PAPER No. 344

A Stable and Impervious Lining for Canals of West Pakistan

By

NAZIR AHMAD* AND ABDUR RAZZAQ†

1. Synopsis

The subject of canal lining has acquired an international importance. More than once, it has been discussed by various world organizations. However, problem of Pakistan, in this regard, differs slightly from those of other countries. In our country because of the nature of the underground formation, waterable is continuing to rise and so the lined canal have to be protected against uplift pressure of water, pores pressure of the soil on sudden closure of the canal and the revages of floods. Large temperature variation, possibility of fungus formation increasing the rugosity co-efficient necessitating ample provision of free board unprecedent dimensions of canal are a few other problems which require intimate attention. As to the material of construction for this purpose, bricks or tiles seem to be the only easily available with which all our lining projects have to be completed. The experience in the Research Institute on the application of the suitable type of materials for canal lining in this country is discussed. Due to the vastness of this subject, a fairly detailed bibliography on the subject is given at the end.

2. Introduction.

During the recent years the subject of canal lining has been discussed more than once at various International meetings. It was also a subject of discussion at the 4th meeting of International Association for Hydraulic Research held in Bombay in 1951 (1). The same year, the International Commission on Irrigation and Canals (2) which was later renamed International Congress on Irrigation and Drainage, discussed the same subject at its first meeting held in new Delhi. At the third meeting of this Congress held in San Francisco in 1957, canal lining came up again for discussion. (3) Twenty-One papers were submitted by twelve member countries and the subject was discussed in great details.

---

*Physicist.

†Research Assistant, Irrigation Research Institute, West Pakistan, Lahore.

The United States has quite a few lining projects and naturally it (7,8) has produced several publications on this subject, which constitute a treasure-house of information. Of these, the publications of the Bureau of (4, 5, 6) Reclamation are more useful and instructive for those seized with this problem. This country has not in any way lagged behind in giving useful information on the subject at the international meetings (1, 3,) and even at home there are seven contribution's on this subject, (9, 10, 11, 12) discussed in the proceedings of the Engineering Congress. The last paper on canal lining was discussed in 1943 and was presented by the present Prisident of the Engineering Congress[4]

During these sixteen years, Pakistan has completed many lining projects, some of which are the biggest in the world. The lining of Thal Canal and its branches, Balloki Suleimanki Link, Bombanwala Bedian Link, headrace channels of Chichoki and Shadiwal Hydels main feeder of Kurrum Garhi Project and some minor schemes have been completed after Independence. In connection with the new replacement works and Link Canals, there is a big programme of canal lining. This subject is thus of great importance in our future construction programme where canal lining alone will cost us millions of rupees.

In the lining projects of West Pakistan we have to take into account—

(*i*) The nature of the sub-soil formation with respect to drainage and quick rise of watertable.

(*ii*) Stability of side slopes under sudden closure of canal and provision of drainage.

(*iii*) Stability of lining against high flood levels.

(*iv*) Protection against development of temperature cracks.

(*v*) Increase of Rugosity Co-efficient and provision of proper free board.

(*vi*) Protection against salts, and

(*vii*) Structural stability of big lined canals.

Suitable types of lining for this country are discussed under "Material for use in canal lining" where all types of lining alternatives including those for lining of the existing earthen canals are given.

A summary of the precuations required to be adopted while lining the canals of this country is given at the end.

3. Nature of Sub-Soil Formation of West Pakistan and its Drainage Characteristics.

The sub-soil formation of the vast alluvium deposits of the Indus plains, as revealed by exploratory borings, carried down upto 600 ft. and more, below the surface show that the formation consists of

deposits of clay, silt and sand. At different elevations, varying in dimen-
(13)
sions, the clay deposits now and then obstruct the sub-soil flow. The regions of such obstructions are many and are located in haphazard manner. Along with this source of obstruction, the flow gradient in a large part of the country is very flat which is another cause for slow sub-soil flow. After the advent of the canal system, the sub-soil watertable started to rise, mainly as a flat sheet. It rose in the whole area with an equal
(13)
increment in a unit period. The steepness of the sub-soil gradient even due to the presence of canal sources was not much. The nature of the soil formation is thus one of the causes for the rise of sub-soil water levels. The top surface soil is usually 5 to 20 ft. thick and contains 10 to 20% clay, 20
(14)
to 40% silt and the rest is sand. This soil has 50 to 70 percent pores space. Its field capacity moisture is 20 to 27 percent, the rest being soil. An addition of 5 to 10 percent more moisture in such a soil can create water-logged
(15)
conditions with free water appearing at the top. These two characteristics of our soil are the cause of rise of watertable even in the regions of lined canal. The linings are not impervious and 5 to 10 percent moisture causing waterlogging can percolate through these. Wells record of the area around Haveli, Thal and B.S. Link canals was examined. The rise of watertable per year in the area before and after the construction of canals is shown in tables I (*a*) (*b*) (*c*) which show that for the lived Haveli canal, the rise has continued without any appreciable effect after its running in 1938. In the case of Thal canal, the rise upto the year 1946 was 0·07 ft. per year but from 1946 to 1955, it times, attaining a figure of 0·71 ft. per year.

TABLE No. 1 (*a*)

Rise of Watertable in Haveli Canal Zone

Well line No.	Total No. of wells.	Mean Rise is ft./year before construction of canal. 1916—40		Mean Rise in ft./year after the construction of canal 1941—57	
		June	October	June	October
XV	9	0·35	0·34	0·35	0·37
XVI	7	0·296	0·235	0·39	0·45
XVII	5	0·452	0·07	0 48	0·47
	Mean rise per year	0·363	0 215	0·373	0·43

TABLE No. 1 (*b*)

Average June to June rise in Water table of Thal Canal Area

Year	Watertable rise in ft. before opening of the canal	Year	Rise of watertable in ft. after opening of the canal.
1935-36	-0.190	1946-47	0·27
1936-37	0·361	1947-48	0·23
1937-38	-0 030	1948-49	0·24
1938-39	-0·030	1949-50	0·61
1939-40	0·430	1950-51	0·44
1940-41	-0·180	1951-52	0·38
1941-42	0·010	1952-53	0·68
1942-43	-0·090	1953-54	1·52
1943-44	0·100	1954-55	1·99
1944-45	0·250	—	—
1945-46	0·145	—	—
Mean rise per year	0·07		0·706

TABLE No. 1 (c)

Rise of Watertable in B.S. Link Canal Area

Well line No.	Well No.	Distance from canal	Rise/year before the construction of the canal in ft.		Rise/year after the construction of the canal in ft.	
			June	Oct.	June	Oct.
XXX	4	1 Mile	0·08	0·025	0·75	1·4
XXV	5	2 Miles	0·2	0·28	1·02	0·4
XXVI	4	,,	0·4	0·034	0·65	0·05
XII	60	,,	0·006	0·02	0·7	0·5
VII	1	3 Miles	0·013	0·03	0·97	0·77
VIII	4	,,	0·3	0·3	0·8	1·8
XII	62	,,	1·04	0 34	0·702	1·57
VII	3	4 Miles	-0·025	-0·058	0·85	0·7
VIII	2	,,	0·46	0·2	0·75	1·55
VIII	5	,,	0·1	0·35	1·05	2·47
VIII	7	,,	-0·08	-0·1	0·2	1·65
VIII	8	,,	-0·17	0·1	0·12	1·7
XII	65	,,	0 06	0·01	0·45	0·12
II	1	Beyond 4 miles	0·13	0·12	0·65	2·2
VII	4	,,	0·058	-0·18	1·4	-0·42
VII	5	,,	0·06	-0·2	1·97	2·8
	Mean rise per year.		0·163	0·086	0·814	1·203

In case of B. S. Link (Table 1 C) the rise before the construction of the canal was $\frac{0.16 \text{ ft. June}}{.086 \text{ ft. Oct.}}$ per year which after the construction of canal has increased to $\frac{0{\cdot}81 \text{ ft. June}}{1{\cdot}20 \text{ ft. Oct.}}$ per year. Already in certain reaches of B. S. Link, watertable has risen above the bed level of the canal.

Sometimes there is a temporary increase in the elevation of watertable during summer. This is due to the elimination of the capillary deficiency of the soil which results in rise of watertable by a few feet. (15) This rise of watertable is sometimes 2 to 5 ft. and water becomes free to exert pressure at the bed and the sides.

4. Sudden closure of canal and the failure of the side slopes :—

The canals recently lined such as B. S. Link, B. B. Link and some of the proposed ones are feeder canals joining one river with the other, which may have to be suddenly closed during flood season, not allowing sufficient time for the drainage of the pores water from the sides. The free pores water of the soil exerts pressure and causes failure of the sides (see Plate 1 & 2). For the stability of the lining measures will have to be devised to quickly drain the pores water.

5. Flood Damages :—

The link lined canals cut across the natural drainage of the country which consists of small streams and nallahs, practically dry during 10 months of the year and suddenly passing high discharges during the two or three summer months. Whatever type of passages are arranged for these floods, they develop functional defects due to silt deposits and weeds growth, etc. Sometimes the sudden discharges are far beyond the capacity of a syphon to discharge. The inefficiency of these cross drainage works, blocking the flood water on the up country side, causes extensive damage to property, crops and life and creates a high infiltration head on the back of the lined canal which very often is closed due to sudden high floods in the river. Thus the lining is subjected to infiltration head and is damaged. One such accurance even in a number of years can cost the country lakhs of rupees to repair the damages besides causing exceptionally long closures of the canal.

Again the lined canals of this country, with great depths, have usually to cross the country partly in digging and partly in filling. Sometimes a canal cuts through the soil crust. The thickness of soil is less than the depth of the canal. The sides of the canal are thus formed of stratified materials having different orders of permeabilities and yeilds and thus behave differently as regards stability under saturated conditions. The lined canals of this country are to be constructed to have protection :—

(*i*) Against rising sub-soil water.

(*ii*) Against temporary increase of sub-soil water due to elimination of capillary deficiency.

(*iii*) Side slopes against sudden canal closure.

(*iv*) Stability of stratified bank formation, and

(*v*) Stability against floods.

6. Protection against rising sub-soil water and elimination of capillary deficiency :—

We have stated that due to the nature of our soil formation, which has low and insufficient drainage, a small addition of moisture, seeping from partially impervious lining, can create water-logging conditions. A suitable measure to keep the watertable under control is a proper drainage system close to the canal. An open drain running along the the canal is not very effective in controlling the sub-soil watertable and it is also difficult to be maintained. It it suggested that all new canals lined or unlined, should have one, two or more rows of deep tile drains running along these. Their depths should be sufficient to check the rise of watertable. The drains should be of baked clay properly shrouded at joints and opening out into suitably located sumps. Before a canal is put into operation, there can be no difficulty to install such drains. At that time the watertable will be deep in nearly all cases.

As a further safeguard against the flow lines going into the soil formation, it is suggested that these horizontal tile drains should have also vertical strainers of baked clay going down upto 20 or 30 ft. They will intercept the deeper flow lines and thus protect the land from becoming water-logged. The details of this measure is shown in Fig. 1. This method will stop the rise of sub-soil water along the new canals. For instance, at present, along the proposed alignment of M. M. Link, the water-table is fairly deep. If this device is installed along with the digging and lining of the canal, it will keep the rise of watertable under control.

7. Stability of side slopes.

During the running condition of an earthen canals, sides are found to stand at a slope of ½ to 1 but during closure and drainage of warer back into the canal, the sides fall down, attaining a much flatter slope.

In the case of a lined canal, the usual side slopes adopted are 1½ : 1 (4, 5, 3-R_2, 11) or 1¼ to 1. In a few cases slope equal to 1:1 has also been constructed. The side slopes adopted by various countries for a few lined canals are shown in Table 2.

These inclinations of sides are within the safe limit at which a bank made of sand or silt can stand. These slopes attain a flatter order than before under quick withdrawal of water. Terzaghi (16) and Mahbub (12) have given some data about the side slopes under various conditions. These are reproduced below in Table 3.

TABLE No. 2

Side Slopes of Lined Canals

Serial No.	Name of Canal	Full supply discharge in cusecs	Bed width in feet	Full supply depth in feet	Side slopes adopted
	CANALS IN PAKISTAN				
1.	Haveli Canal ...	5,1ſ5	84	12-0	1 : 1
2.	Thal Canal ...	6,000 to 10,000	...	17·0	1·25 : 1 & 1·5 : 1
3.	B. S. Link Canal ...	15,182	300 to 112	13-0 to 18	2 : 1
4.	B. B. Link Canal ...	6,000	...	12	1·5 : 1 & 2 : 1
	CANALS IN INDIA				
1.	Bikanar Canal ...	2,144	52	8·0	1 : 1
2.	Nagal Hydel Channel	12,500	88·0	20·6	1·25 : 1
3.	Bhakra main line ...	12,455	87·0	19·0	1·25 : 1
4.	Narwana Branch ...	4,459	42·5	16·0	1·25 : 1
5.	Bhakra main Branch ...	4,970	31·1	18·0	1·25 : 1
6.	Sadul Branch ...	1,244	...	13·6	1·25 : 1
7.	Tungabhadra Dam Project left bank, Hyderabad Canal ...	7,000	84	14·0	1 : 1
8.	Tungabhadra low level canal ...	1.323	32	9·3	1 : 1
9.	Sarda Saga Project ...	7,500	93	11·5	1 : 1
10.	Mahi canal, right bank	7,000	54	17·0	1·5 : 1

TABLE No. 2—*contd.*

Serial No.	Name of Canal	Full supply discharge in cusecs	Bed width in feet	Full supply depth in feet	Side slopes adopted
	CONCRETE LINED CANALS IN AMERICA				
1.	Kittitas main canal, Yakima Project ...	1,320	12	9·75	1·25 : 1
2.	North canal, owyhee Project ...	451	7	5·76	1·25 : 1
3.	Yakima Ridge Canal, Yakima Project ...	2,201	14	11·2	1·25 : 1
4.	Black Canyon Canal, Boise Project ...	1,001	12	9·13	1·25 : 1
5.	Madera Canal, Central Valley Project ...	823 to 1,000	8 to 10	7·08 to 8·98	1·25 : 1
6.	Coachella Canal, Boulder Canyan Project ...	1,200 to 1,300	12	10·8	1·5 : 1
7.	Praint-Kern Canal, Central Valley Project ...	4,000 to 5,000	36	15·2 to 17·2	1·25 : 1
8.	Delta Mendotta Canal, Central Valley Project	4,399	48	16 to 16·2	1·5 : 1
9.	Main Canal Columbia Basin Project ...	13,200	24	23·7	1·5 : 1
10.	West Canal, Columbia Basin Project ...	5,100	12 to 38	16·4 to 16·9	1·5 : 1
11.	East Low Canal, Columbia Basin Project ...	4,500	20	18·9	1·5 : 1
12.	New Briar Canal Boulder Canyon Project ...	350 to 700	8 to 18	5·07 to 5·92	1·5 : 1

TABLE 3

Stable slopes for dry, moist or saturated sand.

