Performance Evaluation of Sodium Bentonite Material for Seepage Control in Irrigation Channels

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Abstract-Irrigation canals in Pakistan suffer tremendous water seepage losses due to unlined section of the canal. As most of canals are unlined, large amount of water is wasted in terms of seepage especially in link canal. When link canals pass through coarser areas, e.g. C-J link canal in Thal, a large portion of water is lost in the form of seepage. The present study aimed to investigate performance of sodium bentonite mixture blanket placed in the canal bed for seepage control and to find the sort of mixture combination that could be used under specified canal conditions for seepage control. Experimental study proved that sodium bentonite admixture layer can successively serve as seepage barrier as its swelling fills the pores or voids between the sand particles and effectively control the seepage through soil. Best mixing percentage of sodium bentonite with sand is 5% by weight for effective and practicable canal seepage control. The efficiency of seepage controlled by sand bentonite mixture is 100% under lab condition and 92% to 96% under field condition. The best results can be obtained by applying soil bentonite mixture depth of 25 to 30 cm. For dry mixing the soil material should be dry with moisture content of 15% or less.

Keywords-Seepage, Clay, Lining, Link Canal

I. INTRODUCTION

The poor performance of irrigation system in Pakistan has been a source of concern since 1960's and since then it has been subject of considerable external aid and internal policy. Pakistan will suffer 16 to 23 MAF water shortages till 2025. As most of the canals are unlined, large amount of the water is wasted in terms of seepage especially in link canals. When link canals (e.g. Chashma-Jhelum link canal) pass through coarser areas like Thal, a large portion of water is lost in the form of seepage which will cause the water logging condition adjacent to the canal as well as shortage of water in the tail areas. In Pakistan about one half of the water from canals to farm channels doesnot reach the farmers fields [i]. According to United States Bureau of Reclamation (USBR) unlined canals can lose 30 to 50% of their transported water to seepage. About 25 to 30% of the water is being lost in the conveyance system of the different countries of the world [ii]. In the farm channel of Colorado and Pakistan losses increased about 9% to 12% per cm of water level increase respectively [iii]. Seepage is not only a waste of water, but it may also lead to other problems such as water logging and salinization of agricultural land [iv]. Factors causing to these losses included disintegrate channel junctions, over toping of banks and leakage through highly permeable upper portion of channel sides. According to WAPDA, more than 5 MAF of irrigation water could be saved by lining the minor canals only, and more 3.6 MAF could be saved by water course improvement. Seepage can be reduced by various methods including canal lining (brick, concrete, plastic membrane) but these options have their own challenges (cost, stability, life, efficiencies, diversion requirements etc.) like most of the link canals contain water throughout the year which will make lining impossible. Also that diversion arrangement may not be possible for such large canals [v]. With the same canal bed slope and with the same canal size, the flow velocity in a lined canal is 1.5 to 2 times that in an unlined canal, which means that the canal cross -section in the lined canal be smaller to deliver the same discharge [vi]. Other possible benefits of lining are that water will be conserved, seepage of water into adjacent land or roads will be minimized, canal dimensions will be reduced and maintenance will also be reduced [vi]. An extensive study on the development and the use of sediment lining is in progress at present. The amount of material deposits in the canal surface will be proportional to the extent of the seepage, since the most water will be moving through the bed at these locations. Various dispersing agents have been used and the results obtained to date are encouraging. Because of cheapness of constituent material, it has great possibilities even if the treatment must be repeated at fairly frequent intervals. This can be done by using bentonite or other chemical by grouting or by direct mixing. Due to the higher density of bentonite than that of water, it protects a trench from water inflow from outside sources. “Water-soil-bentonite” mixtures inside the trench form a “clay-lock. Moreover, a bentonite clay crust develops as the wall of trench dry out over the time which improves the stability of the trench side shape. Due to low viscosity of bentonite slurry, it could keep its slurry state for nearly unlimited amount of time, and as result trenches are able to keep their shape. Another technological advantage of bentonite slurry is reversibility of its viscosity. Contractors can place any structural element required within bentonite slurry. The main objective of this study was to develop a method for mixing and placing of soil bentonite admixture on canal parametric surface and to evaluate seepage rate with these intervention.

