Permeability Tests of Irrigation Canals

Essais pour déterminer la perméabilité des canaux d'irrigation

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Summary

During 1959 and part of 1960 the author served as an expert with the United Nations (Food and Agriculture Organization) in East Pakistan on the Ganges Kobadak Irrigation Project. He investigated the permeability of irrigation canals by field tests in a test section and by laboratory tests. The influence of silt load, brought by the River Ganges to irrigation canals, was studied in detail and he gives the results of these studies.

Sommaire

En 1959 et 1960 l'auteur a travaillé avec l'Organisation des Nations Unies (Organisation pour l'Alimentation et l'Agriculture), dans l'Est du Pakistan, à la réalisation du projet d'irrigation Ganges Kobadak. Il a eu à y étudier la perméabilité des canaux d'irrigation au moyen d'essais sur le terrain et en laboratoire, considérant plus spécialement l'influence des charges silteuses charriées par le Gange. Les résultats en sont donnés dans cette communication.

1. Introduction

The Ganges Kobadak Project was the first irrigation scheme set up in East Pakistan. The first phase, the Kushtia Unit, situated near Dacca, capital of East Pakistan, is under construction. Some canals have been completed and water may be expected to enter the canal system in 1961.

As no experience existed about the permeability of the soil and seepage losses likely to occur through the irrigation canals, tests were performed in 1959 and 1960 to determine these.

First of all laboratory tests were carried out on samples taken from the site and tested for permeability. The same samples were again tested after a 1 mm layer of suspended river material had been allowed to settle on top of the samples. In some cases a 2 mm layer was applied. In that way the influence of the suspended load on the permeability could be estimated.

By carrying out investigations in the field on a test section of a tertiary irrigation channel, which was filled by temporary pumping, positive information was obtained about the decrease in seepage losses due to the staunching of the canals.

2. Laboratory tests

1. *First Series :*

On February 12, 1959 at Baradi Pilot Farm near Kushtia from the bottom of several canal parts 20 samples (BAR 1-20) were taken with an apparatus for undisturbed sampling. The position of the samples is indicated in Fig. 1.

The first stage of sampling involved the excavation of a small pit about 30 cm deep in the bed of the canal. This pit was filled with water some hours before taking the samples in order to facilitate the operation, the soil being hardened through the dry sunny winter period. Notwithstanding this wetting of the soil, the sampler had to be hammered down for almost 2/3 of its height and in the case of the more sandy samples for nearly the entire height.

(a) *Location of the samples*—The samples BAR 1-5 were taken in the last reach of the tertiary canal. The pits from which the samples were taken appeared to be dry some hours after having been filled with water. This pointed to a rather high seepage. Close inspection of the canal bed and slopes revealed several small holes in the soil, probably due to insects, worms, roots and so forth.

The samples BAR 6-20 were all more or less sandy samples. The soil showed no holes. No compaction was noticed while taking the samples.

The samples BAR 6-10 were taken in field channel III, near the tertiary channel, from what appeared to be very sandy subsoil, below clay layers of about 20 cm thickness. At the spot where the samples BAR 11-12 were taken the upper layer of the soil consisted of clayey sand, about 30 cm thick.

The samples BAR 13-20 were not soaked with water before being taken out of the bed and the lower parts of the slopes All samples were rather sandy.

It must be emphasised that the indications of the soil as given here are as they were deduced from visual inspection. The results of the grain size analysis in the laboratory will be given later.

(b) *Laboratory Tests*—The samples were used to determine the permeability in the usual type of laboratory apparatus for that purpose. First the permeability was tested on the samples as they were taken from the field. After the test had been completed, a layer of 1 mm thick of clay was applied on top of the sample in the manner described later. Then again a permeability test was performed delivering information about the staunching effect of the clay layer.

