	1180	1171	1167	1160	..	..	..	10.0	39,746	
..	1188	1185	1179	1171	1167	1160	1158	..	..	10.0	40,014	
..	1186	1183	1177	1170	1166	1160	1160	..	..	10.0	43,301	Southern spillway, 10 feet surcharge, floor further lowered 5 feet throughout.

and h is corrected for velocity of approach.

TABLE II.—BURRINJUCK STORAGE-RESERVOIR. BEHAVIOUR OF SPILLWAY UNDER CONDITIONS OF FLOOD OF OCTOBER, 1916.
(ASSUMING THAT STRUCTURE HAD BEEN COMPLETED.)

Day.	Date.	Ordinate on Mass Curve.			Rating (Average).	Discharge over Spillway.			Depth of Surcharge at End of Interval. <i>Alternate Method of R. E. Horton.</i>
		Aggregate Flood.	Spillway Aggregate Waste Water.	Net Aggregate Storage above Spillways.		Period.	Increment.	Depth of Surcharge Interval.	
	Time.	Acre-Feet.	Acre-Feet.	Acre-Feet.	Acre-Feet per Day.	Hours.	Acre-Feet.	Feet.	Feet.
4th	4 p.m.	6,000	138	5,862	1,656	2	138	0.45	0.45
	6 "	12,000	390	11,610	3,024	2	252	0.80	0.80
	8 "	19,000	895	18,105	6,060	2	505	1.15	1.15
	10 "	26,000	1,767	24,233	10,464	2	872	1.81	1.62
5th	12 m.n.	34,000	3,030	30,970	15,156	2	1,263	2.32	2.13
	2 a.m.	43,500	4,798	38,702	21,216	2	1,768	2.90	2.72
	4 "	55,000	7,231	47,769	29,196	2	2,433	3.57	3.40
	6 "	69,000	10,537	58,463	39,672	2	3,306	4.35	4.18
	8 "	85,000	14,899	70,101	52,344	2	4,362	5.19	5.10
	10 "	102,000	20,500	81,500	67,212	2	5,601	6.00	5.89
	12 noon	117,800	27,203	90,597	80,436	2	6,703	6.70	6.58
	2 p.m.	137,000	34,848	102,152	91,740	2	7,645	7.18	7.05
6th	4 "	147,000	43,319	103,681	101,652	2	8,471	7.70	7.56
	6 "	160,500	52,456	108,044	109,644	2	9,137	7.93	7.85
	8 "	173,500	62,096	111,494	114,600	2	9,550	8.16	8.07
	10 "	186,000	71,923	114,077	119,004	2	9,917	8.34	8.25
	12 m.n.	197,600	82,093	115,507	122,040	2	10,170	8.44	8.36
	2 a.m.	209,000	92,423	116,577 X	123,960	2	10,330	8.52	8.45 X
	4 "	219,000	102,799	116,201	124,512	2	10,376	8.49	8.43
	6 "	223,400	113,106	110,294	123,684	2	10,307	8.43	8.39
7th	8 "	236,600	123,230	113,370	121,488	2	10,124	8.29	8.27
	10 "	245,000	133,124	111,876	118,728	2	9,894	8.19	8.18
	12 noon	254,200	142,903	111,297	117,348	2	9,779	8.14	8.15
	2 p.m.					2			

APPENDIX B.

BEHAVIOUR OF SPILLWAYS—REFERENCES.

- "Irrigation Manual" of Madras Government, p. 215. Lieut.-General J. Mullens, 1890.
- "Reports of the State Engineer and Surveyor of New York." G. W. Rafter, 1894, p. 390 ; 1896, p. 722.
- "Water Power." J. P. Frizell, 3rd Edition, p. 223.
- "A Method of Computing the Size of Spillway for a Dam." H. K. Palmer. *Eng. News*, 21st March, 1912.
- "Filling and Emptying of Reservoirs." T. R. Running. *Eng. Record*, 17th January, 1914.
- A. S. Fry. *Engineering Contracting*, 19th April, 1916.
- "Method of Computing Waste Weir Capacity and Reservoir Rise." Professor W. S. Pardoe, *Eng. News-Record*, 20th January, 1921 (and *Engineering Abstracts*, No. 7, p. 209).

PLATE 6
BURRENLUCK DAM.

SECTIONS OF MODEL SPILLWAY-CHANNEL — SOUTHERN SPILLWAY