State and type of material	Angle of repose ϕ	Cot ϕ or slope	Authority
Sand			
Loose dry or moist, round ...	29°	1 in 1·8	Terzaghi
Loose dry or moist, well graded uniform or angular ...	34°	1 in 1·45	,,
Dense dry or moist, round ...	35°	1 in 1·43	,,
Dense dry or moist, well graded uniform or angular ...	46°	1 in 0·97	,,
Dense saturated, round ...	33°	1 in 1·54	,,
Dense saturated, well graded uniform or angular ...	44°	1 in 1·0	,,
Sand or gravel soil ...	33° to 26°	1 in 1½ 1 in 2	Etchevery reported by Mahbub.
Silt			
Silty sand, loose ...	27° to 30°	1 in 1·96 to 1 in 1·7	Terzaghi
Silty sand, Dense ...	30° to 35°	1 in 1·73 to 1 in 1·43	,,
Silty sand, quick shear tests ...	17° to 22°	1 in 3·3 to 1 in 2·5	,,
Clay			
Firm dry well drained ...	45°	1 in 1	,,
Clay loam or average sand loam	36° to 33°	1¼ to 1 or 1½ to 2	,,

In fact for quick withdrawal of water, 1½ : 1 side slope is not suitable for banks made of silt and clay. These materials have low yield and have no stable slope at liquid limit under which conditions a slope of 2 : 1 and 3 : 1 is even not stable.

The side slopes of B. S. Link and a certain portion of B. B. Link were made to 2 : 1 and these have behaved satisfactorily. In fact for the conditions of quick closure of a canal and drainage of pores water from the sides, some device is very necessary and a few alternatives are briefly discussed below.

8. Filter behind lining to increase stability.

During certain experiments the behaviour of compacted soil under (17) moisture was studied. It was noted that even compacted soil developed cracks, expanded and settled at certain places. It was found that if a protecting filter was kept on top of the soil to take away the excess moisture, the above stated defects did not appear.

On the basis of these experiments, during the lining of B. S. Link, it was decided to add a sand filter under neath the lining. It consisted of water-saturated coarse sand and was to be trowelled on the dressed sides, mainly in the filling reaches. The thickness of this filter was to be 2·0″. As a safeguard against incomplete saturation of sand, about 3% (1:30) cement sand was added to this sand. Close to the sides, one foot diameter holes were augered down to reach the sand formation. These holes which were 50 ft apart were filled with coarse sand and were connected with the side filter.

It was expected that the seeping water through the lining will pass down into the sub-soil without effecting the compacted soil formation of the sides.

This device has a few defects. Our present lining system is not impervious. All the seepage from the lining will directly go into the sub soil formation without being checked by compacted soil. This can cause quick rise of watertable as has happened along the region of B. S. Link canal (Table 1c).

The second defect of this filter is that if sand is not fully saturated, (18) it may bulk and settle down leaving hollows behind the lining. It is true that such defects have not appeared on B. S. Link and on the lining of head-race channel of Chichoki, where filters had been installed.

This type of filter can help in the stability of slope of a lined canal on sudden closure of the canal as there will be no excess moisture in the soil to exert pressure.

The working of this device thus depends only on the efficient drainage of the filter and which can lose its effectiveness on the rise of sub-soil water. As a further safeguard, it is necessary that there should be weep holes connected with the filter, opening into the canal.

9. Drainage filter for a lined conal.

It appears, that it is very necessary to have a filter behind lining which may draw out the excess moisture on sudden closure of the canal.

The necessity for such a filter has been felt in United States and in India during the execution of the lining projects in these countries. In the case (3-R 11) of Nangal Hydel Channel, drainage arrangements have been provided at those sites of the lining, where the permeability constant was found to be greater than 10 and less than 100 ft. per year.

In case of Sarda Power Channel in Uttar Pardesh, safety valves have been left in the bed and the bottom of sides, spaced from 15 ft. to 25 ft. depending upon the spring level. They are of one foot diameter, and two ft. length consisting of unreinforced pipes filled with graded material. Low regulators have also been provided one mile apart, to hold up water in case the channel has to be emptied in an emergency.

In the bottom of the sides anchorage have been provided, so that the lining does not slip forward due to earth pressure from the wet soil. These anchorages go about two feet deep and are reinforced.

Similarly in case of lining of Mahi Canal of Bombay, in the bed, a sand blanket four inches thick and on the sides a graded filter of three layers, each having four inches thickness, has been provided. The drainage system consists of three longitudinal drains, one in the centre and two at toes connected by cross drains, 250 ft. apart from centre to centre, to relieve water pressure under the lining.

Drainage provision is also made in the lining of American canals. (4, 5)

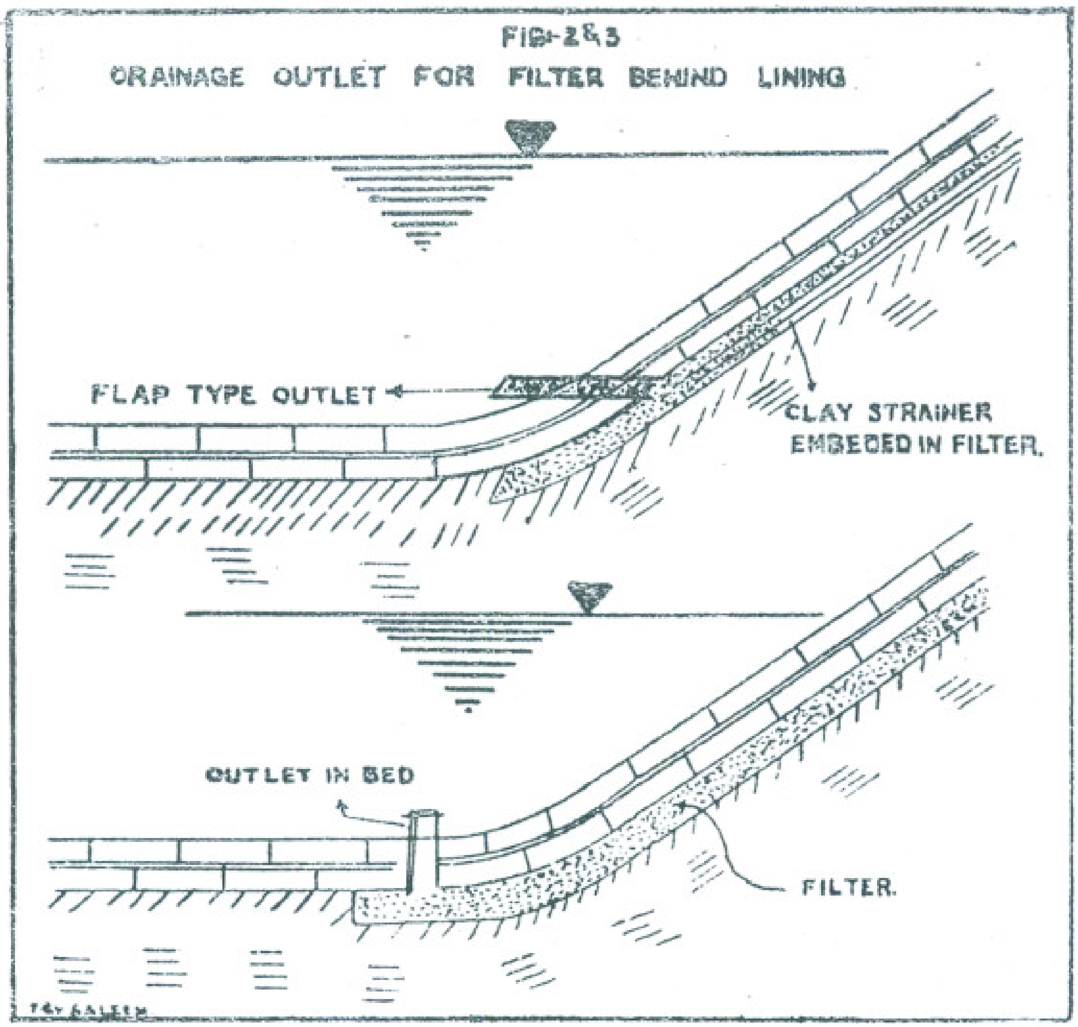
Evidently a filter behind canal lining is necessary where the back fill consists of soil of low permeability. Its installation will not only be essential for the banks in filling but also in digging, as the formation in both cases can behave identically.

If the suggestion, put forth earlier about the provision of tile drains along the canal to deal with the seepage from the canal and to control the watertable, is made use of and a filter behind the canal lining, similar to that installed in B. S. Link or head race channel of Chichoki, work efficiently, the two devices combined can give a measure of stability to the soil bank, when quick withdrawal of canal supplies takes place.

In cases where the seepage drains do not exist, it will be necessary to have weep-holes connected to the filter and opening into the canal so as to drain back the excess water into the empty canal. A simple type of a weep-hole Fig 2 seems to be a pipe fitted with a flap, which will remain closed during the running of the canal and will open out when the back pressure increases.

It is, however, suggested that the thickness of the coarses sand filter may be increased to at least three inches if not more and in each of the ten feet wide compartment of the lining, there may be installed small baked clay strainers connected to the flap type weep-holes. This filter should also extend below 'Domalies' to inter-co-nnect these different compartments. The method of drainage to sub-soil effected by one foot diameter drill holes may be brought closer to 30 ft. This suggestion is explained in Figure 1 This method to deal with the seepage from the canal lining can be more effective and simpler as compared to the drainage outlets carried underneath the bank to dispose off the seepage outside. In case the soil crust is thick and sand formation is much deeper, it is suggested that side filters may be connected to flap type weep holes opening into the bed of the canal as explained in Fig. 3. This device will be simpler as compared to the disposal below the bank.

PAPER NO. 344



It is, however, submitted that performance of such measures need trials in the field.

10. Lined canal provided with gates.

In case of the existing lined canals where watertable has risen above the bed level or is rising and where the imposition of seepage drains and filter is no longer possible, it is suggested that gates may be provided at suitable points, which on sudden closure of the canals can be lowered to keep the canals full of water. It is true that the provision of humps in the bed of a lined canal is much simpler and cheaper but humps suffer from size limitations and constitute a hinderance to the free flow of bed silt etc. Usually the top soil has more clay and low yield and thus needs a protection, but a hump is ineffective for that height of the lining.

11. Protection against flood water.

This device of keeping the canal full of water can be a safeguard against high flood water level on the outside of the banks. No doubt filter behind lining can be a safety measure against the bank flow from outside into the canal but keeping canal full, with the help of gates can do the same job more efficiently. This device can be put to another use. Where-ever the conditions permit, the cross drainage may be allowed through the full canal. It becomes necessary to have gates on two or three sites but this can do away with the defects of chocked syphons. This device might be workable at certain sites, where provision of gates might be cheaper and safer, considering the havoc caused by chocked syphons.

12. Protection of bank against settlement and development of hollows.

A canal during its course of several miles passes through land surface which at some places has been dug out and at other places has been built up by the filling of the soil. Very often a canal is kept balanced partly by digging and partly by filling. The back fill, to be stable and free from settlement and formation of hollows, must be compacted to bring it in line with the naturally compacted soil. Punjab soils are not usually heavy, containing high percentage of clay. A common type of soil contains sand, silt and clay in the portions of 50 to 60, 20 to 30 and 10 to 20 percent respectively. If the sand content increases beyond 60 to 70% and clay content falls below 10% the soil has the properties approching that of sand. The soil under natural condition has usually a dry bulk density between 1·45 gm. per c.c. Such a soil can be compacted to a density of 2 to 2·2 gm. per c.c by artificial compaction. But as a canal bank is not to bear heavy loads, attainment of such high order of density is not necessary. A dry bulk density of 1·7 gm. per c.c. at which a soil does not settle or form hollows, is good enough for canal lining projects This density of soil can be attained by the usual compaction methods. It may, however, be added that according to the latest

investigations, addition of 5 to 10% more moisture above the optimum percentage can help in removing soil air and binding the soil particles closer. A sandy bank is difficult to be compacted by normal means of compaction particularly if the sand is fine and contains small amount of moisture which causes the sand to bulk. Compaction of the soil in filling, is essential to protect it against development of hollows and settlement.

13. Temperature variation of a lined canal and development of cracks.

As will be explained later a suitable type of canal lining for this country is to consist of double layer of tiles, sand-wiched with one or more courses of other materials. Now different matetials have varying orders of expansion and contraction with changes of temperature and moisture.

In this country there is considerable variation of temperature. A change of nearly 100°F on surface between winter and summer seasons is not uncommon, although variation depends more on the texture, colour, compaction, moisture content and several other factors such as conductivity, specific heat and diffusion, etc. There is also some variation in the temperature of water flowing in the canal during different seasons. Usually monsoon flood water is the warmest having temperature range of 80° to 90°F and water from melting of the snow particularly during winter attains a low temperature of 50° to 60°F.

Some of the new link lined canals will be either non-perennial, remaining dry from October to April or will be passing low supplies during winter. Thus they will be subjected to variation of temperature.

The co-efficient of expansion of some of the commonly used building materials is given in Table 4.