The grain size distribution of all samples was determined by the usual sieving and hydrometer methods. Swelling of the samples, caused by soaking before the permeability tests, was also measured. The testing procedure was as follows :

1. The samples were first soaked for 24 hours before being put into the permeability apparatus. For this purpose water was taken from the nearby Buhri-Ganga River, a branch of Bhramaputra. However, this does not differ very much from the Ganges water as to chemical composition. At least it was better than taking water from the Dacca water supply or distilled water for testing.

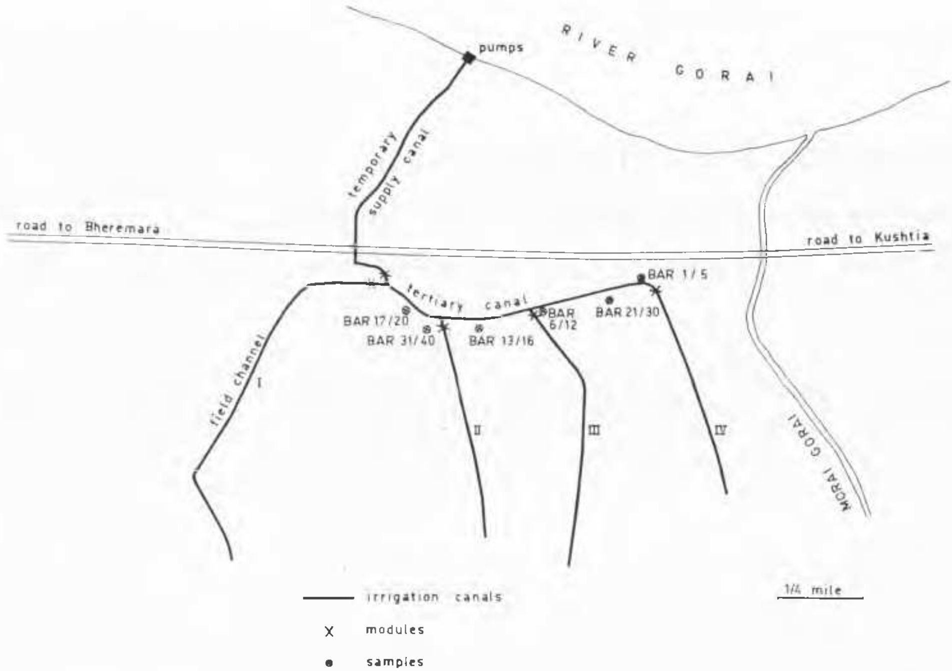


Fig. 1 Samples taken at Baradi Pilot Farm.
Echantillons prélevés à « Baradi Pilot Farm ».

2. The swell in the vertical direction after soaking was measured; the maximum swell along the axis of the sample is given .

3. The samples were then put into the permeability apparatus; the permeability was tested for from 7 to 8 hours. The average is given as a result.

4. After completion of that test, the water column above the samples was very carefully mixed with a prepared clay suspension. This suspension was allowed to settle on top of the sample for some time. The amount of clay added was such as to allow for a 1 mm thick clay layer on top of the sample, if no penetration of clay into the upper layer of the sample occurred.

5. After that the seepage test was continued for another 7-8 hours; from that the influence of the clay layer could be detected.

6. As no suspended load from the Ganges was available in sufficient quantity for the composition of the clay suspension, clay from Baradi Farm was used. Before use this clay was passed through a 50-micron sieve in order to exclude particles of that size. At the time of testing it was already known that particles larger than 50 microns were not likely to be found in the suspended load of the Ganges River. A comparison of the grain size distribution of the suspended load and the clay used for the purpose of testing is given in Fig. 2. From this it can be seen that the soil contains more fine particles than the suspended load; the grain size distribution does not differ widely, so that the results of the tests can be regarded as representative.

