PAPER No, 221.

LINING OF THE HAVELI MAIN LINE CANAL

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Introduction.

The Lining of the Haveli Main Line Canal is a bold attempt to avoid the evils of waterlogging which would arise from an earthen channel and to do this with due attention to economy. Due to the percolation from a suitably lined channel being relatively small, as compared with an earthen channel, a certain additional quantity of water is made available for irrigation. Further, due to the smaller section required, the cost of excavation, land and masonry works decreases appreciably. Another advantage possessed by a lined channel is considerably reduced maintenance cost.

In the case of the Haveli Main Line Canal the comparison of capital figures is as follows :—

	Lined (lakhs rupees)	Unlined (lakhs rupees)	Saving due to Lining (lakhs rupees).
Excavation	.. 10·1	13·7	3·6
Land ..	.. 2·5	3·0	0·5
Masonry Works	.. 3·2	5·0	1·8
Cost of Lining	.. 57·4	..	Minus 57.4

Therefore the net extra cost of Lining is 51·5 lakhs of rupees. (Establishment, Tools and Plant and Audit Charges omitted).

Taking the net annual revenue accruing to Government from the additional water available due to less percolation at the round figure of Rs. 1,000 per cusec, the estimated total net revenue for 330 cusecs now anticipated to be saved would wipe off the extra cost of Lining in 16 years. This assumes that these 330 cusecs would be able to be used somewhere.

Selection of type of Lining.

In 1937-38, experiments were conducted by Mr. R. K. Gupta, I.S.E., Executive Engineer, Main Line Division under the direction of Mr. F.F. Haigh, I.S.E., Superintending Engineer to find out the actual percolation losses through different types of floors due to a head of three feet of water. These experiments were made on the left bank of the Lahore Branch of the Upper Bari Doab Canal, about half a mile downstream of the Ferozepore Road Bridge. A full-time overseer took observations daily and every care was taken to obtain reliable results. Plate I shows the results graphically for the important types of floors.

These experiments showed that a Lining made of a "sandwich" of two layers of brick tiles in cement mortar with an intermediate layer of cement plaster provided a comparatively efficient and cheap lining. Further, it obviously lent itself to rapid execution. The criterion of supply of materials is the brick kiln (assuming a ready supply of cement) and the number of kilns can within wide limits be made whatever one pleases. Also, the importation of sufficient masons presented no real difficulty.

A concrete lining would have meant obtaining mixing machinery on a big scale, e.g., it would have taken a dozen 1 cubic yard mixers to do the Lining in one year. And so many mixers, along with power sets to run them, could not have been obtained quickly enough. The supervision of concrete is also generally admitted to be more difficult than that of brick masonry. Again, the cost of 1:3:6 concrete with brick ballast is Rs. 8-8-0 per % cubic feet more than that of the tile-cum-plaster "sandwich" lining and with stone ballast Rs. 13 per % cubic feet more. Even 1:4:8 brick ballast concrete costs Re. 1 per % cubic feet more than the "sandwich" lining.

Type of Lining selected.

The "sandwich" lining as finally decided on is shown in Plate II. It consists of a lower course of tiles $12'' \times 5\frac{7}{8}'' \times 2\frac{1}{2}''$ thick in 1-cement 6-sand mortar, bedded on a half inch layer of the same mortar. On top comes a half inch layer of 1-cement 3-sand plaster in which longitudinal and transverse reinforcement of $\frac{1}{4}$ inch mild steel round bars is enclosed. These bars form $12\frac{1}{4}$ inch squares in the side-slopes and $24\frac{1}{2}$ inch squares in the bed. On top of the plaster is the upper $2\frac{1}{2}$ inch course of tiles in 1 cement 3 sand mortar.

The arrangement of reinforcement bars calls for four different patterns of tiles in the lower course. The upper course tile is plain and without a frog in its bottom or top surface. This omission of the frog, on the *top* was to avoid possible friction with the flowing water and on the *bottom* was to avoid the possibility of cavities due to the frog not being properly filled with mortar. The five patterns of tiles are shown in Plate V.

Organization of Work.

(*a*) *Length of Lining*. The lining will be from R.D. 2,000 to 2,27,800, i.e. 2,25,800 feet or 45·16 canal miles in length.

(*b*) *Kilns.*—There are 31 kilns spaced at distances as equal as possible, along the canal. Due to suitable soil not always being available the distances between successive kilns differ appreciably. Kilns were selected by sending representative soil samples to the Physical Chemist of the Irrigation Research Institute, Lahore, who tested them for suitability for brick-burning. Much time was expended on kiln site selection. I point out the obvious necessity of moulding and burning enough sample bricks before selecting a site.

Usually a favourable report by the Physical Chemist meant a good site but in a few instances soils favourably reported on gave bricks which collapsed when released from the moulds (in the unburnt state). Also, nearly double the land (about 10 acres) has been ultimately acquired to what was at first thought necessary for each kiln site. This is due to the soil in many kilns being good in patches, the defective soil containing either *kankar* or salts. The cost of the land now means about Rs. 0-8-0 per thousand tiles.

The basic rate of Rs. 15-8-0 per thousand tiles, paid to kiln-contractors, was fixed after receiving tenders from a large number of contractors. An addition of Rs. 0-1-6 per mile of distance from the nearest railway station is given for extra carriage of coal. At first it was thought that difficulty would be felt in burning solely $12'' \times 5\frac{7}{8}'' \times 2\frac{1}{2}''$ tiles and so the kiln contractors were given the option of burning a certain number of $10'' \times 4\frac{7}{8}'' \times 2\frac{1}{2}''$ bricks. The rate however for the latter was kept low at Rs. 7 per thousand with the object of discouraging their manufacture. The result has been that very few smaller bricks have been burnt. All stores, tools and plant for brick-burning are supplied by the contractors.

The average dimensions of the kilns, which are of the usual Bull's Trench type, are 710 feet outside perimeter by 26 feet wide. The required output as per Agreement varies at different kilns and is usually between 30 and 35 lacs, at a rate of $3\frac{1}{2}$ to 4 lacs per month. The accelerated Lining programme has necessitated a second pair of chimneys in many kilns and in some cases an extension of the kiln.

(*c*) *Lining Headings*. Each kiln serves a "Heading" or working site whose reach of canal usually coincides with the reach to be served by the kiln and is about 7500 feet long. To keep carriage down to a minimum, the ideal position of the kiln is opposite the centre of the reach it has to serve. Due to the accelerated Lining Programme the 31 Headings were increased by five more in November and December, 1938, to finish all Lining by the end of March, 1939.

(*d*) *Staff*. Each Heading is in charge of an overseer who also looks after the kiln excavation and other masonry works in his reach. The Sub-Divisions are:—

Diraj Sub-Division	Kilns 1 to 7	R..D. 2,000 to R.D. 50.000
Haveli ,,	Kilns 8 to 14	R.D. 50,000 to R.D. 103,000
Kakki ,,	Kilns 15 to 20	R.D. 103,000 to R.D. 145,633
Darkhana ,,	Kilns 21 to 27	R.D. 145,633 to R.D. 199,621
Sidhnai ,,	Kilns 28 to 31	R.D. 199,621 to to R.D. 227800

and, of course, the Sub-Divisional Officers supervise the excavation and other masonry works in their reaches as well. The work up to R.D. 103,000 is in the Quarries Division and beyond that, with the Main Line Division.

The work-charged establishment looking after each Heading is as follows:—

Designation	No.	Rate	Duties.
Mason Mistri	4	Rs. 35 to Rs. 45	Supervising masonry, two on bed and one on each side-slope.
Earthwork Mistri	1	Rs. 22	Supervising dressing of bed and sideslopes.
Mate. ..	1	Rs. 15	Watching soaking of bricks.
,,	1	Rs. 15	Rejecting bad tiles.
,,	2	Rs. 15	Fitting reinforcement, one on bed, one on sideslopes.
,, ..	1	Rs. 15	Watching watering arrange-ments.
,,	2	Rs. 15	Testing joints.
,,	1	Rs. 15	Mixing mortar.
Beldar	1	Rs. 12	For levelling.
Chowkidar	1	Rs. 12	Watching plant at site of work.
,,	1	Rs. 12	Watching stores at godown.
Material Mistri	1	Rs. 22	Assisting subordinate in receipt and issue of stores.
Earthwork Mistri	1	Rs. 22	Supervising puddling.

(*e*) *Materials*. *Tiles* have been referred to previously. The Sub-Divisional Officer classifies 2% of the output of each kiln, accepting only *pacca* tiles and bricks.

Cement is supplied by the Punjab Portland Cement Company from Wah at a rate which is Rs. 5 per ton cheaper than the cement used on the rest of the Haveli Project. Carriage from the railway stations to the kiln godowns is done by motor lorries or camels.

Sand is obtained mostly from the canal excavation but in some reaches it is dug out of local sandhills. It is screened before use.

Steel reinforcement is supplied by the Indian Steel and Wire Products, Ltd., Tatanagar at specially reduced terms. As the lengths of the bars reach 25 feet a bogie is used for the railway journey which always contains at least 30 tons of steel. Carriage from the railway station to the kiln godowns is done by motor lorries or bullock carts.

M. S. Washers are supplied by the Upper India Metal Works, Chheharta.

(*f*) *Plant*. The plant is mainly comprised of (*a*) steel tanks $\frac{1}{8}$ inch thick, for soaking bricks, (*b*) wooden scaffolding for building the masonry in side slopes, (*c*) wooden templates for dressing the side slopes to the exact shape, (*d*) wooden planks for crossing over fresh masonry, and (*e*) G. I. piping for supplying water. The plant is listed in detail in Appendix A.

The steel tanks were obtained from Calcutta, Karachi and Amritsar firms and some made locally. To expedite the supply of tanks, welded ones were taken in addition to rivetted ones but have proved a mixed blessing. Due to the necessarily rough handling involved in shifting them every second day and partly due to inferior welding, the corner joints of an appreciable number burst open. I therefore do not recommend welded tanks for any future Lining work.

The sizes of soaking tanks are 10ft.$\times$10ft.$\times$1$\frac{1}{2}$ft., 8ft.$\times$8ft$\times$2ft., 8ft$\times$6ft.$\times$2ft. and 8ft.$\times$4ft.$\times$2ft. Different sizes are necessary to get separate soaking tankage for each pattern of tile fairly proportional to the number of each pattern. Separate tankage is obviously necessarry for each of the five patterns of tiles to enable the different patterns to be sent to the masons in correct proportion with the least delay. One half of the daily consumption of tiles is soaked overnight and the other half during the working day. To ensure proper soaking of the tiles in the working day it is essential to start taking out early in the morning some of the tiles soaked overnight. In estimating the tankage capacity required 50% was added to the volume of tiles to be soaked at one time. Photo 1 between pp. 43 and 44 shows some tanks in use.

The side-slope scaffolding supports (as shown in Plate VI and photo 2) the 12ft.×10″×2½″ scaffolding planks, and the 12ft.×10″×1¼″ walking planks are made from 12ft.×10″×5″ *chir* sleepers. The sideslope templates are made from 12ft.×10″×5″ deodar sleepers, as *chir* ones would warp and not last long, and one is shown in Plate VI and photo 3 between pp. 43 and 44.

(g) *Watering arrangements.*—Headings 1 to 5 are served by a watercourse running along the outer toe of one of the banks of the canal, starting at Trimmu Weir where about 3 cusecs are delivered into the watercourse from the weir pumping. Lower down, the watercourse at the toe of the banks gets water from temporary outlets in the nearby channels of the Lower Chenab Canal. In the reach traversing the Burala non-perennial area where no canal supply is obtainable in the cold weather, tube-wells have been sunk at R.D. 1,92,000 and 2,07,500 by a Lahore firm.

To supply water during Lower Chenab Canal closures, tube-wells were also sunk at R.D. 47,500, 74,175, 117,600, 131,500, 153,300. The particulars of all the tubewells are as follows:—

R.D.	Minimum length of strainer.	Discharge (cusecs).	Diameter (inches).	Pumping set.	Cost of complete installation including housing.
47,500	↑	1	6	8 H.P. Bernard engine, type W 3/6 direct coupled to 5″×5″ centrifugal pump.	Rs. 4,000
74,175		1	6		Rs. 4,000
117,600	85 ft. of 7¼″ diameter	1	6	8 H.P. Bernard engine, type W3/S4 direct coupled to 4″×5″ centrifugal pump.	Rs. 4,100
131,500		1	6		Rs. 4,100
153,300		1	6		Rs. 4,100
192,000		1	6	As per R.D. 47,500 but 2 sets each.	Rs. 5,600
207,500	↓	1	6		Rs. 5,600

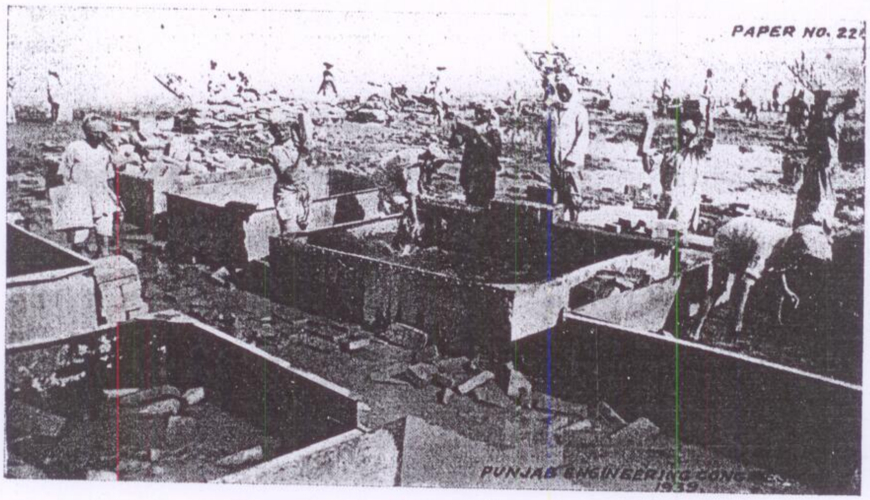

Photo No, 1. Brick Soaking Tanks.