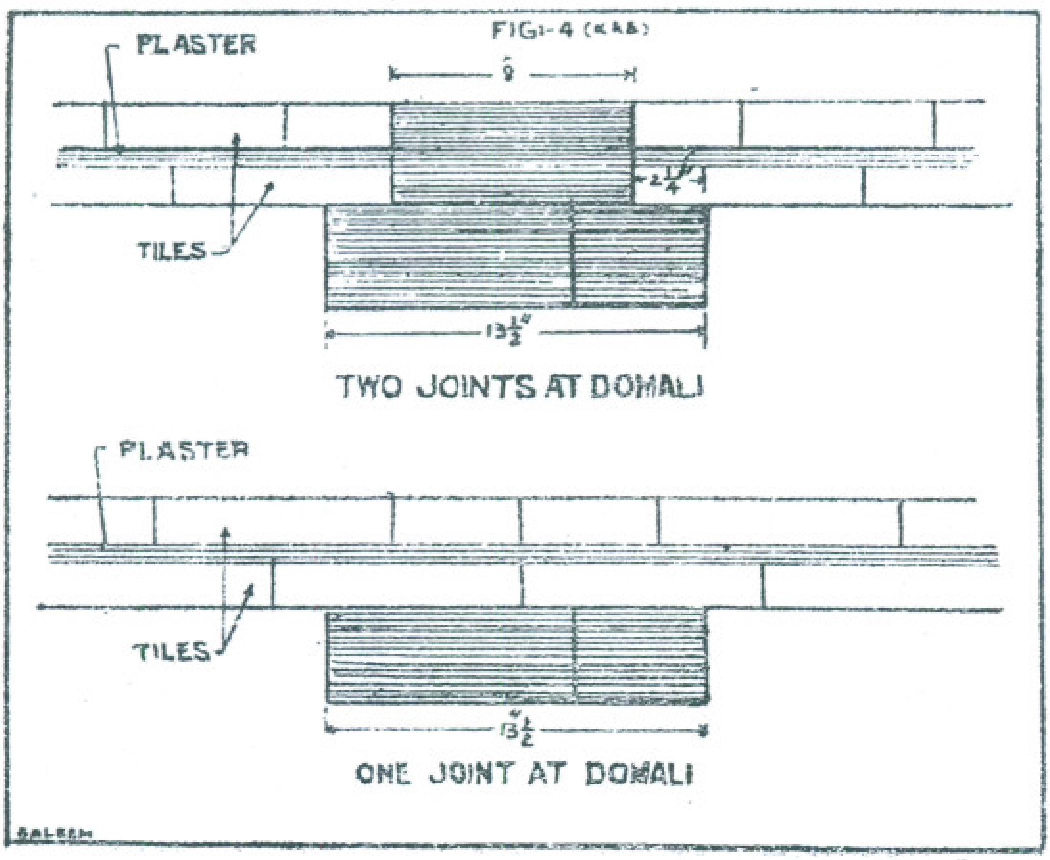
TABLE 4.

Co-efficient of expansion of various materials.

No. of Mould & Reference	Composition of mixture	Increase in unit length per degree F rise in temp.	Reference or authority.
M_4	Cement sand (1 : 3)	$9{\cdot}8\times10^{-6}$	Institute data (3-R_2)
M_1	10% replacement of cement by surkhi.	$6{\cdot}3\times10^{-6}$	,,
M_2	15% replacement of cement by surkhi.	$6{\cdot}05\times10^{-6}$	,,
$M_4/_3$	20% replacement of cement by surkhi.	$3{\cdot}16\times10^{-6}$	,,
M_5	25% replacement of cement by surkhi.	$4{\cdot}22\times10^{-6}$	,,
	Neat cement (Portland).	$7{\cdot}8$ to 9×10^{-6}	Concrete to Manual Bureau of Reclamation.
	Cement sand plaster 1 : 3.	$6{\cdot}0\times10^{-6}$	,,
	Cement sand plaster 1 : 6.	$5{\cdot}5\times10^{-6}$	,,
	Brick.	$2{\cdot}6$ to 5×10^{-6}	,,

A cement sand plaster, 1 : 3, constructed into a slab of ten feet long will expand 2·94 mm. with a change of 100°F. Bricks on the other hand have nearly 1/2 of this expansion. The plaster used in the lining is thin and has little strength to expand as a rigid slab, with the result that it can develop cracks. Bricks on the other hand have innumerable joints and cracks appearing in this type of masonry are at the joints and being microscopic, are invisible. Bricks or plaster mixed with surkhi puzzolana has a lower order of expansion co-efficient than 1 : 3 cement sand plaster and hence show less number of cracks. Usually these are visible at the joints. While lining canals, certain reference points, to fix the size of slabs, are constructed. These are usually 10 ft. apart and in this country are called 'Domalies'. Slabs are constructed at a later stage between these 'Domalies'. It is generally noticed that there exists a crack at the joint of the slab and the Domali. These cracks are a source of considerable seepage, the main reason being that the width of the Domalies is only 13½" at the bottom and 9 inches long bricks are fixed on edge on the top separating the two slabs (Fig. 4a).

PAPER NO. 344



Water percolating through the cracks has only to flow over 2 inches of domalies and thus a fair amount of seepage takes place through the hair cracks. In order to reduce this percolation, it is necessary to use a suitable joint filling material. This will increase the cost considerably. An alternative is to do away with the top nine inches brick so as to gain about nine inches long path to the flow. This idea is illustrated in Fig. 4-b and it will be convenient to fill one joint with some bituminous material.

Yet another alternative is to do away with this 'Domali' completely. This is shown in Fig. 5 in which the reference 'Domali' is made staggard. It gives a long path to the percolating water and thus the seepage is reduced considerably. This arrangement will also do away with the filling of the joints. It is suggested that this may be given a field trial.

PAPER. NO. 344

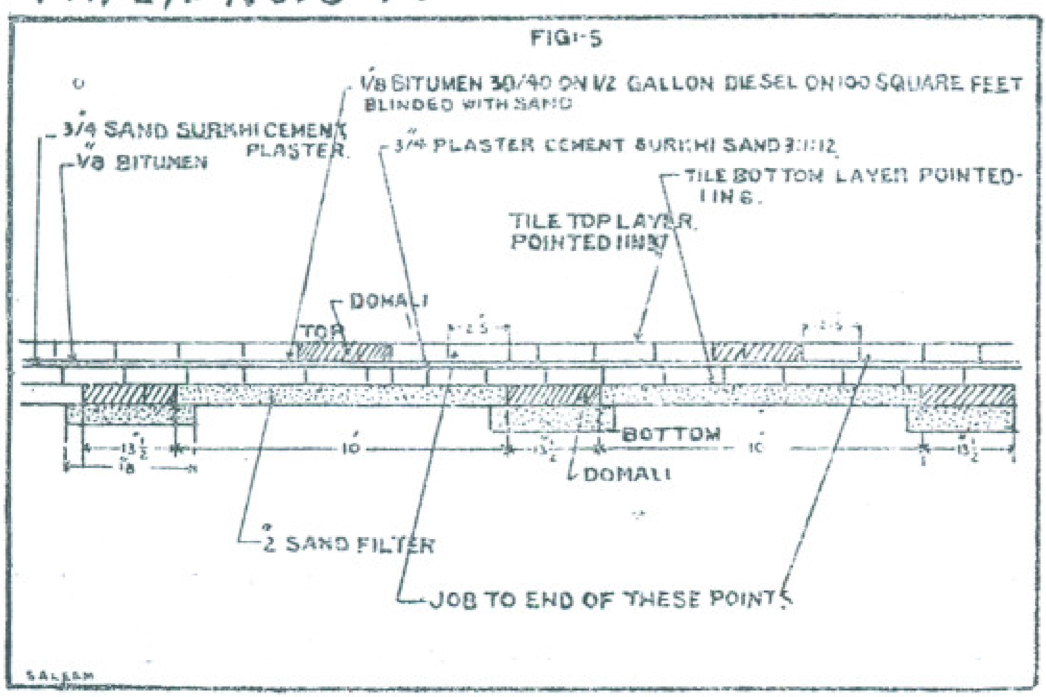


FIG-5

14. Co-efficient of Rugosity for a lined canal.

One of the advantages of a lined canal is that it possesses a low order of rugosity co-efficient. For earthen channel its value lies between 0·02 to 0·025. For brick lined canal, its order is taken in between 0·012 and 0·017. The order of this factor as given by Mahbub or by Rouse in (11) Engineering Hydraulics is shown in Table 5.

TABLE 5

Rugosity co-efficient

S. No.	Condition	Range of 'N'				Reference
1.	Cement concrete trowelled smooth without Algae or moss growth.	0·015 to 0·017				Rouse
2.	Cement plaster trowelled very smooth.	0·016 to 0·017				Rouse
3.	Very large earthen channel from growth.	0·02 to 0·022				Rouse
4.	Small earthen canals with growth and cobbles in bed.	0·025				Rouse
5.	Earth canal choked with moss growth.	0·035				Rouse
6.	Mountain stream with clear loose cobbles.	0·040 to 0 050				Rouse
		Perfect.	Good.	Fair.	Bad.	
7.	Brick work in cement mortar.	0·012	0·013	0·015	0·017	Mahbub
8.	Cement mortar surface.	0·011	0·012	0·013	0·015	Mahbub
9.	Concrete lined channel.	0·012	0·014	0·016	0·018	Mahbub

As our workmanship is not very perfect, an expected low order of rugosity co-efficient has never been attained. In fact trouble was experienced with Haveli canal when the co-efficient was assumed equal to 0·0146. It was found difficult to pass the full capacity discharge. The (10) lining had ultimately to be raised by 2·0 ft. In the actual condition a rugosity co efficient equal to 0·018 was found for this canal. According to Manning's formula for a change of 0·001 in rugosity, a change in slope by

7% can be attained. An earthen canal with a discharge capacity above 10,000 cusecs has the rugosity co-efficient equal to 0·022 or 0·025, so that in a lined canal with the co-efficient equal to 0·018, about 28 to 40 percent increase in slope and corresponding increase in velocity can be had. It is a common practice to adopt a velocity order of 5 to 8 feet per second in a lined channel. It has been noticed that even with high order of velocities, a type of fungus formation appears on the bricks close to the

(10)

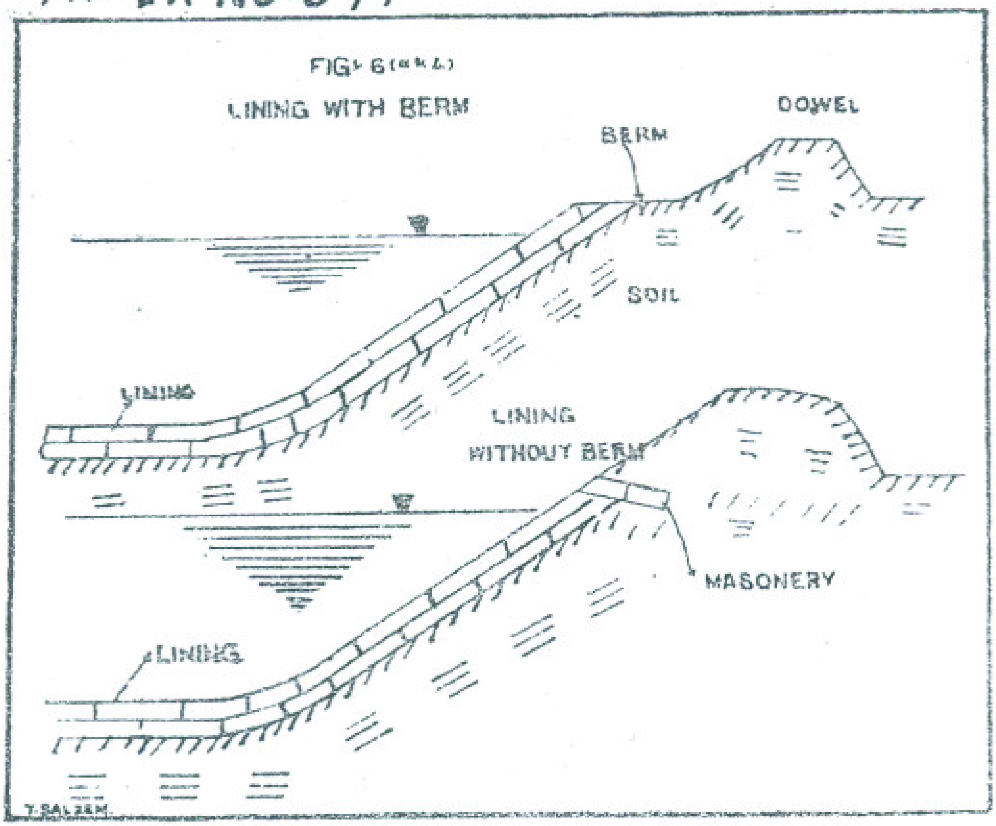
water surface. This fungus formation entraps fine silt and clay and may be a cause of increase in the rugosity co-efficient.

15, **Free board and safety of lining :—**

It is always advantageous to keep the rugosity co-efficient a bit higher. For brick lined channels, it is prefeuable to keep it equal to 0·018, so that there may always be sufficient space above the full supply depth of the canal, for the wave wash to remain within the top level of the banks. The safe depth of a canal above the full supply surface depends upon many factors such as wind velocity, wind storm, curvature of the canal, velocity of flow, etc. The safe depth will vary with these factors and the discharge in the canal. If the free board is not sufficient, water will over-top the bank and will enter behined the lining. Provision of small free board or assumption of low order of rugosity coefficient may cause failure by over-flow of low water. It happend in the case of Haveli canal It is thus suggested that for a canal upto 10,000 cusecs a free board of one foot and for a canal of 20,000 a free board of 1½ ft. to 2 ft. is very necessary. In this connection it is necessary that the infiltration of water behind the lining should be checked. If a bank or a 'Dowel' is kept away from the top of the lining as shown in Fig. 6. (A), there will be a danger of water entering behind the lining. In this connection two small changes are proposed. The first is that the top of the lining may be extended about 13½″ to 18′ behind the lining and the second is that 'Dowel' should rise nearly along the same slope as the canal lining.

This suggetion is illustrated in Fig. 6-b.

PAPER NO.344



16. **Action of salts on lining and its protection :—**

Salts are always present in soil. In West Paki tan at certain places the concentration of sulphates is fairly high. When bricks made of this soil are burnt, the salts remain in the bricks and in some cases, these are multiplied as the local coal contains a significant amount of sulphur.