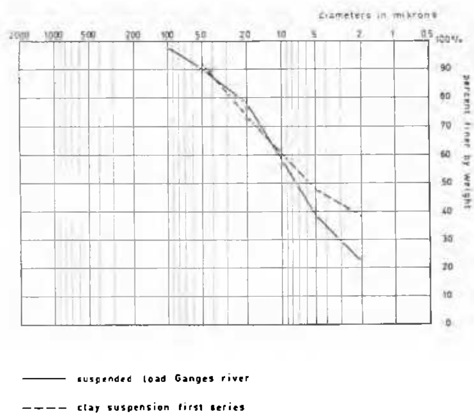


Fig. 2 Grain size distribution in the loaded Ganges river water and in laboratory samples.
Analyses granulométriques de l'argile en suspension dans le Gange et de celle ayant servi aux essais au laboratoire.

7. After the seepage tests of all samples were finished, bulk density in a saturated condition and the voids volume were determined.

8. Finally, the grain size distribution of all samples and the

clay used in suspension were determined by combined sieve and hydrometer analysis.

(c) *Results*—Grain Size Distribution : There appears to be a striking difference between the samples **BAR** 1-5 and the other samples, the former being clay or silty clay and the latter loam or sand.

	500-250	250-100	100-50	50-20	20-5	5-2	2 microns
BAR 1-5	—	—	7·2	10·5	38·0	10·8	33·5
BAR 6-20	0·3	8·9	32·3	40·5	11·7	1·2	5·1

For the sake of comparison, both distributions have been plotted in Fig. 3. As the deviations of individual samples from an average value are not excessive, the graph serves its purpose adequately. It appears that the soils found in the canals which were tested are of two different types, a fact which must be borne in mind when comparing laboratory with field tests.

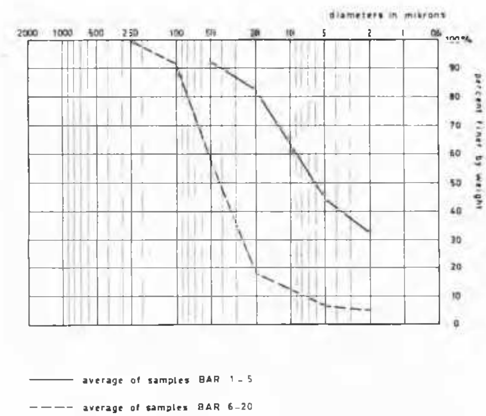


Fig. 3 Average grain size distributions at Baradi Pilot Farm (first series).

Analyses granulométriques moyennes (« Baradi Pilot Farm ») (première série).

It will be seen from comparison between the permeability as measured before and after application of a clay suspension, k_1 and k_2, respectively that in nearly all cases the permeability has decreased through application of the clay.

Fig.4 illustrates this result.

On the horizontal axis the original permeability k_1 is indicated; on the vertical axis the permeability k_2 (after application of a clay suspension) is given. Each dot represents one test giving the original permeability k_1 on the horizontal axis and the permeability k_2 on the vertical axis.

The graph is divided by a line sloping at 45 degrees; above that line is the region where permeability k_2 is less than k_1. Nearly all the dots are confined within this area, which means that a clay suspension tends to reduce permeability.

In order to get a more numerical view of the problem, the theory of Darcy concerning flow of water through soil was applied to this particular case.

The following symbols apply :

k_1 : the permeability of the sample;
k : the permeability of the deposited clay layer;
k_2 : the permeability of the sample and clay layer;
h_1 : the thickness (height) of the sample (85 mm);

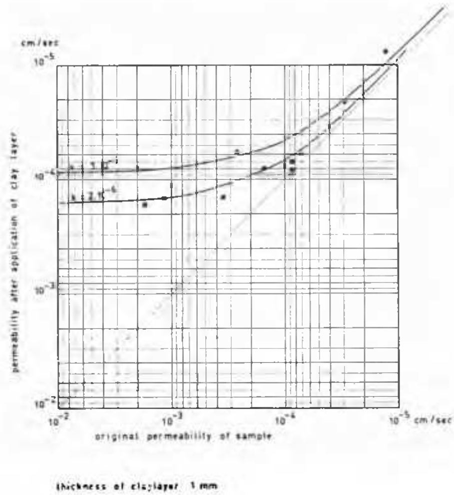


Fig. 4 Permeability before and after application of clay layer (first series).

