WATER-PROOFING OPERATIONS ON THE JHANG BRANCH OF THE LOWER CHENAB CANAL DURING 1913-14.

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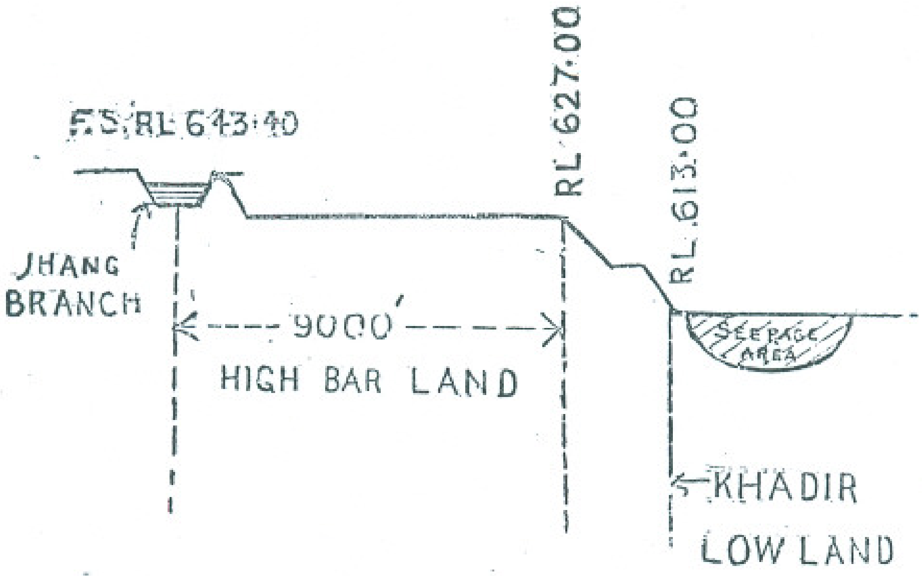
Preliminary.

The Jhang branch of the Lower Chenab Canal is, for a great portion of its length in filling, and after over twenty years use the result has been considerable flooding of the surrounding low-lying land. The evil has begun to present so serious an aspect that the necessity for preventing further flooding has forcibly presented itself to the officers and administration concerned.

One of the areas affected most seriously by the seepage is that opposite the reach extending from R. D 1,22,000 to R. D. 1,52,000. On the south side of the branch, opposite this reach, the land is at a slightly higher level than on the other side, and here the waterlogging is not so evident. An exception, however, is the Beranwala Reservoir, but as this is at present utilised as an escape, the presence of a large area of water excites no surprise. On the north side the land slopes down fairly rapidly, and at a distance of about 1½ miles from the canal, there is a distinct and sudden fall in the level of the natural surface. Thereafter the ground slopes down at a steep gradient until the river (Chenab) is reached. The river bank is, on an average, about nine to ten miles distant from the canal and it is on this, the right or north side of the Jhang branch, that the seepage water is most in evidence, and especially opposite R.D. 1,44,000. There are other tracts traversed by the branch, which are similarly affected by seepage, but with these the author is not so well acquainted, nor is this a matter of great importance, as the object of this short paper is to describe the operations undertaken to render such a channel more or less waterproof.

A section taken roughly at right angles to the canal and nto the swamped area gives the following result :—



From this section it will be seen that less than two miles away from the canal there is low khadir land, with a level thirty feet below the level of the full supply in the canal ; the result of which is obvious. The situation is not an uncommon one in the Punjab, where there are artificial channels flowing in close proximity to low riverain beds, causing heavy seepage, until a final state is reached, when the low-lying lands become hopelessly waterlogged, and no longer culturable. Other examples of this state of affairs are to be found on the Upper Bari Doab Canal, where seepage into the Beas lowlands occurs, and on the Sirhind Canal near Garhi.

The *nahri* irrigation in the tract under consideration cannot be said to increase the waterlogging to any appreciable extent, as it has been wisely restricted ; hence the responsibility for the waterlogging must be placed entirely on the canal.

Loss of Revenue through seepage,

The loss of revenue through seepage, and the remedial measures to be undertaken, were discussed by a committee of leading engineers and district officers appointed by the Government of India in 1910, and their conclusions may be briefly summed up as follows :—

(*i*) Abandon the existing Beranwala reservoir as an escape, and construct a new escape channel on the right bank of the Jhang branch, with an outfall into the Chenab.

(*ii*) Any scheme to silt up the swamped and low-lying areas affected by seepage from the canal would be inadvisable.

(*iii*) A drainage scheme should be prepared for the swamped tract, for the purpose of lowering the subsoil water by draining it into the river.

Theoretically, the loss of water from a channel is calculated according to the following formula :—

$$Q = C \times \sqrt{D} \times \frac{L x B}{10,00,000}$$

Where Q. = Quantity in cusecs.

C. = 3 (a constant).

D. = Depth of water in feet.

L. = Length of reach in feet.

B. = Breadth of water surface in the channel in feet.

In the reach under consideration this gives a

$$\text{loss} = 3 \times \sqrt{8 \cdot 6} \times \frac{30,000 \times 110}{10,00,000}$$
$$= 3 \times 2 \cdot 9 \times 3 \cdot 3.$$
$$= 29 \text{ cusecs.}$$

Actually the loss of water is found to be $4\frac{1}{2}$ cusecs per mile, or in this length from R. D. 1,22,000 to 1,52,000, about 27 cusecs.

On the Lower Chenab Canal the average duty at the canal head, per cusec of supply utilized, is roughly, 78 acres for the kharif season and 187 acres for the rabi season. The average water rate (including owners' rate) per acre irrigated, is Rs. 4·4 per acre for the kharif crop and Rs. 4·2 per acre for the rabi crop, while the average working expenses per acre irrigated per year, are Rs. 1·07, say, Rs. 0·54 during the kharif season, and Rs. 0·54 during the rabi season.

If the canal can be rendered waterproof the direct revenue retrieved will be :—Rs. 4·4—Rs. 0·54 = Rs. 3·86 per acre irrigated during the kharif season, and Rs. 4·2—Rs. 0·54 = Rs. 3·66 per acre irrigated in the rabi season.

Assuming that the Jhang branch is open throughout the kharif season and for two-thirds of the rabi season, the net return per annum will be :—$78 \times 3{\cdot}86$ = Rs. 301 per cusec in the kharif season and $\frac{2}{3} \times 187 \times 3{\cdot}66$ = Rs. 456 per cusec in the rabi season—a total of Rs. 757 per cusec.

The total loss of water in the reach is twenty-seven cusecs so that, even assuming that only sixty per cent will be retained by the waterproofing, the annual direct return will be :—

$\frac{60}{100} \times 27 \times$ Rs. 757 = Rs. 12,263, which amount, at twenty-five years purchase, represents a capital of Rs. 3,08,575.

In addition to this substantial saving, there will be a reduction in the spring water level, which will make it possible to bring a considerable area, estimated at over three thousand acres, under cultivation, and will materially improve the cultivation in many other villages which at present suffer from the same cause in a lesser degree. The inhabitants of the affected areas will also be materially benefitted by a reduction in the seepage, as at present they suffer acutely from rheumatism and fevers, which will probably be greatly reduced when the improvements have been effected. It will, therefore, be readily granted that Government is justified in spending freely on such a financially sound scheme.

Remedial measures.

The remedial measures being undertaken comprise :—

(*a*) The abandonment of the low-lying Beranwala reservoir as an escape.