II. Materials and Methods

A number of experiments were conducted in Model Tray Hall of Centre of Excellence in Water Resources Engineering (CEWRE), University of Engineering & Technology Lahore, Pakistan, to obtain the research objectives. The soil sample was selected which had the same characteristics as of canal bed material of Thal area. The samples were taken from the flood bank of River Ravi near Lahore Shahdra bridge by physical observation. Moreover, sieve analysis and hydraulic conductivity was measured by lab experiments to establish coarser nature of the soil material. Considering these results the sample was selected for further experiments. The soil material was fine sand with hydraulic conductivity of 0.1m/hr. Experiments were performed to find out a sand bentonite mixing ratio that gave best results for seepage control, and the application of this mixing ratio under dry and flowing conditions. Following works were conducted to fulfill the study objectives.

A. Measurement of Hydraulic Conductivity

Constant Head Permeameter was used to measure hydraulic conductivity of the soil sample. The hydraulic conductivity of the medium was found to be 15.01 cm/hr.

B. Placement of Sand Bentonite Mixture in Field under Dry Conditions

Admixture slurry can be applied on canal parametric surface under dry condition as a uniform layer of minimum depth 12 inches. The first step is to prepare the surface to be sealed. Remove all rocks, trash, and vegetation, including trees and roots. Roots left in the ground will decay over time, leaving the potential for future leakage problems. Fill any deep holes and smooth the area by roller or drag. Cover the area with the prescribed amount of dry sand bentonite mixture. It is very important that the sand bentonite mix layer is even and that there are no bare or thin spots. This will ensure complete coverage and a water tight seal. This can be done by preparing mixture of sand bentonite with rotary mixing tools then spread it over the bed surface uniformly with the help of planker or any other machine. Finally, compact the canal bottom surface by rolling or tamping. A gentle water flow is recommended to prevent erosion of the soil and bentonite layers during this final phase. It may take several days for the bentonite to reach the point of full saturation and fill the voids in the underlying soil.

C. Placement of Sand Bentonite Mixture in Field under Wet Conditions

The admixture slurry can be applied through a pipe (circular or rectangular) under the water having depth up to 5 feet. It should be ensured that material can transport through pipe having opening on the bed surface, then move the pipe gently on the bed surface so that the slurry layer can be spread uniformly on canal bed surface under water. The thickness of layer will depend on the moving velocity of pipe. This procedure needs further perfection and testing.

D. Placement of Sodium Bentonite under Different Moisture Contents

Sodium bentonite was mixed with soil at the place under different moisture contents of base soil i.e. at 20%, 15% and 0%. No seepage was observed when sodium bentonite was mixed under the moisture contents of 0% and 15% but seepage rate of 3 cm/hr was observed at 20% moisture content. At 20% moisture content, the mixing was not thorough and clods were formed. It shows that sodium bentonite can be mix uniformly with soil at canal surface under the moisture content of 15% or less.

Test-1

In this trial bentonite was mixed in two inches depth of sand in cylinder, the percentage of bentonite was 20% by weight of the two inches depth of sand, 2 inches depth of sand was weighed after completely drying it, and then calculate the 20% of this weight and took the bentonite having weight equal to this 20% weight (0.675 kg). After weighing these two samples it was mixed by hand. Now the water was poured in this mixture and slurry was prepared. Then this slurry was applied in cylinder over the sand surface which already had water depth of 5.08 cm (2 inches) above its surface and left it undisturbed for 24 hours. Hydraulic conductivity was later measured for the bentonite treated sample.

Test-2

This trial also had 20% of bentonite but the application was different from first. The sand bentonite mixture was applied without making slurry i.e. dry mixture was applied on the surface of sand sample in second cylinder having two inches of depth of water above its surface.

Test-3

It was mixture of two inches depth of sand with 10% of bentonite by weight (337 kg), after making slurry (by same method as for test-1) it was applied on the saturated sand.

Test-4

This mixture was made with 5% of bentonite by weight (169 gms) and made layer of 5.08 cm (2 inches) on surface by spreading over it manually. The sample was placed undisturbed for 24 hours so that bentonite swelled completely on next day before taking hydraulic conductivity measurements.

E. Experiments on Physical Model of Canal Parametric Surface

The results obtained from previous experiment it was observed that the 5% bentonite mixture was the desired ratio that could be apply for seepage control on canal parametric surface. Now it was needed to apply the sand bentonite mixture of this ratio (5% by weight) on large scale so that the accurate results and recommendation could be made. For this purpose two cubical lined boxes each of 1 m^3 were constructed.