Perméabilité avant et après application d'une couche d'argile (première série).

h : the thickness of the clay layer (1 mm);
h_2 : the thickness of sample and clay layer (about 86 mm);
then

$$k_2 = \frac{kk_1(h_1 + h)}{hk_1 + h_1k} \qquad (1)$$

(as indicated in Fig. 5).

As h_1, h_2 and h are given, formula (1) can be written in the form :

$$Akk_1 + Bkk_2 + Ck_1k_2 = 0 \qquad (2)$$

For a given value of k, the formula (2) becomes :

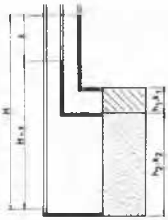
$\overline{A}k_1 + \overline{B}k_2 + \overline{C}k_1k_2 = 0$, which is a curve of second degree.

In Fig. 4 this curve has been drawn for $k = 1 \times 10^{-6}$ cm/sec. and $k = 2 \times 10^{-6}$ cm/sec.

It appears that nearly all the dots are confined within the limits of the two curves. This means that the permeability of the deposited clay is about 1 to 2×10^{-6} cm/sec.

2. *Additional Laboratory Tests :*

In order to check the obtained result, permeability tests were performed on two clay samples, both 1 cm thick, obtained



$$Q = \frac{H}{h_1 + h_2} k F = \frac{x}{h_1} k_1 F = \frac{H-x}{h_2} k_2 F \qquad 1) \text{ and } 2)$$

$$x = \frac{h_1}{k_1} \frac{k}{h_1 + h_2} H \qquad 3)$$

$$H-x = \frac{h_2}{h_1 + h_2} \frac{k}{k_2} H \qquad 4)$$

From 4) it follows that

$$k = \frac{k_1 k_2 (h_1 + h_2)}{h_1 k_2 + h_2 k_1} \qquad 5)$$

Fig. 5 Permeability of two layer systems according to Darcy's law.

Perméabilité d'un système à deux couches d'après la loi de Darcy.

by sedimentation of the clay suspension. These tests lasted for 5 days. At the beginning of the tests the permeability was 1×10^{-5} resp. $1{\cdot}5 \times 10^{-5}$ cm/sec·; at the end it was 5×10^{-6} resp. 6×10^{-6} cm/sec.

This permeability is about 3 to 5 times as high as according to the series of tests mentioned before.

The difference is probably due to the penetration of clay particles into the upper part of the soil samples. Visual inspection of the soil samples after the permeability tests were finished confirmed that such penetration had occurred, at least in the case of the most sandy samples. Here it was to be seen that about half the amount of clay had penetrated into the sample, so that a layer of about 0·5 mm was measured on top of those samples.

In the case of the clay samples no penetration occurred.

This " penetration capacity " of the clay into the soil seems to be of the greatest importance. The deeper the penetration, the thicker, the layer with reduced permeability.

A thin layer which is concentrated on the canal bed is susceptible to erosion by water, puncturing by animals, deterioration by drying and destruction by canal cleaning.

Practical experience appears to confirm that the best results are obtained when the sediment penetrates into the cracks and voids.

3. *Second Series :*

While the investigations in the laboratory were going on, in March a second series of soil samples were taken from Baradi Pilot Farm in the same manner as described above. Ten samples : BAR 21-30 were taken from a clayey reach where in 1958 permeability tests had been performed. Another ten samples : BAR 31-40 were taken from the more sandy reaches, nearer to the temporary intake at Gorai River. The samples were tested in about the same way as BAR 1-20.

Again there is a striking difference between the first ten samples and the remaining ten samples. The average grain size distributions are given below :

	500-250	250-100	100-50	50-20	20-5	5-2	2 microns
BAR 21-30	—	—	5·7	10·8	33·6	14·0	35·9
BAR 31-40	0·8	15·6	63·0	15·8	3·0	0·4	1·4

Both grain size distributions have been plotted in Fig. 6.