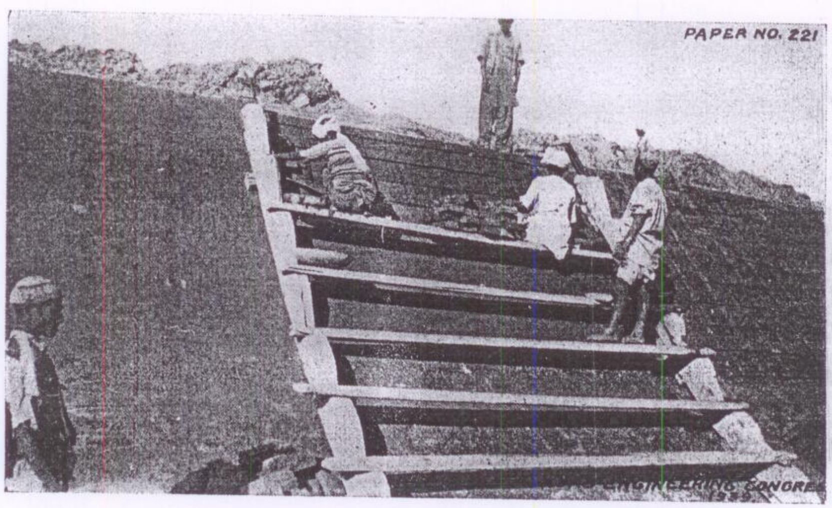

Photo No. 2. Side-Slope Scaffolding.

The cost of running these pumps for the whole job is expected to be Rs. 9,000.

Gaps were left at every 500 feet in the bank of the canal and water is led from the toe watercourse through these gaps to within about 20 feet of the berm. From there it is taken in a 2-inch G.I. pipe down to the bed of the canal and then led in a $1\frac{1}{2}$ inch G.I. pipe to the soaking tanks and mortar mixing tanks. This $1\frac{1}{2}''$ G.I. pipe is made up of five 40-feet lengths, flanged to permit of quick assembly and dismantling. As Lining proceeds the $1\frac{1}{2}''$ pipe is lengthened or shortened as need be. A 60-feet length of $1\frac{1}{2}''$ india rubber outside armoured hose is attached to the end of the $1\frac{1}{2}''$ pipe. Thus a distance of 250 feet upstream and 250 feet downstream can be served from one gap.

Working Operations.

(*a*) *Puddling side-slopes.* Almost all the canal is such that the natural surface is several feet below the top of the side-slope Lining. To minimize subsequent settlement of the earth backing behind that portion of the Lining above the Natural Surface, well rammed puddle in 6-inch layers is put as shown in Fig. 1.

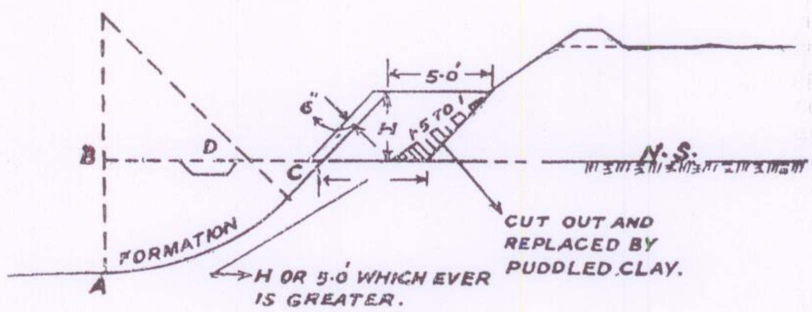

FIG. 1

The clay for puddling is usually obtained from the triangle *ABC* left unexcavated. By leading water from the gaps, referred to above along a small channel *D* the puddle is made right at the place required, Some 6 inches extra puddle is made projecting towards the centre of the canal, the object being to ensure a smooth regular surface when fine dressing on the side-slope is done.

(*b*) *Dressing bed and side-slopes.* Excavation is done by the usual means down to the section shown in Fig. 2:—

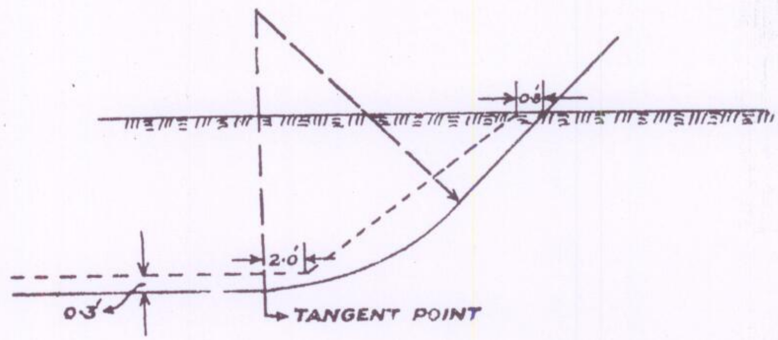

FIG. 2

The centre line of the canal was marked on brick pillars at 500-feet intervals prior to excavation and these brick pillars are left unexcavated till the dressing work comes within a few hundred feet of them. The centre line is then marked with a theodolite in the bed on bricks on end with their top ends at correct formation level, the bricks being 25 feet apart. The tangent points from where the side-slope curve starts are set out from the centre line similarly, on bricks 25 feet apart.

The side-slope templates, usually three in number at each side, are then placed in position as seen in photo 3 between pp. 43 and 44. They are made such that the correct profile of the canal is given when the outside edge of the vertical scantling is truly vertical over the tangent point given on the brick in the bed. Three templates give two spaces of 25 feet each and the dressers work standing on two $2\frac{1}{2}''$ planks spanning each space and supported on ladders leaning on the side-slope.

They work first with *kassis* and then with the scraper shown in plate VI, using a mason's line stretched between the templates to give a true surface. Work proceeds downwards from the top, the earth being removed on donkeys. The weight of a plank leaning on a template is enough to hold it in position. The scraper gives an accurate smooth surface and as this surface is the base for the masonry lining, really fine dressing is insisted on. Photo 4 between pp. 43 and 44 shows a dresser at work.

In many reaches sandy strata occur in the bottom half of the side-slope and in some reaches it is practically all sand. In such reaches the slopes are wetted when being dressed and then covered with a thin layer of mud plaster. This prevents the sand from slipping.

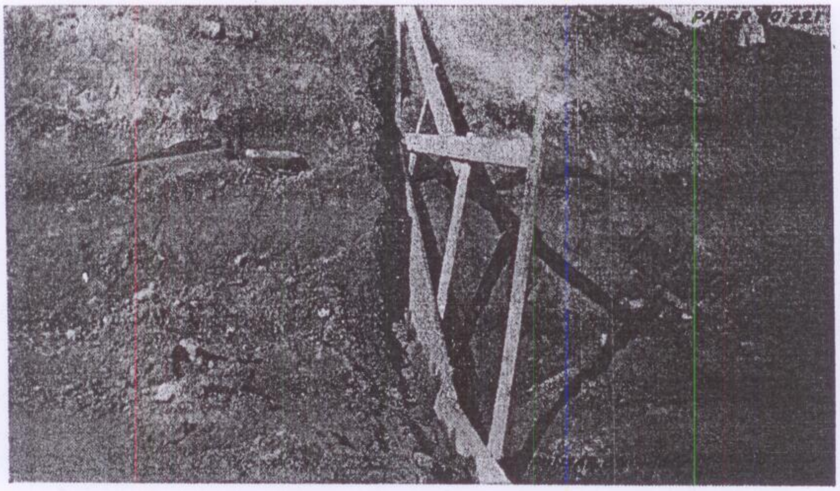

Photo No. 3 Template for Dressing Side-Slope.

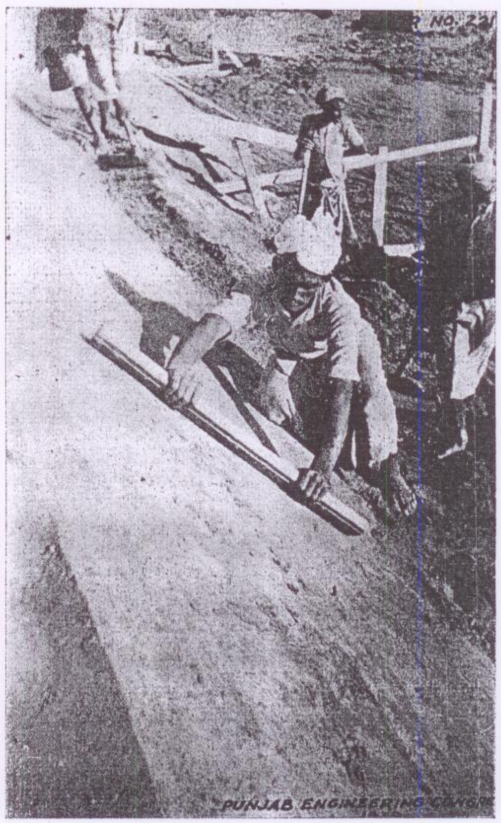

Photo No. 4. Drèssing Side-Slope.

The dressing of the bed is done by *kassis* and scrapers, levels being given on brick bats placed in the bed at about 12 feet intervals longitudinally and transversely. If the bed is sandy it is watered and rolled with a 3 ft. × 1 ft. 9 in. diameter concrete roller mounted on ball bearings and weighing 7 cwt. The dressing of bed and side-slopes is kept two or three chains ahead of masonry work to avoid earth being mixed up with the lining materials and to prevent mud being formed near soaking tanks and such places where water is being used.

(c) *Laying of bottom course of tiles.* The masons work spread out across the bed, laying a transverse row of tiles and retreating longitudinally. The bed is first sprinkled with water, and liberally so, if sandy. This sprinkling is kept up with and just in front of the masonry. Half an inch of fairly wet 1-cement 6-sand mortar is spread on the bed and the tiles laid at the same time on top. This mortar layer helps to even out inequalities in level. It is obviously necessary for the joints to be continuous in straight lines so that the grooves for the reinforcement are straight; hence mason's lines are stretched longitudinally from the grooves forward for 20 feet or so at 6 feet intervals across the bed. These lines give the correct levels also.

As it is very difficult to clean the grooves when the mortar is hard, this is done while the masonry is being laid by a man sitting on a $1\frac{1}{4}''$ plank a few rows to the rear of the working face. He uses a thin steel wire brush which fits the grooves and rakes out the joint below the grooves for about a quarter of an inch.

The side-slope masonry is laid from scaffolding shown in photo 2. The curved scaffold supports are kept in position by a small pile of tiles near the tangent point as they have a slight tendency to slide inwards. The 12 ft. planks enable a 10 ft. length of masonry to be laid between two supports and if a daily progress of over 25 lineal feet is desired then three supports giving two working spaces are necessary. A longitudinal row of tiles done in advance near the tangent point or, if the bed masonry has been done first the longitudinal edge near the tangent point, is taken as a guide. A wooden template (in two parts for the curve and straight of the slope) has the breadths of all courses marked on it and it is placed in position but on the guiding row of tiles near the tangent point.

It does not really matter much whether the bed is done ahead or whether the side-slope is. If the former, then occasional labourers crossing the fresh bed masonry can walk on the curved slope near the tangent point. Further, the up and down joints of the slope can take their guide for true transverseness from the bed joints. This is an advantage especially when the canal is in a curve. It means however a certain amount of walking over the bed masonry near the tangent point which is one day old, though that masonry is covered with planks.

The side-slope mortar requires to be better than the bed mortar and more sprinkling of the formation is needed while work is going on.

The presence of hollow joints is detected by a mate who goes over each joint with a broad chisel-pointed 5/8" diameter iron bar weighted at the middle, as shown in photo 5 between pp. 47 and 48. The weight of the bar breaks the upper crust of a hollow joint. This testing is done on the third fore-noon, counting the first day as the day of laying. Repairing the joints is done at the same time.

(*d*) *Cleaning the bottom course of tiles.* It is most important to have the bottom course really clean and rough before the reinforcement and the plaster layer are laid. To this end the surface is scraped and cleaned on the third forenoon with four types of steel wire brushes. One stiff wire brush $7\frac{1}{2}'' \times 3''$ (handle 6" extra) scrapes the surface and at the same time another thin stiff one, having three rows of bristles, scrapes the grooves and removes any hard mortar lumps. The presence of one small mortar lump will raise the reinforcement in that area out of position and there will be a risk of the plaster being thin. A still thinner stiff brush with two rows of bristles bites into the groove joints and gives a rough surface.

The mortar and dust collected are brushed off by a soft steel wire broom something like an ordinary housewife's broom. Bass brooms last only two or three days while the wire brooms last about 12 months. The $7\frac{1}{2}'' \times 3''$ brush and the wire broom can be had in a good quality of Indian manufacture but good Indian thin brushes for the grooves could not be obtained.

(*e*) *Laying reinforcement.* Immediately after the cleaning of the bottom course of tiles the reinforcement is laid and this is an easy matter. The bars across the canal are received in exact lengths so that they have a minimum overlap of 40 diameters (=10 inches) and a cover of 3 inches at the top of the side slopes, without being cut. Breaking joint is effected as shown in plate IV. The longitudinal bars are of the same length as the transverse bars and have the same overlap. The bars are sufficiently pliable to adopt the curve of the side-slope without bending.

Cleaning of bars, straightening of bent bars and stringing on washers are done outside on the berm. The overlaps are tied with binding wire and in the side-slopes each up-and-down bar is tied to every sixth horizontal bar. Photos 6 and 7 between pp. 47 and 48 show reinforcement in position.

(*f*) *Laying plaster.* On the third afternoon the plaster is laid *in the bed* as shown in photo 8. To ensure an even thickness of $\frac{3}{8}''$ it is laid in strips 4 feet wide bordered by thin laths $1\frac{1}{2}'' \times \frac{3}{8}''$ extending across the canal for about 10 feet. When about 10 feet is finished the laths are lifted and

Photo No. 5. Testing Joints.

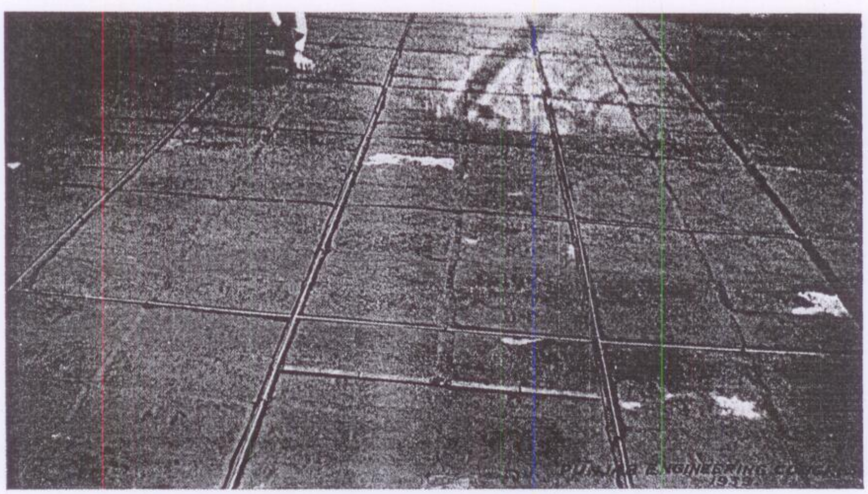

Photo No. 6. Bed Reinforcement.