(*b*) The construction of a new escape, taking off from the branch at R. D. 1,22,000, and discharging into the river.

(*c*) Lining the bed of the branch from R. D. 1,22,000 to R. D. 1,52,000.

The proposal to deal directly with the swamped areas by means of a system of seepage channels has been abandoned for the present, on the grounds that any system of seepage drains would not cure the swamping, though they might for a time diminish it, while they would eventually become so silted and choked with vegetation, etc., as to become ineffective, whereas, if the lining of the canal is waterproof, or nearly so, a drainage system will be unnecessary.

Preliminary experiments.

The preliminary trials consisted of laying short lengths of linings of various compositions and thicknesses, in the bed of the canal, and subjecting them to the same conditions as would obtain when the finally approved lining had been laid.

Similar trial linings were also tested for porosity in specially made tanks, while experiments were carried out separately to determine the comparative tensile breaking stresses, and degrees of absorption. Dealing first with the linings laid in the canal bed, the following were tried :—

LININGS LAID IN THE BED.

No.	Cement parts.	Sand parts.	Thickness of lining.	Description of sand.
1	1	5	1"	Coarse Chenab river sand from Khanki.
2	1	2	$\frac{1}{2}$"	Local river sand not so coarse as the Chenab sand. (Nos. 2–7)
3	1	3	$\frac{5}{8}$"	
4	1	$3\frac{1}{2}$	$\frac{3}{4}$"	
5	1	4	$\frac{1}{2}$"	
6	1	8	$1\frac{1}{2}$"	
7	1	8	$\frac{3}{4}$"	
8	1	1	$\frac{1}{4}$"	Fine silt from the Jhang Branch. (Nos. 8–12)
9	1	2	$\frac{1}{2}$"	
10	1	3	$\frac{5}{8}$"	
11	1	4	"	
12	1	5	$1\frac{1}{2}$"	

In addition to the trial linings laid in the canal bed itself, an extensive series of experiments were carried out on linings of various mixtures and thicknesses in tanks, with the results tabulated on the next page. The tanks were rectangular in shape, seven feet deep, measuring seventeen feet square at the top and three feet square at the bottom, the side slopes being one to one. The linings were plastered on the dressed sides of the pits, and at the bottom on a foot of sand which had been substituted for the natural soil. A gauge was then painted on the side of each tank. Water was run in daily to a depth of five feet on the gauge, and any diminution in depth during the twenty-four hours carefully noted, with the results tabulated.

In addition to the porosity tests, in tanks, briquettes of the same composition were tested for tensile strength, and three inch cubes were made and tested for absorption. The last were weighed dry, and also after immersion in water for seven, fourteen, twenty-one and twenty-eight days. The results of the two sets of experiments are given in Table II on page 98.

Final decision regarding the composition of the lining.

Of the twelve kinds of lining laid in the canal bed,* that composed of one part of cement to five parts of Jhang Branch silt, laid 1½" thick, was found to be the most satisfactory, having regard to impermeability, facility in laying, and cost.

There is a wide divergence of opinion among engineers, regarding the respective advantages of coarse and fine sand, when mixed with cement for such purposes as obtaining a water-proof lining. As already mentioned Chenab river sand from Khanki is a coarse sand ; that designated as local river sand (*i.e.*, sand obtained from the Chenab bed in the same locality as that in which the lining work was being done) is finer than that obtained from Khanki ; while the Jhang Branch silt is very fine.

At first it was proposed to employ a coarse sand in the plaster, but later, after an inspection of the experimental linings laid on the canal bed, it was decided to use fine sand, as it was found that as regards impermeability, when the proportion of cement in a mixture is small, the finer the sand the better the plaster. Small patches of the various linings, when dug out and broken, shewed that, where the coarser sand had been used, the voids were larger and more numerous than where the finer sand

* See page 95.

JANG BRANCH-EXPERIMENTAL TANK

SCALE 5 FT. = 1 INCH

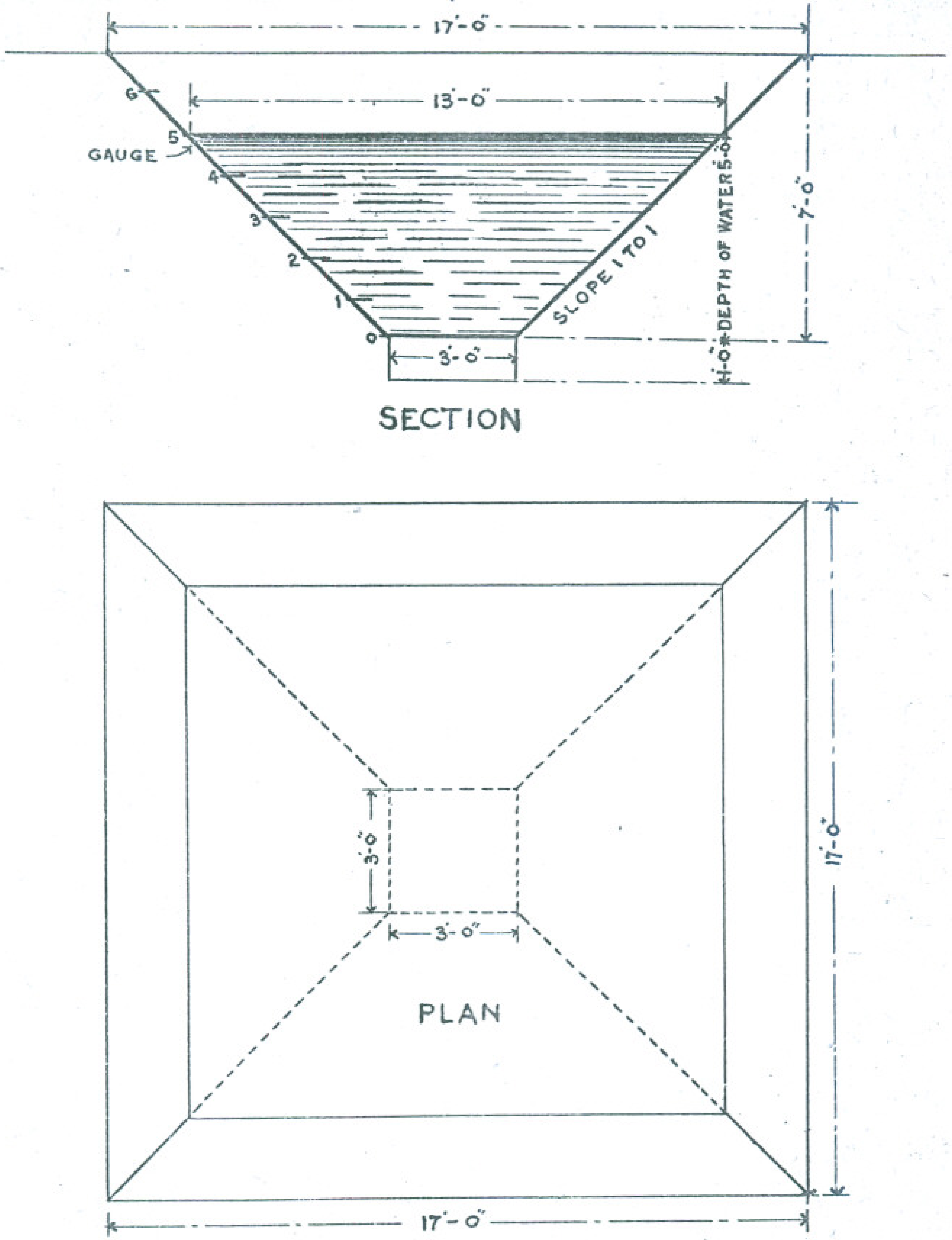


TABLE I.—POROSITY TESTS.