Sulphates are harmful for cement concrete and cement plaster in particular if pervious. They destroy the concrete both physically and chemically. They also react on bricks, particularly if these are porous or under burnt. Sulphates usually appear above the water level in the capillary region in a canal. In the rest of the canal within the body of the lining, seeping water takes away the salts of the soil It is only the capillary surface which needs protection.

The usual protection is to use rather over burnt bricks, which are less pervious and are not easily reacted upon by salts. The use of surkhi

(20)

puzzolana in the cement sand plaster adds considerable resistance to it. In areas where salts are excessive, use of tiles impregnated with bitumen oil emulsion resist the action of salts due to their relative imperviousness.

In case no such precuations are observed and salts have appeared on the surface, a coating of Shellmac R.C. 3 can check the movement of salts.

Though it is true that its application shall have to be repeated after every three or four years. Double boiled linseed oil is another substance which can be used with advantage. Both these stuffs, however, disfigure the lining.

Recently extensive work has been done in India to use soap solution (34 a, b) to make plaster and bricks impervious to capillary rise of water. It has been found, as will be stated later that the use of 0·2 to 0·4 % soap solution can effectively resist the capillary rise. It is yet too early to say about its durability.

17. **Structural stability :—**

Canal lining is designed not to stand any tension. It is just like a layer of a material resting on the formation. If there is an uplift pressure or a lining is subjected to soil pressure from sides, failure occurs. If a lining is to stand a pressure, its dimensions and reinforcement would become quite uneconomical. For these reasons, the practice of using reinforcement in lining has been given up. The only lining project in this country where reinforcement was used, is Haveli canal where steel bars ¼ inches thick, were used, 12½ inches centre to centre at sides and 24½ inches apart at the bed. The quantity of steel bars used for 50 miles long canal was 2782 tons.

(4, 5)
In the earlier stages of the lining projects of the United States reinforcement was used in concrete but now it has been given up.

In the United States, the thickness of the rigid type lining, made of cement concrete or asphalt concrete, is generally between 6·0″ and 4·0″. In this country the thickness of double tiles masonry is also 6·0 inches. It consists of two layers of tiles each 2½ inches thick, with ½ inch thick, 1 : 3, cement sand plaster. (21)

This was the thinkness used in Haveli Canal where the tiles consisted of 12×5½ inches and were 2½ inches thick. The thickness of kankar lining of Bikaner canal was also 6·0 inches but later on, in the lining of Thal canal and in B. B. Link the thickness of the tile was reduced to 2·0″. This was the case particularly for single tile lining where the lower course of tiles was replaced by 1 : 6, cement sand plaster of 1½ inches thickness. The top surface of the tile was also reduced to the same dimensions. This has been the case for lining of big canals carrying 15,000 to 18,000 (3 R, II) cusecs. In India for the lining of Bhakra Canal carrying 12,500 cusecs at 20·5 ft. depth, tiles 12″ × 2″ thick have been used. For certain other canals such as Sarda Power Channel (Uttar Pradesh), Mahi Canal Lining (Bombay) of 7000 cusecs, the size of tiles adopted has also been 2 to 2½ inches.

Our new lined canals, will be unprecedently big canals, carrying 25,000 cusecs with depth rising upto 25 ft. It is a question whether to stick to the same thickness of the existing lining or to increase it. From the crushing pressure point of view, there is no danger to thin slabs, but laboratory experience shows that thin plaster, ½ inch thick, often gets cracked under 20 ft. deep water. The two layers of tiles can certainly be a protection for a sand-wiched plaster under such high heads. It will, however, be preferable to use slightly thicker tiles and a layer of plaster thicker than ½ inch. It will be shown in the next paragaraph that increasing the thickness of tiles to 3·0 inches and that of plaster to 3/4 or to 1·0 inch, gives a considerable reduction in seepage. This size of bricks and plaster will also improve the structural strength considerably. It is thus suggested that for a canal with discharge above 15,000 cusces the thickness of tiles should be increased to 3·0″ and that of plaster to 3/4 or to 1·0″.

18. **Types of canal lining.**

The most common types of canal lining in use in the world are :—

(*i*) the rigid cement concrete lining, and

(*ii*) the bituminous and other types of flexible lining.

19. Cement concrete lining.

The rigid type of lining is made of cement concrete, cement sand plaster, cement pointed bricks, etc. All linings in which cement or materials similar to these are used can be classed as rigid lining.

For flexible Lning bituminous materials are used in various forms. Lining of compacted earth, stabilized soil, chemical or bitumen treated soil and such other materials are also mentioned under this head.

Cement concrete lining is well tried in the world. If all precautions are taken in its laying, cement concrete made in the ratio of 1 : 3 : 6, four to six inches thick, is the most durable, rigid and impervious to water heads as are to be encountered in the canals. A richer mix, 1 : 2 : 4 is impervious to higher heads but it is costly and possesses greater capacity for expansion. If concrete is made with proper expansion joints, there is no lining better than this. In other countries machines have been developed with which it is possible to lay a proper type of concrete. Temperature cracks, destruction due to salts, formation of snow and its thawing with temperature changes, etc., are some of the agencies which deteriorate a concrete lining. The causes of failure of side slopes enumerated earlier are effective in this case also.

This type of lining is the most expensive and in our country due to the difficulty of procurement of materials from long distances and having insufficient and expensive means of transport, it is not possible to use it commonly except at places where the materials are available within reasonable distances.

20. Shotcrete lining.

Shotcrete is a term adopted for applying cement sand mortar under pneumatic pressure. The process is sometimes named at Gunite or jet crete. If shot crete is used in thin layers upto ¼ to ½ inch on soil it often gives trouble. A thicker coat 1·0 to 1½ inches, is durable but it is more costly than a cement concrete layer of equal thickness. Use of shot crete on rigid but porous or deteriorated concrete is very useful. Recently it was used to improve the deteriorated and porous cement concrete lining of Thal canal near Pai Khel. The thickness of this lining is 4 inches and is made to a specification of 1 : 3 : 6. The thickness of shot crete used was $\frac{1}{4}$ inch and the results were very encouraging.

21. Brick or tile lining.

In this country the rigid type lining of bricks or tiles has been commonly used due to the availability of good soil every where and bricks can be burnt close to the site of use. The difficulty of procurement of materials from long distances is thus eliminated, skilled labour is available and lining can be satisfactorily constructed.

The thicknesses of tiles generally used in the lining, are $2\frac{1}{2}$, 2 and $1\frac{1}{2}$ inches. It has been found that under 10 to 15 ft of water head, tiles of the above stated size, give considerably high percolation. Several experiments have been conducted in the laboratory and at Niazbeg on a field scale. Practically in all cases seepage from $9 \times 4\frac{1}{2} \times 1\frac{1}{2}$ inches tiles pointed with 1:3 or 1:6 cement sand has been excessive. In Table 6 results of five tests conducted at different occasions in the laboratory using 36 square feet of each test specimen, are given. The order of percolation has been excessive except when 3·0″ thick bricks were used.

When these tiles or bricks were impregnated with $\frac{1}{2}$ inch thick plaster of cement sand mixed in the ratio of 1:3, the seepage order was reduced considerably as shown in the same table 6. Thus it is very necessary that porous tiles should have a layer of impervious materials.

Similar results of seepage tests at Niazbeg from different specimens of double tiles lining are shown in Table 7.

TABLE 7

Experiments conducted at Niazbeg in Tanks

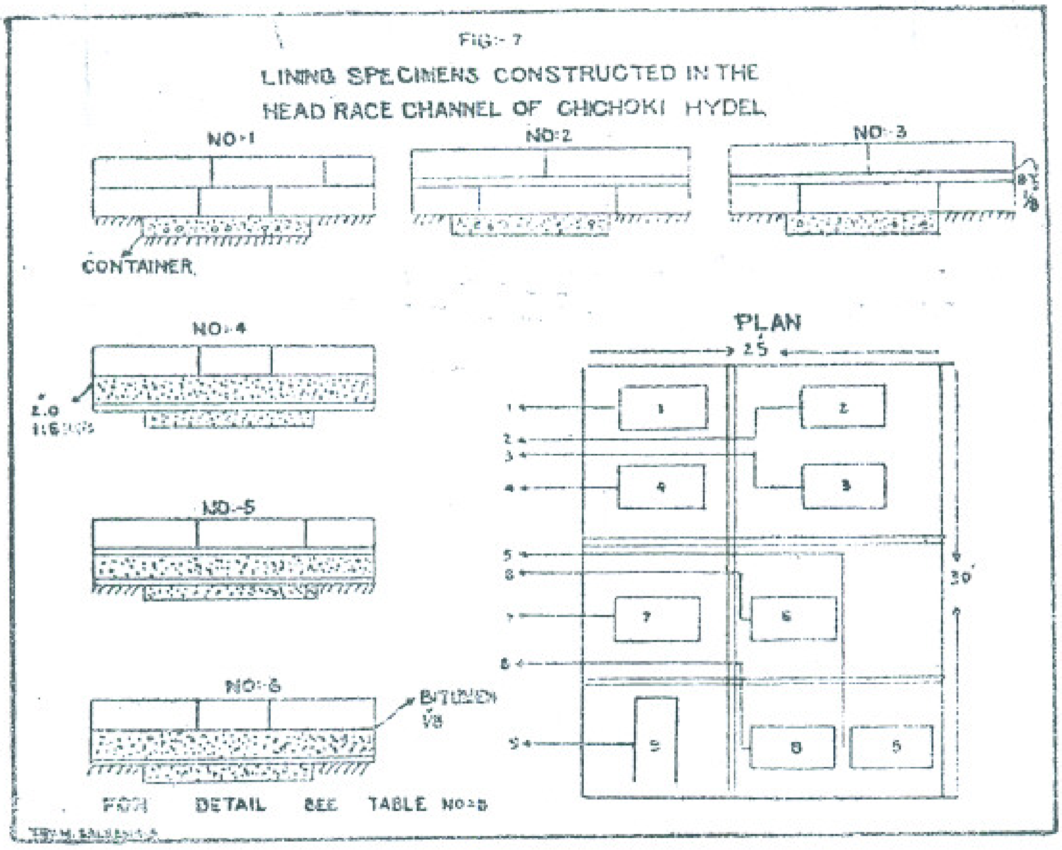
Test No.	Serial No.	Water head in ft.	Mean seepage in cus /10^6 sq. ft. at 20°C from	
			Double tiles sand wiched with $\frac{1}{2}$″ thick 1:3::C:S plaster	Double tiles sand wiched type lining with the addition of $\frac{1}{8}$″ bitumen on 1:3 C:S. plaster
I	1	2·8	2·1	
	2	3·5	1·96	0·25
	3	3·9	2·2	0·23
	4	4·5	2·1	0·33
	5	5·2	2·6	0·43
	6	6·7	3·3	0·5
	7	8·2	3·6	0·68
				0·93
II	1	3·3	2·5	0·08
	2	4·5	3·7	0·23
	3	5·1	4·8	0·40
	4	6·0	5·6	0·55
	7	5·5	7·2	1·55
	6	9·8	8·5	1·5

TABLE 6

Seepage at 20° C form double layers of tiles pointed with 1:3 cement sand mortar, with and without ½″ thick 1:3 cement sand mortar in between. Size of specimen tested = 6′x6′.

Test No.	Serial No.	Water head in ft.	Seepage in cusecs/10^6. sq. ft.		Remarks
			Double tiles sandwiched with 1:3 cement sand mortar ½″ thick	Double layers of tiles pointed with 1:3 cement sand without a layer of mortar	
I	1.	6·59	0·697	61·14	Size of tiles used 9″x4½″ x1½″ Pressure could not be increased further due to high water losses.
	2.	8·2	2·464	90·2	
	3.	13·48	4·376	162·44	
II	1.	3·91	2·4	42·7	,,
	2.	7·88	4·27	53·8	
	3.	15·22	6·58	107·1	
	4.	18·8	7·13	123·8	
III	1.	6·8	1·9	17·61	
	2.	8·2	1·76	26·01	
	3.	9·8	2·35	46·53	
	4.	11·4	8·57	72·94	
	5.	10·7	12·47	116·2	
IV	1.	5·82	2·695	26·96	
	2.	6·79	2·86	37·504	
	3.	13·63	3·55	67·486	
V	1.	5·0	0·61	2·0	Bricks (9″ x4½″ x3″) used in place of tiles.
	2.	7·0	0·y3	2·3	
	3.	10·0	0·81	3·2	
	4.	12·0	0·97	3·5	
	5.	15·0	1·29	4·8	
	6.	20·0	2·26	7·8	
	7.	25·0	3·8	11-2	

Recently it was arranged to construct different types of lining in the head race channel of Chichoki Hydel. Six different specimens, the details of which are given in Fig. 7, were constructed. Just below the lining specimen containers touching the bottom of the lining and filled with coarse sand were installed. These containers had pipe connections outside.. Since the period, headrace channel had been filled with water, percolation coming out from different specimens was measured.



In the beginning double tiles lining without impregnation of 1:3 cement sand plaster gave very high order of percolation as is illustrated in table 8 column No. 1. The seepage from double tiles having ½″ cement sand (1:3) impregnation as shown in the next column is fairly low.

As a result of these experiments, it became evident that double tiles lining, sand wiched with ½ inch thick cement sand (1 : 3) plaster reduced the percolation considerably, but under high water heads the order of percolation was still high.

22. Effect of increase in the thickness of plaster and mixing of surkhi puzzolana.

Seepage tests were conducted on ½ inch and 1·0 inch thick cement sand plaster. The size of specimen was only 4·0 sq. ft. The results of these tests are shown in Table 9.

TABLE 8

Seepage from various lining specimens, (detail given below) constructed in the Chichoki Hydel Head-race Channel

1	2	3	4	5	6	7
Water depth in ft.	Double layer of tiles no sand-wiched plaster	Double tiles sand-wiched with ½" 1:3 C:S plaster	Double tiles with 1", 1:3 C:S and 1/8 thick bitumen layer.	Single tile on 2·0" thick 1:6 C:S: plaster without 1:3 plaster	Single tile on 1½" thick 1:6 plaster with 1:3 plaster ½" thick	Single tile on 1:6 cement sand 1½" plastet, with ½" 1:3 plaste and 1/8" bitumen
10·3	23·57	0·43	·205	19·47	Not in working order	0·284
10·3	16·61	1·245	1·27	18·68	,,	0·265
12·42	14·9	0·33	0·017	6·47	,,	...
12·52	0·06	0·076	0·077	4·42	55·84	0·077
12·42	1·5	0·258	...	0·041	261·14	...
12·32	0·038	0·145	...	0·009	238·18	...
13·5	0·042	0·135	0·0007	0·004	267·38	0·0007
13·6	0·325	0·125	...	0·002	236·11	...