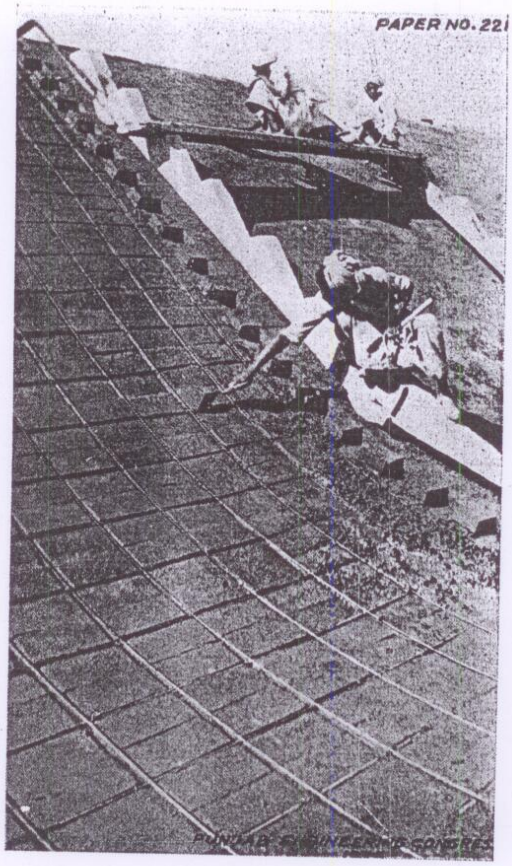

Photo No. 7. Side-Slope Reinforçement.

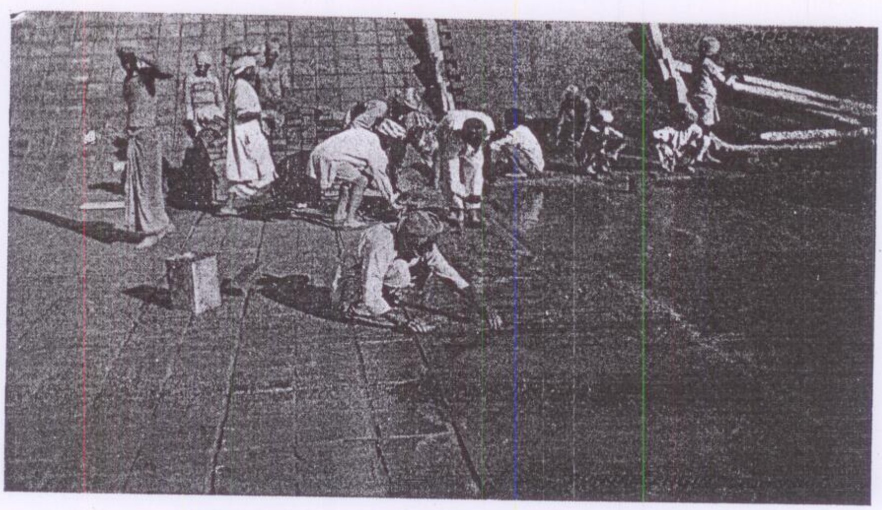

Photo No. 8. Laying 1 : 3 Plastering.

advanced and another pair of masons start the neighbouring 4 feet strip across the canal. The plaster is spread with a trowel and levelled with a straight edge (*chapti*) and made slushy enough to be able to be worked round the reinforcement bars. Just before the plaster is laid the grooves are again cleaned. The usual wetting of the masonry surface prior to plastering is of course carried out.

On the fourth day (the day after laying the plaster) the plaster is lightly scraped with the wide wire brush as shown in photo 9 between pp. 49 and 50. It is then covered with mats of cement bags and kept wet.

(*g*) *Laying of top course of tiles.* On the fifth day the plaster (laid in the bed only) is cleaned and lightly scraped and the top layer of tiles laid on a $\frac{1}{8}$ inch layer of 1-cement 3-sand mortar. The vertical joints are $\frac{1}{4}$ inch. To prevent damage to the plaster and bottom course of tiles by the labourers bringing tiles and mortar, walking planks are provided as shown in Plate VII. Also a 4 feet gap is left for the same purpose in the bottom course of tiles of lengths equal to two days' progress (about 70 feet).

On the sixth day the top course is kept wet by sprinkling water and on the seventh day it is tested for hollow joints and the latter repaired. On the eighth day a small earth cross *bundi* is made and the area flooded by letting in water from the shallow pond existing on the masonry already done.

The 1-cement 3-sand plaster is not laid on the side-slopes separately as in the bed, due to the fact that the reinforcement bars are easily disturbed and would thus rupture the plaster while setting. The top course of tiles in the side-slopes is laid on the fourth day by spreading rather slushy mortar somewhat over half an inch thick on the bottom course and then laying the top course tiles as in ordinary masonry but with enough pressure to force mortar up the joints and leave the bedding mortar half an inch thick. The same scaffolding is used as is employed for the bottom course.

(*h*) *Curing the masonry.* At least six inches of water always remains on the finished bed masonry for two or three months and is retained by a small earth cross bund. The pond thus formed is extended daily by a fresh length of masonry being included for watering. Photo 10 between 49 and 50 shows this pond which is fed from a four-inch pipe leading from the toe water course.

The side-slopes are kept watered for 30 days by labourers throwing water from the bed with 9" buckets. The water is retained by mats of cement bags cut open to give double area. Photo 11 between 49 and 50 shows men throwing water. Eight men, paid Rs.15 p.m. each, can cope with 900 feet lineal progress per month in the summer and at least 1100 feet in the winter. This method was found to be much the cheapest and simplest.

Four hand force-pumps were tried but gave much less discharge than eight men throwing. Also a 3 H.P. pumping set on a small trolley running in the bed was tried but was not flexible enough, taking too long to move round its beat and occasionally stopping. Besides, it cost about double to work (including the cost of the set), compared with the watermen.

Some 2,000 bags per Heading are enough from outside sources to start off the curing and as work progresses enough cement bags are made available to complete the 6,000 bags required per Heading (for monthly progress of 900 lineal feet). It is just as cheap in the long run to use the 4,000 new or nearly new bags made available from the cement used on the work as to import old bags from various godowns over the Province.

Layout of soaking tanks, etc.

Plate VII shows the usual layout. The soaking tanks, mixing tanks, sand brick and cement dumps shift forward every two days.

The Lining programme depends on the excavation programme and therefore the latter must be arranged to give each Heading length sufficient excavated canal. It is desirable to have at least 1,000 feet of excavated canal always ahead of the Lining and the more the better. The ideal Lining programme for any Heading is to do the upstream half length working downstream and the downstream half working upwards. In this way materials from the kiln godown can be carried with the minimum carriage. This ideal is difficult to obtain in practice.

Experimental Lining and Tanks.

The methods of working and devising scaffolding, etc. were evolved on a 500 feet length of Lining R.D. 10,500—11,000 before work started elsewhere. To see whether the 1—3 plaster layer of half an inch should be done separately or in combination with the top course of tiles, this experimental reach was done in two longitudinal parts. In one part the 1—3plaster was laid separate of thickness $\frac{3}{8}$ inch and the top course laid on a bedding of $\frac{1}{8}$ inch mortar. In the other part the half inch plaster was laid along with the top course of tiles. Two tanks were made in each part of inside measurements 20 feet $\times$20 feet with walls in 1—4 mortar, 10 inches thick and 3′—6″ high. The walls were plastered inside with 1—3 plaster and fillets made at corners. On being tested with a 3 feet head all tanks gave a percolation of practically nil amount. Sometimes when the evaporation was deducted from the total daily drop the result was negative.

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Phot No. 9. Scraping Plaster.

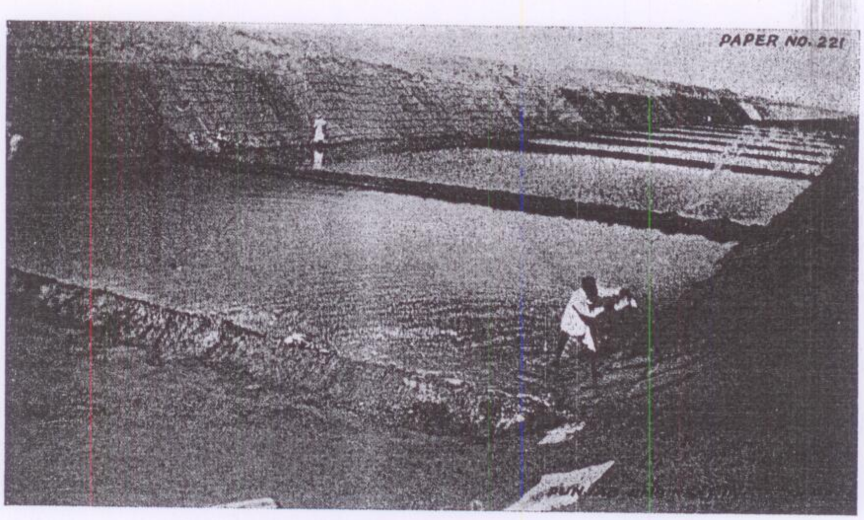


Photo No. 10. Curing Bed.

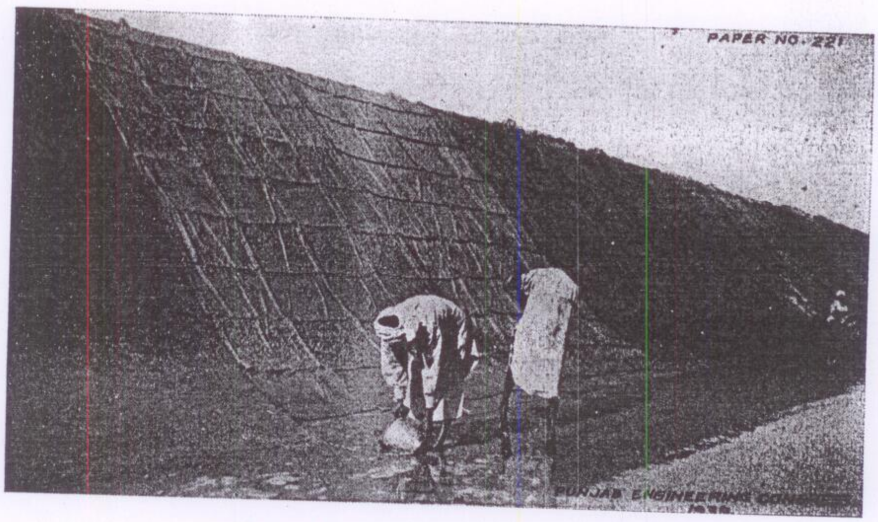


Photo No. 11. Curing Side-Slope.

The observations started in July 1938 and up to the end of November the percolation is still practically nil. The evaportion is measured in a 3 feet×3 feet×2½ feet tank of thin sheet metal filled to within about two inches of the topand resting on a support in a 20 feet×20 feet tank such that about one inch free-board is left on the outside. An angle iron rigidly fixed to the walls of the 20 feet×20 feet tank provides a fixed reference point. Readings are taken with a vernier point gauge to one thousandth of a foot.

As the two methods of laying the plaster gave similar results it was decided to adopt the separate layer method as this ensures a water-resisting layer without a break. A rough test showed adhesion of 10 lb. per square inch between the plaster and the top course after 14 days.

Test on 900 feet length of Lining with 10 feet head

It was decided to test the Lining as built and a tank about 900 feet long was obtained by making two earth bunds across the finished lined canal between R.D. 11,000 and 12,000 where the bed formation was pure sand. The inside slope of the bunds was made 1 to 1 and lined with the standard type of Lining. The bed of the tank was thoroughly cleaned of silt and then filled with water to 10 feet depth. Gauge wells 2 feet by 2 feet inside were made at each end and in the middle of the tank.

Daily readings of the water level are taken early in the morning with a vernier point gauge. The percolation, with relevant data, are shown graphically on Plate VIII. The percolation was still falling at the end of November 1938, being then less than point one (0·1) cusec per million square feet of wetted perimeter.

Appendices A, B and C.

These give particulars of plant, materials and analyses of rates for the Lining.

APPENDIX A.

PLANT FOR ONE HEADING.

			Rs.
Soaking Tanks, M.S. 1/8" thick ..	8'×8'×2'	6 No. =	996
Do. do. ..	8'×6'×2'	3 No. =	418
Do. do. ..	8'×4'×2'	1 No. =	106
Water Tanks, M.S. 1/16" thick ..	4'×4'×2'	2 No. =	64
Mortar Mixing Tanks, M.S. 1/16"	3'×3'×1'	8 No. =	121
R. C. Roller, 3ft.×1 ft. 9" dia. on ball bearings.	7 cwt.	1 No. =	35
Miscellaneous Ironwork ..	4 cwt.	=	90
Iron Rammers ..		8 No. =	12
G. I. Watering Cans ..		12 No. =	33
Sand Screens ..		6 No. =	24
Wire brushes, miscellaneous ..		30 No. =	60
Chir planks 12'×10"×2½" ..		132 No. =	388
Do. 12'×10"×1¼" ..		80 No. =	160
Slope templates, deodar ..		8 No. =	130
Miscellaneous deodar woodwork ..		24 c.ft. =	66
Chir Slope Scaffold Supports ..		12 No. =	153
Chir ladders, straight ..		16 No. =	154
Do. curved for slope ..		2 No. =	40
2" inlet, to be moved every 500 feet consisting of 60 feet of 2" G. I. Pipe. 200 feet of 1½" G. I. Pipe .. 60 feet of 1½" I. R. Outside armoured hose. .. Miscellaneous Connections.		=	290
4" inlet to feed curing reservoir, consisting of 40 feet of 4" G. I. Pipe and connections.		=	108
			Rs. 3448

APPENDIX B.

MAIN MATERIALS AND TOTAL COST OF LINING.

Reach From R. D.	Reach To R.D.	Trapezoidal Bed-width (feet)	Tiles (Nos.)	Reinforcement (tons)	Washers. (cwts.)	Cement (tons)	Tile Masonry (sq. feet).	Lining Estimate (rupees).	Puddling and Dressing (rupees)	Tools and Plant (rupees)	Tube-wells including Maintenance (rupees)	Complete Cost of Lining. Columns 9 to 12 (rupees)
1	2	3	4	5	6	7	8	9	10	11	12	13
2,000	20,000	115	1,06,38,000	258	108	3,227	26,16,000	5,29,000	17,000	↑	↑	..
20,000	63,000	84	2,09,91,000	553	228	6,382	51,58,000	10,79,000	43,000			..
63,000	1,30,500	75	3,02,79,000	818	340	9,279	74,84,000	15,68,000	72,000	1,05,000	41,000	..
1,30,500	1,68,313	72	1,63,13,000	450	187	5,074	40,81,000	8,45,000	40,000			..
1,68,313	2,27,800	71	2,54,39,000	703	291	7,894	63,59,000	13,39,000	67,000	↓	↓	..
	Total	..	10,36,60,000	2,782	1,154	31,856	2,56,98,000	53,60,000	2,39,000	1,05,000	41,000	57,45,000

Complete cost per % square feet =Rs. 22-6-0.