Serial No.	Composition of lining. Cement.	Jhang Branch silt.	Sand from River Chenab at Khanki.	Local river sand.	White lime.	Surkhi.	Thickness of lining.	Average daily loss in depth in feet. March 1913.	April 1913.	May 1913.	Remarks.
1	1	...	5	...	...	...	1 in.	...	0·05	0·05	
2	1	...	...	2	...	...	$\frac{1}{2}$ in.	0·06	0·04	0·06	
3	1	...	...	3	...	...	$\frac{5}{8}$ in.	0·07	0·06	0·07	
4	1	...	...	$3\frac{1}{2}$	...	...	$\frac{3}{4}$ in.	0·09	0·05	0·05	
5	1	...	...	4	...	...	$\frac{1}{2}$ in.	0·13	0·08	0·08	
6	1	...	...	8	...	...	$1\frac{1}{2}$ in.	0·24	0·20	0·19	
7	1	...	...	8	...	...	$\frac{3}{4}$ in.	0·38	0·29	0·24	
8	1	1	...	...	...	...	$\frac{1}{4}$ in.		Not tested.		
9	1	2	...	...	...	...	$\frac{1}{2}$ in	0·08	0·04	0·05	
10	1	3	...	...	...	...	$\frac{5}{8}$ in.	0·10	0·06	0·06	
11	1	4	...	...	...	...	$\frac{5}{8}$ in.	0·12	0·07	0·06	
12	1	5	...	...	...	...	$1\frac{1}{2}$ in.	...	0·05	...	
13	1	...	5	...	...		1 in.	...	0·04	0·04	Soap added in the proportion of
14	1	...	...	3	...	...	$\frac{3}{4}$ in.	...	0·03	0·06	one pound of soap to each
15	1	...	...	4	1	2	1 in.	0·10	0·05	0·06	hundred cubic feet of mixture.
16	1	...	...	8	$\frac{1}{2}$	...	$1\frac{1}{2}$ in.	0·22	0·13	0·19	
17	Unlined.				...	...	...	...	2·09	2·40	

NOTE.—These serial numbers correspond with the numbers in the table on page 95.

TABLE II.—TENSILE AND ABSORPTION TESTS.

Serial No.	Composition.						Tensile breaking stress in lbs. per square inch after setting in water for the following periods.				Weight in lbs. of three inch cubes dry.	Weight of 3 in. cubes after immersion in water for periods of				Percentage absorption (Weight.)
	Cement.	Jhang Branch silt.	Sand from river Chenab at Khanki.	Local river sand.	White lime	Surkhi.	1 week	2 weeks.	3 weeks.	4 weeks.		1 week.	2 weeks	3 weeks.	4 weeks.	
1	1	...	5	...	...	...	71	80	86	96	12·	14·3	14·4	14·5	14·5	20·8
2	1	...	...	2	...	...	95	106	141	156	12·9	14·1	14·1	14·1	14·2	10·1
3	1	...	...	3	...	...	77	100	116	132	12·7	14·2	14·3	14·3	14·3	12·6
4	1	...	...	3½	...	...	70	82	106	124	12·0	14 0	14·1	14·1	14·1	17·5
5	1	...	..	4	...	...	71	83	103	118	12 3	13·9	14·1	14·1	14·1	14·6
6	1	...	...	8	...	...	52	68	73	83	10·9	13·0	13·0	13 0	13·1	20 2
7	1	...	...	8	...	...	as No. 6					as No. 6				
8	1	1	...	...	...	...										
9	1	2	...	...	...	...	87	105	126	150	14·4	15·5	15 6	15·7	15·9	10·4
10	1	3	...	...	...	...	59	96	105	126	12·7	14·7	14·7	14·8	14 9	17·3
11	1	4	...	...	...	...	50	79	82	88	11·5	13·5	13·5	13·6	13·6	18 2
							10	20	30days							
12	1	5	...	...	...	...	65	83	95							
13	1	...	5	...	...	...	as No. 1					as No. 1				
14	1	...	...	3	...	...	as No. 3.					as No. 3.				
15	1	...	..	4	1	2	66	78	80	89	13·8	15·3	15·3	15·4	15·5	12·3
16	1	...	...	8	½	...	50	61	70	78	12·4	14·2	14·3	14·5	14·5	17·0
17	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

had been employed. These large and numerous voids might possibly be prevented, either by using a greater proportion of cement, or by using a graded sand. However, as stated above, it was decided that lining No. 12 would give sufficiently satisfactory results, and hence the Jhang Branch silt alone is mixed with cement.

An added advantage is, that the silt is procurable at site, whereas for the coarser sands, elaborate and expensive arrangements would have been necessary. If Khanki sand were used, it would entail carriage by rail from Khanki for sixty-four miles, followed by carriage across country on camels for an average distance of fourteen miles, thereby greatly adding to the cost. The same objection applies to the use of the local river sand, as the river is at an average distance of nine or ten miles from the canal.

Having decided which sand was to be employed, the next points to be considered were the proportions in the mixture and the thickness of the lining. It had to be borne in mind that all processes involved in the lining would be carried out by manual labour ; *i.e.*, the measurement of the ingredients, the mixing (both dry and wet), the preparatory levelling of the canal bed, and the actual plastering.

Proportions of the mixture—

In an ordinary branch rotational closure lasting fourteen days, eleven days are available for cement lining, the remaining three days being required for the water to run off. In these eleven days, with, say, twelve hundred to fifteen hundred coolies available, it is possible to line a length of about ten compartments, equivalent to two thousand five hundred feet length of the branch, the bed width to be lined being ninety-eight feet. It may here be noted that the branch, before being lined, is divided up by masonry curtain or cross walls into compartments two hundred and fifty feet in length. These cross walls have their ends built into the banks, and their top surfaces flush with the designed bed level of the canal. They are 1·3 feet in width and two feet in depth, and rest on six inches of concrete, which is 2·3 feet wide. The lining itself is laid at an average depth of $1\frac{1}{2}$ feet below the designed bed level of the branch.

Mixing tanks, either of iron or of *kacha-pacca* masonry, are provided, on the scale of ten tanks per compartment, or twenty tanks for two compartments. A sub-overseer or a very reliable mistri is required to supervise the proportioning and mixing for every set of twenty tanks, but even then it is possible that in the rush of work the cement may be either in defect or excess, or, if the proportions are correct, the two ingredients may not be thoroughly turned over and intermixed. In deciding the composition of the mixture, it is therefore necessary to consider the worst case, and to allow for the cement being in defect. A true mixture of one part of cement to eight parts of sand will give quite good results. This mixture was tried in the Jhang Branch bed in 1912-1913, but when the lining was examined after a period of nine months, it was found that certain patches existed which consisted almost entirely of sand, proving that either the proportioning or the mixing was at fault. On the other hand, a mixture of five parts sand to one part of cement, without being extravagant, allows for slight errors in the proportioning and the mixing.

Thickness of the lining—

The next point to be decided was the thickness of the lining, and in this, too, allowance had to be made for human error.

