PAPER No. 253

OBSERVATIONS ON LINED (HAVELI) CANAL

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Introductory

During the past after new canals had been constructed it was found that the water table in their proximity used to rise gradually and resulted in water-logging and deterioration of soil etc. on account thereof. To avoid possibilities of this evil, when construction of Haveli Canal was contemplated, it was decided to line it with a suitable material.

Experiments were conducted in 1937-38 to test the water proofing qualities of various materials and finally it was found that lining consisting of a sand-witch layer of reinforced plaster half inch thick (1 : 3) between two tiles $2\frac{1}{2}''$ thick in cement mortar with a bedding course of half inch weak cement mortar 1 : 6 provided a comparatively efficient and cheap lining. Plate I shows the details of the lining section and a fuller description of methods adopted will be found in paper No. 221 presented to the Punjab Engineering Congress by *Mr. R. S. Duncan*. The lining was completed and canal opened in April 1939. The object of this paper is to discuss the behaviour of lining during the past 3 years and the conclusions therefrom with a view to improve it.

Sections of Lining

The Haveli Canal 46 miles long is mainly a feeder channel and drops into Ravi near Abdul Hakim Railway Bridge 5 miles above Sidhnai Headworks. The Limited drop of levels between Sidhnai and Trimmu determined the slope of canal to 1 in 10,500 which for a discharge of 5,000 cusecs would give a value of ·82 to Lacey's "f" or dia of silt $\left(\frac{f^2}{64}\right)$ = ·0105 inch or ·27 mm. To exclude silt coarser han this two Silt Ejectors had to be provided in the Head reach (0—2,000). The discharge provided at head of this Canal is therefore 7,452 cusecs against 5,249 cusecs at R. D. 2,000.

The first 2,000 ft. of the canal had been kept unlined. It was anticipated that as a result of continuous ponding sub soil level in the head reach would rise in course of time and would lift the lining if a certain depth of water were not maintained on it. With this object two regulators have been put in across the canal at R. D. 20,000 and R. D. 35,000. With only one set of gates at the lower end *i.e.*, at 35,000 firstly heading up would have been too frequent and secondly even with full heading up it may not have been possible to effectively load the lining in the head reach. A Non-perennial system with a discharge of 487·3 cusecs takes off at R. D. 63,000 and a Perennial system with a discharge of 247 cusecs takes off at R. D. 1,30,000. Regulators with gates have been provided at both these sites to head up supplies when needed.

F. S. L. of canal at tail is 467·09 against a maximum water level of 470·0 in river in case of floods. During floods in Ravi the canal has therefore to be closed at the tail and all available supply escaped through an escape channel to take off at R. D. 2,14,000. Gates have therefore been provided at the tail also to enable the canal being closed.

The canal has been designed with a 12 ft. depth. Due, however, to high sub soil level in the head reach, it was anticipated that excavation to full depth might become difficult, hence 10 feet depth was given in reach 2,000—20,000. In view of heavy pumping in the weir the difficulty anticipated would however had not arisen if the work had been carried out in cold weather.

The details of design in various reaches are given in the table below :—

Reach	Bed width	F. S. Depth	F.S. Dis. in Cs.	Water Surface Slope	Value of 'N' or Lacey's 'f'	Lined or Unlined
		Feet				
0-1200	175′	12·0	7452	1/14500	0·74 (*f*)	Unlined
1200-2000	155′	12·0	6250	1/16000	0·625(*f*)	do
2000-20000	115′	10·0	5249	1/10500	0·016	Lined
20000-63000	84′	12·0	5244	1/10500	0·016	Lined
63000-130600	75′	12·0	4747	1/10500	0·016	Lined
130600-168313	72′	12·0	4486	1/10500	0·016	Lined
168313-227800	71′	12·0	4478	1/10500	0·016	Lined
227800-230753	153′	9·0	4466	1/10500	0·80 (*f*)	Unlined

History

In 1938, when parts of canal had been completed, full scale experiments were carried out to test the absorption plus evaporation from two reaches 13,000 to 14,000 and 2,12,000 to 2,13,000 by converting them into large tanks, filling them with water and noting the drop in water level with time. The results showed absorption of ·1 and ·25 cusecs per million s.ft. of wetted perimeter. The actual absorption in the canal is roughly of an order of 20 to 40 cusecs in the cold weather and 40—80 cusecs in the hot weather. Experiments were started in 1940 to actually work out the absorption losses but no conclusive results had been obtained till the time of writing. The absorption on the Gang canal is 1·5 cusecs per million sq. ft. according to which the absorption loss on this canal should be 38 cusecs.

In Summer of 1939 after a rain fall the canal showed two bulges at R. D. 39,000 and 46,000. In both these reaches high spoil banks existed behind the banks and it was considered that rain water had gone behind the lining and bulged it, as per sketch in margin. These bulged portions were dismantled and relaid. It appeared that surface drainage of top of lined canal banks was an important factor and needed serious consideration.

FIG. 1

In the lower reaches the canal runs through a heavy filling and the banks were apparently unconsolidated. When the canal was opened for the first time, the banks showed settlement. Probably the water leaked through some open joints and a definite cleavage was noticed between the puddle backing and lining. The two segregated and at places the segregation was as much as 3 inches. This segregation had to be filled up by earth made into slurry and poured in behind the lining.

The canal had to be closed in hot weather of 1939 and a large number of horizontal cracks particularly at the natural surface level were noticed. These were grouted. In the December closure all joints were carefully examined and all open joints grouted. A considerable debris was also found collected on the bed of canal which was removed. In about three places the banks had settled and the lining on the sides had also settled, this was dismantled and relaid.

A large number of tiles were showing attack by kallar and efflorescence and it was considered that replacement of some tiles would before long become necessary. At places water was oozing out of the tiles on the side slopes which phenomenon was termed "weeping" of the lining. This was more marked in certain reaches.

A Committee consisting of Messrs. Mcleod, Stuart Louis of the Concrete Association and Mckenzie Taylor along with *Mr. Haigh* inspected the lining to suggest the improvements needed after examination of the present lining for incorporation in future works. Amongst other things they found that the reinforcement in the lining laid on side slopes had corroded while that in the bed was for most part unattacked, the bedding plaster had yielded part of its water to earth below and had not properly set. In addition they suggested methods to obtain better control on material and workmanship during course of construction. The committee recommended the use of a cheap water proofing material under the bedding course if one could be found and spraying the surface with a water proofing emulsion or composition to prevent deterioration of tiles, if experiments showed it to be feasible and effective. None of the two "ifs" however materialised.

They further recommended that provision of reinforcement in the bed of canal was of no use. On sides it could give extra strength but as provided it was a definite disadvantage as if sufficient forces were called into play to disturb the lining the reinforcement would merely delay relief being obtained by local failure and thus extending the damage. The corrosion found on reinforcement showed that it could not be much use in the long run unless it was completely embedded and hermetically sealed in the layer of cement plaster.

A very frank but practical and useful note on the difficulties experienced in construction was also submitted by Mr. Barkat Ram Lamba one of the Sub-Divisional Officers on lining, who apart from suggesting the improvements in the organisation of work from constructional point of view suggested a material change in the section of puddle backing behind lining with the object of eliminating segregation noticed. This is shown in Plate II and will be discussed later.

Another important point that came to notice during closure was a sort of black growth in the joints of lining in which there were shells inhabited by a funny type of insects. This black growth covered all the joints in a reach and was more marked in the head reach and went up to nearly R. D. 80,000. An attempt was made at one place to remove this by rubbing with wire brushes but the stuff was so sticky that it would not be removed unless rubbing was so hard that the top crust of the brick was also rubbed off. The progress was also very low and the attempt to completely clean the joints by wire brushes had to be given up.

During the cold weather when the waters were very clear, moss growth was also noticed on the sides of the lining. It was also noticed that kallar showed itself more markedly on the band of tiles on the sides subject to alternate wetting and drying (caused by variation of levels between Rabi and Kharif supplies) and the top course of bricks was being attacked by kallar.

In April 1940 a very funny phenomenon not experienced on other canals was encountered. Along the banks of canal there were swarms of flying insects which made it well nigh impossible to go on the banks in the evenings. With the rise of temperature they however died out in the following months.

With the opening of non-perennials in Kharif 1940 with a discharge of 3,895 cusecs against 5,249 as designed it was found that in the reach 35,000 to 90,000 the canal had reached the designed full supply levels.

Between the night of 1st May, 1940 and 2nd May, 1940 a severe storm occurred and at R. D. 63,000 where free-board was only 0·9 ft. the water splashed over the top of lining, caused heavy settlement and cavitation behind and a breach occurred. The canal had to be kept closed for 2 days but whereas reach below 63,000 became dry that above 63,000 could not be completely dried out as water had been headed up at this place.

In this heat many insects on the bed of canal below 63,000 must have died.

As a result of the water getting splashed over the top of lining on to the berm behind heavy settlement of banks took place at places there were wide cracks in the banks, the lining showed wholesale segregation from the puddle fill behind. It was found from watermarks that waves had been 2 to 3 ft. high. The locality being known for storms and the bank filling being loose it was realised that 1 ft. free board for lining was inadequate against wave action and it was highly unsafe to run the canal during storms with 12 ft. depth of water.

After the breach was closed the canal capacity showed a slight improvement below 63,000 but the conditions were much the same above 63,000.

A detailed examination of the bed was further made towards end of May which disclosed sand and insects in the bed of the canal. The depth of sand was however not more than 1½" at the worst place although at places it was just ¼ inch.

To enable the water to pick up this sand, extra supplies were passed into the canal for about 3 hours a day. This was done for about a week.

With the above and with the rise of temperature of water the capacity of the canal started showing improvement and on 15th June, 1940 it could take 4,494 cusecs with a depth of 12 ft. at R. D. 2,350.