APPENDIX C.

Analyses of Rates for Haveli Sub Division.

A.—**Materials.**—

Tiles.

Kiln No.	Reach (L).		Rate payable to kiln contractor (R).	(R)×(L).
1	7·5×120/111	=8·1	Rs. 15 15 6	Rs. 129·36
2	5·5×120/111	=6·0	15 15 6	135·75
	2·5	=2·5		
		8·5		
3	7·5	=7·5	15 14 0	119·03
4	7·5	=7·5	15 14 0	119·03
5	7·0	=7·0	15 15 6	111·79
6	7·5	=7·5	16 1 0	120·45
7	8·0	=8·0	16 1 0	128·48
	Total	54·1		863·89

Cost of land 77 acres at 180 per acre = Rs. 13,860
Approximate number of tiles to be burnt = 240 lacs.
∴ Cost of land per thousand tiles = 13860/24000
= Rs. 0·57.

∴ Average rate=863·89/54·1 = Rs. 15·99 per thousand.
Add for land and kiln debit = 0·57 per thousand.

Total = 16·56 per thousand.

		Rs.	A.	P.
1000 No. tiles at kiln at 16/9 per thousand No.	=	16	9	0
1000 No tiles carriage, average lead 3000 feet., at 1/4×5/4 per thousand No. ..	=	1	9	0
Total	=	18	2	0

Cement.—

	Rs.	A.	P.
Concession rate f. o. r. Wah	20	0	0
Cost of bags $\frac{4/6}{4}+0/8/0$	1	9	6
Concession freight N.W.R. at 0-6-0 per maund	10	3	0
Railway freight on returning 20 empty bags ..	0	8	0
Unloading and stacking in godown at R. S. at Re. 1 per % cwt.	0	3	3†
Carriage to sub-godown along the canal average distance by camel 7 miles at 0-2-1 per cwt. ..	2	9	8†
Stacking in sub-godown at Re. 1 per cent cwt.	0	3	3†
Rehandling from sub-godown to site average lead 3000 feet at Re. 0-0-3 cwt.	0	5	0
Total ..	35	9	8
Deduct 2 p. c. on items marked† ..	0	1	0
Net ..	35	8	8

∴ Rate per cwt.=Re. 1-12-6.

¼" M. S. bars Reinforcement per cwt.

	Rs.	A.	P.
F. o. r. Waryam per ton (Contract rate) ..	230	7	0
Unloading at Railway Station at 0-2-6 per ton ..	0	2	6†
Carriage from Railway Station to sub-godown by lorry average distance 7 miles at 0-2-1 per cwt.	2	9	8†
Rehandling from sub-godown to site average distance 3000 ft. at 0-5-0 per ton	0	5	0
Total ..	233	8	2
Deduct 2 p. c. on items marked † ..	0	1	1
Net ..	233	7	1

∴ Rate per cwt.=11-10-10 Say Rs. 11 11 0

Washers per cwt.

	Rs.	A.	P.
F. o. r. Waryam per cwt. (Contract rate) =	24	6	0
Unloading at Railway Station at 0-2-6 per ton =	0	0	2†
Carriage to godown average distance by camel 7 miles at 0-2-1 per cwt.	0	2	1†
Rehandling from Sub-godown to site average distance 3000 feet at 0-5-0 per ton =	0	0	3†
Total =	24	8	6
Deduct 2 p. c. on items marked † ..	0	0	0
Net ..	24	8	6

Say Rs. 24-9-0 per cwt.

Sand.

	Rs. A. P.
Supplying sand at Re. 1 including lead up to 1000 feet	1 0 0
Additional average lead 4000 at Re. 1-8-0 per mile .. .. =	1 8 0†
Total =	2 8 0
Deduct 2 p.c. on item marked † =	0 1 0
Net =	2 7 0

(*B*) **Items.**

(*a*) *Tile Masonry in bed* 100 *s.ft.*

400 No. tiles at 18-2-0 per cwt. at site =	7 4 0
2·42 cwt. cement at Re. 1-13 per thousand at site =	4 6 0
11·9c.ft. sand at Re. 2-10-0 per cent c.ft. at site =	0 5 0
Total P. ..	11 15 0
Labour at Rs. 9-2-0% c.ft. =	4 9 0
	16 8 0 % S.ft.

(*b*) *Tile masonry in slopes* 100 *s.ft.*

Total as per P under (*a*) .. =	11 15 0
Labour at 10/14 p. c. c.ft. .. =	5 7 0
Total =	17 6 0

(*c*) *Reinforcement per cwt.*

1 cwt. ¼″ M.S. Bars at 11/11 per cwt. at site =	11 11 0
1/28 lb. S.W.G. wire No. 24 for binding at Rs. 16 per cwt.	0 0 1
Labour for placing, etc. .. =	1 4 0
Total =	12 15 1

Say Rs. 12-15-0 per cwt.

(*d*) *Curing Lining.*

(*i*) A bag opened out=2·8 ft.×2·4 feet.

30 feet per day for 30 days gives 1800 both sides.

There are 9 rows of bags 2·8 feet along the canal.

This means $\frac{1800\times 9}{2\cdot 8}$ =5786 say 5800 No.	=	5800 bags.
Add 50 p.c. No. for replacement ..	..	2900 ,,
Total	=	8700 ,,
Area of 8700 bags=$1800\times 1\cdot 5\times 2\cdot 4\times 9$	=	58320 s.ft.
Labour of stitching into mats 58320 s.ft. at Rs. 3-12-0 p. c.	=	Rs. 219 0 0

(*ii*) Small *bundis* 25 ft. apart, earthwork 3 chains including dressing=$\frac{7500}{25}\times 83\times 6\cdot 75$

=168075 Cu. ft. Rs. 5/6 per thousand = Rs. 903 0 0

2 No. big bunds for holding reserve water 9 chains lead including dressing =$2\times 100\times 92\cdot 5$=18500 at Rs. 8-6-0 per thousand = Rs. 155 0 0

(*iii*) *Watering men.*

Take progress of 25 feet per day=750 feet per month, and work must be cured for one month.

One man can do 200 feet per day.

∴ 8 men are required per day.

∴ Men—days required for 7500 feet =$7500\times 8\times 30$=2400.

∴ Cost at Re. 0-8-0 per man per day =Rs. 1200 0 0

Grand Total = 2477 0 0

∴ Cost per thousand sq. feet=$2477/7\cdot 5\times 120$= 2 12 0

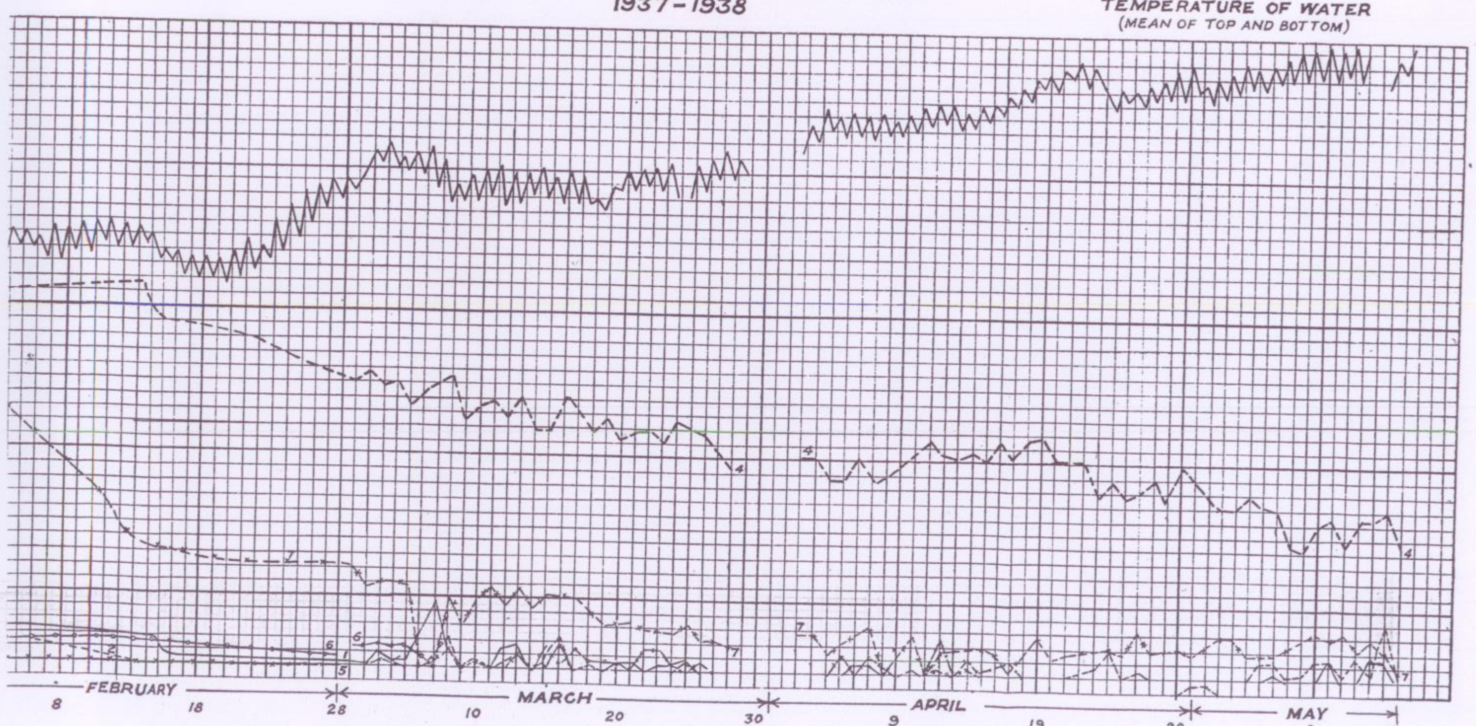
(*e*) *Removing brick bats and kattals per cent. c.ft.*

		Rs. A. P.
Collection in bed per cent. c.ft. ..	=	0 8 0
Carriage 7 chains including lift at Re. 0-12-0 per c.ft.	=	0 12 0
Total	=	1 4 0

PLATE I

PAPER NO. 221

VARIATION OF PERCOLATION LOSSES WITH AGE UNDER 3·0 FT. HEAD 1937-1938



PUNJAB ENGINEERING CON. 1939.

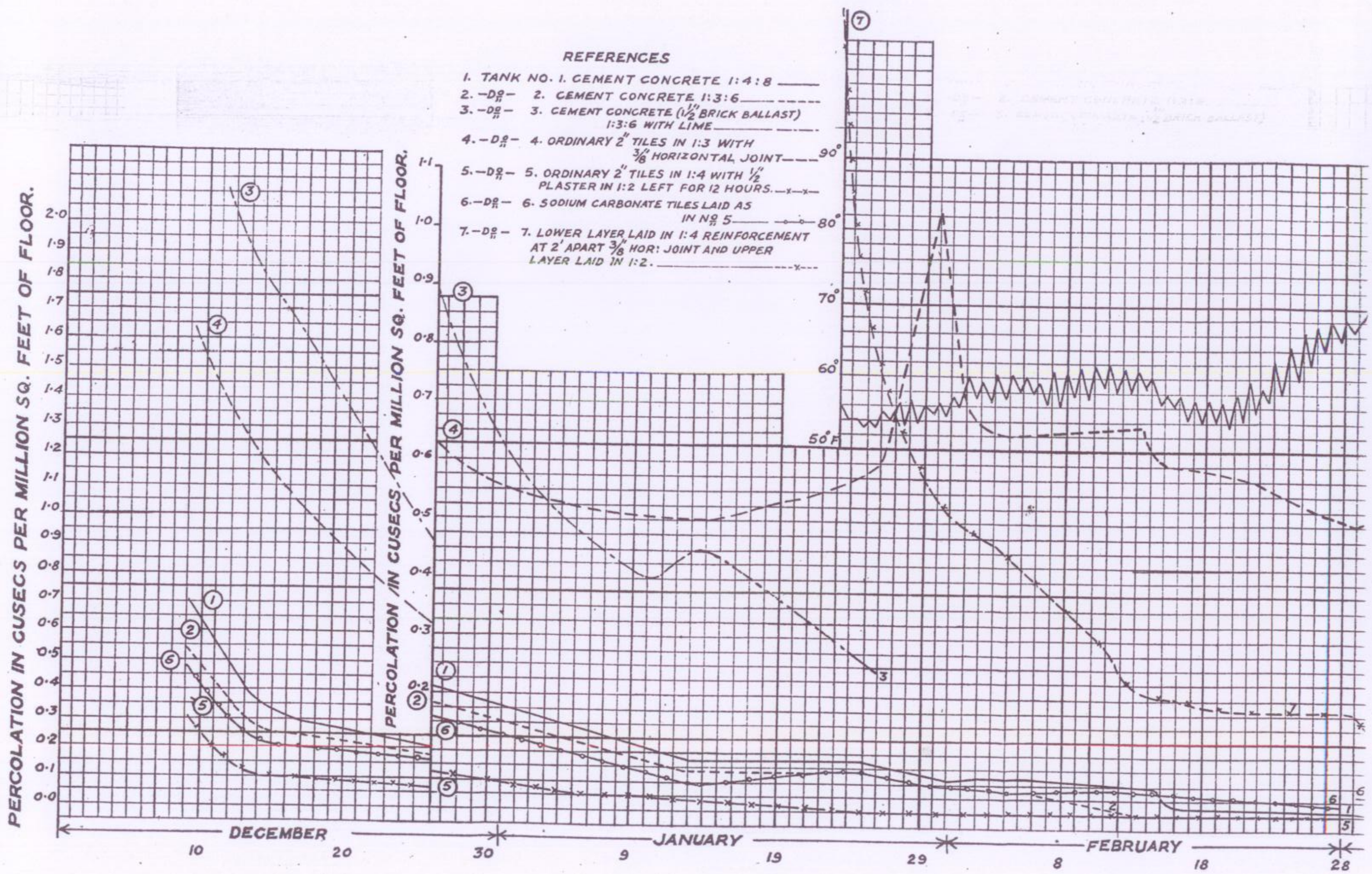
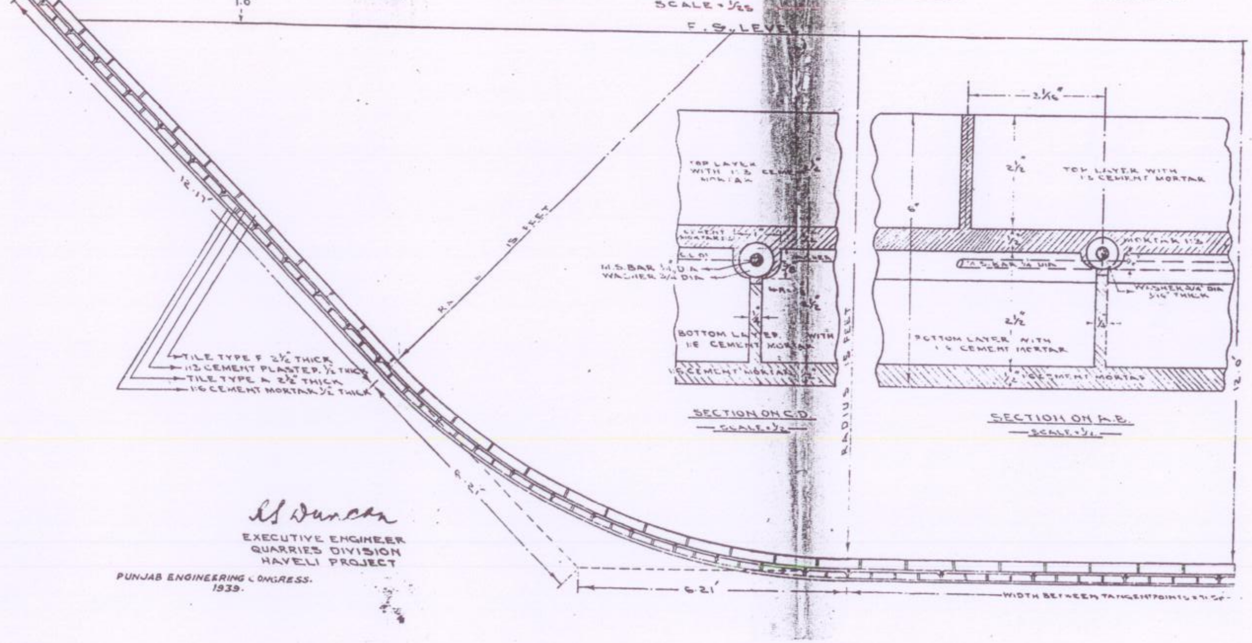