Permeability tests were performed on all samples. In the case of samples BAR 21-20 the measured permeability was zero and no further tests with clay in suspension were performed. In the other cases the tests were continued ; after the permeability had been measured a second clay layer, 1 mm thick, was applied. Two types of clay were examined. They were obtained by taking Baradi clay as mentioned before and passing it through the 50 micron and 20 micron sieve respectively. In this way clays were obtained with no particles smaller than 50 or 20 microns.

The tests were prolonged for about a week at each stage ; the average of the readings during the last days were taken. The results are represented in Fig. 7. They are slightly different from the first series. Then the permeability of the clay layer (< 50 micron) was computed to be 1 to 2×10^{-6} cm/sec. Now it appears that the permeability k_1 of the clay layer (< 50 microns) is 5×10^{-6} cm/sec. In the case of a 1 mm layer of clay (< 20 microns) $k_1 = 10^{-5}$ cm/sec.

In the case of the 2 mm layers it appears that :

$k_1 = 2 \times 10^{-6}$ cm/sec. if the clay particles are < 50 microns

$k_1 = 5 \times 10^{-6}$ cm/sec. if the clay particles are < 20 microns

4. *Permeability Tests on Clay :*

Four samples were tested, two in duplicate for each clay sample, viz., < 50 microns and < 20 microns. The thickness of each sample was almost 10 mm ; 18 grams of clay were put in suspension and then allowed to settle. The results were :

A. clay particles < 50 microns.

$k = 1{\cdot}7 \times 10^{-5}$ and 2×10^{-5} cm/sec.

B. clay particles < 20 microns.

$k = 3{\cdot}5 \times 10^{-5}$ cm/sec. (one test failed).

The conclusion may be that particles bigger than 20 microns apparently play their part in decreasing impermeability.

This is apparent from both the tests on the pure clay and on the samples with 1 mm and 2 mm clay layers.

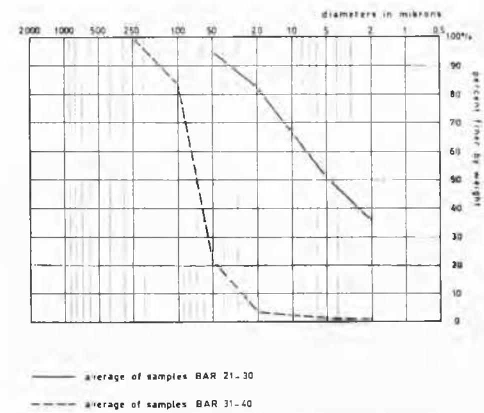


Fig. 6 Average grain size distributions at Baradi Pilot Farm (second series).

Analyses granulométriques moyennes (« Baradi Pilot Farm ») (deuxième série).

5. *Summary of First and Second Series on Permeability of Clay Layers (Suspended Load) :*

Permeability in cm/sec. × 10^{-6}

	First series	*Second series*
1 mm layer		
1. <50 microns	1 to 2	5
2. <20 microns	—	10
2 mm layer		
1. <50 microns	—	2
2. <20 microns	—	5
10 mm layer (direct test)		
1. <50 microns	5 to 10 6 to 15	17 to 20
2. <20 microns	—	35

1. The results of the tests show that the permeability of the clay < 20 microns (that is when the particles bigger than 20 microns have been removed) is likely to be higher than of the clay < 50 microns (that is when only the particles bigger than 50 microns have been removed).

In practice the permeability is halved if particles ranging from 20 to 50 microns in size are removed. Those particles therefore reduce the permeability.

2. The permeability as measured " indirectly " (1 mm layer on top of soil sample) is in all cases lower than measured " directly ", viz. 4 to 6 times lower. This may be due to penetration in the underlying samples, as explained before.

3. The permeability of the clay < 50 microns in the second series of tests was about 2 to 3 times higher than in the corresponding first series. The only possible reason that can be given for this is that the clay may have been slightly different in the two cases.