A severe cyclone occurred in the afternoon of 20th June, 1940 and lasted for about 2 hours. It was of an extraordinary violence which could be judged from the fact that B. G. trucks were blown away from Trimmu upgrade to near Mudduki—a height of 9·8 ft. over 7 miles where they got derailed due to sand having blocked the line. 1·1 inch rainfall was recorded in just 20 minutes and although the canal was reduced at the head by 3·3 ft. but the effect naturally could not travel too far. The canal got severely damaged in reaches 2,000—13,000, 40,000 to 82,000 and 1,70,000 to 2,11,000 *i.e.* in a length of about 19 miles. A man who actually witnessed the damage during storms said that the lining of sides moved forward and backward.

Heavy segregation occurred, water from waves and rain was found to have run on the top of the berm behind the lining (See photographs) until it found a weak spot and made its way down between the lining and the puddle core on which it rested. There were heavy settlements of banks, there had been innumerable leakages particularly in the tail reach and at places the bank top was found to be simply arching over big hollows that had occurred. (See photographs). The water got behind the lining which bulged out, then cracked and as a result thereof slipped down at many places, got twisted and bent and displayed the like of the damage to a tent covering when torn asunder by a severe storm. (See photographs). Evidently the reinforcement in the sides and the curved bottom which gave the entire section a continuity did not permit collapse of each individual bit strained but strained a bigger length making the damage widespread rather than localised. Damage was temporarily repaired and the canal reopened with lesser supplies. The canal now apparently depended for its safe running on the earthen banks which were gradually strengthened as described on page 10 and the canal raised to 4,489 cusecs by 14th October, 1940.

The deterioration or improvement of the capacity was being watched from the correction factor as a result of daily discharge observations and it was noticed that the canal after an improvement in May and June showed a sudden and quick deterioration in the first fortnight of October and during the cold weather its capacity based on above observation remained low. Graph (Plate VII) shows the variation in capacity and affords an interesting study. During closure in January, 1941 it was noticed that the insect growth on the bed of the canal had now become intense and had travelled far down the canal.

The canal had again to be closed in April for about 10 days and a considerable mortality must have taken place in the insect kingdom on the bed of canal due to intense heat. The canal capacity showed another jump up after this closure.

Dr. George Mathai, I.E.S. was requested to investigate into this insect problem which seemed to be roughening the canal bed and affecting its capacity. This required a detailed study of the complete cycle of life of the insect, its habits, place from where it had imported itself, its capacity to multiply and the type of fish that would eat it and would prevent its going into the canal. It was also probable that due to a *pacca* hard bed and high velocity the lined canal was unsuitable for fish to stay in and as such the problem might have to be dealt with in the river itself. Unfortunately this useful investigation could not be started upto the time of writing. The maximum discharge run in the Haveli canal during 1941 was 5,038 cusecs on 19th June, 1941 with a depth of water 12·56 ft. against 12 ft. designed. With the start of clearer waters the capacity again deteriorated in October by 14·5 per cent.

The above is a brief history of observations on the canal during its short life of 2½ years. Experiments were carried out to determine the absorption losses but no conclusive results as to absorption figures have so far been made known although it is considered to be varying between ·8 and 2·5 cusecs per million s.ft. including leakage through open joints and evaporation. Gauges have also been fixed at every mile which are read and are plotted and this indicates the value of Kutters N for the various seasons in different reaches against the designed value of ·016.

Damage. Its Causes and Remedies

Segregation

Below N. S. level the lining rested on the excavated formation. Above N. S. however it was realised that the bank would be loose and unconsolidated and would provide an unreliable backing for the lining as such a puddle core 5 ft. parallelogram (Plate II) was constructed behind it out of the loose earth of the bank. Plate II also shows detailed method of preparing it. Apparently if the supervision was at any time slack the labour would increase the thickness of the layer for consolidation and mix more dry earth of the bank so as to give a trapezoid with a narrower base and wider top as shown. The efficiency of this puddle core would also be different with different soils. The lining if left to itself seeks support on this puddle parallelogram which in turn seeks on the loose backing a case of heavy structure resting on weak and unreliable foundations. Any slight shrinkage or settlement in bank as a result of rolling, rains, wave splashes, leakages etc. would naturally result in settlement of bank and consequent tilting of this puddle parallelogram and subsequent shrinkage noticed as segregation. It is easy to see that thereafter the 6″ lining at a slope of 1 to 1 functioning as a cantilever would not be able to support the weight of water and would crack at the natural surface level.

To ensure that there will be no segregation the puddle core should be an independent self-supporting unit and a trapezodial section as per figure 2 Plate II would be more desirable. This should be built before the bank so that there is not only no chance of mischief by labour but has also stood the test of weather for some time and cracks, if any, appeared subsequent to shrinkage or drying, have been refilled with dry earth and caulked.

The present segregation afforded a very narrow and deep trench to be filled up and to ensure complete filling earth made into slurry was poured behind the lining. This too could not be very satisfactory as it might not only have left interstices in the segregation unfilled but on drying might develop cracks as well but this was the best under the circumstances.

An ideal support for lining would be provided by silted berms if the channel could run for a few years as *kacha* and berm up but it is a matter which may or may not be permissible under local conditions. It would in any case mean lesser discharges during early periods when the area may yet be developing and later the same sections when lined could serve the entire area when fully developed. This would prevent all possibilities of settlement to banks, danger of breaches etc. and would not subject lining to any great strains.

Settlement of Banks

The banks along Haveli Main Line were consolidated by opening out a trench in the top of bank down to N. S. as shown in Plate II Fig. 3. The earth was relaid in 4 to 6 inches layers each layer being watered and rolled before laying the top one. This provided a consolidated corewall against breaches. It will be realised that in earthen channels the soaking of banks makes it leak proof which factor is non-existent in a lined canal bank. It would be seen that the consolidated trench is wider at the top and narrow at bottom and seeks support on unconsolidated bank. A settlement of the bank or berm would cause looseness in this trench, where the soil is granular and hard possibilities of development of leakages through open joints would still persist but this was the best under the circumstances and ultimately leakages would be stopped by grouting all open joints as they appear.

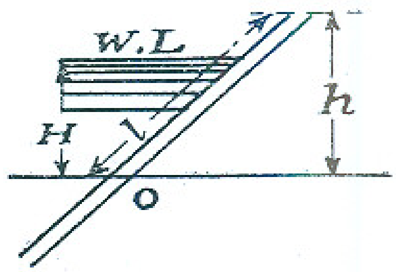
On new construction, complete settlement could be obtained by laying earth in layers and rolling the same before adding another layer and the amount thus spent on consolidation would be well repaid in subsequent maintenance.

Drainage

Consider a 6 inches thick lining with water pressure h & H on the two sides. Taking moments round point O.

Resultant moments in case of equilibirum are :—If w & W be the weight of water and lining per c.ft.

FIG. 2



$$\frac{wh^2}{2} \times \frac{h}{3} = \frac{w}{2}H^2 \times \frac{H}{3} + W \times l \times \cdot 5 \times \frac{l}{2\sqrt{2}}$$

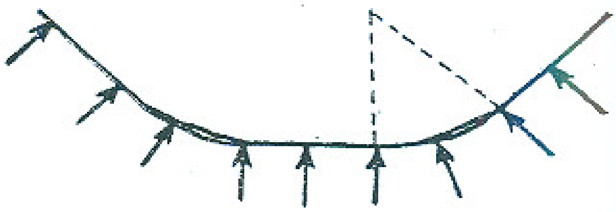
Or $\frac{w}{6}(h^3 - H^3) = \frac{W \cdot l^2 \times 1 \cdot 4}{8}$ where $W = 2w$ nearly and $w = 62 \cdot 5$ lbs/c.ft. & if l be $h/\sqrt{2}$ then $\frac{w}{6}(h^3 - H^3) = \frac{2 \times 1 \cdot 4}{8} \times w \times 2\,h^2 = \cdot 7\,wh^2$

OR $h^2 (h - 4 \cdot 2) = H^3$

Normally, $h = 13$ ft. then $(13)^3 - 4 \cdot 2\,(13)^2 = H^3$ or $H = 11 \cdot 4$ nearly.

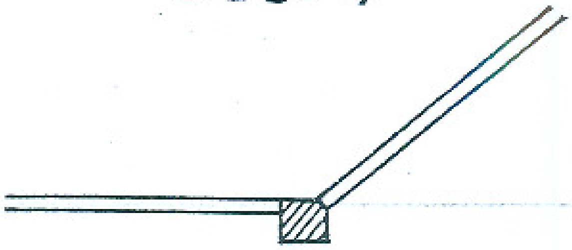
which means that lining will not be able to stand a head of more than 1·6 ft. If therefore water gets behind the lining either as a result of rainfall or wave action the lining will be pushed forward and will probably crack somewhere below the N. S. It is seen that the sides and bed are continuous, this might also result in water getting under the lining and the section would be subjected to stresses as per sketches and in addition to cracking the sides may also tend to lift the bed.

FIG. 3



It would therefore seem essential to (*a*) prevent water getting behind the lining, (*b*) to provide cut off between the bed and side so that neither the stresses nor the pressures on them are transmitted. This could be got by constructing bed and sides independently and providing a toewall as per sketch.

FIG. 4



To prevent water getting behind the lining, the lining should be sufficiently high so as not to permit waves over it. The height of the wave, apart from the force and direction of storm will be a factor dependent on the width of canal and the roughness provided by surface to kill the waves action.

No data exists nor are any instruments installed anywhere in the Irrigation Department at present to measure the intensity and direction of storms and it would be desirable to install a few anemometers to measure the same so that exact conditions in various tracts are known and correctly provided for.

It is considered that a 3 ft. free board should suffice. In the pond at Trimmu waves as high as 4 to 5 ft. are reported to have been observed.

Even if the waves get over, it would be necessary to provide a slope in the bank so that water be drained away rather than get behind the lining.

It would be preferable to keep the top of bank lower than top of lining. Where the canal runs through spoils proper drainage has to be provided by excavating drainage at the outer end and leading them out through gaps cut in spoils.