TABLE 9.

Seepage at 20°C from 1 : 3 Cement sand plasters.

Test No.	Thickness of the mortar layer	Size of the specimen tested	Water head in ft.	Seepage in cus/10^6 sq. ft. area	Remarks
I	$\frac{1}{2}''$	$2' \times 2'$	8·9	7·2	S. S. Curing 9 days.
			11·2	9·92	
			13·5	11·16	
			16·4	12·0	
			21·7	17·77	
			25·6	40·1	
II	$\frac{1}{2}''$	$2' \times 2'$	10·4	2·46	S. S. Curing 28 days.
			17·6	4·66	
			22·5	7·85	
			25·9	10·23	
			28·6	12 0	
			32·5	16·12	
III	$\frac{1}{2}''$	$6' \times 6'$	7·8	1·89	S. S. Curing 4 weeks.
			10·4	26·32	,, 4 ,,
			12·2	6·62	,, 5 ,,
IV	1·0″	$2' \times 2'$	7·6	Nil	S. S. Curing 3 weeks
			11·1	Nil	
			14·1	0·22	
			17·6	0·40	
			20·4	0·47	
			21·6	0·57	
			26·6	0·877	
			32·4	0·33	
			34·9	0·366	

The increase of thickness of plaster to $\frac{3}{4}$ inch was tested sandwiched in tiles. In this plaster 20% of the cement was also replaced by surkhi.

The results with two different tests are shown in Table 10. There is reduction in seepage by the increase of thickness of plaster and the use of surkhi.

It is necessary that the limit of surkhi may be fixed within 15 to 20%, as increase of it above 20% start [giving increase in percolation.

This conclusion is drawn from the tests whose results are shown in Table 11.

TABLE 10

Permeability tests on lining specimens each 18 sq. ft. in area in 6′×6′ lining testing tank.

Test No.	Serial No.	Water Head in ft.	Seepage in cus/10^6 sq. ft. at 20°C from double tiles sand-wiched with		Remarks
			½″ thick 1 : 3:: C : S plaster	¾″ thick cement sand plaster (1 : 3)	
I	1	5·0	0·1	·03	2·0″ thick tiles were used.
	2	10·0	0·2	·09	
	3	15·0	0·4	0·24	
	4	20·0	0·72	0·43	
	5	25·0	1·2	0·63	
II	1	1·7	0·12	0·096	20% replacement cf cement by surkhi in ½″ and ¾″ thick mortars.
	2	4·2	0·17	0·125 0·15	
	3	7 0	0 26	0·22	
	4	10·4	0·28 0·32	0·22	
	5	12·3	0·345	0·22 0·3	
	6	14·7	0·35	0·28	
	7	16·0	0·3	0·21	
	8	20·8	0·38	0·32	

TABLE 11

A. Permeability test on ½ inch thick plaster, six inches in diameter with 25,30,35 and 40% replacement of cement by brick surkhi. Cement Sand ratio 1 : 3. Seepage at 20° C.

Serial No.	Water Head in ft.	Seepage in cus/10^6 sq. ft. by replacement			
		25%	30%	35%	40%
1.	11·0	0·71	0·28	0·86	0·13
2.	13·5	0·52	0·4	0·88	0·13
3.	21·2	3·54	2·23	3·94	1·28
4.	24·1	2·9	2·75	6·76	2·06
5.	28·2	3·9	2·77	8·26	4·85

B. Size of specimen tested 2′ ×2′, thickness ½ inch.

Specification : Cement sand 1 : 3 with 15 & 25% replacement of cement by Surkhi.

Serial No.	water Head in ft.	Seapage in cus/10^6 sq. ft. replacement of cement by Surkhi upto.	
		15%	25%
1.	8·3	Nil	Nil
2.	10·7	Nil	Nil
3.	14 4	0·88	0·377
4.	17·6	0·87	1·77
5.	21·3	1·53	2·08
6.	23·1	1·77	2·36
7.	28·3	2·48	3·54
8.	31·7	3·66	4.13
9.	33·1	3·82	4·37

In these tests cement was replaced by surkhi up to 40%.

23. Addition of bitumen layer on cement sand plaster.

In order to reduce the percolation of sand-wiched lining, the spraying of a thin coat of bitumen was tried. The plaster was coated with crude oil at the rate of $\frac{1}{2}$ gallon per 100 sq. ft. and bitumen 30/40 heated to 400°F was sprayed in two operations, each time spraying about 1/16th of an inch thick, so as to make a thickness of 1/8th of an inch. Dry sand was spread on the hot bitumen before laying the second layer of the tiles. This type of lining was found to give very low percolation. The results of experiments on this alternative conducted at Niazbeg are shown in Table 7. The percolation was reduced considerably by the spraying of bitumen. Similarly the seepage from the lining specimen with bitumen coating constructed in the headrace channel of Chichoki Hydel is very low. These results are shown in Table 8 columns 3 and 6.

24. Experiments on replacement of the first layer of tiles by cement sand plaster or soil cement bricks.

Three specimens of lining were made in the headrace channel of Chichoki, in which the lower layer of tiles was replaced by cement sand plaster (1 : 6). Unfortunately the specimens with and without 1 : 3, cement sand plaster are not behaving properly. There is, however, no percolation from the specimen containing a coating of bitumen (Table 8 column 6). Experiments on this type of specification were conducted at Niazbeg also. Here no coating of bitumen was used. The results of seepage measurement from this specimen were very high. May be, there had appeared some cracks in the 1 : 6 cement sand plaster. In some of the experiments conducted at Niazbeg, the cement sand plaster was replaced by soil cement (100 : 5) compressed bricks. The results of three alternatives tested at site are shown in Table 12. It was found that use of $\frac{1}{8}$ inch thick bitumen gave considerable reduction in seepage. The other two specimens gave high order of seepage. It was concluded that a thin layer of bitumen was of considerable help in reducing the percolation from the lining specimen.

TABLE 12

Seepage tests Conducted in Tanks at Niazbeg

Test No.	Serial No.	Water Head in ft.	Seepage in cus/10^6 sq. ft. at 20^0 C from		
			Soil cement bricks protected by tiles with a layer of ½ ″thick cement sand plaster ½″ and bitumen	Soil cement bricks protected by tiles having ½″ thick 1:3 :: C: S plaster without bitumen	Soil cement bricks protected by tiles only without 1:3 plaster or bitumen impregnation
I	1.	2·4	Nil	0·14	1·05
	2.	2·9	,,	0·66	3·2
	3.	3·6	,,	0·24	4·6
	4.	4·1	,,	0·47	3.02
	5.	4·8	,,	0·26	4·95
	6.	8·4	,,	0·32	6·1
	7.	6·4	,,	0·49	7·0
	8.	7·9	0·19	1·22	7·9
II with the same samples.	1.	2·90	Nil	0·96	Very high seepage.
	2.	3·20	,,	1·18	,,
	3.	4·80	,,	1·64	,,
	4.	5·70	,,	1·84	,,
	5.	7·12	0·12	2·29	,,
	6.	9·45	0·40	3·11	,,
	7.	10·83	0·50	0·92	,,
	8.	12·83	0·71	4·15	Very high seepage with sand coming out

25. Use of bitumen sand mastic in double tile lining.

Large scale field experiments were conducted in 1952-53 on the use (25 *a* & *b*, $3R_9$) of bitumen sand mastic for Canal lining. The details of the results are g ven in various departmental reports. Recent experiments were conducted to use pit sand mixed with bitumen for the lining of Abbasia canal. Labora- (26) tory experiments showed that ½ inch thick bitumen sand mastic containing 7 to 10 percent, 30/40 bitumen mixed hot with sand gave an impervious mastic. This mastic could be used either sand-wiched in between the lining or underneath the lining on the soil.

The results of tests with this mastic are shown in Table 13.

TABLE 13

Permeability test on bitumen sand mastic using 7 to 10% bitumen, 30/40. Size of specimen 9 sq. ft. tested in 6′×6′ lining tank.

Specification :— (*i*) ½″ thick 1 : 10 : : C : S. plaster.

(*ii*) Primer coat of (50% K. Oil+50% bitumen) at the rate of 1 gallon per 100 sq. ft.

(*iii*) ½″ thick bitumen sand mastic.

(*iv*) Tiles (12″×6″×2″) pointed with 1 : 3 : : C : S.

Serial No.	Water Head in ft.	Seepage in cus/10^6 sq. ft. at 20°C. from lining samples using bitumen in sand mastics equal to				Remarks
		7%	8%	9%	10%	
1.	4·39	0·42	0·27	0·18	0·14	Initial test.
2.	8·68	1·04	0·32	0·54	0·37	
3.	12·16	1·15	0·29	1·08	0·64	
4.	14·46	1·17	0·22	1.5	0 79	
5.	22·13	2·81	0·81	3·67	1·55	
1.	4·55	0·29	—	0·092	0·243	Retested after
2.	8.7	0·33	—	1·11	0·333	allowing the
3.	12·28	0·42	—	1·74	0·415	specimen to dry
4.	15·13	0·54	0·019	1·76	0·418	for 1½ months
5.	21·13	2·16	0·68	5·97	1·24	

Some times working of the mastic and trowelling it at site in the hot state is a problem and unless it is properly layed, it is not very effective. As an alternative, laying of jute cloth impregnated with bitumen at the bed of the double tiles lining with ¾ inch thick, 1 : 3 cement sand plaster is easier to lay and at the same time gives an impervious lining under normal heads of water.

26. Flexible type of canal lining.

Concrete or brick lining is expensive, and efforts have constantly been made during the last fifty years to develop a cheaper type of lining. For the solution of this problem the U. S. Bureau of Reclamation in Denver has been leading the field and has tried several alternatives with considerable success. A perusal of the published information, shows that although considerable success has been achieved in reducing the cost of lining, but the types of lining other than concrete and bricks, have not been found so durable.

The common type of flexible linings are those in which bitumen or soil is used in one form or another.

27. Bitumen lining.

Bitumen is extensively used in hydraulic works for several purposes. Several countries of the world have large stocks of bitumen and they can use it in many forms.[27,28,29] Unfortunately Pakistan has pretty sources of indigenous bitumen. It has to be imported in large quantities even for road construction. For canal lining, large qnantities of this material would have to be imported, which would need lot of foreign exchange. There is no doubt that where perfect imperviousness is needed, use of bitumen is the best and most efficient. Even to reduce the permeability of sandwiched double tile lining, coating of bitumen was found necessary.

28. Bitumen concrete.

In this country no experiments have been conducted to use bitumen concrete for canal lining. A few experiments were only conducted in the laboratory on a ¾ inch thick bitumen, grit, sand mastic made with 10% addition of 30/40 grade bitumen. The mastic was fonnd to be impervous to 20 ft. of water head.

Nowhere in the canal lining this type of mastic has been used. In fact bitumen concrete has not been given a trial in this country.

29. Bitumen coated fabrics.

In connection with the use of bitumen to seal off pervious sites, many types of bitumen coated fabrics, the base of which was made of jute, canvas, cotton or wool, etc., have been tried. A properly coated material particularly if it is closely woven and thick and made by using double layers of bitumen impregnated fibres, was found to be impervious to 20 ft. of water head. Large number of samples have since been tested in the laboratory, results of some of which are reproduced in the Table 14. Several of these speimens were tested by changing the range of temperature and retest-

TABLE 14

Seepage results of various types of bit umen impregnated

Serial No.	Name and Number of sample	Name of the Coy. that supplied the sample.
1	Bitumen impregnated Hessian Fabric.	Burmah Shell Bitumen Department, Calcutta.
2	P. L. 361	,,
3	P. L. 362	,,
4	P. L. 363	,,
5	30/40 Mexhatti	,,
6	Water proof rolling felt	,,
7	P.B.S. 2-*a*.	,,
8	P.B.S. 2-*b*.	,,
9	P.B.S. 3-*a*.	,,
10	P.B.S. 3-*b*.	,,
11	P.B.S. 3-*c*.	,,
12	Water proof $\frac{116}{487A}$	,,
13	Water proof $\frac{116}{487B}$	,,
14	M. I	,,
15	M. 2	,,
16	3-A	Shalimar Tar Product Ltd. Calcutta.
17	3-B	,,
18	3-C	,,

fabrics tested in the Laboratory.

Seepage in cusecs to begin with per 10^6 sq. ft. of W.P. at 32°C.		Seepage in cusces after six months immersion under water per 10^6 sq. ft. W.P. at 32°C.		Remarks
Head of Water		Head of Water		
15 ft.	20 ft.	15 ft.	20 ft.	
4·12 cus.	8·80 cus.	High	Seepage	Unsuitable as a canal lining material.
0·00 ,,	0 00 ,,	0 00 cus.	0·00 cus.	Ditto
0·00 ,,	0·62 ,,	18 20 ,,	not tested.	Ditto
20 82 ,,	42·23 ,,	High	Seepage	Ditto
0·00 ,,	0·00 ,,	0·00 cus.	0 36 cus.	Water tight but it cracks on rolling.
92·90 ,,	Not tested	High	Seepage	Bitumen impregnation not satisfactory.
26·79 ,,	,,	,,	,,	Ditto
1·59 ,,	5·43 cus.	,,	,,	Ditto
6 73 ,,	11·72 ,,	,,	,,	Ditto
10·19 ,,	26-68 ,,	,,	,,	Ditto
43·63 ,,	Not tested	,,	,,	Ditto
1 47 ,,	3·48 cus.	,,	,,	Ditto
0·6 ,,	1·62 ,,	,,	,,	Ditto
21·0 ,,	66·2 ,,	,,	,,	Ditto
35·5 ,,	63·4 ,,	,,	,,	Ditto
2·90 ,,	5·30 ,,	,,	,,	Unsuitable as a lining material
2·67 ,,	3·78 ,,	,,	,,	Ditto
Not tried	9·48 ,,	,,	,,	Ditto

TABLE 14—*contd.*

Seepage results of various types of bitumen impregnated

Serial No.	Name and Number of sample	Name of the Coy. that supplied the sample
19	412	Shalimar Tar Product Limited Calcutta.
20	413	,,
21	414	,,
22	410-A	,,
23	410-B	,,
24	411-A	,,
25	411-B	,,
26	TM/CAN/I	,,
27	TM/HESS-I	,,
28	TM/TWL-I	,,
29	22/TM/CAN/D-I	,,
30	2/TM/CAN/D-2	,,
31	2/TM/CAN/D-3	,,
32	2/TM/CAN/S-1	,,
33	2/TM/CAN/S-2	,,
34	Panel craft	Uited Traders, The Mall, Lahore.
35	Fans (Fibre glass material)	Steel Brother Ltd., Lahore.

fabrics tested in the Laboratory.