F. Preparation of Sand Bentonite Mixture for Lab Experiment

The sand and bentonite was mixed on 5% bentonite ratio by weight. The sand sample was taken equal to the volume of box with 15.24 cm (6 inches) depth of box having total volume equal to 0.15m^3. Sand unit weight was measured separately for a smaller sample volume. After collecting the exact volume of sand its weight was measured and corresponding weight of bentonite was also measured. The given volume of sand was placed by spreading it on the floor in model tray hall in order to dry it. After 24 hours when all the sand was dry now that was time to mix the dry sand with bentonite. The mixture was made by uniformly mixing the material by hand. Slurry was made by pouring water into the mixture so that all the particles of mixture completely saturated. Then this slurry was applied on the sand surface in the experimental box manually with care that equal layer of 15.24 cm (6 inches) depth was made over the surface of sand. Before applying the sand in experimental box it was fully saturated and a depth of 5.08 cm (2 inches) of water above its surface was maintained. After making a layer of depth 15.24 cm (6 inches) of sand bentonite mixture over the sand surface in still water it was left for 24 hours for complete swelling and forming a barrier for seepage control. The bottom pipe opening was completely lowered to allow seepage through the profile. No seepage was observed through pipe opening in 24 hrs. At this time it was observed that a thin layer of bentonite particles was formed on the surface of mixture in the water. Observations were repeated for a number of days but no seepage was observed.

G. Sustainability of Mixture in Flowing Water Channel under Lab Conditions

It was observed that some bentonite particles have floated out of top layer of the sand bentonite mix layer. It was considered to test the performance of the seepage barriers in flowing water. To do this a section of length 152.4 cm (5 ft) was isolated in channel by constructing two brick walls at the start and at the end of 152.4 cm (5 ft) long section. The depth of this channel was 61.08 cm (2 ft) i.e. the side wall was of 61.08 cm (2 ft) but the walls that constructed at start and at end point were 38.1 cm (1ft and 3 inches) in depth. With this a pipe of 5.08 cm (2 inches) was placed at bottom of end wall to allow discharge of seepage water and measure the hydraulic conductivity of the sand bentonite mixture fill. The base packing of sand gravel was placed in this section. The gravel layer was of 5.08 cm (2 inches). A filter paper was placed on top of gravel and then 20.32 cm (8 inches) sand layer was placed. The total depth of this packing was 25.4 cm (10 inches). Sand packing was saturated by giving water through its bottom pipe until a water depth of 5.08 cm (2 inches) was attained on the sand surface. Then 5.08 cm to 7.62 cm (2 to 3 inches) of layer of sand bentonite mixture was applied on this sand surface under water. Here the same ratio i.e. 5% of Bentonite by weight (9.3 kg) was mixed with sand. After applying the admixture it was left undisturbed in still water for two days to obtain maximum swelling of bentonite. After two days the water was passed in the channel for two hours and seepage rate was determined. At that time upper suspended layer of bentonite particles was removed from the surface but the layer was still undisturbed even during and after the flow of water on its surface. It also gave the significant results as obtained from previous experiments. Two hours run time was selected due to limited power supply and water in the overhead storage tank. The hydraulic conductivity was measured for four days with running time of water 2 hour per day. However this running time was too short and did not represent the field conditions where water flows the whole year, so to fulfill this condition it was decided to run the experiment in a channel which had flows throughout the month. For this purpose a water course was selected in Multan region near Kabirwala.

H. Sustainability of Mixture in Flowing Channel under Field Conditions

A seepage measurement box was designed in the water course. A bypass channel was constructed to divert the water to do preliminary work in the experiment channel. The experimental box was constructed of rectangular shape with the following dimensions.

Length of box	=	152.4 cm
Width of box	=	91.44 cm

Depth of box = 60.96 cm

A plastic sheet was placed at bottom and sides of channel to prevent downward and lateral flow of seepage water through that section as shown in Fig.1 (b). A pipe was installed at the bottom (floor) of box to measure the hydraulic conductivity. Gravel was placed at the floor of box up to 10 cm of uniform depth as shown in Fig. 1(c). A filter paper was placed over the gravel layer. The box was then filled with sand up to 30 cm shown in Fig. 1(d). A small flow of water was run in the channel to find the seepage rate of sand bed by opening the valve and take five readings to get average hydraulic conductivity.

Fig. 1. Experimental layout.