Further the provision of a berm at a level lower than the top of bank provides a place for storage of water before getting behind lining and prevents rainwater or wave water to be drained out.

With this object the dowel on the Haveli Canal was pushed onto the top of lining. If, however, a berm is desired to be kept it should be at a level higher than the bank top and should slope out.

With successive rains the cross slope on the top of bank may tend to disappear and ultimately as a result of settlement or otherwise, rain water may flow towards lining. To prevent water getting close to the lining and to provide reserve earth for making up settlements or regarding cross slopes a small pushta is also provided next to dowel. This incidentally keeps the motorists also well away from the dowel. A suitable bank Section is shown as figure IV plate II.

Bulging

The analysis of damage to lining in form of bulging, twisting, crumbling and slipping showed that initially when rain water or wave water fell heavily on the bank or berm it caused serious settlement. The puddle in the form of a parallelogram at back of lining as a result of this settlement shrunk and fell back causing segregation between the lining and puddle. With the next splash or gush of rain-water, water got behind the lining rose to very nearly top and with water in canal heaving due to waves a greater head than what the lining could stand was caused which moved the lining forward resulting in drop of water level behind it. This reduced the head and the lining fell back. The lining thus moved forward and backward.

When the lining moved forward some earth from back got washed into the cavity thus created and the lining could not completely return to its original sloped position.

Whereas the settlement and segregation probably occurred at one place the lining for some distance on the two sides moved forward as it was pulled by the reinforcement provided in the sides and thus the damage extended to a greater length than demanded by segregation. If there had been no reinforcement probably the portion actually segregated would have crumbled and avoided further damage.

When ultimately the lining fell back and found an obstruction under its lower end in form of slipped earth it cracked by its own weight and pressure of water on it. It may also be probable that lining being one continuous section covering both sides and bed found itself too inelastic to respond to the heaving and a crack appeared at the bottom of the bulge separating the top portion and permitting it to move forward and backwards independently. The reinforcement certainly did not permit localisation and increased the extent of area damaged when ultimately it became too big to move as one piece and cracked at the ends. It was noticed that where profiles existed in the lining sides the damage localised between the profiles, probably these provided an easier means of cleavage and were thus helpful. Where the cracks were wider or where the detached portion of lining found no support it slipped. Where the mortar was poor it crumbled, where earth got slipped at the back it bulged and so on. (See photgraphs.) Because of the continuity of section the damage became extensive otherwise it would probably not have extended so far down the depth and crack might have appeared higher up. The construction of bed and sides independently would therefore be definitely advantageous. It has been stated that no such damage occured on the Gang Canal. The damage on Haveli Main Line was also in two definite reaches. Plan of Haveli Canal (Plate III) shows that it could not be definitely stated that the direction of storm or wind had anything to do with it. One thing is however clear that the soil of reach 96,000 to 1,60,000 is good and contains sand. In this reach the banks have also shown no signs of settlement. The soil of Gang Canal is also stated to be good. May be that when water waves got out due to the good soil there was no settlement and no segregation and therefore no pressure behind lining. In any case good consolidation of banks behind or an independent support for lining is a matter which cannot be too well stressed.

It also points out clearly that the section should be statically sound and suitable to withstand the pressures that may come on to it if the bank recedes or water enters behind it. To prevent cracks subsequent to segregation and the lining functioning as a cantilever with the weight of water on it a steep side slope would be desirable as it would provide less weight and less moment arm against overturnings but to prevent water entered behind overturning the lining, a flatter side slope would provide more resistance due to greater weight and longer moment arm.

It is also a matter of consideration how in an unsupported section the weight of sides would be transferred over the curved section on to horizontal bed and if this would not tend to cause a distortion as shown and it would appear desirable to construct the sides founded on toe walls independent of and weighted by the bed.

FIG. 5

Capacity as Effected by Various Causes. Variations in Discharges Run.

The value of Kutter's N taken for purposes of design is ·016. The canal has however to transport silt laden waters and discharge carried varies between 770 and 5,249 cusecs in extreme cases. There is no fall on the canal nor is one available at the tail where it drops into Ravi. Heading up is required at various sites. Even where it tails into Ravi a constant ponding up always exists. This naturally would result in low velocities and tiled surface rather than getting its irregularities removed and its surface polished with higher velocities as designed gets fine silt deposited into the joints or pores over the surface of the tile. Apart from that insects grow and make the surface rough with coating of their shells and sticky matter. During cold weather the moss appears on sides. Kallar also appears in places and renders the surface rougher as a result of deterioration of top surface. All these factors combined result in a coating on surface giving different grades of roughness at different times. The value of N for different reaches has actually been varying from ·015 to ·025 and to reduce this range it would certainly be desirable to maintain proper velocities in lined channels and as such to reduce wide variations of discharges and to avoid heading up as far as possible.

Effects of Deposits of Sand

It would also appear that if even a small layer of sand existed on the bed of the canal the lined canal would be functioning with the material of a silted channel and therefore the rugosity factor would be same as of a *kacha* channel. Great care will therefore be necessary to see that there is no silt on the bed of the canal. On the Haveli Canal it so happens as would probably happen with most new canals that it passes through a belt of sand dunes and during storms sand is blown into it coarser particles of which cannot be carried by water and get deposited on the bed. This sand was found on bed both in June 1940 and April 1941 when canal was closed. Once sand has entered the canal it has got to be pushed out by creation of high velocities either by a combined silt ejector and escape or running higher supplies for a short period so as to cause a flush. These flushes can however be effective only in head reaches as they would flatten out towards the tails. Another alternative would be to run high discharges for some time till the silt is washed out.

Provision for Increased Capacity

It is reported that on the Gang canal also when higher supplies are run for the first time in the season the capacity is found to be out by as much as 25 per cent. but is gradually restored in about 15 days time. In the case of Haveli Canal this period for regain seems to cover nearly 2 months. As however Haveli Canal is mainly a feeder channel and there is no water in Ravi for the first two months this is also the period of keen demand when full supply must be passed. This also unfortunately is the period of storms forbidding great risks. It was worked out that with N=·02 the depths would need an increase as below

Reach	*2,000—20,000*	*20,000—63,000*	*63,000—130,600*	*130,600—tail*
Existing D ..	10′	12′	12′	12′
Proposed ..	11·5	13·75	13·8	13·85

It would thus seem that during early periods in order to pass full supply discharge water level in head reach may go up by nearly 2 ft. Lining was therefore raised by 2 ft. as per section *vide* Plate II Fig. V. As a measure of economy the top 3″ layer is cement masonry and bottom 3″ dry masonry sand grouted and joint with top of old lining clean. It rested on a trapezodial puddle core.

During 1941 at places the puddle backing which is resting on an unconsolidated portion settled in places and the raised lining also settled but the damage of this nature was not very extensive. The joint between the old and new work however cracked in long lengths but on the whole the section seems to have served quite satisfactorily. It certainly gives room for extra water to be passed but no margin during the storms which are frequent. If escapes were provided at the head of each bad reach immediate release could be provided and extra supply could then be safely run.

Effect of Insect Growth

It had already been expressed that there is a peculiar insect growth on the bed of the canal which probably plays an important part in the deterioration of the capacity of canal. These insects start disappearing when silt contents are increased and when temperature of water goes up. They have six legs, live in shells made out of their own secretions and particles of brick dust and sand either out of bed or mortar are found in considerable quantities in their shells. It has not so far been found possible to determine how to eliminate them but is a feature which cannot be overlooked and in any case it needs determination whether it is a feature of tiled lining or the location or lining in general. These insects are found in river also but no such insects are found in the same rivers at Khanki and Rasul and there seems to be no such trouble with Gang Canal.

It has been noticed that deterioration in capacity occurs practically from October to April or May—this seasonal phenomenon leads one to think that this probably coincides with general cycle of life of the insects found.

No remedies have so far been suggested or found as the question yet remains to be investigated but its importance cannot be too well emphasized as it is probable that they might not only become a permanent feature but lead to quicker deterioration of the lining.

Changes in Sections

The section of Haveli Canal changes several times as shown below. The velocities and F. S. discharge are also given for the various sections

Reach	*0—1,200*	*1,200—2,000*	*2,000—20,000*	*20,000—63,000*	*63,000—130,600*	*130,600—168,313*	*168,313—tail*
B.W. ..	175′	155′	115′	84′	75′	72′	71′
D. ..	12·0′	12·0′	10′	12′	12′	12′	12′
V. ..	3·32	3·12	4·23	4·59	4·59	4·49	4·54
Q. ..	7,452	6,250	5,249	5,244	4,747	4,486	4,478

FIG. 6
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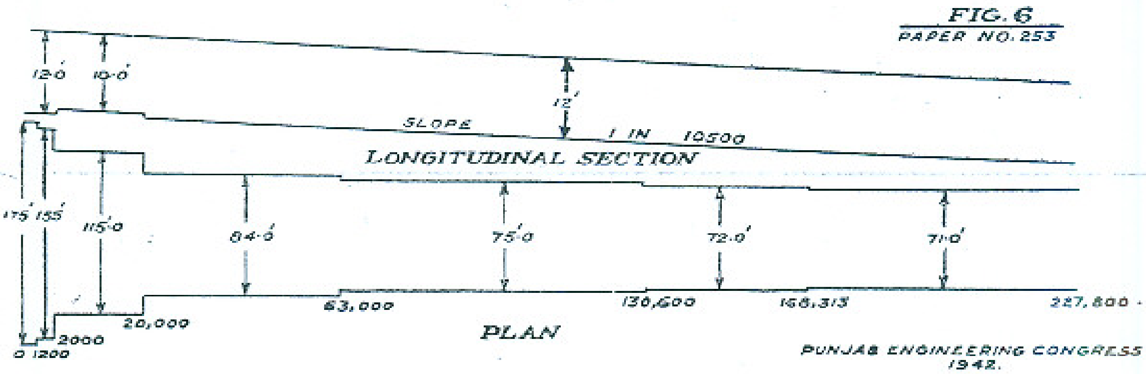

PUNJAB ENGINEERING CONGRESS 1942.