The bed of the canal is first excavated roughly to the required depth with *kassis* and spades, and the final dressing is effected with long straight edges nine feet in length, by a scraping process, and, though this is a practical method, a billiard table surface is impossible, and consequently an absolutely uniform thickness of the lining is not attainable. Further, though short straight edges are given to the masons as a guide to the thickness of the plaster, it does not follow that this thickness will conform to that of the straight edges. Unless the supply of mortar is ample, and the supervision very close, even skilled masons are apt to skimp the plaster, or to go on smoothing the surface until it is at the same level as that of the top surface of the straight edge near the latter, at the expense of the thickness of the plaster further away. It follows, therefore, that the lining is always liable to be in places less than the prescribed thickness. A thickness of $1\frac{1}{2}''$ will provide a very strong lining, and, if the thickness is slightly reduced owing to careless workmanship, or to unavoidable inequalities in the bed surface, the lining will still be thick enough to efficiently serve its purpose.

Lining the side slopes.—

As an experiment, in the season 1913-1914, the side slope of one compartment were lined to above the full supply depth and of another to half this depth. In the latter case the top edge was curved off and taken one foot into the bank. The slope lining was not a success, and the following conclusions were drawn :—

(*a*) It is absolutely futile to lay the side slope lining on even the slightest filling, so that cement lining the sides of a canal is impossible where the banks have been at all scoured. It is first necessary to create berms by means of staking and bushing, &c., until sufficient silt has been collected to bring the cross-section of the channel within the designed limits.

(*b*) Until the berms have been formed, it is impossible to so dress the sides of the channel, preparatory to lining, that the cross sectional width will everywhere be maintained.

(*c*) If side slope lining be attempted, it should be carried above the full supply level of the water in the channel.

Conclusion—

For want of space several important points have not been dealt with in this paper, as, for instance, the washing and cleaning of the sand to get rid of the dirt and clay. Again, the amount of water required is a most important point. Coolies do not like carrying water, and will always try to give too little, which results in the cement plaster caking and subsequently cracking, instead of setting.

The amount of water required changes in the course of a day, being determined by the state of the canal bed, the state of the atmosphere, and the position of the sun. By the last is meant that less water is required in the plaster laid in the late afternoon, which will be followed by a dewy night, than in the forenoon, when the setting process has to take place under a strong sun.

As regards the efficacy of the lining, the bed width of the Jhang Branch in the length being treated is, as already stated, ninety-eight feet, and this width only is being lined. The wetted perimeter on an average is about one hundred and twenty-five feet, so that seventy-eight per cent of the wetted perimeter is being waterproofed.

As is well known, the greater proportion of seepage occurs through the bed of a channel, and hence, after allowing for a slight porosity of the lining, it may be assumed that the sixty per cent efficiency, mentioned on page 94 will be attained, and that the financial expectations based on this figure will eventually be realised, but, at the same time, it is not claimed that the process described in this paper is a universal panacea for all seepage troubles.

The bed slope of the Jhang Branch is steep, and the bridges afford very tight waterway, while the waterway of the channel is also restricted opposite the heads of distributaries owing to these heads having been built slightly projecting into the channel. The result is, that downstream of every bridge and opposite each distributary head, a persistent scouring action takes place, and it remains to be seen whether the immature plaster, exposed to such conditions on the reopening of the branch after a closure, will have acquired sufficient strength to withstand the scour.

Up to the time of writing no opportunity had been found for examining the lining laid in 1913-1914, but it is probable that in such special and abnormal cases as those mentioned, cement tiles, reinforced for preference, would prove more satisfactory than a weak and newly laid mixture of cement and sand protected only by a comparatively thin layer of loose sand ; but this point, no doubt, will be decided in the course of time and after further trials, when the present experimental stage has been passed.

Discussion.

Mr. Curry introduced his paper by emphasising the necessity of a remedy for lessening leakage in canals, and so preventing water-logging. They were still in the experimental stage, but, as far as experiments had gone, it would appear that in canals where the water spring level was not above the bed level, the use of a sand and Portland cement lining was superior to other remedies.

Rai Bahadur Bishambar Nath pointed out that apparently up to the present experiments in this direction had been confined to Portland cement and sand or silt ; but he would like to know why clay puddle had not been used. Perhaps it was because suitable clay could not be had everywhere. If so, could not coal tar puddle be used ? Tar was suited to any soil—even sandy soil—and the adoption of a tar puddle would obviate the necessity for transportation of good clay from long distances to places where it was not obtainable. His contention was that they should turn their attention to other waterproofing compositions, and not confine themselves to Portland cement and sand. He had just started experimenting with tar puddle, and had constructed a tank similar to the one shown in Mr. Curry's paper, but sixteen feet square on top with half to one slopes, lined at the sides with three-quarters of an inch, and on the bottom with one inch thickness of a tar puddle, consisting of five parts of coal tar, twenty-three of clay, and thirteen of cowdung.

Mr. Bagley here asked why cowdung was used in the mixture, and the speaker explained that it became insoluble in water if treated with a certain chemical, which had been omitted for the present to keep down the cost, but, if the experiment proved unsuccessful, this chemical would be tried and the effect noted. The tank was six feet deep, and filled with water to a depth of $5\frac{1}{2}$ feet. His experiment was, however, only in its initial stages, and he could not say how far it would be successful ; it also remained to be seen in practice how the puddle would withstand the force of running water, and resist cracking and crumbling influences. The experiment would also show how tar puddle compared with Portland cement, his object being to endeavour to turn the attention of engineers into other directions in the search for a suitable waterproofing composition.

Rai Bahadur Baij Nath said that several years ago when he was on the Sirhind Canal in charge of the Ludhiana

Division, he had carried out experiments with tar as a medium for linings, and he mentioned, for the last speaker's information, that coal tar had proved a perfect failure. It had been used in two ways :—as a surface lining on earthen watercourses, and as a covering for bricks which were then used as pitching, but in both cases it had been a failure. He believed that the results had been published in one of the Irrigation Technical Papers.

Regarding Mr. Curry's paper, the author in a very interesting way had shown and proved, if proof were needed, that the expenditure of the large sum of over three lakhs of rupees would be justified on *partially* waterproofing the bed of six miles of the Jhang Branch, but it had not been stated what the cost of the selected lining was going to be. The question of waterproofing canals had been under experiment and serious consideration for several years. All were agreed that lining the very leaky reaches with some form of a waterproofing mixture would be a lasting remedy for water-logging troubles, but what had not so far been evolved was the form that lining should take, so as to satisfy the following requirements :—

(*i*) Cheapness combined with efficiency.

(*ii*) Rapidity of construction during the short canal closures.

It would accordingly be interesting to know what the actual cost of Mr. Curry's lining had been per hundred square feet, or per mile of the canal, so as to enable comparisons to be made with other linings elsewhere.

In the case of all plaster linings, the position of the lining in the bed was a most important consideration, especially in a canal so subject to erosion as the Jhang Branch, and the author had not mentioned at what depth below the existing or actual bed the lining was being laid, though he states * it was eighteen inches below the theoretically designed bed, so that if there was one foot of scour the thin plaster would have a covering of only six inches. This was a very material point.

The final grading and design of the Jhang Branch did not appear to have been sufficiently considered. Mr. Curry mentioned † that the bed slope of the canal was steep, the bridges tight, and the distributary heads projecting into the canal, and as

* Page 99.

† Page 102.

these were serious defects which would soon necessitate remodelling the canal, it would appear very desirable to make the final grading and design of the canal the basis of all lining work.

Again, the lining selected was No. 12 in the table on page 97, but this did not appear to have been tested during the hot months of May and June. The loss in the case of No. 14 during May was double what it had been in April, when it gave better results than any of the other linings tried.