Seepage in cusecs to begin with per 10^6 sq. ft. W.P. of at 32°C.		Seepage in cusecs after six months immersion under water per 10 sq. ft. W.P. at 32°C.		Remarks
Head of Water		Head of Water		
15 ft.	20 ft.	15 ft	20 ft.	
0·00 cus.	0·00 ,,	0 00 cus	0·00 cus.	Water proof but mechanical strength low high
0·00 ,,	0·00 ,,	0 00 ,,	0 00 ,,	,,
0·00 ,,	0·00 ,,	0·00 ,,	0·00 ,,	Water proof but mechanical strength low high and contract on immesion under water only 0.31°/₀ suitable Most suitable lining material of the whole lot having mechanical strength lowest construction.
0·00 cus	0·00 ,,	0·00 ,,	0·00 ,,	Water proof mechanical strength high and contraction on immersion small.
0 00 ,,	0·00 ,,	Not yet	tested	
0 00 ,,	0·00 ,,	0·00 cus.	0·00 cus.	,,
0 00 ,,	0·00 ,,	0 00 ,,	0·00 ,,	,,
32·20 ,,	100·10 ,,	Not	tested.	Unsuitable as a lining material-
32·20 ,,	100·10 ,,	High	Seepage.	,,
26·8 ,,	91·3 ,,	,,	,,	,,
0·00 ,,	0.00 ,,	Not yet	tested.	,,
0·000 ,,	0·00 ,,	,,		,,
0·00 ,,	0·00 ,,	,,		,,
0·00 ,,	0 00 ,,	,,		,,
0·00 ,,	0·00 ,,	,,		,,
3·4 ,,	6·0 ,,	,,		,,
0·0 ,,	0 0 ,,	,,		Suitable for canal lining but cracks on handling.

ed after being kept immersed in water for six months and were still found impervious and durable. In one sample the basic material used was glass fibre as a protection against deterioration under water.

30. Use of visqueen plastic films.

Recently I. C. I., Pakistan has tried to introduce the visqueen plastic films in canal lining projects. A thick range of these films was found (30) to be impervious to a fairly high water head but the main defect was the flimsy nature of the films which got damaged by rough handling in the field. These needed protection of soil or bricks, and formed no joints with the masonry. The fact that these are to be imported at high cost, is a matter of great consideration.

31. Protective cover for bitumen coated Fabrics and films.

Bitumen coated fabrics have been used for canal lining in other parts of the world. A coating of these fabrics below double tiles lining can give an impervious stuff but it is expensive. A soil protection of about three to four feet has been found necessary for such type of lining but this method can be helpful for small canals. The canals giving excessive seepage are fairly big, usually 2 to 3 hundred feet in width and sometimes scour the bed by two or three feet.

Even for small canals, the soil cover should be sufficient to stand the damages caused by cattle.

32. Bitumen membrane lining.

Along with the development of bitumen coated mastics, spraying of pure bitumen on the bed, has been tried particularly in the United States. The thickness of the membrane has often been $\frac{1}{2}$ inch with a protective cover of one to three feet of soil. Sometimes it includes six inches of gravels. This type of lining has not been used in this country, except recently at the small Fateh Sher Distributary in Chej Doab where $\frac{1}{2}$ inch thick bitumen was sprayed on soil and covered by a foot of the same material.

Certain experiments with spraying of bitumen on wet sand were tried in laboratory and it was found that hot bitumen boiled the water content of the sand, which blew holes through the bitumen layer and punctured it.

It was found that a spraying of crude oil followed by a coating of hot bitumen considerably reduced the air blew holes. Double spraying of bitumen gave a satisfactory membrane.

This type of bitumen membrane has not been tried in this country, but its use is possible at small distributaries passing through sandy beds, where hot bitumen can he sprayed on dry beds followed by a protective layer of soil.

33. Use of bitumen water emulsion.

Spraying of hot bitumen is always a problem and particularly if it is to be sprayed on wet surface. It has been possible to make water emulsion of bitumen which can be applied in the cold state. This emulsion contains soft or low melting point bitumen and dispersed with water by adding some chemicals. When it is applied on a surface as for patch work on roads, water is evaporated, leaving the bitumen to bind the gravels. The use of materials was tried for coating of bricks and sand plaster. It was found that when water evaporated, bitumen was left in patches with big hollows in between. On more than one occasions coating was also not free from this defect and hence its application wa s considered unsuitable for canal lining.

34. Bitumen soil stabilization.

If a soil contains a minimum percentage of 7% of clay particles smaller than 0.002 mm under compaction, it can be a good medium for lining of canals, but unfortunately a compacted soil, if exposed to
(IR_2)
wetting and drying cycles, it loses its compaction and after sometimes its percolation increases. Bitumen emulsion can be used to stabilize soil to retain its compaction. A few laboratory experiments were tried to study the stabilization of the Punjab soil with bitumen emulsions supplied by Burmah Shell Company. But it was found that it was difficult to compact such a mixture and the stuff after sometimes developed a form of fungus. which appeared on the surface. Perhaps some other type of bitumen emlusion might be successful but detailed investigations were not carried out.

35. Bitumen impregnated bricks.

It has been found that if bricks or tiles before soaking in water are put in a hot oily emulsion of bitumen, it penetrates to a depth of 1/8 to 1/4 of an inch. These bricks, if used for construction, are very resistant to the movement of moisture and become partially impervious. Examples
($3R_2$)
of brick walls built at Chuharkana in 1933—35 have often been quoted (See plate 3 & 4). The walls in which bitumen impregnated bricks were used, as damp proof coating, have resisted the movement of moisture and the upper portion of the wall had remained intact, whereas walls having damp proof course of cement concrete had badly deteriorated. This alternative is thus good for lining purposes.

In fact it can be stated that bitumen can be used in several forms to reduce water losses, but its extensive use is possible if sufficient supply of this material is available in the country. Foreign exchange is a big hurdle in the use of bitumen.

36. Soil lining

Soil is a natural gift which can be used very successfully for canal lining. Had our formation been such that during the alignment of our canals, there would have remained about 5 ft. thick soil formation under the bed of the canal, the seepage losses would have been much less. But unfortunately for giving a proper gradient to a canal, the soil has to be dug out, leaving sand at the bed of the canal which is a source of high order of percolation. If, however, we can replace the sandy bed with 5.0 ft. or more thick soil our seepage loss will reduce to an insignificant order.

Replacing such thick soil at the bed is nearly impossible. As an alternative a thin layer of compacted soil about one foot thick if placed at the bed of a canal can serve as an impervious medium.

This was tested in the laboratory and it was found out that a soil with a minimum of 7 percent clay particles, when compacted was impervious to 20 ft. of water head. Unfortunately this compaction was not lasting as wetting and drying cycles eliminated the compaction and brought the soil back to its original state. A cover of bricks or tiles reduced this de-

(IR_7)

terioration and compaction was fairly lasting. Thus an alternative for small canal if one foot of good soil is compacted and covered by a layer of bricks it can form a cheap and impervious lining.

37. Soil Cement lining.

In order to attain a lasting compaction and imperviousness of the soil, mixing of cement and compacting the stuff at proper moisture is most essential. Laboratory investigations have shown that minimum 3% of cement can stabilize a soil but the exact quantity of cement depends upon the nature of soil. It has been found that for the Punjab soil 5 to 8% cement can give a very durable impervious medium which does not lose its compaction. It was, however, found that rolling of big slabs of soil cement was defective as uniform compaction was not possible and uncompacted portions showed quick deterioration. Another defect was the presence of soluble salts and carbonates. They slowly deteriorate the material. All weaker portions crumbled slowly. Another alternatve is to use soil cement compressed bricks. They are quite uniform in compaction and show much less deterioration particularly if they have a protective cover. In unprotected soil cement bricks weathering appeared after one or two years.

38. Use of Bentonite.

Bentonite is an alkaline fine clay with high order of expansion when it is wet. Due to its high colloidal content on wetting and formation of a jell, it becomes impervious. It can be successfully laid under a thick cover of soil or sand. A thin layer of bentonite can reduce the seepage considerably. In that case its action will be similar to laying of a clay layer under a pervious bed. It is said that bentonito due to its alkaline properties and fine grains can penetrate through a sandy bed and can ultimately seal it off but there is no information available in this country on that subject as it has not been tried so far on a field or laboratory scale. It is expected that very soon some trials will be conducted similar to those conducted in America where the working of this substance is being investigated on a very large scale for the last several years and several publications[31] have been issued on its use in canal lining.

The last item on which some information has been collected in this country is the use of chemicals for making the indigenous materials impervious. Some information on the results of the tests conducted in this laboratory is given below.

39. Chemical lining

As early as 1936, it was found that if about 0·2% of sodium carbonate is added to the soil, it can be made impervious. Investigations were conducted on a distributary in Lower Bari Doab canal and it was found that sodium carbonate lining did not last for more than two seasons.[32] It was damaged by the movement of cattle and other causes.

40. Use of sodium silicate and calcium chloride to improve imperviousness

Sodium silicate and calcium chloride are the two chemicals commonly used for increasing capacity of foundation to bear the pressure. These are sometimes used for reducing seepage also.[33] A trial of these chemicals was made by injecting these one after another in fine sand. It was found that sand, particularly if it was coarse, formed a very hard stuff. Sodium silicate stabilized sand when subjected to water pressure gave no percolation for sometime but after a day or two became soft and gave way. This method of treatment of pervious sites was even tried in the field and results were as reported above.

41. Effects of coating by sodium silicate 'Pucca Kaam' on pervious concrete.

A certain material sold under the trade name of 'Pucca Kaam' is being produced in this country. It is claimed by the manufacturer that coating of this stuff on the surface or using it integrally while preparing concrete can produce an impervious stuff. This material was tried in the laboratory by making cubes and cylinders of different proportion of cement sand using this stuff for coating them. It was also used integrally in the mortar. Absorption tests in Table 15 showed no improvement in the materials. Permeability tests also showed no improvement.

TABLE 15

Absorption test on cement sand briquetts coated with Pucca Kaam

Serial No.	Briquetts Specification	Coating by Pucca Kaam	Mean absorption percentage after 24 hrs. immersion in water	Remarks
1.	1 : 6	Nil	13·8	2 percent diff.
2.	1 : 6	3 Coats, 1 : 4 1 : 3 & 1 : 2	11·8	
3.	1 : 3	Nil	7·6	0·59 percent diff.
4.	1 : 3	3 Coats, 1 : 4, 1 : 3 & 1 : 2	7·01	
5.	1 : 6 Cylinder	Nil	10·4	0·5 percent diff.
6.	1 : 6 ,,	3 Coats, 1 : 4, 1 : 3 & 1 : 2	9·4	
7.	1 : 6 ,,	Nil	11·79	0·02 percent diff.
8.	1 : 6 ,,	One coat of Pucca Kaam no dilution	11·79	

This chemical was tried on a 1000 ft length of the Thal Canal near Pai Khel for reducing the permeabilty of the porous concrete. The field reports confirmed the laboratory tests. The whole coating was washed away in a month or so.

42. Use of soap solution for reducing permeability.

(34 a & b)

During recent years some work has been conducted in India on the use of soap solution to reduce permeability and capillary rise in cement sand and in bricks. Recent laboratory tests were conducted on lean cement sand plaster in which different percentage of sun-light soap was used. This plaster was also laid in between two layers of bricks. On testing a considerable decrease in absorption, permeability and capillary rise were noticed. Use of soap, however, reduced the crushing strength of the cement sand mix. It seems that use of this stuff if properly practised, may help in reducing percolation. It seems its working is similar to air entrant agents. Further durability tests are needed for this material.

TABLE 16.

Seepage Losses from canal worked out by various

Serial No.	Site of observation	Doabs	Length of reach
1	2	3	4
1	Jhang Branch of the Lower Chenab Canal.	Rechna.	R. D. 260 to RD 32, 260
2	Kasur Branch of the Upper Bari Doab.	Bari	R. D. 8, 500 to R.D. 104, 400.
3	Mianwali Branch of the Lower Chenab Canal.	Rechna	R. D. 0 to R.D. 134, 850.
4	Kot Nikha Branch of Lower Chenab Canal.	Rechna	...
5	Kasur Branch	Bari.	R. D. 8,500 to R. D. 104, 400.
6	For Punjab Canal	All doabs	...
7	Lower Chenab Canal	Rechna	Main Canal & Branches.
8	Upper Chenab Canal	Rechna	...
9	Lower Jhelum Canal	Chaj	...
10	Upper Jhelum Canal	Chaj	...

persons.

Methods used	Seepage in Cusecs per million square feet of wetted perimeter	Reference
5	6	7
Statistical Examination Malhotra	10·3	A. R. I. R. I. 1938 Page 73.
Current meter and sounding rods by Malhotra	10·5	,, ,,
Statistical analysis by Malhotra	13·7	,, I. R. I. 1940 Page 130.
By Blench in 1941.	6·0	,, I. R. I. 1941, Page 112.
By estimation of discharge passing two sites with the help of a sharp-crested weir.	4·8 7·5	,, I. R. I. 1941, Page 112.
Analysis by Crump of data of the last 20 years.	8 to 25	,, I. R. I 1941, Page 112.
Mhangar data, based upon discharge measurement.	16·6 % =1130 Cs.	Punjab Engineering Congress Report No. 284, 1947.
,, ,,	7·0 % =162 Cs.	Punjab Engineering Congress Report No. 284, 1947.
,, ,,	14·3 % =340 Cs.	Punjab Engineering Congress Report No. 284, 1947.
,, ,,	31·5 % =305 Cs.	Punjab Engineering Congress Report No. 284, 1947.