It would seem that the velocity increases in certain sections and if the water line were to be constant it would mean a jump in total energy line which is not possible and therefore afflux is caused at all these sites.

Reach 2,000 to 20,000 produces a hump and at low supplies it must therefore cause considerable afflux. Further these abrupt changes must cause a certain amount of afflux as explained below. Let OO′ be the supply line with no discharge off-taking at A and let depth (*d*) be the natural depth for this discharge for the section. If discharges in reach BA is increased to correspond to a depth D, there will be no drop at point A and water line would follow OLO′ and N. L. would measure the afflux.

FIG. 7
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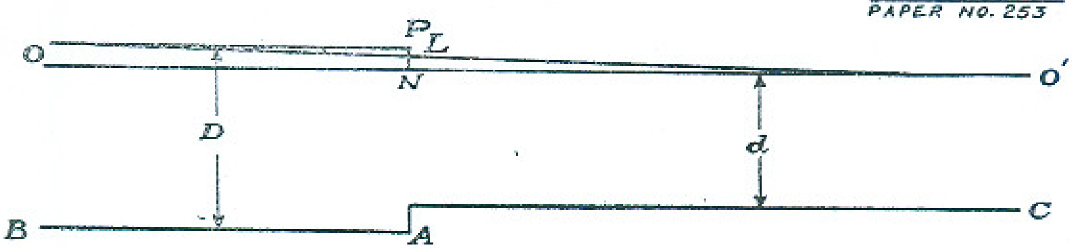

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In support of this it may be stated that when Silt Ejectors at R. D. 2,000 were first opened the same gauge at 2,000 would give lesser discharges for some time. This was due to the afflux as explained above, although it was wrongly considered at the time that capacity deteriorated by opening silt ejectors.

It would, therefore, seem desirable that design should provide decreasing velocities towards the tail and the changes in sections if there is to be no drop in water levels should be smooth and gradual and should cover about 500 Lft. of the channel so that transition is gradual and causes no afflux.

Raising of full supply levels in a canal may, however, not always be possible as it increases pondage at the Headworks also. It is therefore to be considered if a lined canal should not be initially designed wide enough to take full supply with $N = \cdot 02$ as it would give room for expansion without involving any risks, extra pondage or rise of levels. It certainly means more initial cost but would be better than raising of lining subsequently which had to be done both in case of Gang and Haveli Canal.

It is stated that the cost of lined canal decreases considerably with increase of depth as it reduces wetted perimeter width of land and spans of bridges etc. On Haveli Canal the cost of land per mile is R. 4,000 (against a lac—the cost of lining) being based on an average of Rs. 128 per acre and it is believed that on all new canals land being *banjar* would be cheap and would not be of any great consideration. Greater depth during low supplies is, however, a source of considerable nuisance would cause quicker deposits of silt increase in the cost of gates and difficulties of unwatering during closures. It would cut out the cost of a span or so in bridges but increase the height of piers, as such a mean has to be struck.

The discussion in the foregoing paras has shown that it is desirable to have sides and bed of the lining independently laid as the curved section is unsuitable from statical considerations. A trapezoidal section would therefore be better and if required it could be modified as per Plate IV to give the advantages of a curved section and with its defects eliminated.

Experiments in Repairs

The damage that occured to the lining on 20th June, 1940 involved very large area approximating 2,00,000 square feet. As has been seen the canal had been giving lot of trouble by not taking designed discharge and the tiled lining had been showing damage to the side slopes in different ways. Advantage was therefore taken of the repairs to try different types of lining to determine its suitability from structural and rugosity considerations.

It was originally intended to try a new material for the surface and repair the damaged portions in concrete laid at a slope of 1 : 1

without any form work. Experiments were therefore conducted with different water ratios and it was found that with the means available it was not possible to get a smooth surface.

Alternate Proposals

(*a*) *Precast system*

Alternate methods to obtain good surface finish without the use of form work were therefore considered. Different types of precast concrete units were proposed which could be laid one over and by the side of the other and concrete filled at the back. These consisted of (Plate V).

(*i*) Double faced blocks with lugs connecting the two faces.
(*ii*) Single faced blocks with solid legs to rest on the slope and thus to give an over all thickness of 6 inches.
(*iii*) Single faced blocks with perforated legs to permit free flow of concrete at the back.

These blocks could be precast in advance at leisure, thereby ensuring a good speed in execution and as smooth a surface as desirable. They could then be laid like masonry at the same time providing their own form work for concrete to be filled behind.

The proposal as finally adopted is shown on Plate V. The slope is first made up with puddle and when puddle dries up the slope is to be cement plastered carefully so as to give one plane. Percast concrete blocks $2' \times 1'$ with perforated legs are then built up in cement mortar after which reinforcement is threaded in and a lean concrete 1 : 4 : 8 filled at the back.

(*b*) *Proposals by the Concrete Association*

Two alternatives were also suggested by the Concrete Association and they consisted of laying $1 : 2\frac{1}{2} : 5$ concrete at a slope with the help of vibrators. The mix was to be comparatively dry and the use to vibrators worked with compressors would permit a smooth surface at the top. The second alternative that the Association recommended (Plate V) consisted of laying reinforced beams spaced on the slope 4 feet apart. These beams were strengthened by two more beams cast at site, one at the top and the other at the bottom so as to give a complete self supporting framework. This framework was then to be covered by $4' \times 3'$ slabs bolted on to these beams and the hollow left behind was then filled with puddle (See photographs).

During the course of repairs cement plaster was also proposed on a lined reach in about 6 chains length to see how the plastered surface behaved. At another place the tiled lining was given a wash of cement slurry. Where however the damage was small and the quantity was less than 100 c.ft., it was not considered advisable to try the repairs in concrete and such patches were repaired in ordinary tile masonry.

The detailed description and the difficulties experienced with each type are given in the paras below.

(*i*) *Precast Block Method :—*

The size of the block was kept $2' \times 1'$ so that the weight was just what a mason could handle. This required a large number of moulds. During the course of precasting the Concrete Association supplied a Vibrating Table and its use not only permitted a better progress but enabled a comparatively drier mix to be used which gave a very much better surface. The carriage of these precast blocks required careful consideration to avoid breakages in transit. All these blocks were finally transported by means of boats and this ensured minimum breakage. Before the concrete blocks could be laid on the slope, the puddle of the back filling was completed and cement plastered with a very lean mortar the object being that when concrete is filled at the back of the block it did not get mixed with earth or puddle filling behind. The plastering also enabled an accurate and true slope on the sides being obtained which was necessary to obtain uniformity and one plane at the surface. During the course of execution it was first attempted to lay 4 layers of blocks and to fill the concrete behind. The back fill was well wriggled and flowing concrete was poured to ensure thorough filling. The aggregate however seemed to be getting separated from water with wriggling. Part of the first day's work was dismantled to see how far the work was satisfactory and the bottom layers showed that between the top of concrete and the under-surface of the block 1 to 2 inches hollows existed throughout. Thereafter the blocks were laid in two feet layers and the mix kept relatively stiff, so that it could be stuffed into by wooden *chapties* and thus the concrete was forced to flow from behind one block to the other. Further dismantlings showed the process to be thoroughly satisfactory.

The normal practice adopted was that blocks were laid in two feet layers, concrete filled behind, another two feet layer laid and the process repeated till the patch was completely done. This permitted completion of a section before moving to the next and therefore avoided unnecessary shifting of the plant which would otherwise have become necessary if only a 4′ layer could be done in a day. The reinforcement was threaded from the sides and rested on the bottom member of the hollow leg as shown in Plate V. The staging for the work presented difficulty in the beginning but after a few days' trial was successfully solved by hanging planks from pegs driven at the top of the berms. These planks were sufficiently strong to permit masons and coolies to stand on them. During concreting operations the legs of the blocks laid permitted an easy staging and men could stand on them (See photograph).

Slab and Beam Method (*See photographs*)

It was originally intended to construct slabs $4' \times 3' \times 2''$ and in order to get a good surface it was intended to use the Vibrating Table.

The weight of an individual slab of this size was, however, of an order of about 4 maunds. Consequently the dimensions were reduced to $4' \times 1\frac{1}{2}'$. All these slabs were to be bolted to a 5″ wide beam and to permit proper cover round the bolt staggard blocks of the size shown were adopted.

Both the beams and slabs were cast close to the work as otherwise their heavy weight would not only have made carriage difficult but also caused breakages. Bolts were cast in the beams and were suitably placed to permit accurate bolting of slabs on to the beams. During the course of actual execution, the alignment of the beams called for a layout of higher degree of accuracy as unless the slopes were dead accurate not only would it be impossible to bolt the slabs properly but the slabs on bolting might be subjected to torsional stresses due to the 4 corners not being in the same plane.

The weight of the beams added further to this difficulty as they had to be kept hanging all the time on a slope without a substantial support at the bottom and if the work got delayed a displacement due to their own weight invariably necessitated a realignment. On a new work however this could be overcome by laying the bottom toewall in advance which would provide substantial support and casting the sloped beams in position and at correct distance and slope. This would necessitate greater clearance in the slab holes to permit their adjustment.

After the beams had been aligned, puddle was filled under them and also on the sides so as to leave no cavity and embed them completely. The bottom toewall was then laid at site. Thereafter slabs were bolted on to the beam. Due to the unevenness of the moulding platform the thickness of slabs was not and may not be exactly 2 inches, slabs at the end had therefore to be chiselled to give even surface at the top. Unless the moulds be very accurate and therefore very expensive, slight displacements of bolts in beams and holes in the slabs are bound to occur. Bending of bolts in beams or widening of holes in slabs had therefore to be done to fit them properly.

Plate V shows a groove running round the slab. The original intention was to grout the same with cement slurry by a grouting machine so that the adjacent slabs could be keyed in. This was, however, not found to be practicable and the grooves had to be filled in with cement mortar before laying and thus to perform the same function as the frog of a brick. As however it means jointing the previously set concrete slab by means of fresh mortar it is not likely to give a leak proof joint. The sucking of the moisture from the mortar was however reduced as far as possible by wetting the slabs for 24 hours before they were laid.