REFERENCES
1. TANK NO. 1. CEMENT CONCRETE 1:4:8
2. –Do– 2. CEMENT CONCRETE 1:3:6
3. –Do– 3. CEMENT CONCRETE (1½" BRICK BALLAST) 1:3:6 WITH LIME
4. –Do– 4. ORDINARY 2" TILES IN 1:3 WITH ⅜" HORIZONTAL JOINT
5. –Do– 5. ORDINARY 2" TILES IN 1:4 WITH ½" PLASTER IN 1:2 LEFT FOR 12 HOURS.
6. –Do– 6. SODIUM CARBONATE TILES LAID AS IN No 5.
7. –Do– 7. LOWER LAYER LAID IN 1:4 REINFORCEMENT AT 2' APART ⅜" HOR: JOINT AND UPPER LAYER LAID IN 1:2.
PERCOLATION IN CUSECS PER MILLION SQ. FEET OF FLOOR.
PERCOLATION IN CUSECS PER MILLION SQ. FEET OF FLOOR.
DECEMBER
JANUARY
FEBRUARY
10
20
30
9
19
29
8
18
28
50°F
60°
70°
80°
90°

PLATE II
PAPER NO. 221

CROSS SECTION WITH 12 FEET DEPTH

SCALE = 1/25



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QUARRIES DIVISION
HAVELI PROJECT

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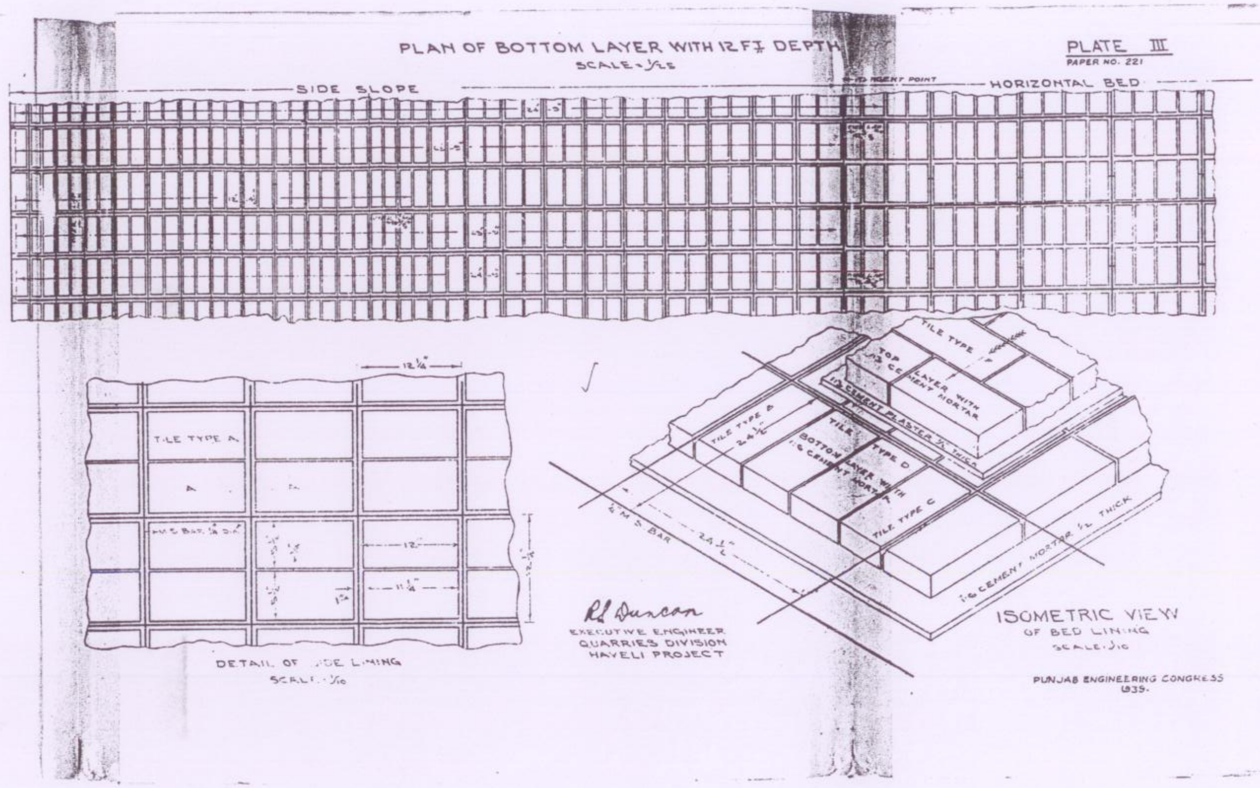
PLAN OF BOTTOM LAYER WITH 12 FT DEPTH
SCALE-1/25
PLATE III
PAPER NO. 221
SIDE SLOPE
HORIZONTAL BED
TILE TYPE A
DETAIL OF SIDE LINING
SCALE-1/10
R. L. Duncan
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QUARRIES DIVISION
HAVELI PROJECT
TOP LAYER WITH 1:3 CEMENT MORTAR
1:3 CEMENT PLASTER
BOTTOM LAYER WITH 1:6 CEMENT MORTAR
TILE TYPE D
TILE TYPE C
1:6 CEMENT MORTAR 1/2" THICK
ISOMETRIC VIEW
OF BED LINING
SCALE-1/10
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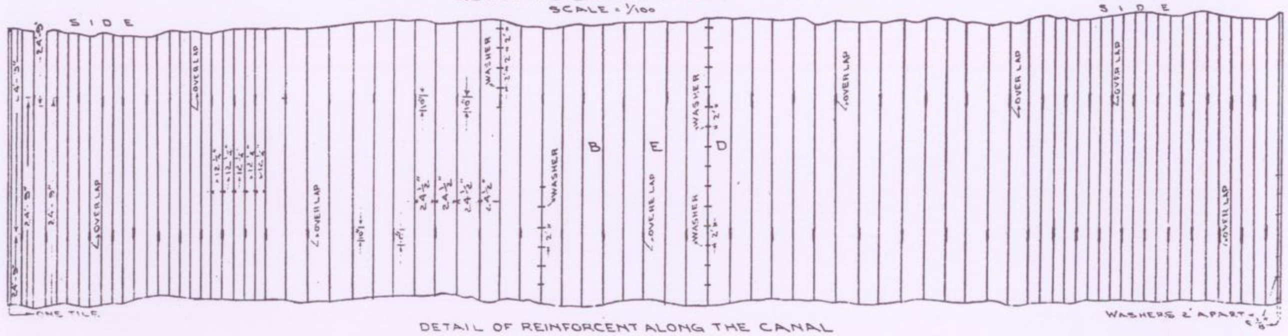
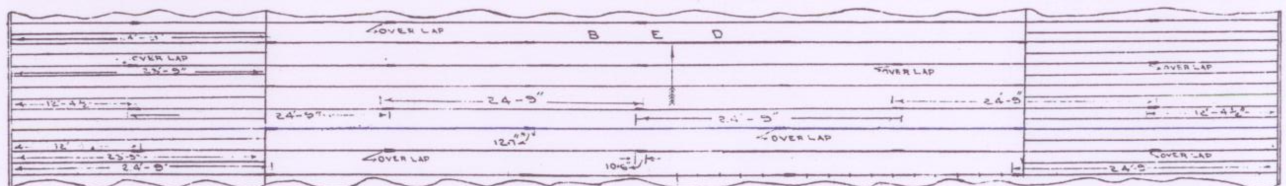
PLATE IV
PAPER NO. 221

DETAILED ARRANGEMENT OF REINFORCEMENT BARS IN LINING OF HAVELI MAIN LINE CANAL REACH R.D. 20000 TO 63000

SCALE = 1/100



DETAIL OF REINFORCENT ALONG THE CANAL



DETAIL OF REINFORCEMENT ACROSS THE CANAL

3" COVER OF CEMENT MORTER AT THE END OF REINFORCEMENT BARS ON EITHER SIDE

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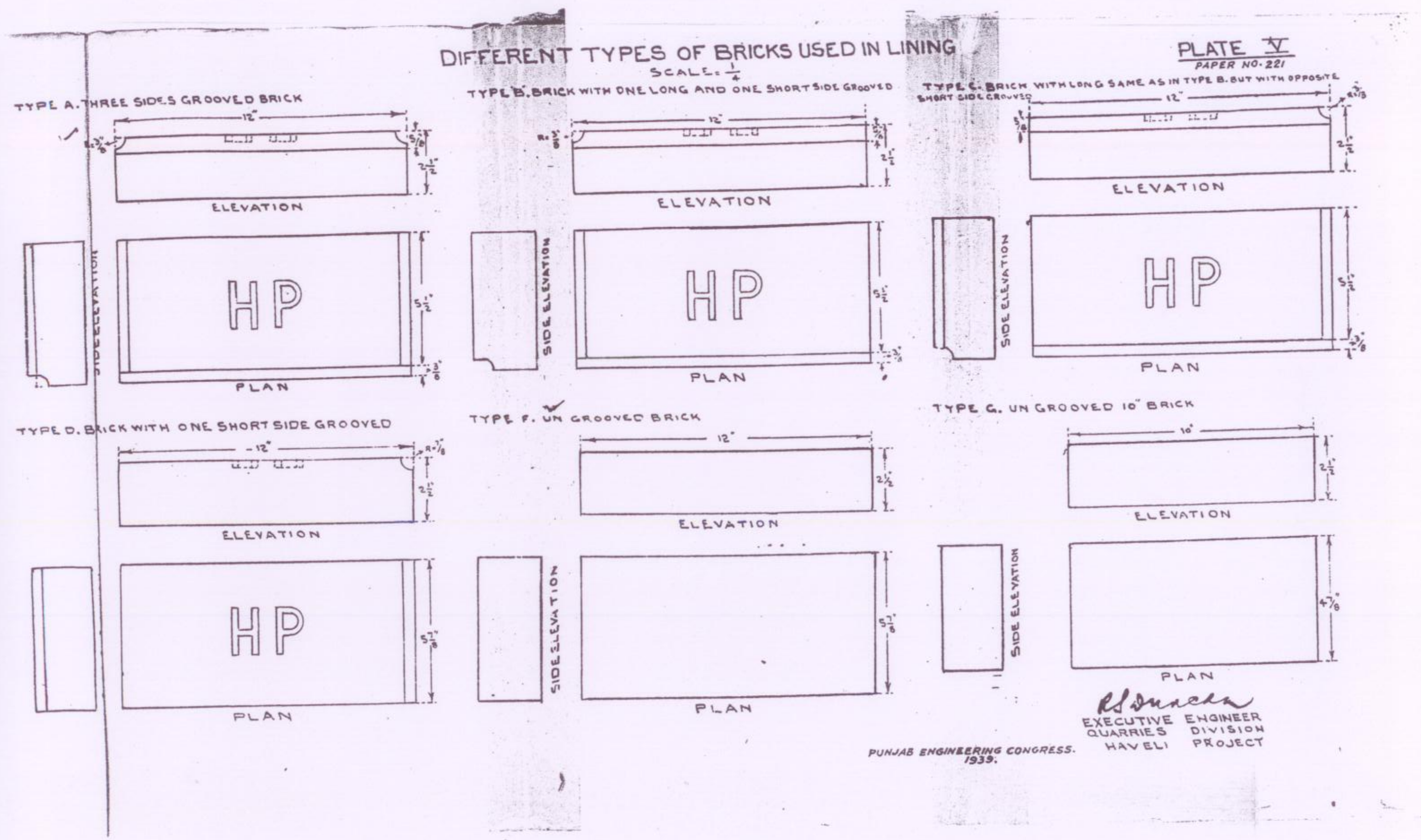
PLATE V
PAPER NO. 221
DIFFERENT TYPES OF BRICKS USED IN LINING
SCALE = 1/4
TYPE A. THREE SIDES GROOVED BRICK
TYPE B. BRICK WITH ONE LONG AND ONE SHORT SIDE GROOVED
TYPE C. BRICK WITH LONG SAME AS IN TYPE B. BUT WITH OPPOSITE SHORT SIDE GROOVED
ELEVATION
PLAN
SIDE ELEVATION
HP
TYPE D. BRICK WITH ONE SHORT SIDE GROOVED
TYPE F. UN GROOVED BRICK
TYPE G. UN GROOVED 10" BRICK
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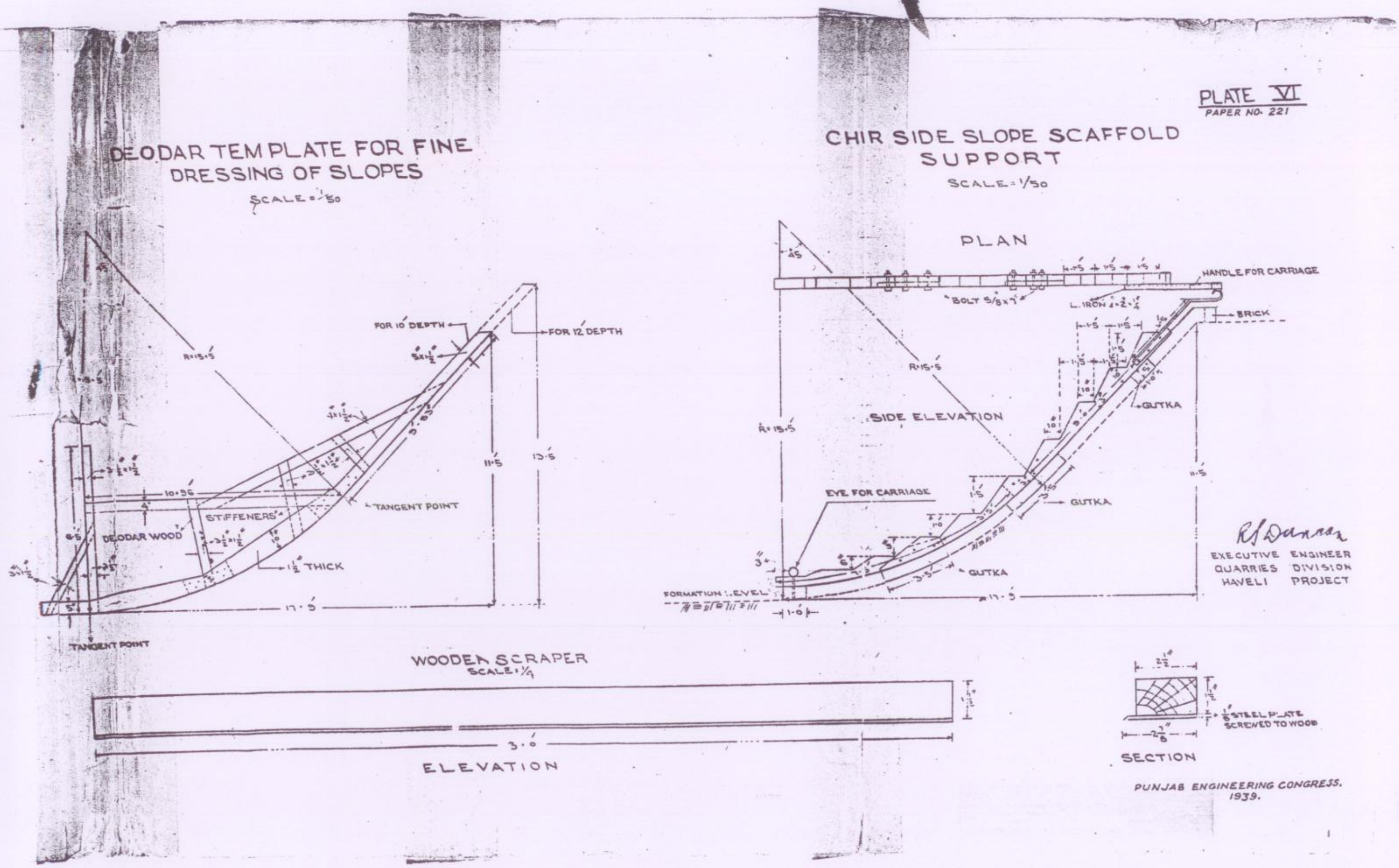