TABLE 16—*contd.*

Seepage Losses from canal worked out by various

Serial No.	Site of Observation	Doabs	Length of reach
1	2	3	4
11	Lower Bari Doab	Bari	Three sites R.D. 154,000 R.D. 165,000 R. D. 126,000
12	Upper Chenab Canal	Rechna	Mian Line Upper Mian Line Lower.
13	Lower Chenab Canal	Rechna	Main Line Upper and Lower-
14	Jandiala Distributry	Bari	R. D. 7,000.
15	M. Gopal and Sharma paper No. 209, 1938.	Ghaj	R. D. 41,5000.
16	Upper Gugera Canal	Rechna	Seepage measurements in Tank No. 1(400×50×4)
17	Upper Gugera Canal	Rechna	Tank No. 2 (400×50×4)
18	Upper Gugera Canal	Rechna	Tank No. 3 Tank No. 3
19	Upper Gugera Canal	Rechna	Estimation by permeability and drainage, etc., from S.S. Obs.
			Discharge 6,000 W. depth 10·0′ F. S. L. & W. T. 3 to 5.
20	Upper Chenab Canal	Rechna	Discharge 14,000 Depth 14·0′
			Diff. & F. S. L. & W. T. 3 to 6. FT.

persons—*contd.*

Methods used	Seepage in Cusecs per million square feet cf wetted perimeter.	Reference
5	6	7
By installing pipes and observing the rise of water-table and moisture content.	4·2 5·0 3·0	A. R. 1938 Page 18 Summer 1937-38. Winter 1937-38.
Blench data S.S. Wells records.	5-2 Cs. Total 563Cs. 11·2 Cs. ,, ,,	Water logging investigation report Juue 1940.
,, ,,	7·0 Cs. ,, ,,	Water logging investigation report June 1940.
Vadianathen by pipe observation W. T. at 2·0′ blow bed.	3·0	A. R. 1943, Page 19.
Seepage from tanks 205×26 with 1:1 side slope.	5·0 to 34·0 Cs. under 5·0 ft. head.	PB. Engineering Congress 209, 1938.
Vadianathen and Haigh beginning after one month, after two months.	Original after scraping 5·0 bed, 5·0 11·3 Cs. 1·6 5·5 ,, 1·4 2·0 ,,	A. R. I. R. I. 1946 Page 8.
Beginning. after one month	4·0 40·0 ,, 20·0 ,, 0·5	A. R. I. R. I. 1946 Page 8.
Beginning of least after 3 monts.	3·8 16·0 × 8·0 0·5 16·0 × 4·0	A. R. I. R. I. 1946 Page 8.
Clay bed.	1·2	Permeability Survey of canal special reports.
Silty bed.	3·6	
Sandy bed.	4·8	No. 115 Ph/Seepage 16/56.
Silty bed.	4·0	Special Report No. 142-Ph/Seep-28/57.
Sandy bed.	6·0	

43. Lining of the existing canals.

A large number of the existing canals in this country are unlined. Their alignment is such that in the course of their length at several places, particularly below falls or in digging. the canal bed had cut through soil crust and the canal is flowing on sandy beds. After running these canals, water-table has slowly risen and now in major lengths of these, particularly where the bed is sandy or the canal is in filling, the watertable exists several feet above the canal bed. During the short closure, the water is continuously drained back into the canal and in fact the full canal is never dry. There is a serious matter as any lining constructed in the existing canal will be subjected to high uplift pressure. Only that type of lining for these canals will be successful which can release the drainage pressure.

The closure of the canals for a long period of time offers another difficulty. Only that type of lining can be successful which can be quickly laid.

Wide section of these canals, uneven beds, high frictional co-efficient are other factors which reduce the advantages to be gained by lining these. But inspite of all these difficulties, at least the pervious reaches of these canals should be lined, i f we want to tackle successfully the problem of water-lodging and salinity.

It is true that at present the seepage from the canals is not much as the difference is not much between the full supply level and the sub-soil watertable. The loss is being maintained by fairly flat gradient of flow and by evaporation. An estimate of seepage losses conducted by various authorities is given in Table 16. The latest estimate based upon permeability survey of some of the canals is also given in the same statement.

For a success of salinity control operations, watertable shall have to be lowered and according to the well established conceptions, lowering of water-table is bound to increase the seepage from the canals and in order to cut down the increased seepage, lining must have to be adopted.

The only lining which can be successful in keeping with the problems of unlined canals will be semi-previous soil lining. May be the sedimentation lining by the use of bentonite as being developed in the United States (31, 35, 36) prove helpful but so far this problem is not within the reach of a solution.

It is suggested that injection of bentonite or colloidal clay during a running canal might prove successful. So far these experiments are under investigations in the laboratory.

34. Summary of the main inferences for a type of canal lining most suitable for West Pakistan.

Having considered the various problems to be encountered in the lining projects of West Pakistan canals and the results of tests of various materials, we give a summary of the main inferences to construct a most suitable type of canal lining in this country.

(*i*) **Stability against rising sub-soil water.**

Canal linings in this country are to be subjected to the pressure of rising water-table sooner or later. In order to safeguard against this pressure it is necessary to control the level of the sub-soil water. It is proposed that deep tile drains perferably connected with vertical strainers may be provided along both sides of the canal (see Fig. 1). One or more such lines of these drains will be necessary to check the rise of water-table and stop water-logging of the region.

(*ii*) **Frequent canal closures.**

The link canals will have frequent sudden closures, so that provision be made to quickly drain out the pores water. This is particularly essential for places where the embankment consists of low permeability soil. It is suggested that a three inches thick filter of fine grit or coarse sand carfully mixed with sufficient water for complete saturation and with a small quantity of cement, say one part of cement to 30 parts of sand, be added behind the lining. Preferably 1½ inch diameter baked clay strainer may be used in this filter and at the end a small pipe may be come out of the lining to serve as a weep hole. A flap to check water flow during the running of the canal and the draining out water during closure should also be provided to this pipe. This weep hole should be two or three feet above the bed of the canal.

For draining out the moisture accumulated behind the lining, it is proposed to provide vertical sand filters made of one foot diameter holes filled with coarse sand and connected to the under-ground sand formation. These outlets may be 30 to 50 ft. apart, where the soil is thick the side filter may be connected to a weep hole opening in the bed of the canal. These measures will drain out the excess moisture of the sides, will keep the water-table in control and will protect the soil formation from expansion and development of cracks. A filter connected outside the embankment might be too expensive. Drainage into the bed of the canal might be cheaper and appropriate.

(*iii*) **Stability against floods.**

Link lined canals have to stand against high flood levels. This is mainly due to restricted water ways of cross drainage, particularly the syphons which invariably get choked. An embankment with high water level on one side and empty canal with a lined surface on the other, is subjected to infiltration head from behind the lining and causes its failure. An obvious safeguard is to keep the canal full, so that the differential head is reduced. Provision of gates in a canal is suggested so that as soon as the canal is closed, the gates are lowered to keep the canal full of water. If cross drainage can also be combined with these gates many of the present defects of floods will be eliminated.

(*iv*) **Stability against temperature cracks.**

Link canals subjected to closure of non-perennial running with fluctuation of supplies are subjected to about 100°F temperature variation, Development of cracks is possible particularly at the 'Domalies' although brick masonry shows very few cracks probably because each pointing between two bricks serves as a joint. Half an inch thick cement sand plaster being a rich mix. of 1 in 3, has greater expansion co-efficient than bricks and is liable to develop cracks. A lean mix may have more cracks. Domalies which have only 2 inches of space under the lining slab and possess cracks at joints are potential sources of percolation. Either filling of the joint by a bituminous material or increasing the width of the slab below the lining slab can be of help. It will still improve the imperviousness if 'Domalies' are eliminated by providing staggered reference construction points as shown in Fig. **5**.

The thickness of the plaster should also be increased to $\frac{3}{4}$ or 1·0 inch and 20 to 25% of the cement may be replaced by brick surkhi.

(*v*) **Free Board.**

In a lined canal, mean velocity of flow equal to 5 to 8 ft. per second can be maintained. The rugosity co-efficient of brick or cement lining is fairly low as compared to earthen channels. It has been found that an appropriate co-efficient for brick lining is 0·018 and on this basis a free board of $1\frac{1}{2}$ to 2 ft. may be provided for canals discharging above 10,000 cusecs.

(*vi*) **Infiltration of water behind the lining.**

There should be no berm on top of the lining as it is a potential sources of infiltracion of water behind the lining. It is preferable to have a Dowel right above the top of the lining in continuation of the slope of the lining. As a further safeguard it is suggested that the top of the lining may be extended to atleast $1\frac{1}{2}$ ft. slightly sloping downwards buried under the Dowel.

(*vii*) **Suitable side slope for a lined canal.**

A stable slope for saturated sand and coarse silt is $1\frac{1}{4}$ to 1. In case of quick lowering of water level in canal a stable slope for sand attains a value equal to $1\frac{1}{2}$ to 1 and for coarse silt about 2 :1. There is no stable slope for soil at liquid limit and hence drainage is necessary. With provision of drainage facilities, a slope of $1\frac{1}{4}$ to 1 or $1\frac{1}{2}$ to 1 will be stable. It has, however, been found that a side slope of 2 : 1 without a filter has behaved better than $1\frac{1}{2}$: 1.

(*viii*) **Protection from salts.**

Soluble salts particularly sulphates deteriorate that portion of concrete and bricks which is above the water surface and within the capillary range. A plaster containing 20% replacement of cement by surkhi and bricks pointed with the same mortar resist action of salts. Addition of air entering agent or soap solution reduces the capillary rise and appearance of salts. A coating of shelmac R. C. 3 or double boiled linseed oil in the capillary region can protect the lining from the salts. Bricks impregnated with oil solution of bitumen placed in the capillary region can also check the salt movement.

(*ix*) **Structural stability.**

Lining is not supposed to stand any tension. With increasing depth of lined canals upto 20 to 25 ft. a thin ½ inch thick plaster is liable to be cracked. It is thus preferable to use 3·0 inches thick tiles against the present thickness of 2½ inches and raise the thickness of plaster to ¾ or to 1·0 inch.

(*x*) **Rigid lining.**

For this country concrete lining is too expensive as the materials have to be brought from far off distances. Shotcrete is also suitable only on a rigid base. Its cost is more than concrete.

Bricks can be manufactured every where close to work and their laying with local labour is also cheap. These are quite suitable for lining projects of this country. Bricks are pervious and for canal lining it is necessary to have a sand-wiched layer of ¾ to 1·0 inch thick plaster made of cement and, with 20 to 25% replacement of cement by surkhi and provided with an additional 1/8 inch thick layer of bitumen. This type of lining is practically impervious to 20 or 25 feet of water head.

Use of ¼ inch thick bitumen sand (7 : 100) mastic placed above the soil, followed by conventional double tile lining with a course of ¾ to 1·0" thick 1 : 3 cement sand plaster, is another alternative.

A third alternative is to replace bitumen sand mastic by a bitumen impregnated fabric. It will be impervious to 15 to 20 ft. of water head.

(*xi*) **Flexible lining.**

(*a*) Bitumen coated fabrics with base of jute, canvas, fibre glass, coir fibre can easily be made to with-stand water pressure of 10 to 15 ft. These must have protection of 2 to 3 ft. of soil which should not be scoured out.

(*b*) Spraying of pure hot bitumen on wet surface is not possible without blow holes puncturing the film unless the surface is quite dry. Spraying crude oil followed by a thick coat of ½ inch bitumen is recommended. This film must also be protected from damages.

(*c*) Use of cold bitumen emulsion is not successful as it forms patches after evaporation of the water.

(*d*) Bitumen stabilized soil has not proved successful as it developes fungus formation.

Bitumen impregnated bricks are impervious to moisture movement although under high heads these also need a layer of impervious stuff such as bitumen sand mastic.

(*e*) Use of plastic films called Visqueen have been tried between two layers of tiles. The film being very thin gets damaged by bricks.

(*xii*) **Soil lining.**

(*a*) Compacted soil is ideal as a lining material provided the soil contains at least 7% of clay particles, is compacted and this compaction remains permanent with cycles of wetting and drying. A compacted soil protected by burnt bricks remains as such for a very long time.

(*b*) Soil cement is another alternative and it should be uniformly compacted. Presence of salts and non-uniform compaction causes deterioration.

(*c*) Soil cement compressed bricks are very satisfactory provided these are pointed properly as improper pointing causes percolation. The quantity of cement shall have to be adjusted according to the type of soil.

(*d*) A layer of bentonite or colloidal plastic clay under the bed of a canal and protected by 2 to 3 ft. of soil can work as impervious medium.

(*xiii*) **Chemical lining.**

(*a*) Use of sodium carbonate with soil has not behaved proprely.

(*b*) Use of sodium silicate and calcium chloride to stabilize pervious sandy medium has not proved permanent and stable.

(*c*) Soda silicate or Pucca Kaam used as coating on pervious concrete or used integrally has not proved helpful and lasting.

(*d*) Use of soap solution in lean plaster reduces the percolation but decreases strength at the same time.

(*xiv*) Lining of existing earthen canals is full of many problems. Perhaps injection of bentonite or colloidal clay in the sandy beds of running canal may reduce percolation. This needs field trials.

45. Acknowledgement.

This paper is a result of investigations which the author has been conducting on canal lining problem for the last fourteen years. In collecting the material, extensive use of the literature given in the bibliography has been made.

Although laboratory investigations have been conducted by many Reaserch Assistants but the largest amount of information has been collected by the junior author who has remained on the problem for many years. A considerable amount of work reported in this paper was done by Mr. Fazal Karim now Research Assistant, Mangla Dam and Hashim Raza now an Officer in the Geological Survey Department of Pakistan.

ERRATA FOR PAPER No. 344.