The porosity tests appeared to have been carried out in very small tanks. The sketch at page 96 shews a tank with a bed area of 9 square feet and a slope area of 204 square feet. The bed area was thus only about four per cent. of the slope area, so that the porosity tests carried out in the tanks, with a head of only five feet, could not be accepted as applicable to the canal, when it is admitted that the greatest loss by seepage is through the bed (*vide* last paragraph on page 101), and in the case of the Jhang Branch itself the bed area is at least five times the area of the side slopes.

On the Sirhind Canal, where the speaker had carried out porosity experiments with various lining materials and mixtures six or seven years ago, big tanks, $20' \times 30'$ on the bed, were adopted, and these were filled to 11·5 feet in depth. The results of a large number of the experiments had been published. Speaking from memory, so far as rapidity of execution, and cheapness consistent with efficiency, were concerned the best results had been obtained with one-seventh of an inch of neat cement slurry. This had also been tried on a large scale in the canal. A plaster of a quarter to a third of an inch in thickness, consisting of one part of cement to two parts of coarse crushed sand, had also given good results. The thin cement lining laid on the canal bed had been examined a year after it had been laid by a Superintending Engineer, who declared it to be intact and in excellent condition.

MR. HADOW asked Rai Bahadur Baij Nath to give the conditions of the canal where the cement slurry lining had been laid by him.

RAI BAHADUR BAIJ NATH, speaking from memory, replied that the bed width was a hundred feet, full supply depth about eight feet, and full supply discharge of the canal 2,500 to 3,000 cusecs. The mean velocity was four feet per second, and the bed had a strong tendency to erosion. There had been bed borrow pits varying from three to four feet in depth, and the bed for half a mile above the fall had silted up these borrow pits, so that immediately upstream of the fall the lining was laid on a silted bed. Higher up where there was no sand the clay bottom had become so soft that the bed had to be specially prepared by mixing and spreading sand. The lining was laid in the hot month of May, and had of necessity to be done in the cool of the mornings and evenings. Spring level in that locality was about two or three feet below ground level, while the canal bed was at ground level. During the rains the spring level used to rise to natural ground surface.

MR. WADLEY remarked that, as far as submerged lining went, he thought they were right in adopting 1½ inches of cement mortar. The larger channels of the Umatilla Project* were lined with 1½ inches of cement mortar, consisting of one part of cement to four of sand. A curb four inches wide and three inches thick was given at the top. The price of cement was Rs. 6/4 per barrel, and the lining cost Rs. 8/12 per hundred square feet.

Oil, though cheaper, was unsatisfactory; clay puddle was better, but concrete lining was best. It prevented nine-tenths of the seepage and stopped vegetation. The watercourses in the Umatilla Project were given a one-inch lining, which reduced seepage to five per cent. In other cases the lining was one to four inches thick according to the size of the channel; in the thicker linings one part of cement to eight parts of sand and gravel were used, while in some of the 1½ inch linings a thicker curb was used at the top. As the velocity in lined channels is increased, so the sectional area could be reduced. Falls would no longer be required, and fifteen to twenty per cent. of the cost of an unlined channel could be spent in lining the channel without increasing the ultimate cost. Referring to sample No. 15 in Mr. Curry's paper, a mixture of one part of white lime, two parts of soorkee, four parts silt, and one part cement, gave as good results as one part of cement to five parts of silt. The speaker thought that the former mixture had probably been rejected because of the soorkee, the "reh" from which might disintegrate the lining. He considered that canals should be lined from the very beginning. There was the case of a channel † in California carrying 909 cusecs, lined with six inches of concrete, the side slopes being one to one, and the velocity 4·4 feet

* Engineering News, 10th October 1912.

† Engineering News, 19th June 1913.

per second (N = ·014). Elsewhere the velocity was as much as nine feet per second, but he thought six feet a second would give good results, and not be too high. The Boise Irrigation Project* was another example; with a bed width of forty feet and side slopes of $1\frac{1}{2}$ to 1, the depth of supply was $9\frac{1}{2}$ feet and the thickness of the concrete four inches. Expansion joints had been used sixteen feet apart transversely, and also parallel to the centre line. The mixture used was one cement to three sand and six gravel.

The question then arose if a channel were lined throughout, what about the "made" earth? There were two suggestions; first, mud masonry behind the lining (which had probably been considered), and secondly, lining the made earth section with reinforced concrete, backed up behind either with brickwork struts or reinforced concrete struts, with earth rammed behind in the ordinary way with a little moistening and tamping immediately behind the slab. It was pointed out in the paper before them, that every cusec saved was worth Rs. 757 a year.

It appeared from the paper that one pound of soap had been used to every hundred cubic feet of lining mixture, but the speaker said he had found no mention made of the use of soap in work done in America.

MR. CARNE pointed out that the author had given a formula for absorption in which he had taken C as equal to 3.†

$$Q = C \times \sqrt{D} \, \frac{L \times B}{1{,}000{,}000}$$

This formula indicated that the absorption varied as the square root of the depth of the water, but this was contrary to the accepted theory that the flow varied directly as the depth. In experiments made on the Sirhind Canal to find the relationship between the amount of percolation and depth, quite different results had been obtained by using pipes and a brick well with impervious sides. In sandy soil the flow into the ground was approximately proportional to the depth, that is as the depth to the power of one. This was found to increase in more impervious soils, and also with a greater depth than about seven feet. The author's equation gave a percolation flow of three cusecs per million square feet of water surface with a depth of one foot, or

* Engineering News, August 1913, p. 552.

† Page 93.

nine cusecs per million feet of surface with a depth of nine feet. It would appear to be more desirable to use the formula

$$Q = C \times D \frac{L \times B}{1,000,000}$$

from which the discharge for a depth of 8·6 feet in the Jhang Branch would be $8{\cdot}6 \times 3{\cdot}3 = 28{\cdot}4$, if $C = 1$, instead of $3 \times 2{\cdot}9 \times 3{\cdot}3 = 29$, against an actual observed loss of 27 cusecs. A reliable formula for calculating percolation loss would be of much value, but loss by absorption in running channels was usually difficult to obtain, and the results were liable to be vitiated through errors in observing the discharges. Moreover, the loss must vary considerably with variations in the permeability of the soil. If it could be assumed that the flow varied directly as the head, it would still be necessary to fix the co-efficient in the equation

$$Q = CD \frac{LB}{1,000,000}$$ on account of the varying quantity of flow in different classes of soil. The author had applied to the Jhang Branch * the duties based on the figures for the duty at the head of the canal, whereas the actual duty for the branch should have been taken.

The author stated that of twelve kinds of lining laid, that composed of one part of cement to five parts of Jhang Branch silt, 1½ inch thick, was found to be the most satisfactory.† Evidently the porosity tests had much to do with this decision, but it seems to have been a mistake to judge of the impermeability of a lining tested in a tank under only five feet head, when the working depth was over 8½ feet in the channel in which it was to be used. For relative tests of permeability, the tank system also appeared to be unsatisfactory, because any sediment the water contained retarded the filtration after a time in just the same way as dirt in water choked a Berkefeld or Pasteur filtering candle. It was noticeable from the author's porosity tests that a mixture of one cement to two of river sand, and one cement to two of Jhang Branch silt, did not produce an impervious layer. This was extraordinary under the low pressure head at which the tests were made. With ordinary sand a mixture of one cement to about 2½ sand produced a mass in which all the voids were filled with cement, or, in other words, an impervious slab.