PLATE VI
PAPER NO. 221
DEODAR TEMPLATE FOR FINE DRESSING OF SLOPES
SCALE = 1/50
FOR 10' DEPTH
FOR 12' DEPTH
R=15·5
TANGENT POINT
STIFFENERS
DEODAR WOOD
1½" THICK
TANGENT POINT
CHIR SIDE SLOPE SCAFFOLD SUPPORT
SCALE = 1/50
PLAN
HANDLE FOR CARRIAGE
BOLT 5/8"x7"
BRICK
SIDE ELEVATION
GUTKA
GUTKA
GUTKA
EYE FOR CARRIAGE
FORMATION LEVEL
R. D. Dunnas
EXECUTIVE ENGINEER
QUARRIES DIVISION
HAVELI PROJECT
WOODEN SCRAPER
SCALE = 1/4
ELEVATION
STEEL PLATE SCREWED TO WOOD
SECTION
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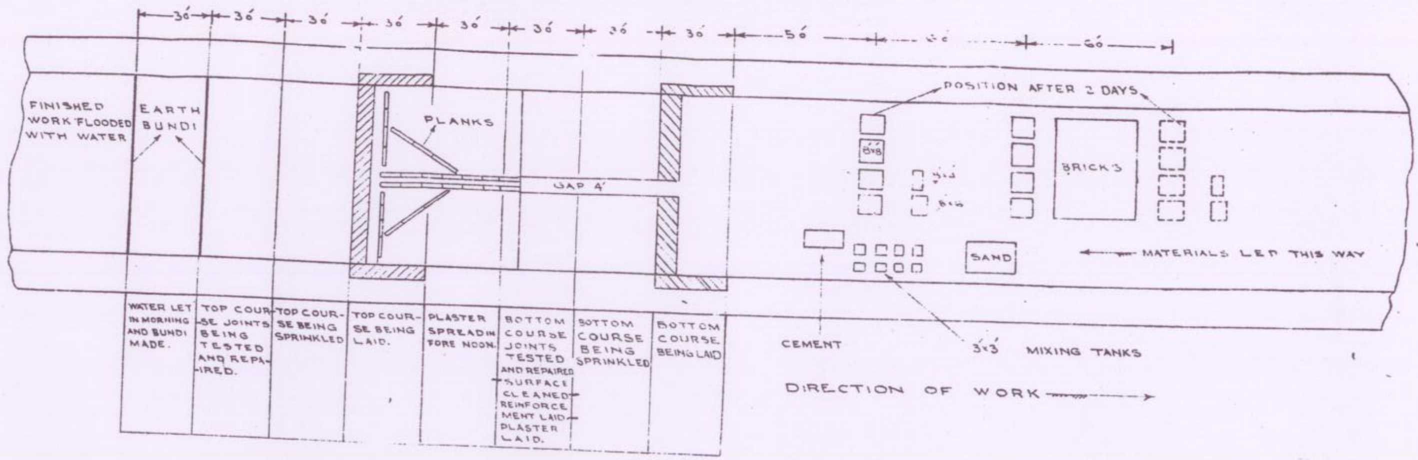
PLATE VII
PAPER NO. 221

LAY-OUT OF HEADING WITH PROGRESS 30' FEET PER DAY AND POSITION IN FORE—NOON



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100°
80°
60°
40°F
TOP OF FLOOR
DEPTH OF SUBSOIL WATER
BELOW TOP OF FLOOR.
0·2
0·1
0·02
0·01
PERCOLATION CUSECS PER MILLION SQ. FT.
PERCOLATION - FEET PER DAY
27
31
6
11
16
21
26
30
OCTOBER
NOVEMBER
DEC

PLATE VIII
PAPER NO. 221

DATA FOR PERCOLATION TESTS IN TANK FORMED BY 900 FEET LENGTH OF HAVELI MAIN LINE CANAL

NOTE:- ON 27 Th. OCTOBER 1938 DEPTH OF WATER ON FLOOR WAS 9·99 DECREASING TO 9·561 ON 13 Th. NOVEMBER. REFILLED ON 13 Th. NOV. TO 9·987 AND DECREASED TO 9·669 ON 1ST DECEMBER. REFILLED ON 1ST DEC. TO 10·067.

REFERENCES

1. MAXIMUM SUN TEMPERATURE.
2. MEAN RELATIVE HUMIDITY.
3. MAXIMUM SHADE TEMPERATURE.
4. BOTTOM WATER. —DO.—
5. MINIMUM SHADE. —DO.—
6. EVAPORATION.
7. NET ABSORPTION.

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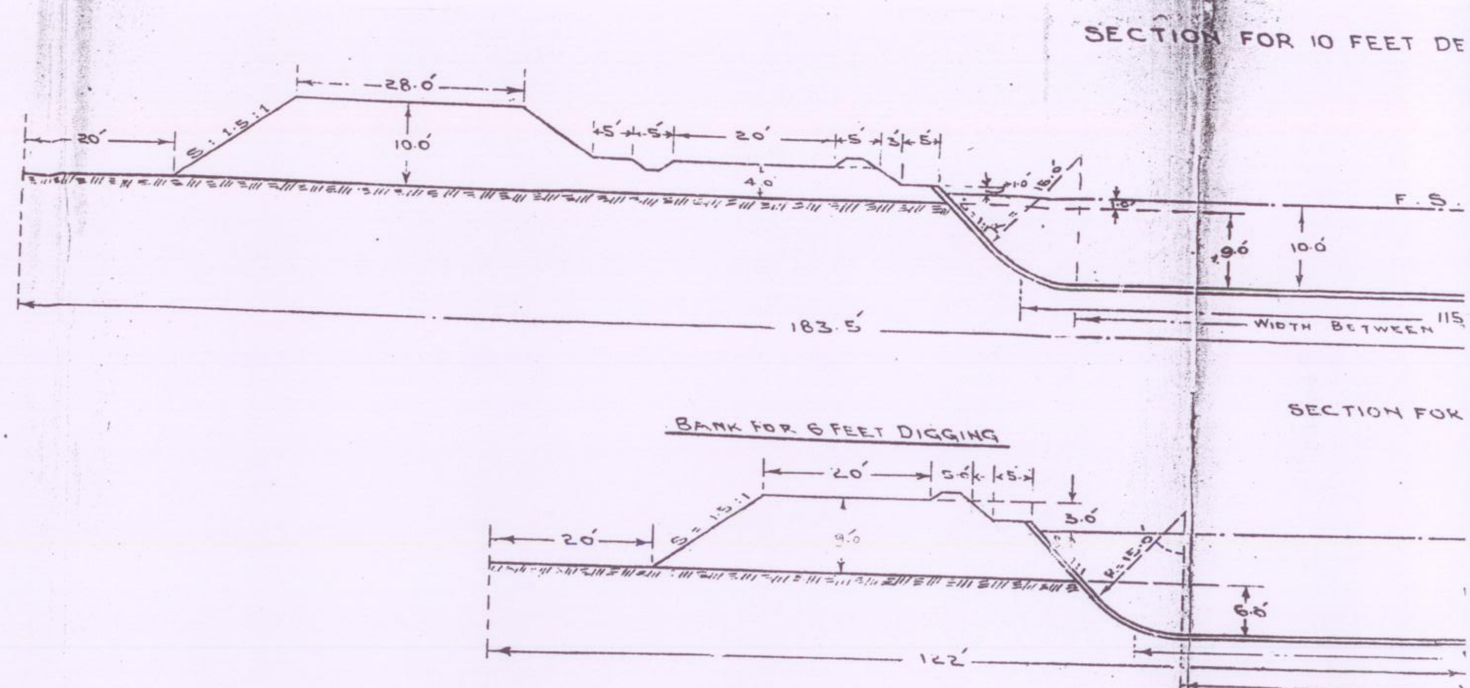
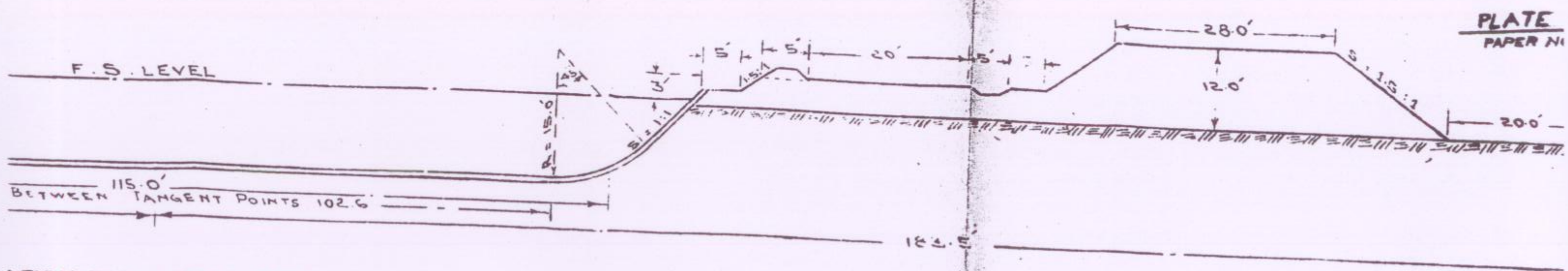
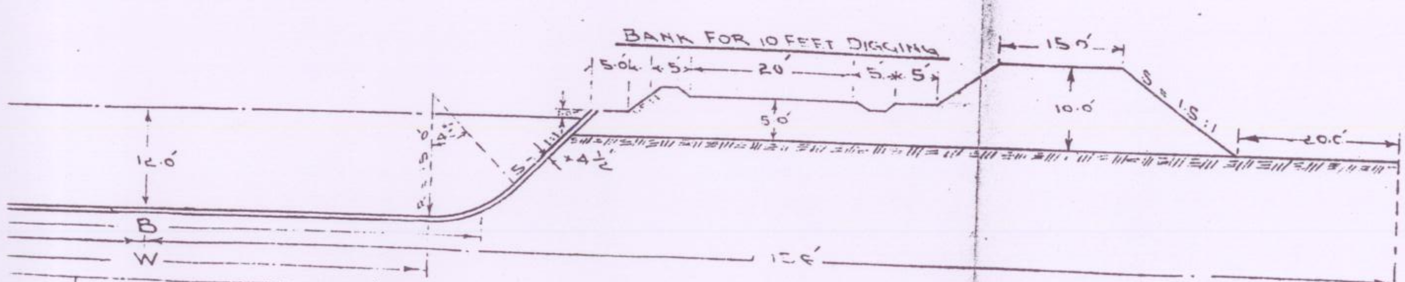


FROM R.D.	TO R.D.	TRA BED
23000	63000	84
63000	130400	7'
130400	168313	7
168313	227800	-

) FEET DEPTH WITH 9 FEET DIGGING.