Before the slabs were laid the cavity behind them was to be filled with puddle. (See photographs.) It can, however, be seen that shrinkage of puddle fill behind is not improbable and the difficult nature of work may even result in cavities being left behind the slabs.

In case of shrinkage the slab would be required to withstand the water pressure over the entire 4-feet span and as filling starts right from the bed irrespective of excavation the maximum head may be 12 ft. A 2-inch slab would have to be heavily reinforced to stand it ($\frac{1}{2}''$ bars $2\frac{1}{2}''$ centres), but the cost of the reinforcement would be prohibitive. (Appendix B.)

Originally it was intended to provide rabbit wire reinforcement in the slabs, this however would not permit even the handling. The following reinforcement was therefore proposed.

Reinforcement

Bottom 6 slabs $\frac{1}{4}''\theta$ bars $4\frac{1}{2}''$ apart horizontally and $\frac{1}{4}''\theta$ bars 1 ft. apart vertically.

Next 4 slabs $\frac{1}{4}''\theta$ bars $6''$ apart horizontally and $\frac{1}{4}''\theta$ bars 1 ft. apart vertically.

Next 2 slabs $\frac{1}{4}''\theta$ bars $9''$ apart horizontally and $\frac{1}{4}''\theta$ bars 1 ft. apart vertically.

Due to the greater weight the complicated layout and nature of filling required the execution was not only a difficult but an expensive affair.

In Situ Work

Plate V shows the arrangement for laying the concrete on the slope. The concrete is proposed to be laid in 8 ft. bits at a time. Alternate spans have to be done up so that a joint could be got as shown in drawing.

The concrete mix is to be as dry as practicable and is to be laid at slope. A channel iron guide (See Section) carried two vibrators worked by a Compressor. These vibrators are like two small pneumatic rammers which transmit the ramming through the entire channel piece. The channel piece at the ends works in guides so that it cannot be lifted or lowered and gives uniform thickness and is pulled up and down by means of a winch over a pulley as shown in plate V.

The quantity of work done by this method was too small to warrant definite opinion on the difficulties encountered as opportunity to surmount them by further experience was not available. It was however found that with heavy vibrations the concrete started flowing and the period of vibration and water ratio of the mix had to be adjusted.

To provide for shrinkage and settlement subsequent to ramming the thickness of concrete had to be kept slightly more than 6 inches. Due to unequal settlement or unequal original thickness the channe iron guide got jammed or one end worked higher than the other. It was also found necessary to lay concrete uniformly over the entire span to the same thickness so that ramming of all area is uniform.

To obtain this it would be necessary to provide a bottomless chute which would also serve as gauge guide ahead of the channel iron and means should also be provided to spread the concrete evenly. This would mean that an exact 6-inch layer would be laid before the vibrator was pulled on to it.

The surface as given was however not found to be satisfactory and masons had to be employed after the vibrator had passed to smoothen it and properly finish it before the concrete was set.

Patches dismantled however showed that the concrete was well rammed and was not spongy.

The details at the joints are shown on Plate V which apparently can permit absorption. Further, it is probable that the lining piece $8' \times 20'$ might show temperature cracks and provide further cracks.

Comparative Costs

An analysis of rates is attached to show the cost of various types (Appendix A). For tile masonry it comes to Rs. 25-5 per 100 s.ft., for precast block system Rs. 56-10-0, for cost in situ work Rs. 67-4-0 and Rs. 98-3-0 for the beam and slab method.

To determine the relative advantages of the various types it would be necessary to analyse them and to judge them from the considerations of (*a*) ease of working (*b*) its water proofing qualities (*c*) the smoothness of surface and (*d*) its structural strength.

Ease of Working

From consideration of collection of material brick lining would be the easiest as normally bricks can be burnt all along the canals whereas ballast and sand is not easily available and has to be carried over long distances. For a concrete lining a number of mixers, pumps for washing ballast bins for stacking sand ballast, etc., would be needed which are not needed for a brick lining.

A brick lining would therefore be the easiest as it neither requires extensive working arrangements nor extraordinary mechanical organisation nor extraordinary skilled labour or material *bandobast*.

The precast blocks would come next as they would very nearly permit the same speed as brick lining. They further involve ordinary concreting operations and not much of skilled labour. Carriage of blocks would however call for a careful operation.

The cast in situ work would require more mechanical arrangements, due to the working of Vibrators. The proper jointing of adjacent spans would also need careful attention but otherwise no great skilled labour would be required.

The beam and slab method is likely to present maximum difficulties as the process is not only slow but would require la ge number of skilled labour and artisans for fitting. It would also need a number of precasting platforms along the work.

Water-proofing Qualities

As far as absorption is concerned the precast block system would provide the best mode of lining because, firstly, there is a cement plaster layer at the bottom, then there exists a mass of dense concrete with no joints behind the blocks and lastly the top surface of blocks being 1 : 2 : 4 concrete, provided an extremely homogeneous mass. The 1 : 4 : 8 filling behind would develop few temperature cracks. At the face the small size of blocks would restrict the temperature cracks to something too fine to be perceptible and the blocks being embedded in the concrete behind, there will be no possibility of through cracks to permit leakages.

The cast in situ work would come next, but due to its bigger size a span of 8′ × 20′—a number of through temperature cracks might appear. The joints between adjacent spans would provide a further source of weakness and if the concrete at any place were left spongy there is no plaster underneath to prevent loss due to absorption.

The defect in the brick lining is the existence of a large number of joints and a probability of a large number of them being left open in the execution of work or rendered open later due to settlement, etc. Further, the phenomenon of "weeping" observed on the Haveli Canal shows that soil in some reaches may permit porous bricks and the lining would not be so efficient. In any case the range of porosity in brick moulding can be very great.

As to the slab and beam method calculations (Appendix B) show that once a cavity is formed behind the slab it would be crushed due to water pressure and direct contact of water would be available with the backing.

The joints between adjacent slabs and the holes round the bolts would provide further places for cracks to develop and as such this type would not be so efficient.

Structural Strength

Appendix B gives calculations for various types and shows their relative strength in case of cavitation behind.

It would appear that the precast blocks give the best type as the reinforcement for same thickness could be placed very low also as the legs are spaced one ft. apart in case of cavitation, these points would provide weak spots and the adhesion between blocks and back fill concrete would try to give way and a big span would be avoided.

In the case of tiled masonry the reinforcement is placed at neutral axis and will come into play only when the lower layer has failed by which time some joints would have opened. Further, there are no cut-outs to limit the span and a bigger area is likely to be affected by any damage.

In the case of in situ work the span is 8 ft. and if each block is to behave independently suitable reinforcement will have to be provided. The disadvantage however is that there are no cut-outs and the weight of alternate spans will have to be taken by intermediate spans in view of the joints.

The slabs on beams are however very weak and so unsuitable to withstand any pressures, unless heavily reinforced.

Smoothness of Surface

The tiled masonry presents a very rough surface because of depressions caused by a large number of joints and a large number of pores existing in the top of brick. Unevenness caused by these permits deposition of fine silt and growth of insects. A precast concrete surface will naturally be very smooth. The concrete laid in situ does not give that smoothness of surface as a precast piece would give specially if it has been cast on a vibrating table.

A portion of the lining was cement plastered, another portion was given a wash of cement slurry to see if insect growth would appear. In April, 1941, it was seen that insects had grown on these plastered reaches although the growth was less. Whether it was due to plaster or insufficient time available for growth is a matter that yet remains to be seen. The reach given cement wash showed almost the same results but with further lapse of time the wash seemed to fade away.

It is not possible to judge the relative value of "N" as no one reach has been completely done up with any method nor is there a fall available on Haveli Canal to permit its being divided up into various reaches.

Unless a complete reach is taken up the tightest section where the material is roughest will control depths elsewhere too, and to obtain relative values of "N" it would be necessary to try independent complete reaches on distributaries between various falls by lining them with different material and observing values of "N."

Suitable Design for Lining

The object of a lined canal may be (*a*) to save excessive absorption (*b*) to permit lesser sectional area for same discharge or (*c*) to permit flatter slopes.

So far as saving of absorption losses is concerned a tiled lining with a sandwich of cement plaster saves most of it. The precast block type if used could cut out further absorption but as it will not be much it will have to be considered whether the extra absorption saved would be enough to warrant the heavy expense on concrete lining.

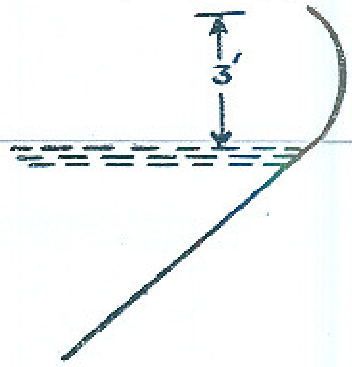
As the river supply in Kharif season is usually more than sufficient to permit even heavy absorption it would appear that lining for a non-perennial supply would not be an economical proposition. Due to its being closed for one season it would also not lead to water-logging and it might as well have to be considered if lined channels be not constructed for perennial capacity only. This would prevent wide variations of discharge and eliminate excessive heading-up.

Requirements for each case would be different and what suits one case may not suit another. The availability of materials locally is an important factor in determining the cost where the concrete is not very expensive it would be preferable as not only may it give smoother surface but would be more durable and lasting. Where however concrete is expensive the extra saving in absorption may not be enough to justify the heavy cost and a tiled lining would be as efficient.

It has been seen above that the cost of land will not be of any great consideration as it may not be an expensive item on new canals.

Experiments on large scale and on a number of distributaries are necessary to determine the relative value of N for various material after which alone it can be possible to say as to what gives the cheapest type under same conditions.