* Page 91.

† Page 96.

He had noticed that the loss in the Jhang Branch was given as 4½ cusecs per mile * but it was not recorded how this figure had been arrived at, nor what degree of accuracy was likely to have been obtained, and perhaps the author would oblige by narrating how this amount of percolation had been arrived at. Presumably the loss given was with depth of 8·6 feet of water. Experiments were much wanted to find the actual loss by percolation in a running channel under ordinary working conditions, and also the variation in the amount of percolation as a function of the depth, and any one who could provide information on these points would be doing the Irrigation Department an inestimable service.

RAI BAHADUR GANGA RAM said he could not gather from the paper whether the remedial measures mentioned † had been considered by the committee of leading engineers, nor did he know if it had ever been considered whether the seepage water could not be pumped up and used, instead of meddling with the canal. He noticed that the reduced level of the seepage water was 613·00, ‡ and that there was a lift of fourteen feet to 627·00, so that for each mile of the canal an engine of only 14½ brake horse power, with a co-efficient of friction of 5, would be required to pump 4½ cusecs. Suppose this engine were used for 170 days in the year, it would require a hundred tons of coal, so that the total running charges, including establishment, lubrication, &c., would be Rs. 2,000 per mile. The capital cost contemplated by Mr. Curry was Rs. 10 per foot, equivalent to Rs. 50,000 per mile, whereas the initial cost of the engine installation would be about Rs. 6,000, which meant an annual charge of Rs. 500 for interest and depreciation, so that with Rs. 2,000 recurring charges the total annual cost of pumping the seepage water would not exceed Rs. 2,500 a mile. The 4½ cusecs would irrigate 1,250 acres, yielding Rs. 5,000 water rate, thus leaving the Canal Department an annual net profit of Rs. 2,500 a mile.

MR. SCHÖNEMANN remarked that Mr. Curry had stated that the Jhang Branch of the Lower Chenab Canal was, for a great portion of its length, in filling, and that the result had been considerable flooding of the surrounding low lying land. This was liable to convey the misleading idea that if the canal had not been in filling, its percolation outflow would not have flooded neighbouring lands. Any such idea however would be incorrect

* Page 93. † Page 94. ‡ Page 92.

as was shown by the remarks further on that on the south side of the canal the water-logging was not so evident; whilst on the north side the water-logging was due to the low level of the land affected. From his diagram* it could be seen that even if the canal had been entirely in digging, with its full supply at the level of the high ground (R. L. 627·0) the lowlying *khadir* land would still have been water-logged by it, other conditions remaining as at present. It was not correct therefore to attribute the water-logging to the fact of the canal being in embankment. The volume of percolating outflow from any earthen channel depended on the depth of water in it, and not on its height above spring level. The rate of percolation outflow from a given channel was the same, whether the spring level was ten feet or a hundred feet below its bed. In a case like that described by Mr. Curry, the swamping of the low land was due to the land being below the surface of the subsoil water table, which stretched from under the canal to the water surface of the nearest drainage basin or river valley, and drainage would be an effective cure for it. Mr. Curry had said that artificial channels flowing in close proximity to low riverain beds *caused* heavy seepage; but the speaker hoped that he would agree, on reflection, that the seepage would be just the same if the low riverain land were high. It would not in the latter case be apparent at the ground surface, but its rate of flow would be just the same, and would neither be increased nor decreased by the relative level of the land. Mr. Curry had said that the *nahri* irrigation in the tract he referred to had been wisely restricted, and that therefore the water-logging could not be due to the intensity of irrigation, but he had given no figure to show what he considered a wise degree of restriction.

The formula given in the paper for the rate of loss of water by absorption in a channel, *viz.* :—

$$Q = 3\sqrt{D}$$

for each million square feet of water surface of the channel appeared to be defective. All the information, both theoretical and practical, that the speaker had hitherto been able to collect had led him to the belief that the rate of percolation flow varied directly with the head of pressure, and not merely with the square root of that head. In the case quoted by Mr. Curry, where the depth of water in the channel was 8·6 feet, it so happened that $3\sqrt{D}$ was practically equal to D; but for other depths there would be a serious difference between D and $3\sqrt{D}$.

* Page 92.

Nor was it correct to base the formula for absorption on the surface width of the water, as the rate of percolation from the sides of the channel was less per unit of surface than from its bed. Mr. Schönemann offered the Congress an absorption formula devised by himself, *viz.* 1·2 cusecs per million square feet of mean width of channel, multiplied by its length for each foot-depth of water.

The assumption that the whole value of water saved by waterproofing the lining of a canal would be clear profit was erroneous, as it was probable that the canal would have to be enlarged, or contracted in capacity to the extent of the saving of discharge effected, and that would cost something. Mr. Curry estimated the loss of water by absorption, in the portion of the canal considered by him, to amount to twenty-seven cusecs, but this was based on full supply conditions, which do not prevail even throughout the kharif season; whilst his estimate of the value of a cusec was based on *average* supplies. In this respect therefore he had overestimated the prospective financial value of his waterproofing operations. He had not given figures as to the cost of his operations, nor as to how the same would compare with the cost of a scheme of drainage, and Rai Bahadur Ganga Ram had very aptly pointed out that seepage drains and pump-irrigation might prove to be cheaper than waterproofing as a remedy for water-logging.

Mr. Schönemann hoped that figures on this subject might be offered to a future meeting of the Congress. Apart from that it was not easy to see how Mr. Curry was able to ascertain that the loss by absorption in this 4½ mile-length of the Jhang Branch was twenty-seven cusecs. The speaker understood that the discharge of the canal was over 3,000 cusecs, and he was not aware that any method of measuring this discharge accurately with less than two per cent. of error was available to Mr. Curry. An error of even one per cent. in his measurement would have completely masked the figure assigned by him to the loss by absorption in the reach considered.

It was stated at pages 92-93 that a committee of leading engineers and district officers, in the year 1910, decided, *inter alia*, that a drainage scheme should be prepared for the swamped tract; but at page 94 it was stated that this idea had since been abandoned, on the ground that any system of seepage drains would not cure the swamping, though they might for a time diminish it, while they would eventually become so silted and choked with vegetation, &c., as to become ineffective. These pessimistic views on the efficiency of drainage as a remedy for swamping were so contradicted by much of the experience gained in Egypt, Italy, and Europe generally, that Mr. Schönemann thought the Congress would require much more proof than had yet been offered to it before it would accept them.

In the Jhang Branch experiments with cement plaster linings it was found that plaster made with cement and fine sand was more waterproof than plaster made with cement and coarse sand. Reinforced concrete experience was, however, to the effect that a mixture of coarse and fine particles of aggregate had fewer voids than an aggregate made entirely of coarse, or entirely of fine particles. No doubt, the cheapness of local silt was a sound argument in its favour, and against the importation of coarse sand from a distance, Mr. Curry referred to the washing and cleaning of the sand to get rid of dirt and clay, but whether this was quite necessary might be doubted. In the case of the Tytam Dam at Hong Kong, an admixture of clay in the mortar of the masonry was found to improve its watertightness, as stated before the Institution of Civil Engineers by Mr. Orange, the engineer who built the dam.