Page of Text.	Line	Add	Read	after	for
115	13	air	...	soil	...
115	22	...	lined	...	lived
115	24	increased by ten	...	it	...
118	7 from bottom	...	yields	...	yeilds
119	11 ,, ,,	...	water	...	warer
123	17 ,, ,,	Delete	sand	cement	...
130	Table 5, S. No. 3	free	...	channel	...
133	7 from bottom	...	12″×6″×2″	...	12″×2″
134	20 ,, ,,	...	lining	...	lning
134	5 ,, ,,	...	as	...	at
138	Table 8, Col. 4	...	$1\frac{1}{2}''$	...	1·0″
138	,, 8 ,, 6	...	plaster	...	plastet & plaste.
144	7	...	given	...	gven
146	Table 14, S. No. 5	...	Mexphalt	...	Mexhatti
148	,, ,, ,, 19	...	omit high	low	...
148	,, ,, ,, 21	...	omit high	low	...
148	,, ,, ,, ,,	...	contracts, immersion	...	contraction immesion
148	,, ,, ,, 22	...	under water	immersion	...
148	,, ,, ,, 35	...	fam	...	fans
152	6 from bottom	...	bentonite	...	bentonito
157	Table 16, S. No. 7 Col. 5	...	khangar	...	Mhangar
158	Table 16, S. No. 19 Col. 5	...	omit " at least after "	...	...
158	,, ,,	after	...	...	before "3 months"
160	13	...	short	...	long
160	20	...	waterlogging	...	waterlodging
161	15	...	carefully	...	carfully
161	19	...	taken out	...	come out
167	S. No. 23		lean concrete	...	Mean concrete
168	S. No. 27	I		...	Vol.

REFERENCES AND BIBLIOGRAPHY

1. International Association for Hydraulic Research 4th meeting, Bombay, 2-5 Jan. 1951. Question 1.

R-1 Ishar Das Design of lined Canal.

R-2 Nazir Ahmad, Lining of Channels, A Short Review on the Laboratory Tests Carried out on the Various Types of Lining Materials.

2. Transactions of First International Commission on Irrigation and Canals, New Delhi. Question 2.

Handa C. L., Chanan Singh, Midha, D. C. "Experimental Investigations on Canal Lining".

3. Third Congress on Irrigation & Drainage 1957. List of papers on canal lining.

R-1 Baron W. F. Asbeck (Great Britain) Asphalt Irrigation Canal Linings.

R-2 Nazir Ahmad. Muzaffar Ahmad & S. L. Shah (Pakistan) Problems of Canal Lining in West Pakistan.

R-3 Armando da Palma Carlos et Automio Pais Gromincho (Portugal) Revetements des Canaux et Irrigation Portugais.

R-4 A. M. Mc. Intyre (Australia) Concrete Lining of Irrigation Channels in Queensland.

R-5 R. D. Dirmeyer Jt. (U. S. A.), Use of Colloidal Clay Sediments in Sealing Irrigation Canals.

R-6 W. G. Holtz (U. S. A.), Thick Compacted Earth Linings for Canals.

R-7 L. M. Ellsperman (U. S. A.), Buried Asphalt Membrane Canal Linings.

R-8 Claude Rattier (France), Reparation de Canaux en Beton a Iaide de Revetemenis Plastiques,

R-9 F. Valirun (France), Problems Poses Pourless Revetements des Canaux par Suite de la Nature des Terres.

R-10 D. Dumany (France), Les Revetements Bitumineux des Canaux dans les chott E. I. Honda (Department de Constantine, Algerie).

R-11 Kanwar Sain (India), Canal Lining in India.

R.12 Ing. Federico Barona de la O. (Mexico), Concrete Lining of Irrigation Canals in Mexico.

R-13 Chowdhry Abdul Hamid (Pakistan) Canal Lining as Practised in Pakistan.

R-14 Japanese National Committee (Japan), Lining of Canal in Japan.

R-15 Fernando Hue Herrero (Spain), Canal Problems in Gypseous Soils.

R-16 C. W. Lausitzen (U. S. A.), Canal and Reservior Lining Materials.

R-17 M. Molin (France), Revetement des Canaux Principaux du Maroc.

R-18 Iltmo Sr. D. Casar Blanco de Cordova (Spain), Canal Lining.

R-19 G. Gres (France), Le Comportement des Revetements en beton bitumeniux dun grand canal de derivation sur le Rhone.

R-20 G. T. Dadayev (U. S. S. R.), Soil Stabilization in Irrigation Construction.

R-21 Giovannvi Padoan, Umbert Terenzio and Ugo Todaro (Italy). Some Aspects of the Problems of Lining of Irrigation Canals in Italy.

4. Lower Cost Canal Lining. A Progress Report on the Development of Lower Cost Lining for Irrigation Canals.

   United States Department of the Interior Bureau of Reclamation, Denver, Colorado, July, 1948.

5. Lining for Irrigation Canals.

   United States of the Department of the Interior Bureau of Reclamation, Denver, Colorado, July, 1952.

6. Ellsperman L. M.,

   The Bureau of Reclamations Uses of Asphalt in Hydraulic Construction in the Western United States First Western Conf. on Asphalt in Hydraulics. Salt Lake City, Utah, Oct. 19-20, 1955

7. Israelsen, O. W. Reave, Reynald,
   "Canal Lining Experiments in the Delta Area, Utah" Bulletin 313 (Technical, June, 1944).

8. C. W. Lauritsen, O. W. Israelsen, W. W. Rasmnseen,
   Agricultural Experiment Station, Utah State Agricultural College, Lining Canals and Reservoirs.

9. Jeffris, C. F.,
   "Concrete Lining of the Gang Canal," Punjab Engineering Congress Paper No. 102, Vol. XIV, 1926.

10. Kapur S. N.,
"Observation on Lined Haveli Canals" Punjab Engineering Congress Paper No. 253, Vol. XXX, 1942.

11. Mahbub S.I.,
"Lining of Channels" Punjab Irrigation Branch Paper No. 22, Class A, 1943.

12. Mahbub S.I.,
"Lining of Channels" Pb. Eng. Cong. Vol. 31, Paper No. 260, 1943.

13. Nazir Ahmad, Dewan Ali & Afaq Ahmad,
A New Conception on the Waterlogging & Salinity Problem of Rechna Doab West Pak. Eng. Cong. Symposium on Waterlogging & Salinity, 1959.

14. Nazir Ahmad,
Soil Salinity in West Pakistan & Means to deal with it. Unesco-Iran Symposium, 11-15th October 1958, Tehran.

15. Asghar A.G. and Nazir Ahmad,
"Drainage of Irrigated Soils in Arid Regions" Proceedings Punjab Engineering Congress Paper No. 312 Vol. 39, 1955.

16. Terzaghi, Karal & Peck R.B.,
Soil Mechanics in Engineering Practice. 1948 John Wiley & Sons Inc. New York, Chapman & Mall, London.

17. Nazir Ahmad, S.L. Shah & Dewan Ali,
Stability of Slopes of Lined Canal. Proc. of 5th Pak. Sc. Conf. Lahore 1953 (Sp. Report 68-Ph/LC-12/52).

18. Muhammad Nazir, Nazir Ahmad and Zia-ul-Haq,
"Bulking of Sand and its Compaction" Pak. Journal of Scientific Research, Vol. 6, No. 3, July, 1954.

19. Dhawan C. L., Bhari J. C.
"Stable Density" Third Inter. Conf. in Soil Mech. and Found, Eng. 16-27th, Aug., Vol. Sec. 2, Switzerland, Zurich.

20. Nazir Ahmad,
Protection of Lean Cement Sand Mixes from Salts Attack. Indian Concrete Journal Vol. 24 No. 3.

21. Duncan R. S.,
Lining of the Haveli Main Canal Pb. Eng. Cong. Vol. 27, 1939.

22. Dhawan C.L., Bhari J.C.,
"Surkhi as Pozzolana." Indian Concrete Journal Vol. 26, No. 4 April, 1952.

23. Hoon R.C.,
"Development of Portland Pozzolana Cement for Mean Concrete Construction." Indian Concrete Journal, Vol. 26, No. 8, August 1952 and September, 1952.

24. Uppal J. C- Mohinder Singh,
Studies in the Use of Pozzolana in Cement Concrete and Mortar, Indian Concrete Journal, Vol. 29, 7th July, 1955.

25. (*a*) Ashraf A.D.,
Interim report on the Experiments in Canal Lining Main Line Lower, Thal Canal. Type written June, 1949.

(*b*) Hakim S.A.
Bitumen Experiments at Main Line Lower Thal. Canal. Type Written Nov. 1950.

26. Nazir Ahmad,
Lining of Abbasia Canal. Sp. Report No. 148-Ph/L.C.-24/57.

27. Asphalt Bulletin Vol. No. 7. Vol. No. 8,
Vol. 2 No. 1, Vol. 2 No. 2. Dealing with Buried Membrane, etc.

28. Asphalt Institute,
Construction Series Nos. 62, 65, 87, 88 & 89. Deals with Buried Membrane.

29. Baron, W. F. Van. Asbeck.
Bitumen in Hydraulic Engineering.

30. Nazir Ahmad,
Testing of Visqueen Plastic films for Canal Lining. Sp. Report No. 147-Ph/L.C-23/57.

31. Colorads A. & M. College,
Department of Civil Engineering Sediment Lining Projects.

32. Sawhney G.R.,
Lining of Channels. Pb. Eng. Cong. Vol. 28, Paper No. 240, 1940.

33. Lewin D. J.
Grouting with Chemicals. Eng. News Records, Vol. 221, August 17. 1939.

34. (*a*) R. N. Dogra, I. S. Uppal,
Water Proofing Cement Sand Mortar No. I & II. The Integral use of Soap. Indian Concrete Journals, Jan. & Feb. 1957.

(k) I. S. Uppal,
A Simple Treatment for Reducing the Capillarity & Permeability of Burnt Bricks and Cinder, Indian Concrete Journal March, 1958.

35. Michaels A.S., Peter, Willian, Randolpls, Kendall N.
Acdic Phosphorous Compounds as Soil Stabilizers. Dept. of Ch. Eng. Mass. Int. of Tech. Camb. Mass.

36. Lamb T. W., Michaels A. S. & Moh. Z. C.
Improvement of Soil Cement with Alkali Metal Compounds, 38-An. Meet. of Highway Rs. Board, Washington D. C., Jan., 1959.

PAPER NO. 344

FIG-1

PROPOSED DRAINAGE MEASURE TO CONTROL S.S.W. TABLE

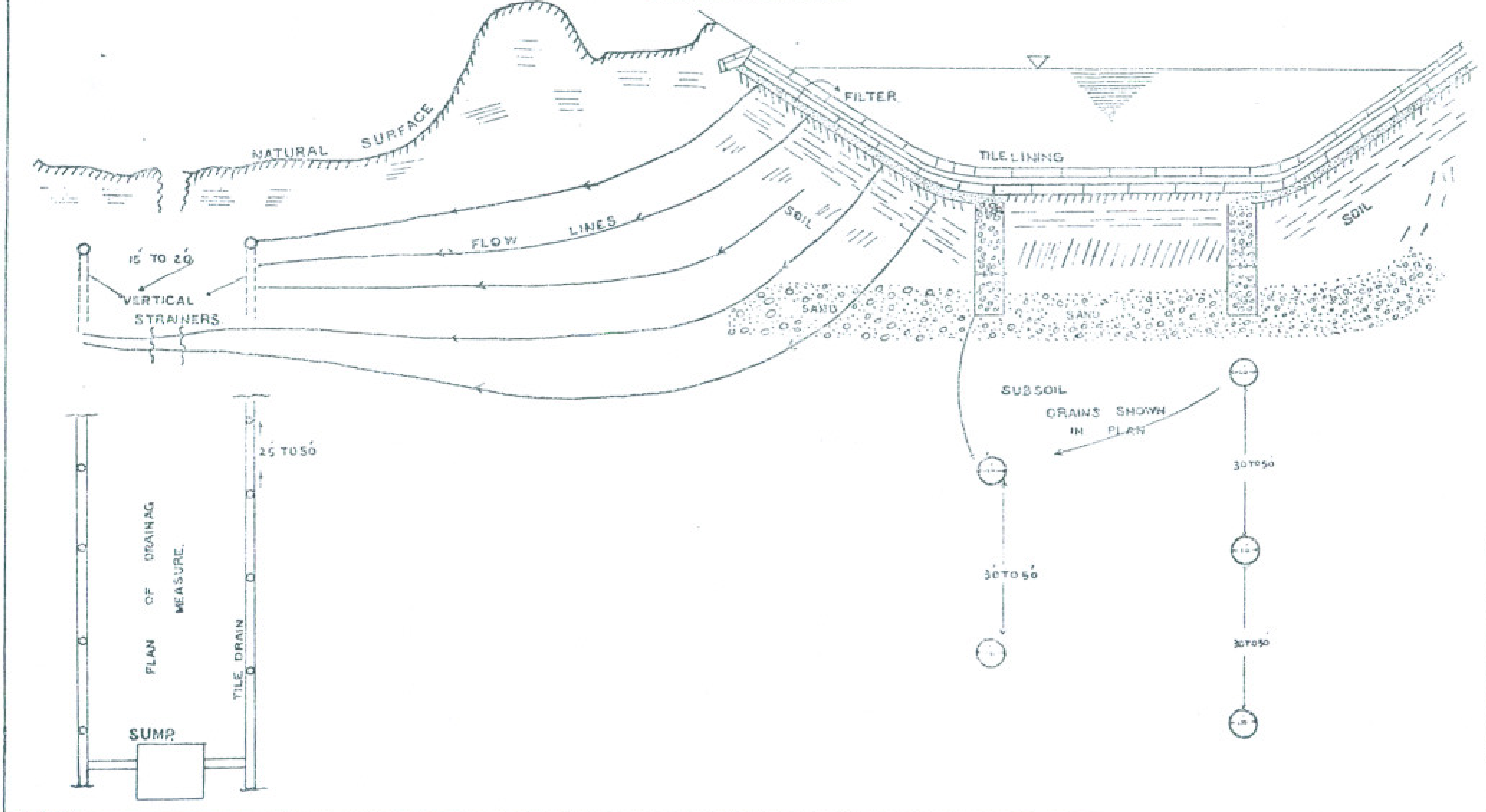


PLATE 1

Damage to canal lining by pressure of wet soil.

PLATE 2

PLATE 3
Deterioration of Masonry Protected by Impervious Concrete Course.

PLATE 4
No Deterioration when Bitumen Impregnated Bricks were used for Impervious Course.