FIG. 8



The smoother the surface of a lined channel the higher will be the waves during storms. T prevent waves getting over the lining various alternatives of roughening the free board portion should be tried. It may be provided by odd bricks projecting out or giving the top a profile a shown in the margin so as to break the waves. In any case the free board should be ample and on main canals be not less than 3 ft.

It has already been stressed that the earthwork on which lining is to rest should be a self-supporting puddle bank. As a further factor of safety the lining should be of a section which should be self-supporting. The first essential ist hat the bed and sides should be independent and the sides should end on a toewall. Below N. S. there is no probability of any water pressure being exerted on to lining as there can be no cavity. Above N. S. the settlement of banks should be provided for in the design. Apparently no reinforcement is needed in the bed or he side slopes up to N. S. and the thickness of lining could also be reduced by using thinner tiles (which may be only 2" thick). Above N. S. the lining should be designed to take the pressure as even in case of wash-outs, *gharas* settlements breaches or cavities behind, the lining should be able to stand independently. To get this construction of intermediate profiles is first necessary to limit the span on which pressure be exerted at a time. Thereafter the slab be designed to withstand water pressure on it and to get the maximum utility out of reinforcement, it should be placed as low as possible.

Appendix C shows calculations for a lining up to 6 ft. depth above N. S. Supports can be provided at 8 ft., 6 ft. or 4 ft. and in form of triangular masonry profiles which are self-supporting. Between these spans the lining is self-supporting. The reinforcement is at the bottom and is embedded between the plaster and the tile which can have a groove moulded to take it. With a steep side-slope the cost of profiles would be lesser. The design however will have to be determined in each case from considerations of relative costs of various materials.

From observation made so far it would appear that a tiled lining designed with value of N=·02 and as per section in Plate VI may be the most suitable. The dowel is on to the edge of lining and the top of bank is lower than the top of lining and slopes out.

It would be seen that extra cost in this type is only for the profile walls and reinforcement provided above N. S. It is however easy to see that due to decreased thickness of tiles the total quantity per ft. run inspite of profile walls and a wider section due to increased value of N (·02) would be very nearly the same. The reinforcement having been omitted from the bed and sides below N. S. the total cost on this score would also be lesser than the Haveli type.

The main thing that saves the absorption is the thick cement plaster layer and all that is further needed is a cover, tiles providing the cheapest stuff. The cost of masonry profile per mile would be Rs. 7,000 nearly as compared with nearly a lakh per mile for the Haveli type lining.

If a smooth service was a great necessity it might as well be considered if precast concrete sets 2′×1′×·1 could not be laid in place of top tile over the sandwich layer. In the bed the size could be increased to 2′×2′.

Precautions for Brick Lining

As it appears that brick lining may be the type to be mostly adopted it would not be out of place to mention some of the precautions necessary for this type of work. Mention has been made of a useful note prepared by Mr. B. R. Lamba on the subject. The Committee that inspected the lining in December, 1939, also made useful recommendations. The author in addition to his personal observations has drawn on the above in formulating the necessary precautions to be taken.

It has been noticed that nature of soil differs from place to place. Analysis of soil made of a random pit in the brickfield can be no proper guide. It is therefore necessary to test the pits twice a week so that if any pits are found to be defective the bricks be not loaded rather than be burnt and rejected.

The work of brick burning must proceed well ahead so that there is no undue haste and bad material does not come in. Overburnr stuff is preferable to underburnt or *pilla* stuff as it would stand weathe effects better.

Water arrangements on work should be ample so that bricks are well soaked and to cover for the neglect of labour number of tanks and period of soaking be doubled than normally necessary. To ensure good sand supply it is advisable to have it carried from river, as good sand is seldom available in sufficient quantities locally and the labour and contractor are forced by circumstances to be dishonest. It has also been suggested that dry mortar—sand and cement be mixed at a central place mechanically and then supplied in bags. This would ensure proper quality of sand and proper ratio of mix and uniformity of mortar.

On a large work fool-proof methods are absolutely essential to be devised to control proper quality and to ensure proper quantity of material going into work.

A great difficulty about mortar is that to get easy mix, more water is added to it and then it is left in the pan for a long time and water appears in it which leaves the rest of mortar poor. To guard against this the mortar should be relatively stiff and instead of using mortar pans the masons be made to use plain iron sheets which wil ensure that mortar is kept sufficiently stiff as otherwise it may start flowing.

Works Executed

The following is a summary of works so far considered necessary to be executed on the Canal :—

Name of work	*Amount*
	Rs.
Making gaps in spoils	8,000
Shifting Dowels	21,500
Consolidating banks by digging trench	1,47,500
Repairs to Lining and grouting open joints ..	{ 11,000
	{ 1,08,500
Cement plastering bed of canal and cemént slurry ..	4,500
Fixing iron ladders	4,500
Raising pitching and lining	2,05,000
Total ..	5,10,500

General

Plantation Avenue

It has often been seen that the roots of the trees have been piercing the steinings of wells or other *pucca* structures. If the roots of plantation were to pierce the lining not only would there be an increase in the absorption losses but serious cracks may appear which in turn may seriously affect the stability of the lining. With this object it became necessary to ensure that the plantation as put in would be safe. The normal practice of planting trees is shown on Plate VI and was being followed on the Haveli Canal also. In this case there is a drain at the end of petrol bank in case of spoils and there are pits at other places and trees are normally planted on the outside of these drains and pits. Mr. P. N. Deogan, Divisional Forest Officer, Chichawatni was invited to advise on the matter of plantation along the lined canal. The roots of the existing trees were traced in the bank and it was found that they were running towards lining within even 3 inches of the top of the bank. Enquiries showed that the plants were being watered every alternate day. Mr. Deogan considered that the plants were getting a very shallow watering and as the duration between two waterings was small the sucker roots found moisture near the top of the banks and had not to exert to go down hunting for the same. Consequently, the main sucker roots were developing near the top of the bank and the pits and the drain retaining moisture being on the canal side, these sucker roots had been directed towards them and thereafter during periods of draught ran towards the lining behind which some moisture was always available. As such, in course of time all the roots of the trees would develop towards the lining and damage it. He suggested that pits or drains should be dug on the far side and heavier waterings given at longer intervals. This would cause the roots to run after the water as it percolated into the sub-soil and the pits being away they would cause the roots to deflect away from the lining and would therefore cause no anxiety.

Life-Saving Devices

The depth of water in this canal is 12 feet and is likely to be of the same order in many lined canals. After the canal was opened a a number of casualties took place. If any body per chance went in he had no means to come out, a number of cattle also got drowned. The velocity and the depth were great. It was therefore decided to fix iron ladders every half mile apart on both sides to help those fallen to get out. It cannot be said as yet how far this is helpful. For a benumbed man this seems useless. In addition a dowel two feet high has been proposed and it is anticipated that this will prevent cars, bicycles, etc., running into the canal. As a further measure of safety a small *pushta* close to the dowel as per Plate II has been added so as to keep the traffic well away from the canal. This canal does not run through populated areas at present but measures of this nature will have to be provided on all lined canals and where they pass through thickly populated areas it may become necessary to provide some sort of fencing close to the dowel to prevent people or cattle falling in. A more desirable type would be as shown in Plate VI. Fencing posts could be fixed in each masonry profile and top of lining finished flush so that any rain water or wave water is actually drained out. The dowel would be eliminated and inspection made easier as with a 2-ft. dowel at present the canal cannot be properly seen.

If odd bricks were to project out in the free board portion this in addition to cutting the waves would provide means for support for a drowning person to come out.

Close to bridges it would however be desirable to provide steps in the canal, which is not done at present. This would permit cattle to come out for which no means exist at present.

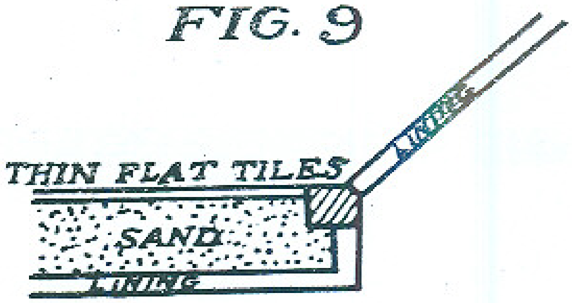
Silt Exclusion

It has already been pointed out that the canal capacity would be reduced if there were even a fine layer of silt on its bed. It was therefore necessary to provide a device for excluding the heavier silt which may not be carried by water. Two Silt Ejectors have been provided in this canal and a scheme of silt ejectors would probably be a necessary corollary to a lined canal. There would be no necessity for any growth of berms on the canal itself but unless all the Distributaries were also lined, silt would be wanted for the growth of berms of the off-taking channels. Apparently the two requirements are of opposite nature and therefore the growth of berms would be slow. With the object of economising in land on Haveli Canal channels deep borrow pits were put in the bed of the channels thinking that they would silt up in course of time. As the progress of silting will naturally be slow, it seems necessary that this fact should be kept in mind when designing distributaries in filling and bad reaches.

Spring Levels

The spring levels in the head reach of the canal are generally higher and after the canal is opened they tend to rise further on account of ponding up at the Headworks or seepage from the canal itself. Lest the high spring levels during periods of low supplies should cause an uplift of the bed of the lining two sets of gates as previously stated have been provided at 20,000 and 35,000 to hold up necessary depth of water. Constant depth of water on the bed of canal however is a perpetual nuisance as it neither permits any repairs if necessary to the bed nor closing and unwatering of canal in this reach in case a serious accident occurred. With the present system a mistake in regulation on part of a gauge reader might damage the lining. A fool-proof method of providing against lift would therefore appear necessary. In lower reaches, it might have proved economical to dig the bed deeper, to line the bed with 6″ layer, fill it up with sand to 3″ below designed bed level and then provide a flat tile on the top. This would mean a cheap gravity section. In the head reach to avoid seepage from the canal itself it may be desirable to line the entire channel. An alternative has been suggested to keep a longer length of the channel in the head reach unlined but this seems to be moving in a vicious circle because the sub-soil reservoir up to the start of lined reach would be definitely fed by supply levels of the canal for a longer reach. The rise in sub-soil would therefore be quicker in the

FIG. 9



upper reach and may rise ultimately to such an extent as to cause uplift pressures under the lined reach lower down unless a good deep cut-off was provided under the upstream end and sides where the lining started.