MR. DUTHY said that last year he had had to carry out a lining exactly similar to that described by Mr. Curry, but under much more adverse circumstances. The water level in the surrounding country was six feet above the level at which the lining was to be laid. Had the results been successful, he had thought of sending in a paper to the Congress, but the result of his experiment was to prove that this type of lining was quite unsuited to these con ditions, and impossible to lay at all if the bed contained much clay or kunker, since as soon as it was excavated, it became a quagmire, and anything approaching a level bed on which to work was unobtainable. It was impossible to completely unwater the whole of the surrounding waterlogged tracts. The best that could be done was to get the level of the water in the drains below the lining bed, and this caused springs, which rose to such an extent through the plaster that they washed out all the cement. He had resorted to an expedient he had found useful in laying concrete under similar conditions, *viz.*, mixing his m aterial dry and laying it in this state, and allowing it to absorb such water as it required from the bed after laying, and immediately putting on the earth covering without waiting for it to set. This metho had been severely criticised, but he had succeeded in laying half a mile of lining, which was found on examination to have set thoroughly, and he believed there was no other possible way in which the lining could have been laid. Cement lining however was not suited to water-logged tracts in Sirhind.

The author had stated that he had mixed his mortar in both iron and kacha pucca tanks, but he did not consider kacha pucca tanks economical. They could only have been used in one compartment, and then would have had to be dismantled and rebuilt, unless a very long lead was to be faced, and if these kacha pucca tanks were to be rebuilt every time, he could not believe their use could have been economical. Mr. Curry had also mentioned that he had considerable difficulty in getting water added to the mixture in sufficient quantities, as the coolies did not like carrying it and would always give too little, with the result that the cement plaster cracked instead of setting. Did he first determine by experiment the exact quantity of water required for each tank, or did he merely tell the mistri that sufficient water was to be added? Mr. Curry also stated that there was great difficulty in getting the mortar mixed in the right proportions, but he himself had never had any such difficulty in getting the proper proportions mixed in tanks; he usually mixed fifteen cubic feet of dry material in each tank of twenty-four cubic feet capacity. He had eight boxes of sand and two boxes of cement, each of $1\frac{1}{2}$ cubic feet capacity, carried to each tank, and he never had to find fault because of any variation of or departure from this proportion.

As regards the cost; his lining cost Rs. 12 per hundred square feet for plaster only; to this must be added the cost of earthwork, and, in his own case, the cost of unwatering, which had been a very large item. He had seen an analysis for plaster work (which he believed referred to Mr. Curry's experiments) which brought the rate for plaster out to Rs. 10 per hundred square feet. But in this analysis it was assumed that twenty-four cubic feet of dry materials could be mixed in a tank of twenty-four cubic feet capacity, and would cover an area of two hundred square feet with $1\frac{1}{2}''$ plaster, *i.e.*, produce twenty-five cubic feet of plaster. His own experience was that there was a shrinkage of nearly thirty per cent. instead of an increase of four per cent. and that not more than sixteen cubic feet of dry materials could be mixed in a twenty-four cubic feet tank. Taking these factors into consideration he considered Mr. Curry's lining must have cost nearer Rs. 20 than Rs. 10 per hundred square feet.

MR. GIBB said that the loss of water from the Punjab canals by percolation was more than one hundred times greater, than the loss from still water tanks and storage reservoirs after they have been in use for a year or two, while canals in Egypt were practically water-tight and the percolation losses from them negligible. The channel bringing water from the Nile to Fayum runs for some two hundred miles without an offtake ; and when in Egypt a short time ago, he had asked the local officer, corresponding to an Executive Engineer, what allowance was made for absorption in indenting for a supply at the head of this long channel. The reply was that no allowance at all was made, as there was no absorption. The soil through which this channel flowed was not water-tight, and except in flood season its water surface was well above the subsoil water level. The channels in Lower Egypt were all equally water-tight, and this astounding difference in the percolation losses evidently arose almost entirely from the difference which existed in the nature and composition of the material with which the channels lined themselves. The Nile carried almost no sand, and canals in Egypt become lined with a deposit of some of the fine mud which is brought down in such large quantities each flood season. This mud forms an impervious, natural, puddle lining for both bed and sides.

Still water tanks and reservoirs also gradually tamped themselves by the deposition of fine mud and more or less gelatinous organic matter, till eventually they also became naturally waterproofed, but the water in the Punjab canals contained, as they knew to their cost, enormous quantities of sand, a thick layer of which formed the channel bed on which the water flowed. An examination of this bed sand showed it to be remarkably clean and free from mixture with clay, in spite of the fact that during floods the river water contained a great deal of clay. What apparently happened was, that the upper surface of the sand was so continually being rolled about, and tossed up into suspension, that any mud that might deposit on or among the sand particles was almost immediately washed off again and returned into suspension. Thus the bed of the channel was maintained permanently in a condition of maximum permeability by reason of the sand, which effectually prevented mud from being deposited. Probably the most effective way of waterproofing their channels would be to exclude all river sand from the water entering them, but they would have to wait till the Research and Investigation Section told them how to do that before it could become practical politics.

The point he wished to bring out, however, was that so long as their channels contained this sand any artificial lining they laid under it must be of itself impervious. It was, in his opinion, quite futile to lay a porous lining and expect it to tamp itself, because the mud for the purpose would never reach the lining so long as the sand was there on the top of it. If any tamping of the beds of the channels were possible they would have become impervious of themselves long ago, just as channels in Egypt had done. One part of cement to five parts of sand did not form an impervious plaster, because obviously there was not enough cement to fill the voids in the sand. This mixture would and apparently did give quite good results in a tank under still water conditions when it got a chance to tamp itself. But the conditions in a still water tank were so different from those on the restless sand beds of the channels in which the canal water flowed that, to his mind, tank tests were not only useless but entirely misleading.

The author of the paper had actually committed himself to the statement that one part of cement to eight parts of sand was good enough. What he meant, the speaker supposed, was that this proportion of cement was enough to stick the particles of sand together, but was there any particular advantage in sticking the sand particles together if the interspaces were still left open for the passage of water ? A lining of this kind could only be justified on the hypothesis that it would eventually become water-tight by the deposition of mud in the interstices, and he wished to ask, if the mud for the purpose could penetrate the over-lying sand how was it that the soil below the sand beds of channels had not been tamped and rendered water-tight by it long ago ?

The speaker thought it was very much to be regretted that no attempt had been made to test in some way the value of the lining described under conditions more nearly corresponding to the conditions it was subjected to in practice. To lay stuff on the canal bed and leave it there could not be called a trial, test, or experiment, unless some means was adopted for ascertaining to what extent the stuff was fulfilling the purpose for which it was put there. Mr. Curry's paper did not indicate that any such means had been adopted, and in fact, it seemed very doubtful indeed whether the lining would fulfil any purpose at all.

There were one or two other points in the paper to which he would also like to refer. It was stated that irrigation in the water-logged tract dealt with did not increase the water-logging. Doubtless the author had good reasons for making this statement, so far as the restricted irrigation of this particular area was concerned, but he was a little suspicious, in view of the present prevailing fashion among irrigation men to attribute nearly all water-logging to percolation from canals. Egypt provided a useful lesson on the subject. As he had pointed out, the channels there were water-tight, and yet water-logging due to bad distribution, and wasteful irrigation, had become so serious that vast sums of money were now being spent on a most comprehensive drainage and pumping scheme, to reclaim the water-logged tracts in the Delta. He admitted that Egyptian irrigation was more wasteful than theirs, but even so the whole of the crops raised by irrigation on the Lower Chenab Canal could be matured with twenty-five per cent. less water than is now used, simply by adopting a system of accurate distribution. This twenty-five per cent excess water went into the soil at present, and this was only a part—the preventable part—of the enormous supply that was at present being poured into the soil, and which, unless it was stopped, was going to make the Punjab into a vast jeel within the next hundred years.