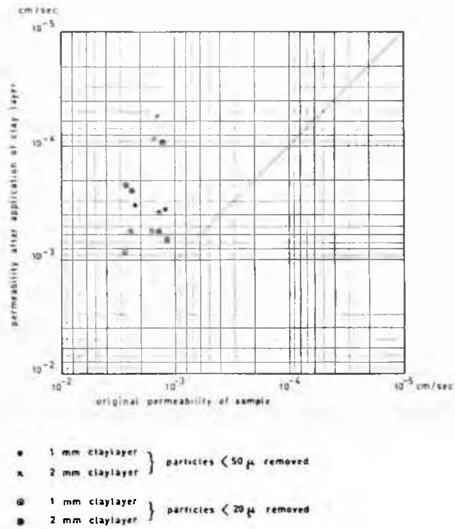


Fig. 7 Permeability before and after application of clay layer (second series).

Perméabilité avant et après application d'une couche d'argile (deuxième série).

3. Field Tests at Baradi Pilot Farm

March 16th and 27th, 1959 seepage tests were performed in the canal parts at Baradi Pilot Farm. The results of these tests were carefully evaluated and are considered later. Moreover, the results of seepage tests are given, undertaken on January 12th and February 22nd, 1958, also at Baradi Pilot Farm.

1. *Test Method :*

The applied method, the so-called pool drop method, consisted of filling a part of the tested canal with water up to about design level. Then, while no water was allowed to flow in or out, the water-level was measured at regular intervals. Apart from precipitation and evaporation, the only influence on the waterlevel is that caused by seepage through the wetted area of the canal. The drop of waterlevel thus enables seepage to be calculated.

Another method is to measure the seepage losses under flow conditions. In that case it is necessary to install measuring weirs at selected intervals. Such weirs must be extremely accurate to enable seepage to be calculated. Continuous readings, if not automatic registration, may probably be necessary. This makes the method elaborate and not very suitable under prevailing circumstances.

In order to measure actual seepage by the simpler pool drop method under flow conditions, the following procedure was adopted. The canal was filled with water to a few centimetres above design level. Then the test started and lasted until the water level was just below design level. The drop in water level was measured at various intervals and plotted on a graph as shown in Fig. 8.

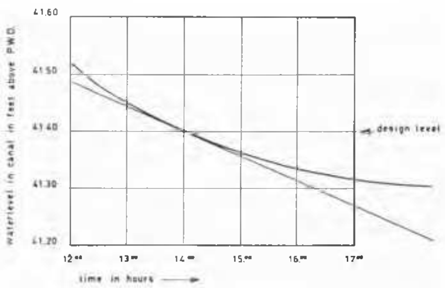


Fig. 8 Interpolation of drop in water level.
Interpolation permettant de trouver la perméabilité pour un certain niveau de l'eau dans les canaux.

As expected, seepage appears to decrease as the water level falls and thus approaches the groundwater level outside the canal embankments. The observed values of the drop in water level, plotted as points in the graph of Fig. 8 can be connected by a smooth curve. The tangent to that curve, where it intersects the design level, gives the rate of seepage loss when the water table is at design level. It may be assumed that this seepage is approximately equal to the seepage under flow conditions.

2. *Location :*

The location of the canal reaches which were tested at Baradi Pilot Farm are given in Fig. 9.

Reaches *a*, *b*, *c* and *d* were tested on March 16th and 27th, 1959.

Reaches 1, 2 and 3 were tested January 12 th and February 22nd, 1958.