.TION FOR 12 FEET DEPTH



R.D.	TRAPEZOIDAL BED WIDTH (B)	WIDTH BETWEEN T.PS (W)
000	84 FEET	71.6 FEET
400	75 -DO-	62.6 -DO-
313	72 -DO-	59.6 -DO-
7800	71 -DO-	58.6 -DO-

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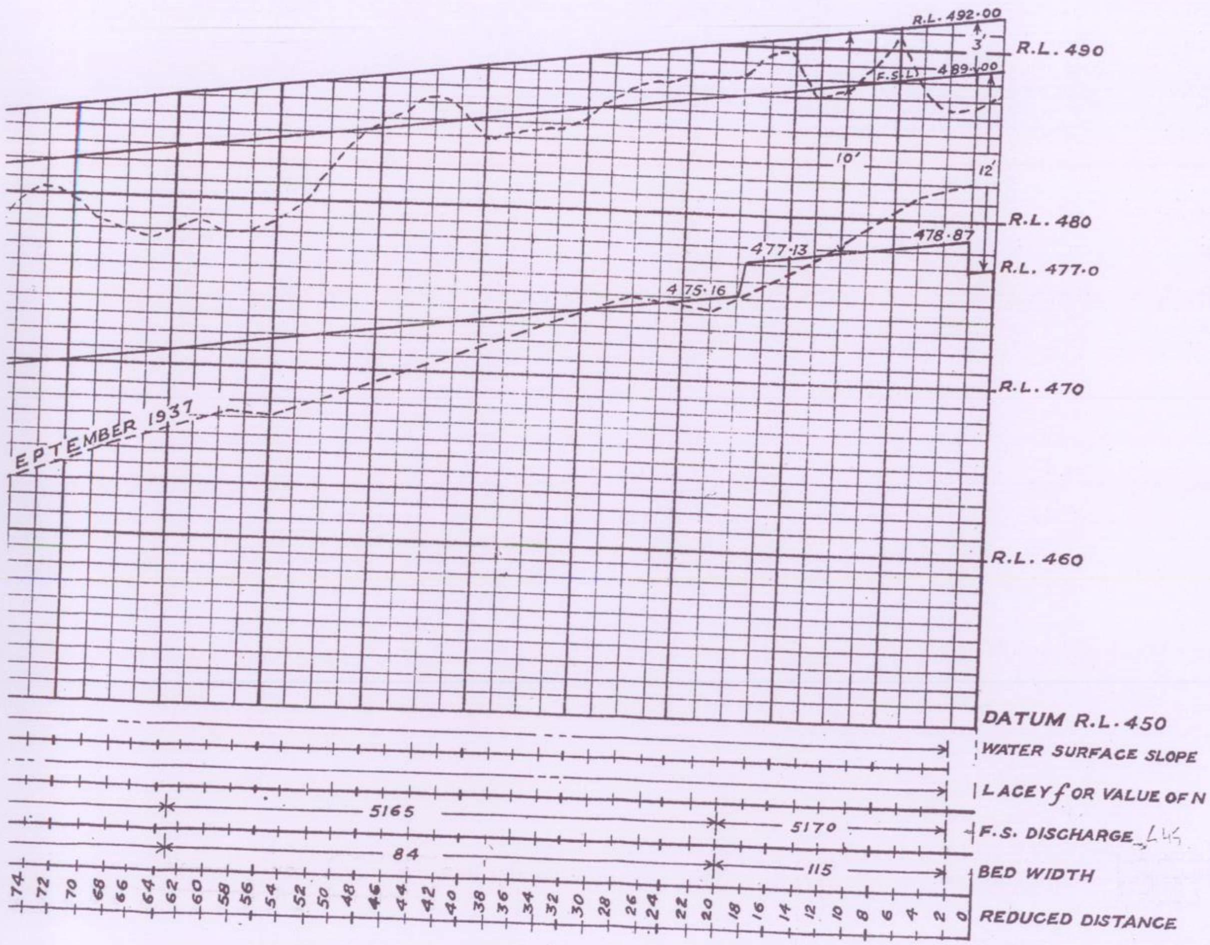
PLATE X
PAPER NO. 221



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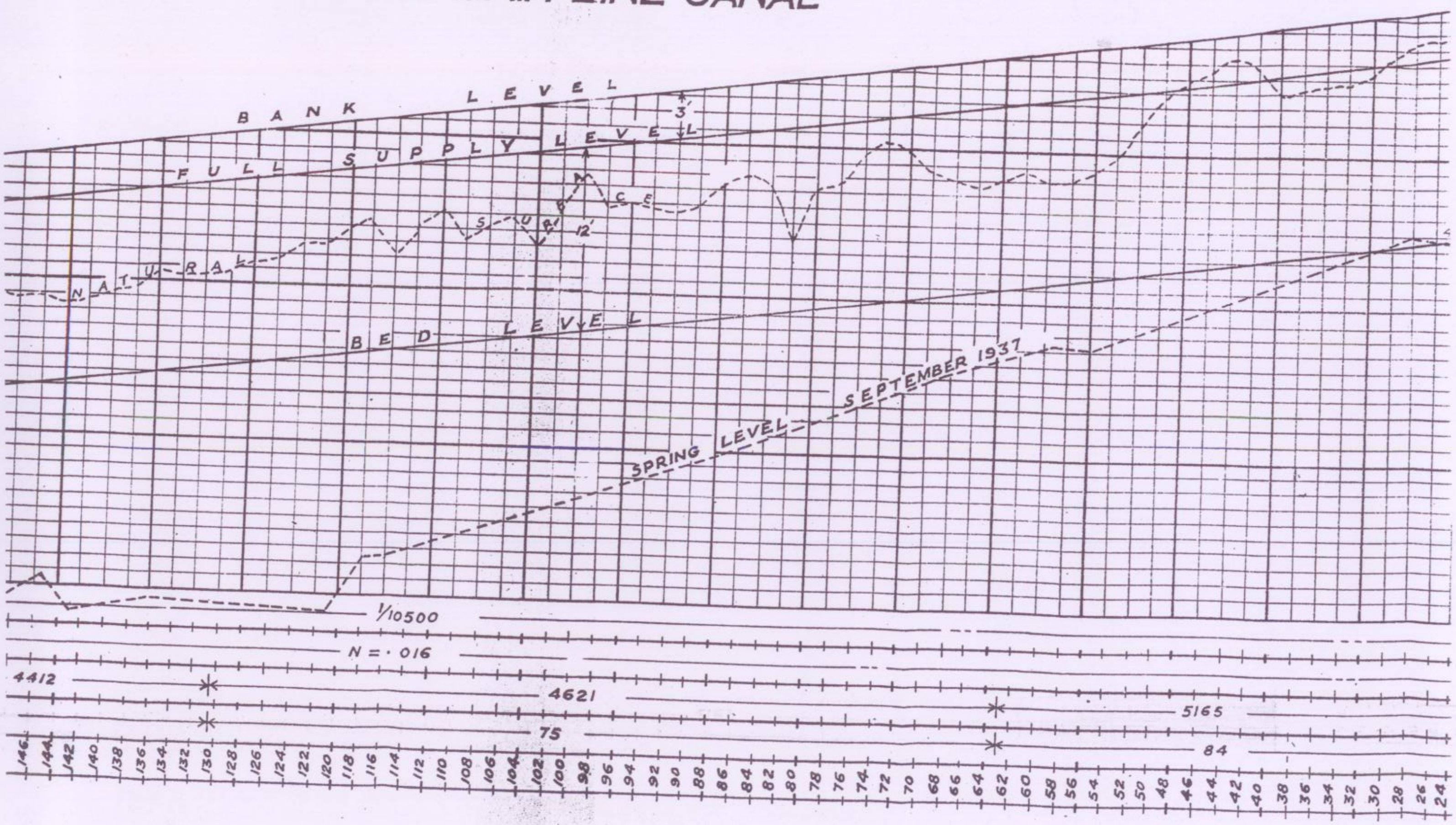
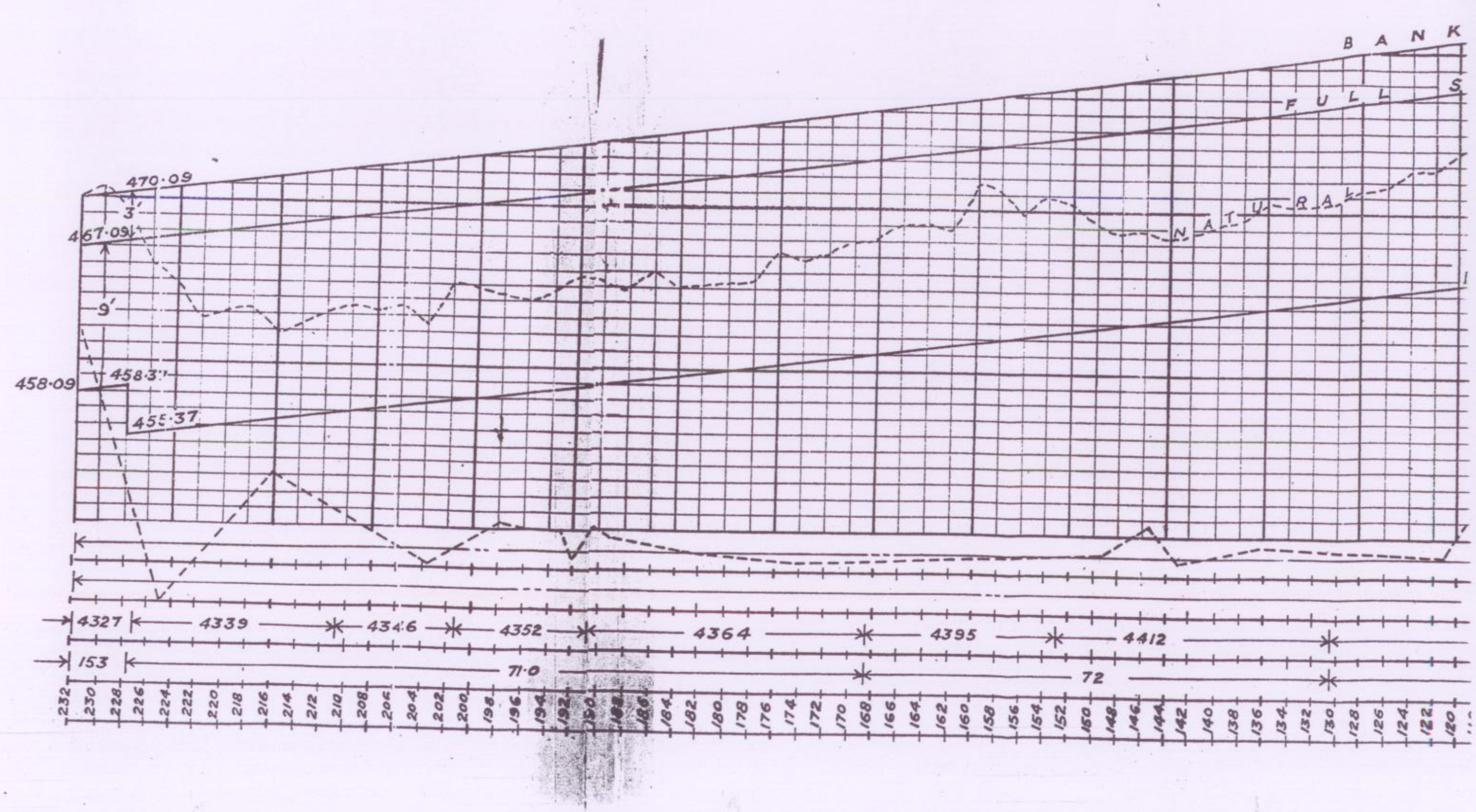
HAVELI MAIN LINE CANAL



HAV



BANKS
FULL
NATURAL
470·09
467·09
3'
9'
458·09
458·3'
455·37
4327
4339
4346
4352
4364
4395
4412
153
71·0
72
232 230 228 226 224 222 220 218 216 214 212 210 208 206 204 202 200 198 196 194 192 190 188 186 184 182 180 178 176 174 172 170 168 166 164 162 160 158 156 154 152 150 148 146 144 142 140 138 136 134 132 130 128 126 124 122 120

DISCUSSION.

Mr. **Duncan** introducing his paper said that he had only two things to say. Firstly referring to the percolation test in the 900 feet length of lining referred to on page 51, the percolation continued to drop steadily after November, 1929 till it became point zero three cusecs per million square feet in the middle of December, 1938 and it had remained about that figure till the end of January, 1939.

Secondly the soaking tanks described on page 43 were based on the tile taking six hours to soak, but it was found by experiment that a tile absorbed two pounds of water in the first hour, one ounce in the second and practically nil in the third. Therefore the number of tanks provided, which was at first thought to be tight was ample for an average daily progress of 40 feet length of canal.

Rai Sahib **Kanwar Sain** remarked that during February, 1939, he had spoken on the paper of water logging on the Upper Chenab Canal by Rai Bahadur Bawa Natha Singh and stated that in all new canals, it would probably pay to increase the initial cost of the project by permanent lining and to recover the interest in the form of water saved and the protection to the country from fears of water-logging. It was pointed out that much smaller channels would be required as the co-efficient of rugosity in lined channels was very small and consequently the cost of land, earthwork and masonry works would be reduced.

Little did he know at that time that an occasion should soon arise of putting this idea into actual practice. No provision for such lining was made in the 1935 Haveli Project as the expenditure involved was a big sum of Rs. 16 lacs and it was very doubtful if the Finance Department would look favourably at a suggestion of incurring such a huge expense. Fortunately for the advocates of lining like himself it was possible to anticipate saving in the project and it was on an assurance that the total project estimate of Rs. 5,36,00,000 would not be exceeded that the Finance Department agreed to this huge expenditure on lining. As will be seen from plate No. 1 of the paper a large number of alternatives were tried before brick lining was adopted. Previous experience of lined canals in America was that of cement concrete. On the Bikaner Canal, kankar lime, being available in the State, was used. On the Haveli canal, the question of kankar lime could not be considered, the material being not available near at hand. The alternatives were cement concrete and brick lining with a layer of cement plaster sandwiched between the two layers of bricks.

In the 1936 Thal Project estimates a portion of the canal near Mianwali was proposed to be lined in this manner. The result actually obtained both as regards cost of lining, the speed and facility of construction and the absence of absorption losses in the experimental tanks fully prove the superiority of this type of lining over cement concrete lining. An actual examination of large lengths of the canal that have been so far lined show the almost complete absence of any cracking tendency in this type of lining.

Here we might with advantage discuss the design of the lined section of the canal.