Leaving the head reach unlined would also add to absorption considerably.

A better alternative might be to have a deep seepage drain on both sides of the canal in this reach which may drain lower down into any of the syphons but which would prevent the rise of the sub-soil under the lining itself. It was proposed to put in filters about 40 feet apart in the bed of the canal with flaps on top so as to afford a pressure relief when the canal was closed. The investigations in Irrigation Research Institute however showed that the relief was not substantial and therefore this proposal could not suitably work. Another alternative would be to provide a number of deep longitudinal walls and to design the floor as a reinforced slab to withstand the pressure in the various reaches.

There has been practically no rise in spring level under the lined canal except in the head reach which is under the influence of pond, at Trimmu.

Conclusions

No one lining could be considered efficient or cheap under all circumstances and the cost of each will depend on the local availability of material and other conditions.

A brick lining would seem to cut off absorption losses and being the simplest would however generally be most satisfactory. The value of "N" taken in design should however not be less than ·02.

To determine the relative value of "N" for various materials, experiments are necessary on complete reaches between adjacent falls on distributaries which should be lined with the different type of material to be tested.

Investigations are also required to be carried out to find out how insect growth on the bed of canal can be stopped.

A lining design should provide for a good free board which should be of an order of 3 ft. for main canals. Above the N. S. the lining design should be statically sound and be able to withstand water pressures even without a backing. Below N. S. level however a good thick plaster layer sandwiched between the two layers of thin tiles would be quite satisfactory and no reinforcement is needed in this portion. The section should be trapezoidal and sides and beds constructed independently. Lined canals are necessarily dangerous therefore life saving devices should be well provided for. It is not advantageous to spend on lining for non-perennial requirements and variations in discharges on lined canals should be reduced to minimum. Provision for silt exclusion is a necessary feature of a lined canal.

Changes in section should be gradual and the transition should be provided in a 500 ft. length at least.

The design should provide for decreasing velocities towards the tail.

On new works sufficient arrangements should exist for analysis of soil used for making bricks and brick burning should advance well ahead of the work.

It is preferable to supply mixed dry mortar on work to ensure uniformity of mix and quality of sand. Surface drainage of banks should receive consideration and the dowel should be on the edge of lining leaving no berms. The puddle core on which lining rests should be of a self supporting section.

The plantation should get deep and delayed watering and the pits should be on the far side so that the sucker roots are deflected away from the lining, and tend to go down into the subsoil.

Considering the heavy absorption that is cut out the lining provides an important measure against water-logging and deterioration of soil. The benefit combined with the fact that with water thus saved further areas can come under irrigation adding considerable to the revenues of Government and prosperity of country makes it an all important measure to be gradually adopted for all canals, specially when it is realised that one cusec saved for a year means Rs. 1,000 to Government and about Rs. 4,000 to the Zamindars.

Acknowledgements

The author has drawn on the recommendations of the Committee appointed to report on the behaviour of the lining as previously mentioned and the note submitted by Mr. B. R. Lamba. He is also indebted to the guidance received on the subject from Messrs. Lyster and Garg. Acknowledgements are also due to Mr. B. S. Talwani who assisted in the preparation of the data.

APPENDIX "A"

	Labour Rs. a. p.	Material Rs. a. p.
(1) Cement concrete precast block 1 : 2 : 4		
90 c.ft. stone ballast ½″ at Rs. 12% ..	..	10 13 0
90 c.ft. washing ballast at As. 12% ..	0 11 0	
45 c.ft. supplying clean sand at moulding platform at Re. 1% c.ft.	0 7 0	
18·2 bags cement at dump at Rs. 2-4 cwt.		40 15 0
Labour for fixing and removing moulds at Rs. 26%	26 0 0	
100 c.ft. carriage of blocks average lead 6 miles @ Rs. 5-14% ..	5 14 0	
Cost of mould depreciation etc. (cost of one mould Rs. 18 life 2 years) ..	2 0 0	3 0 0
M. S. Bars untested and binding wire (12 l.ft.) at 1·126 lbs. per block=3 cwt. at Rs. 14 cwt.		42 0 0
Bending and binding etc. 3 c.wt. @ Rs. 2-4 cwt. (untested) ..	6 12 0	
Oiling and greasing moulds ..		1 0 0
Cost of moulding platform (central to feed 10 miles)		0 12 0
	41 12 0	98 8 0
	Rs. 140-4% c.ft.	

	Labour Rs. a. p.	Material Rs. a. p.
(2) Block masonry :—		
100 c.ft. precast face blocks as above	41 12 0	98 8 0
2 bags cement at Rs. 2-4-0 per bag ..		4 8 0
2 bags carriage of cement lead 6 miles @ Re. 0-1-6 per bag	0 3 0	
Labour for precast masonry ..	18 0 0	
7·5 c.ft. supplying sand including 4 miles lead Rs. 5-10% c.ft. ..	0 7 0	
Scaffolding		0 8 0
	60 6 0	103 8 0
	Rs. 163-14% c.ft.	

	Labour			Material		
	Rs.	a.	p.	Rs.	a.	p.
(3) Cement concrete 1 : 4 : 8 without reinforcement :—						
75 c.ft. ballast 1″ at Rs. 10% c.ft. ..				7	8	0
21 c.ft. ballast ½″ at Rs. 12% c.ft. ..				2	8	0
96 c.ft. carriage of ballast average lead 6 miles at Rs. 5-14% c.ft. ..	5	10	0			
48 c.ft. supplying of sand including 4 miles lead at Rs. 5-10 ..	2	11	0			
96 c.ft. washing ballast at Re. 0-12-0%	0	12	0			
10 bags cement at Rs. 2-4-0 cwt. ..				22	8	0
10 bags cement carriage lead 6 miles at Re. 0-1-6 per bag	0	15	0			
100 c.ft. labour for 100 c.ft. machine mixed concrete for superstructure including wriggling @ Rs. 5-8% c.ft.	5	8	0			
Bin for 150 c.ft. material=75 s.ft. or 19 c.ft. D. B. Work at Rs. 5% ..	1	0	0			
Cost of working mixers and pumps (progress 600 c.ft.)				4	4	0
Petty items	0	8	0			
Scaffolding	0	8	0			
	17	8	0	36	12	0

Rs. 54-4-0% c.ft.

	Labour Rs.	a.	p.	Material Rs.	a.	p.
(4) Cement concrete 1 : 2 ½ : 5 precast work slabs and beams :—						
92 c.ft. stone ballast ½″ at Rs. 12% c.ft.				11	1	0
92 c.ft. washing ballast at As. 12% c.ft.	0	11	0			
46 c.ft. supplying sand including 4 miles carriage @ Rs. 5-10% c.ft. ..	2	9	0			
15·3 bags cement at Rs. 2-4-0 c.wt. ..				34	7	0
15·3 bags cement carriage 6 miles at at As. 1-6 per bag	1	7	0			
92 c.ft. ballast carriage 6 miles at Rs. 5-14 % c.ft.	5	6	0			
Labour for moulds	16	0	0			
Carriage of moulds as per analysis @ Rs. 2/-	2	0	0			
Oiling and greasing moulds at Re. 1 ..				1	0	0
100 c.ft. carriage of beams and slabs within 1 mile at Re. 1 % c.ft. ..	1	0	0			
Cost of moulds at Rs. 10 } ..	10	0	0			
Repairs to moulds at Rs. 2 } ..	2	0	0			
Moulding platform for slabs to be used every 10 days and ordinary plaster for beams to be cast along side work	6	0	0			
Bins for 150 c.ft. material 75 s.ft. or 19 c.ft. D. B. work at Rs. 5 % c.ft.	1	0	0			
Cost of working mixers and pumps (progress 300 c.ft. restricted work)	8	8	0			
	56	9	0	46	8	0
	Rs. 103-1-0 % c.ft.					

	Labour Rs.	a.	p.	Material Rs.	a.	p.
(5) Tiled masonry without reinforcement :—						
800 No. tiles at Rs. 16 ‰ ..				12	13	0
Carriage of tiles average lead 1½ miles @ (Rs. 1-10-0 + 0-10-0)+25% = Rs. 2-13-0	2	4	0			
4·9 bags cement at Rs. 2-4-0 per bag..				11	0	0
Carriage of above lead 6 miles at As. 0-1-6 per bag	0	7	0			
24 c.ft. sand including 4 miles carriage at Rs. 5-10-0 % c.ft.	1	6	0			
Labour at Rs. 8-8-0 % c.ft. ..	8	8	0			
Allowance for scaffolding and replacing timber				0	8	0
	12	5	0	24	5	0
	Rs. 36-14-0 % c.ft.					

	Labour Rs. a. p.	Material Rs. a. p.
(6) Cement concrete 1 - 2½ : 5 by vibrators :		
92 c.ft. stone ballast at Re. 1 % c.ft.		9 3 0
92 c.ft. washing ballast As. 12 % c.ft.	0 11 0	
46 c.ft. sand including 4 miles carriage @ Rs. 5-10-0 % c.ft.	2 9 0	
15·3 bags cement at Rs. 2-4-0 ..		34 7 0
15·3 bags carriage of cement @ As. 1-6 per bag	1 7 0	
92 c.ft. carriage of ballast 6 miles at Rs. 5-14-0 % c.ft.	5 6 0	
Labour for concrete of superstructure	5 8 0	
Bins for 150 c.ft. material=75 s.ft. or 19 c.ft. D. B. Work at Rs. 5% c.ft.	1 0 0	
Profile wall 8 ft. apart constructing and dismantling 25 c.ft. at Rs. 16% c.ft.	4 0 0	
Labour to work vibrators progress 400 c.ft. daily due to restricted work, 2 masons and ~~8~~ skilled coolies for working the guide and vibrators, 2 masons to finish	2 12 0	
Cost of working pumps and mixers ..	6 6 0	
Cost of working compressors ..	5 0 0	
Petty items	0 8 0	
Scaffolding and staging	0 8 0	
Repairs to vibrators, frame work and its holding	2 8 0	Life of vibrators is not known but framework cannot stand long. Two vibrators are required in each frame work
	38 3 0	43 10 0
	Rs. 81-13-0 % c.ft.	
(7) R. C. Concrete 1 : 2½ : 5 in situ As per 1 : 4 : 8;	17 8 0	36 12 0
Plus 5·3 bags at Rs. 2-4-0 bag ..		11 15 0
5·3 bags carriage 6 miles at As. 1-6 bag	0 8 0	
Shuttering at Rs. 2	2 0 0	
	20 0 0	48 11 0
	Rs. 68-11-0 % c.ft.	