3. *Dimensions :*

The tested canal reaches had the following cross-sections :

a :design water level in ft. above *P.W.D.*
b :depth of water in canal in cm (ft.);
c :water width at design level (as designed) in cm (ft.);
d :water width at design level (as measured) in cm (ft.);
e :difference between canal and ground water level in cm (ft.);
f :side slope (cotg *a*).

	a	*b*	*c*	*d*	*e*	*f*
Reach *a*	41·8	70 (2·3)	302 (9·9)	319 (10·5)	75 (2·5)	1·5 : 1
Reach *b*	41·6	55 (1·0)	256 (8·4)	283 (9·3)	50 (1·7)	1·5 : 1
Reach *c*	41·4	55 (1·0)	256 (8·4)	283 (9·3)	60 (2·0)	1·5 : 1
Reach *d*	41·3	55 (1·0)	256 (8·4)	283 (9·3)	45 (1·4)	1·5 : 1
Reach 1		60 (2·0)	273 (9·0)			1·5 : 1
Reach 2		32 (1·04)	273 (9·0)			3 : 1
Reach 3		46 (1·6)	305 (10·0)			3 : 1

The following data were obtained in the 1958 tests :

Reach 1 : "canal III in cutting, bedlevel 60 cm (2'3") below ground level; fine silt, no clay; ground soaked with recent heavy rain".

Reach 2 : "main canal, bed level at ground level; loamy clay, ground dug";

Reach 3 : "canal III in embankment, bed level 15 cm (6") above ground level; clay; ground dry".

4. *Tests :*

The first seepage test in reaches *a*, *b*, *c* and *d* was performed on March 16th, 1959. Pumping of water into the canal started on March 12th; March 13th the tertiary canl III was filled. Irrigation started March 14th. Groundwater levels were measured in the various borrow pits along the side of the canal on March 16th.

March 23rd — the canal was again filled up to about design water level. March 25th — clay was brought into the canal at a point near *A*, not far from the road between Kushtia and Bkeramara. This was done for the purpose of bringing suspended load into the canal water. Coolies puddled the clay in a borrow pit as much as possible while the water containing clay was pumped into the canal. As the coolies appeared to be rather unfit for the job, having been weakened by Ramadhan fasting, and due to bad weather conditions and bad pumping conditions the amount of suspended load, which was pumped into the canal, was less than the anticipated quantity.

The suspended load content was measured at the point *A*, *B* and *C* (Fig. 9). Every five minutes water samples were taken over a period of about two and a half hours. The samples were collected in three different tins. At the Hydraulic Research Laboratory in Dacca the total amount of suspended load in each tin was determined by drying and weighing.

The results were :

A : 0·4 grams per litre;
B : 0·3 grams per litre;
C : 0·205 grams per litre.

This corresponds to the suspended load content found in Ganges River about July.

March 27th, a second seepage test was performed after the suspended load had been allowed to settle in the canal.