The author had written a most interesting and useful paper describing how he laid a cement and sand plaster lining under the sand bed of the Jhang Branch, and it was quite evident that he had put a lot of hard work into the job, but the speaker hoped he would not take it amiss if he suggested that he had mis-named his paper. The title he had given it "Waterproof lining of Channels" begged the whole question, and the speaker at least was not satisfied that the lining laid was, or ever would be, waterproof to any appreciable or useful extent. He supposed they must wait and see, but as an experimental method it was rather like testing whether the contents of a bottle were poison or not by drinking them, and then waiting to see whether you died or remained alive.

MR. LINDLEY remarked that as the estimate of various authorities was, that of the water entering a canal head, twenty-five per cent. was lost by percolation and absorption in the canal and its distributaries, twenty-five per cent. more in water-courses, twenty-five per cent. misapplied or wasted by the cultivators, and only twenty-five per cent. properly used, the water that would be saved by lining the whole of the canal system would still be subjected to a loss of two-thirds of its volume before reaching the fields; while the proportion lost of water saved by lining the head reaches of a main canal was still larger; it therefore seemed probable that it would be better to tackle the problem from the other end.

MR. NICHOLSON said he thought they could get a much superior class of lining by putting down concrete lining instead of plaster, but the question arose where to put it? If it was put in where it could be seen, it would be very much better than burying it 1½ feet under the earth, where it could not be seen. As regards pumping and drainage, this had been tried on the Sirhind Canal, and appeared to have been a failure. There was now no vestige to show where the old drains were; though the oldest inhabitant would probably be able to say, and it would be advisable to look round and see what had happened to drainage schemes in the past before they let themselves in again. Then as to the question of percolation; even if forty per cent. were stopped, it would be only a question of time before water-logging on this account would begin again. When confronted with the question of cost in considering schemes, they were liable to underestimate the value of the water saved.

MR. CURRY, replying to the various criticisms, said that he had made no experiments with puddle treated with tar or cow-dung, but that on the main line of the lower Chenab Canal, clay puddle was being used for preventing leakage. The results however would not be known for some time. Replying to Rai Bahadur Baij Nath, Mr. Curry stated that the lining was being laid 1½ feet below the remodelled bed level of the canal, or where the branch had scoured, twelve inches below the actual scoured level. The cost of the lining was approximately Rs. 10 per hundred superficial feet, plus the cost of excavation, and refilling over the plaster. Referring to Mr. Wadley's remarks, the author explained that soap had only been tried in experiment No. 13 of the porosity tests.

In reply to Mr. Carne, the author stated that the formula quoted in the paper was one evolved by an ex-official of the Department some years ago; no absolutely reliable formula for loss by percolation had been generally accepted, but possibly that suggested by Mr. Schönemann might become so.

The calculations of the probable financial gain were on the safe side, as the working expenses quoted per acre irrigated included expenses incurred on the main line and on the headworks, whereas the working expenses involved by an extension of irrigation, consequent on the prevention of percolation losses, would be much less than the average working expenses for the whole canal. The loss of $4\frac{1}{2}$ cusecs per mile had been calculated from experiments undertaken some years before the author was in charge, and he understood that the degree of accuracy was that of a series of carefully observed discharges.

In connection with Mr. Schönemann's criticisms, the author explained that he had not meant that the neighbouring land had been flooded solely because the Jhang Branch was in filling, but that in the case of the low lying land, the flooding was more apparent. The question of the reliability of the discharge observations, and of the formula for the percolation losses, had been raised by Mr. Carne, to which he had already replied. These points were however largely theoretical, whereas the fact that losses were taking place could not be denied.

He would refer Mr. Duthy to the remarks with which the paper had been introduced. He fully agreed that the adverse circumstances described by him would preclude the laying of a cement plaster in the same manner as that possible in the Jhang Branch. The quantity of water required for mixing could only be determined by the officer in charge, and could not be left to the discretion of a mistri. He did not understand Mr. Duthy's reference to some analyses of rates. As a matter of fact the capacity of the mixing tanks used by the author was $37\frac{1}{2}$ cubic feet. Each tank could contain a full barrel of cement and the corresponding quantity of sand, due allowance being made for the greater bulk occupied by the latter in its loose dry state. By this method, only the sand had to be measured, whereas Mr. Duthy had to measure small quantities of both cement and sand. Payments for mixing were made by the author from measurements of the finished plaster.

The attractive scheme advocated by Rai Bahadur Ganga Ram was a matter for consideration by the Local Government. It could not be initiated by a junior officer.

Mr. Gibb had severely criticised the adoption of the cement lining described in the paper. The work was still in the experimental stage, and it remained to be seen whether it or the criticisms would be justified. Well observations were being made systematically in the tract concerned, and the readings had so far shown that the water level had already been substantially reduced. He was interested to hear Mr. Nicholson's ideas of the value and permanence of a drainage scheme, and to compare them with Mr. Schönemann's. He thought the protection afforded by a covering of 1½ feet of earth outweighed the doubtful advantage of laying a lining where it could be seen.

In conclusion his paper was intended to briefly describe the need of, and the methods being employed in, attempting to prevent the loss of valuable water from the Jhang Branch, and he was glad to see the amount of interest and criticism aroused, though most of the latter was very theoretical. He understood that a mixture of one part of cement to eight parts of sand was considered efficient by many American experts, and he therefore trusted that the stronger Jhang Branch lining would at least be equally efficient.

MR. GWYTHER (Chairman) summed up the discussion with the remark that Mr. Curry deserved credit for introducing a subject in which the Irrigation Branch was deeply interested, and which undoubtedly would prove to be of grave importance in the near future to irrigation operations.

Mr. Curry was obviously, more concerned with the subject as an executive officer, and had not attempted a technical thesis. It had not consequently been sufficiently emphasised that their present lining work was based on a series of experiments extending over a period of something like five years. Starting with many different types of lining (including coaltar and oil) these experiments had gradually eliminated for different reasons the use of all materials except puddle and cement—which were found to give the most consistent results, and were now ur' ersally accepted to be the best waterproofing media—h he Punjab and in America.

Though giving excellent results, clay pudd' very convenient material—it was heavy to handle careful attention, and was not appreciably cheape Moreover in the Punjab it was only found areas, and the available quantity of suitable c the demand. On some canals (*e. g.* the failed to procure any, and the result ha universal use of cement for linings. At pr what costly, but the prospect of securing a the province appeared to be within sight, that defect. In the near future it would material they could confidently adopt.

The questions remaining to be decided were :—

(*i*) the extent to which the cement could be safely diluted with sand,

(*ii*) the form which the lining should take, having regard to the admitted difficulties in securing long closures of canals, and in coping with seepage water,

(*iii*) the means for lining side slopes of channels.

It was in the direction of experimentally deciding these points that much remained to be done. They were by no means out of the experimental stage yet, and confidently looked to officers for help in elucidating the difficult problems involved, but owing to the enormous channel areas which needed treatment, it was obvious that economy was an essential element of all such investigations.

It was admitted that still water tests could not be entirely relied on—in running water for instance cement slurry linings had proved a complete failure—nevertheless they could not be entirely dispensed with—as much good experimental work had at the outset been effected in tanks, and had yielded practical results

It, however, should not be forgotten that similar difficulties were being vigorously tackled in America, and that much in the shape of practical results had been already secured by experiments in the Punjab.