Rates for 100 s.ft. different types.

	Rs.	a.	p.
(1) 100 s.ft. tile masonry :—			
100 s.ft. 100 × ½ = 50 c.ft.			
50 c.ft. tile masonry at Rs. 36-14-0 % ..	18	7	0
35 lbs. % s.ft. reinforcement at Rs. 22 c.wt.	6	14	0
	25	5	0 % s.ft.
(2) 100 s.ft. Block masonry :—			
100 s.ft. masonry of blocks, 50 No. blocks + C. C. 1 : 4 : 8 = 33·5 c.ft. or 16·5 c.ft. precast + 33·5 c.ft. concrete 1 : 4 : 8			
16·5 c.ft. precast concrete at Rs. 163-14 % c.ft.	27	1	0
33·5 c.ft. cement concrete 1 : 4 : 8 at Rs. 54-4-0 % c.ft.	18	3	0
100 s.ft. cement plaster @ Rs. 4-8-0 % s. ft.	4	8	0
35 lbs. reinforcement at Rs. 22 c.wt. ..	6	14	0
	56	10	0 % s.ft.

Beam and slab masonry

Detail for 100 ft. length :—

Area = 100 × 18·33 = 1833 s.ft.

Material required :—Beams 26 No.

Slabs 300 No.

Top beams 100 × 5/12 × 13/12 = 45 c.ft.

Bottom = 100 × 10/12 × 6/12 = 42 c.ft.

100 × 6/12 × 7/12 = 15 c.ft.

57 c.ft.

45 + 57 = 102 c.ft.

Reinforcement :—

Beams ⅜″ bars at 0·376 lbs.

B_2 = 2 × 2 × 18½ = 74 × 26 = 1924

Dowel bar 1 × 6 = 6 × 26 .. 156

3 × 4½ = 13·5 × 26 .. 351

B_1 4 × 111 .. 444

B_3 5 × 111 .. 555

3430 @ 0·376 lbs. ft. = 1290 lbs.

¼″ bars at 0·167 lbs. ft. (stirrups.)

B_1 208 × 3·6 = 728′

B_2 26 × 34 × 3 = 2652′

B_3 208 × 4 = 832′

4312 at 0·167 = 703 lbs.

Slab ¼″ dia.

7,500 l.ft. at 0·167 .. .. 1253 lbs.

Total .. 3246 lbs.

= 29 cwt.

Bolts and nuts with washers including wastage	650 Nos.			
		Rs.	a.	p.
Total cost for 1833 s.ft. of work				
26×5+300=430 c.ft. R. C. concrete 1 : 2½ : 5 precast work at Rs. 103-1-0 % c.ft.		443	3	0
102 c.ft. 1 : 2½ : 5 concrete in situ @ Rs. 68-11 % c.ft.		70	1	0
29.0 c.wt. reinforcement at Rs. 22 c.wt. ..		638	0	0
650 No. bolts and nuts with washers at Re. 0-2-6 each		101	9	0
5 c.ft. concrete 1 : 2½ : 5 plain for remaining portion of beam at Rs. 68-11-0 % c.ft. ..		3	7	0
		1,256	4	0
For $\frac{100 \text{ s.ft. Rs. } 1{,}256\text{-}4\text{-}0 \times 100}{1833}$ ..		68	9	0
Wastage 5%		3	7	0
Extra puddling at the back 100×⅓=33 c.ft. @ Rs. 10		3	5	0

Beam slab masonry

Labour as per actual operation	18	0	0
Material	2	0	0
Contractor's profit if worked out through contractor	2	8	0
0.17 bags cement at Rs. 2-4-0 per bag As. 6	0	6	0
0.5 c.ft. sand including 2 miles carriage at Rs. 3-14 % c.ft.			
	98	3	0 % s.ft.

Concrete by vibrators

100 s.ft. area

50 c.ft. cement concrete by vibrators Rs. 81-13-0 % c.ft.	40	15	0
Reinforcement for top and bottom beam 0·5 c.wt. at Rs. 22 c.wt.	11	0	0
Concrete 1 : 2½ : 5 in reinforcement 9 c.ft. @ Rs. 68-11-0 % c.ft.	6	3	0
35 lbs. reinforcement at Rs. 22 c.wt. ..	6	14	0
Painting and jointing Rs. 2 per joint $\frac{2}{1{\cdot}6}$ ..	1	4	0
Pipe lines, hoses etc.	1	0	0
	67	4	0 per % s.ft.

APPENDIX "B"

Relative strength of Tiled, Precast block and slab lining.

Precast block

Lining F C = 800 lbs/□″
F S = 18,000 lbs/□″

$$\frac{n\,d}{d} + \frac{1}{1+\frac{t}{mc}} = \frac{1}{+\frac{18000}{15 \times 800}} = \frac{1}{1 + 1{\cdot}5} = 0{\cdot}4$$

$$M_t = FS.T_S \frac{(d\text{-}nd)}{3} = 18000 \times {\cdot}05 \times (4\tfrac{1}{2}) \times \tfrac{7}{8}$$

$$= 900 \times \frac{31\tfrac{1}{2}}{8} \text{ in lbs} = 3600 \text{ in lbs. nearly.}$$

To withstand 6 ft. pressure span required will be determined as below :—

Pressure at 6 ft. depth = 375 lbs. /□′ ft.

$$M/\text{ft width} = \frac{375 \times l^2}{8} \times 12 \text{ in lbs.} = 3600.$$

$$\therefore l^2 = \frac{3600 \times 8}{375 \times 12} = 6{\cdot}4$$

$$l = 2{\cdot}5$$

Tiled lining.

FS = 450 lbs./□″
FS 18000 lbs./□″

$$n = \frac{1}{1 + \frac{18000}{30 \times 459}} = \frac{1}{1 + \frac{4}{3}} = {\cdot}42$$

$$Mt = Fs \times ts \times ld = 18000 \times .05 \times 3 \times \tfrac{7}{8} = 2363 \text{ in lbs.}$$

To withstand 6 ft. head of water span required will be determined as below. M/ft width $+ 375 \times \frac{l^2}{8} \times l^2$ in lbs. = 2363 or say 2400 in lbs.

$$l^2 = \frac{2400 \times 8}{12 \times 375} = \frac{64}{15} = /\ \overline{4{\cdot}2} = 2 \text{ ft. nearly.}$$

Slab Lining

Span 4 ft.

In this case $M_t = f_s . t_s . j_d = 18000 \times 0{\cdot}05 \times \frac{12 \times 2}{9} \times \frac{7}{8} = 2100$ in lbs. If the pressure that the slab can withstand is h ft. or $\frac{125}{2}$ h lbs.□′ ft. then $M = \frac{125\ h}{2} + \frac{16}{8} \times 12$ in lbs. = 2100 in lbs.

$$\text{or } h = \frac{2100 \times 8 \times 2}{12 \times 16 \times 125} = \frac{7}{5} = 1{\cdot}4 \text{ ft. against 6 ft. required.}$$

This means that with a pressure of more than 1·4 ft. and cavitation behind the slab will break.

Reinforcement for 2″ thick slab with span 4′ and head 12′

$Mt = 18000 \times ts \times \frac{7}{8} \times {}^5/_4$

M due to 12′ head $= \frac{125}{2} \times 12 \times \frac{16}{8} \times 12 = 18000$ in lbs.

$$\therefore ts = \frac{18000 \times 8 \times 4}{1800 \times 7 \times 5} = 0{\cdot}92\square'' \text{ i.e. } \tfrac{1}{2} \text{ and bars } 2\tfrac{1}{2}'' \text{ apart}$$

APPENDIX C.

Detail of reinforcement for 6″ tiled lining with spans 4′, 6′, 8′ and head 1′ to 6′ Plate VI.

Head in feet.	4 feet span.		6 feet span.		8 feet span.		REMARKS.
	Bars	Spacing	Bars	Spacing	Bars	Spacing	
1	2	3	4	5	6	7	8
1	$\frac{1}{4}''\ \theta$	1·0′ centres	$\frac{1}{4}''\ \theta$	1·0′ centres	$3/8''\ \theta$	8″ centres	Fs=18,000 lbs. per square inch.
2	$\frac{1}{4}''\ \theta$	1·0′ centres	$\frac{1}{4}''\ \theta$	6″ centres	$3/8''\ \theta$	8″ centres	Fc= 450 lbs. per square inch.
3	$\frac{1}{4}''\ \theta$	8″ centres	$3/8''\ \theta$	8″ centres	$3/8''\ \theta$	6″ centres	m= 30
4	$\frac{1}{4}''\ \theta$	8″ centres	$3/8''\ \theta$	8″ centres	$\frac{1}{2}''\ \theta$	8″ centres	
5	$\frac{1}{4}''\ \theta$	6″ centres	$3/8''\ \theta$	6″ centres	$\frac{1}{2}''\ \theta$	6″ centres	
6	$\frac{1}{4}''\ \theta$	4″ centres	$\frac{1}{2}''\ \theta$	8″ centres	$\frac{1}{2}''\ \theta$	6″ centres	