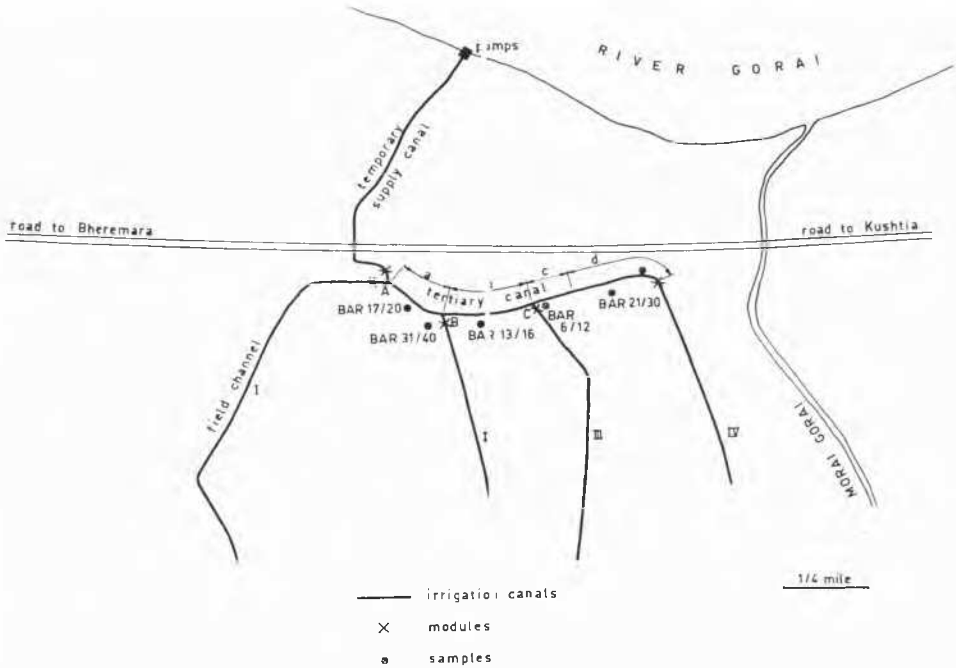


Fig. 9 Canal reaches tested at Baradi Pilot Farm.
Parties des canaux où les essais ont été exécutés au « Baradi Pilot Farm ».

5. *Test Results :*

(a) *Seepage at design level*

	March 16th [1]	*March 27th* [2] *1959*
Reach *a*	26 cm (0·05 ft.)/day	21 cm (0·7 ft.)/day
Reach *b*	36 (1·2)	29 (0·95)
Reach *c*	33 (1·1)	10-29 (0·6-0·95) [3]
Reach *d*	103 (3·4)	— [4]

(b) *Tests* [5] *in 1958*

	February 22nd	*January 12th 1958*
Reach 1	50 cm (1·65 ft.)/day	—
Reach 2	—	110 cm (3·6 ft.)/day
Reach 3	—	150 (4·9)

1. Before suspended load had been brought in.
2. After suspended load had been brought in.
3. As there was influence by rainfall the extremes are given of the seepage rate; it is likely that the actual value is nearest to the lower limit (10 cm/day).
4. It was not possible to measure the seepage in reach *d*, as during the filling of that reach a dike breach occurred which made it necessary to cut off reach *d* by a dam.
5. From the data it cannot be derived at which water level in the canals the seepage losses were measured.

6. *Conclusions:*

1. From the 1959 tests it seems to have been fairly well established that some improvement of seepage due to a sealing effect of sediment load can be expected, as indicated by laboratory tests.

2. It is surprising at first glance that the heaviest seepage losses are found in the clay (reach *d*, etc.), whereas in the laboratory the permeability of the clay as measured appeared to be zero in four out of five cases !

It is not difficult to detect the cause of this phenomenon. From borings taken in the field at the end of March 1959 it appeared that the clay of which the embankments near reach have been made contains little cracks and fissures. Water probably seeps away through those.

When taking " undisturbed " samples, the clay is compacted as the sampler has to be driven in by hammering. A very elaborate sampling device would be necessary in order to obtain a truly undisturbed sample.

3. The important conclusion is that compaction is apparently capable of making the clay more impermeable.

4. The 1958 tests indicate that maximum seepage occurs in clay soil, viz. reaches 2 and 3. Reach 3 had not been used previously, which might account partly for the high seepage

recorded. In reaches 1 and 2 silt was present on the wetted area.

The 1958 tests therefore also give some indication that permeability decreases after accumulation of suspended load in the canal reaches.

Acknowledgements

The author is glad in acknowledging the co-operation and assistance given to him by the various officials of the Government and the Water and Power Development Authority in East Pakistan.

In the first place he likes to mention in that respect the Chairman of the Authority Khan Mohammed Azam. Then he would like to express his appreciation for the support given him in performing the tests by Mr. M. Saeed Minhas, Mr. M. A. Rahman and Mr. M. Sirajuddin, Director, Deputy Director and Assistant Director of Hydraulic Research Laboratory in Dacca, Dr. M. A. Quader, Director of Soils Laboratory in Dacca, and Mrs A. Hai, A. Kashem, H.A. Talukdar and A. Wahab attached to that Laboratory.

In addition the author is much indebted to his colleagues of the United Nations Technical Assistance Team in Dacca, whose Team Chief was Professor Dr. W. J. van Blommestein.