In the case of an earthern channel the depth width ratio fixes the section of the canal. According to Lacy using a value of F=0·8., section of the earthern canal for a discharge of 5000 cusecs worked out as 166 ft. bed width and 9·3 depth. In the case of lined section, the co-efficient of rugosity was taken equal to ·016. This is believed to be on the safe side. In the case of kankar lining on the Bikaner canal, the actual co-efficient is in the order of ·014. As the lined section can withstand higher velocities, the question was then to select the most economical section. Sections with depths varying from 10 to 16 feet were worked out. In fact the deeper the lined canal, the less would be the wetted perimeter and less the cost. It was however considered inadvisable to have the depth more than 12 feet. This depth was fixed after a careful consideration of silt carrying capacity of the canal even when a much smaller discharge is running in the canal. In the first four miles of the head reach, however the spring level being high, the depth of the canal was kept only 10 feet to avoid the necessity of pumping. The actual extra cost of the lined canal over the unlined as provided in the project is of the order of 30 lacs. It has been found possible to utilize the water saved by lining by extending the limit of the perennial irrigation.

Mr. **G. R. Sawhny** said that the lining done on Bikaner Canal shows that a considerable saving could be made in the water which is otherwise wasted in earthen canals and also that, as an anti-waterlogging measure such a lining is really very efficient. It is a very good thing that such a lining in a much cheaper form has now been done on a big scale.

The actual saving in water or the working of this brick pitched bed is yet to be seen.

It is not understood why the reinforcement should have been placed at the neutral axis. This could have been easily avoided by making tiles of different thicknesses.

As the canal would not run full supply all the year round he considered that, in the winter when the supply was low, there was a definite possibility that the bricks above the water level would be attacked by kallar. He wanted to know if this point had been considered, and if so, what precautions had been taken to preserve the bricks against such attacks.

He also anticipated trouble when rain water soaked in behind the pitching and he thought that the pitching should have been stepped back at the top over the earth berms in order to prevent this.

Mr. **F. F. Haigh** congratulated Mr. Duncan on the production of a very well written and interesting paper.

With regard to the author's comparison of costs of lined and unlined channels on page 39, Mr. Haigh suggested that the savings due to lining were not exhaustive. For example, the project provided about $8\frac{1}{2}$ lacs for drains in the areas between the canals and the rivers, very little of which actually be spent.

With regard to the design of the lining, a brick lining was decided upon after the Lahore tests had shown it to be suitable for the reason that it lent itself to rapid and economical construction. Originally it was thought that expansion joints might be necessary but it was decided to omit them later in view of the well established fact that temperature cracks in brick work are extremely rare. Mr. Haigh further gave a scientific explanation of this, viz., that the coefficient of expansion and Young's modulus for brickwork are so low that the stresses set up by temperature in practice do not exceed the strength of masonry. In any case, owing to the nature of the construction, cracks must be closely spaced and consequently so fine as to be negligible.

The bogey of cracking has now been laid, but there is another one about the reinforcement. Will this not separate from the masonry owing to differential temperature effects and rust thus damaging the lining? All what can be said about this is that it has not been known in the many cases where reinforced brick pitching has been used in the past, and in this case the reinforcement is much better protected.

Whether so much reinforcement is necessary, is doubtful, especially on the bed, but engineers would be in a better position to give an opinion on this after the canal has been opened for some time. From the accidental flooding of 6000 feet of lining during the recent floods at Trimmu where the lining was topped, some slight settlement occurred in the filling behind it, but, owing possibly to the reinforcement, the lining was undamaged. This reach of the lining received very much rougher treatment than is likely to occur elsewhere and the way it stood up to it is a good augury for the success of the design.

Mr. **Blench** congratulated the author on a well written paper and **on** excellent work.

He was particularly interested as one of his duties was to recommend on suitable canal linings as an anti-waterlogging measure and, since last July, the Rasul Government School of Engineering had been carrying out compression, tension, abrasion and percolation tests on different concrete mixes. A mix that would cost only some six rupees per hundred square feet for a four-inch lining against the Haveli figure of nearly 20, had been evolved and was now going through the crucial test of being used on a tank long enough to show cracks if the lining were liable to cracking. The success of the Bikaner canal lining and the tremendous saving in costs if concrete proves satisfactory justifies the Rasul experiments. There were two points of major interest about the Haveli lining. Firstly the percolation figures indicated that it had not cracked, for they were of the order to be expected from laboratory percolation tests on concretes allowing for the fact that concrete's impermeability increases with age. Now the whole theory of temperature reinforcement for concrete slabs assumes that concrete *must* crack and the steel can only reduce the cracking interval. A recent lining in the U.S.A. [vide " Journal of the American Concrete Institute " October 1930 available from Secretary C.b. J.] for a full supply depth of 9·75 feet was of 3" R.C. with 3/8" reinforcement at exactly Haveli spacing and with $1\frac{1}{4}:1$ side slope. Construction joints were left at 14 feet intervals and cracks occurred at shorter intervals. Obviously the success of the Haveli lining was not due to its reinforcement but to the use of brickwork. In fact the brickwork shares the property of weak concrete mixes that they will not crack in slabs. The reason is that the stress evoked in a material of a Young's Modulus E, temperature coefficient of expansion of t, and temperature range T, when prevented from contracting is t TE. If this figure is less than breaking stress, the lining will not crack. It seems to be a property of concrete that if the strength is half, the stress evoked by a given temperature range becomes less than half. Mr. Blench inspected Bikaner canal kankar concrete lining and could find no visible temperature cracks in the unjointed 20 miles of head reach. He had also had the losses measured over the whole length and found 1·65 cusecs per million square feet at 20 degrees Centigrade with a standard deviation of 0·28. He had attributed most of this loss to the jointed reach, but had since received some lining samples (exhibited) whose percolation test had just been started and reported to be very porous, but this might have been due to the damage done in removing the samples from the lining. The crushing strength was about that of the G.S.E. type of concrete at 28 days. It seemed on the whole that weak concrete lining had prospects and experiments will be continued. The G.S.E. lining material was exhibited.

The second interesting point about Haveli lining was that there was considerable authoritative opinion against the use of reinforced brickwork, because contact of steel with brick in alternating wet and dry conditions causes corrosion, swelling, and ultimate disintegration of the material. When Mr. Blench inspected the initial work on the Haveli lining, he observed that steel could not avoid contact with the brick. He enquired what expert opinion had been taken before deciding on reinforcement and suggested that any future tile lining should be unreinforced.

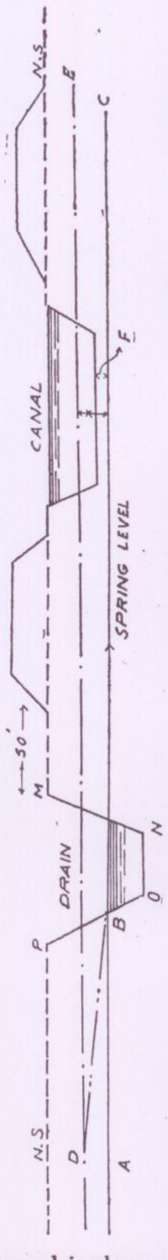
He suggested the adoption on the Haveli canal of the method of measuring percolation that Discharge Division had carried out for him on the Bikaner Canal. This would give reduced percolation at 20 days intervals and give a complete history of percolation. This cost would not be more than 1800 per year in excess of the cost of the routine Headworks discharge measurements. The method was detailed in Water-logging Investigation Division's " Report on Percolation losses from Bikaner Canal."

Mr. **G. R. Bhandari** was thankful to Mr. Duncan for bringing out this useful paper which makes the design of lining and the methods of construction available to the profession at large.

Referring to the longitudinal section (plate 10) of the canal, it will be noticed that the spring level for September, 1937 is above the bed of the canal from the head to R.D. 12,000, R.D. 26—R.D. 30,000 and R.D. 2,30,000 to 2,32,000. It is fairly close to the bed between R.D. 12,000 and 36,000. He requested Mr. Duncan to explain (*a*) how the construction was actually carried out in the reaches where spring level is higher than the bed and (*b*) what steps were taken to guard against the blowing up of the lined bed due to a possible rise in the spring level during the construction period or while the canal was empty.

Luckily for this canal during the last five years, the monsoon rainfall has been comparatively low in the Punjab and the subsoil water has been fairly steady. A heavy monsoon rainfall during 1938 would have caused a sudden rise in the water table as it did during 1933—34 which would have subjected the lined bed in this reach to upward pressure for which it is neither safe as a gravity section nor against which it has been properly reinforced.

In this connection I would like to suggest one way of overcoming the above difficulties and would invite the opinion of members of Congress thereon. In the diagram on the next page, if *ABC* is the subsoil water level in say September 1937 and it rises to *DE* during a heavy monsoon rainfall in 1938, the upward pressure on the lined bed is then *X-F* where *X* represents the rise in the spring level and *F* is the free board kept above the existing spring level. A six-inch thickness of brickwork will by its weight withstand an upward pressure of one ft. only below its bottom if the weight of masonry is taken as 125lb. per c.ft. In a reach where the lining has been laid just above spring level it will be subjected to stresses for which it is not designed if the spring level rises over one foot.



If a small drain is interposed marked M N O P at about 50 feet from the outer toe of the bank to intercept the sub-soil water gradient, the seepage gradient into the drain will change from A B to D B with the rise of the water table and there will be no rise in the spring level under the bed of the canal.

It is hoped that some member from the Research Institute who has made a detailed study of the sub-soil water gradients through clay strata will let us know whether the drain in this case will act as a proper safety valve or not.

Incidentally the drain can be useful during construction in bringing down the spring level in the reaches where slush appears in the bed and the water from the drain can be available for the masonry work. The seepage water from the drain can be disposed off at the next drainage crossing or pumped up at a lower sump into a watercourse for use in the construction lower down where spring level is very much below the natural surface.

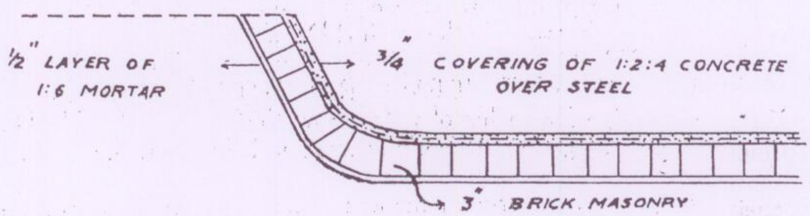
Turning now to the design of the lining adopted and referring to plate No. 1 showing "variation of percolation losses with age under 3·0ft. head" it is noticed that type 5 ordinary 2" tiles in 1 : 4 with ½" plaster left for 12 hours is just as impervious as the sandwich type selected. It is obviously cheaper than the latter.

The plastered surface would be smoother than the brick surface for the sandwich type and will have a smaller value of Kutter's "N" thus enabling the designer to reduce the section for the canal, thus reducing the lined perimeter and the cost. On the other hand, type 5 has several defects. The lining may crack due to settlement of the filling behind or cracks in the face plaster may appear due to variations in temperature. In the sandwich type the reinforcement has been placed at the neutral axis and is thus useless for taking any tension that may be caused in the upper surface of the slab due to the shrinkage of the puddle core behind. This tension can be considerable in the case of the Type section for

6 feet digging (Plate IX) and any shrinkage in the back fill is bound to cause cracks on the face of the slab. After the cracks have occurred in the face layer of tiles, the tension will be transmitted to the reinforcement and the slab will take the bending moment with an effective depth of $3\frac{3}{4}$ inches.

The face layer which at best forms a protection for the steel embedded in the central plaster will by the appearance of these cracks be rendered useless and in course of time the steel will rust, thus rendering the sandwich type no better than type No. 5.

A new type may be suggested as indicated hereafter and he requested Mr. Duncan to let him know what he thinks about it.



The design consists of a single layer of Standard Irrigation bricks in 1 : 6 mortar with the same reinforcement as used in the sandwich lining having a face cover of 1 : 2 : 4 cement concrete (Fine bajri aggregate) $\frac{3}{4}$ inches thick. It is not necessary to mould special type of bricks. The reinforcement can be secured in position by suitable hooks fixed in the joints of the masonry. The face of the concrete will be finished smooth reducing the value of Kutter's " N " from 0·013 and thus making a reduction of about 10% in the wetted perimeter of the channel. Using the same sectional area of steel the spacing can be reduced to 7 inches square in the side slopes and 14 inches square in the bed, if we use $\frac{3}{16}$ inch dia. bars. The smaller dia : will be better for bond and for taking up temperature stresses.

Mr. **Duncan** replying to the remarks of the above speakers, said that by their nature, Mr. Kanwar Sain's comments needed no reply. With regard to what Mr. Sawhny said, he explained that the steel had to be put in the centre of the section to ensure sufficient cover to prevent rusting. In that position the steel would still contribute to the prevention of settlement.

The question of kallar attacking the upper layers of side slopes in winter, Mr. Duncan proceeded, would be dealt with when it arose. As the tiles were pacca, they might not be affected. Regarding rain finding its way between the puddle backing and the lining, this probability was not dangerous as any such rain would help to compact the backing.

Mr. Duncan thanked Mr. Haigh for pointing out the omission of some 8¼ lacs rupees saving due to the probability of no seepage drains being necessary.

Mr. Duncan said he was very interested in Mr. Blench's suggested lining but thought it was too good to be true at Rs. 6 per hundred square feet. He thought it too weak to stand up to actual service and suggested that the competent authorities should line a sufficient length of some branch and see the results. Such practical tests were necessary in view of the ultimate benefits to be obtained from a successful lining. The desirability of the steel reinforcement had been dealt with by Mr. Haigh in his remarks.

Dealing with Mr. Bhandari's remarks, Mr. Duncan explained that the spring level in September was the maximum for the year and the fall during the cold weather work in the reach R.D. 2,000 to 10,000 was started in November, 1938 after the sub-soil water level had fallen below the formation level. From R.D. 10,000 to R.D. 25,000 during September to December 1938, a few inches of water above the formation level had to be dealt with by segregating the working area and bailing out the water.

Regarding cracks occurring, none had so far occurred in the portion of lining made in June, 1938. The lining suggested by Mr. Bhandari would require more supervision especially the concrete layer on the side slopes. A thickness of only ¾ inch concrete seemed to be on the thin side and it would have to be seen what the percolation was. This lining would cost about 3/- per hundred square feet less than the Haveli lining, but would be 2 inches less in thickness. If the concrete were 1¼ inch thick, the cost would be the same. There is also the fear of cracking in the concrete. It was possible that Mr. Bhandari's lining might prove as efficient as the Haveli type and in Mr. Duncan's opinion several types of lining should be tried out in running channels.