III. RESULTS

The seepage rate was found through sand sample in cylinder before applying the sand bentonite mixture over its surface, the following results obtained, seepage rate of 8.91 cm/hr of was observed before applying the sand bentonite mixture on sand bed surface in flowing channel. After treatment the observed results after 1st, 2nd and 3rd day are shown in Table I. On daily basis the results of hydraulic conductivity were taken from the channel which was continuously running for more than two weeks. The day by day results are given in Table II. Table II shows that the hydraulic conductivity through sand bentonite mixture decrease day by day as the pore spaces between the particles are being filled by the swelling of bentonite. On the basis of two weeks of data collection of hydraulic conductivity it can be considered that the bentonite will work with better efficiency as a hydraulic sealant in canal parametric surface. This also showed that bentonite swelling continuous for many days.

IV. CONCLUSIONS AND RECOMMENDATIONS

Experimental study proved that sodium bentonite admixture layer can successively serve as seepage barrier as bentonite swelling fills the pores or voids between the sand particles and effectively control the seepage through soil. Best mixing percentage of sodium bentonite with sand is 5% by weight for effective and practicable canal seepage control. Soil bentonite mix can be applied as slurry or as dry mix blanket. The soil bentonite mixture should be covered with some soil material to minimize floating and flowing away of bentonite particles. The efficiency of seepage controlled by sand bentonite mixture is 100% under lab condition and 92% to 96% under field condition. The results are very near to study conducted by Rollins and Dylla [vii]. The cost of placing a bentonite mixture is relatively high compared to other seepage control methods. This is due to the high cost of bentonite and the large amount of earthworks operations necessary for channel preparation, mixing the bentonite with earth and carefully placing the material on the inside of the channel. The best results can be obtained by applying soil bentonite mix depth of 25 cm to 30 cm. For dry mixing the soil material should be dry with moisture content of 15% or less. It is recommended that soil bentonite mixture by 5% weight basis may be used effectively to control seepage in canals with sandy textured bed materials. Studies should be done to find out best method of mixing and placing soil bentonite mixture (slurry or dry mix) under flowing condition. The seepage results should be observed for long period of time say for six months to find the maximum stability of mixture on canal bed surface.

TABLE I
HYDRAULIC CONDUCTIVITY IN FLOWING WATER AFTER TREATMENT

Data Series	Time	Volume	Conductivity	Seepage rate
	sec	cm^3	cm/hr	cm/hr
First Day				
1	20	130	2.34	
2	20	110	1.98	
3	20	60	1.08	1.79
4	20	100	1.80	
5	20	96	1.73	
Second Day				
1	30	50	0.60	
2	30	41	0.49	
3	50	57	0.41	0.47
4	50	56	0.40	
5	50	59	0.43	
Third Day				
1	20	46	0.83	
2	20	40	0.72	
3	20	37	0.67	0.71
4	20	36	0.65	
5	20	38	0.68	

Fourth Day				
1	300	433	0.55	
2	300	555	0.72	
3	300	435	0.56	0.60
4	300	430	0.55	
5	300	430	0.55	

TABLE II
DAY BY DAY AVERAGE CONDUCTIVITY FROM FIELD EXPERIMENTS

Days	Average Volume	Average Conductivity
	cm^3	cm/hr
1st	102.6	0.205
2nd	98.8	0.198
3rd	95.0	0.190
4th	95.0	0.190
5th	92.4	0.185
6th	89.8	0.180
7th	93.6	0.187
8th	87.6	0.175
9th	85.0	0.170
10th	86.4	0.173
11th	83.4	0.167
12th	82.2	0.164
13th	75.2	0.150
14th	74.0	0.148
15th	68.6	0.137
16th	64.2	0.128

REFERENCES

[i] M. A. Kahlown, T. Masood, S. M. Tariq. Performance evaluation of various types of watercourse linings in Pakistan, Mona Reclamation Experimental Project, WAPDA Colony Bhalwal, Pakistan. 244:69, 2000.

[ii] M. S. Mirjat, A. S. Chandio. Industry and Economy, Water Resources of Pakistan, 2001.

[iii] M. Akram, W. D. Kemper, J. D. Sabey. Water levels and losses and cleaning in watercourses Trans. ASAE 24: 643–650, 1981.

[iv] Z. Iqbal, R. T. MacLean, B. D. Taylor, F. J. Hecker & D. R. Bennett. Seepage losses from irrigation canals in southern Alberta. Canadian Biosystems Engineering 44(1):21-27, 2002.

[v] A. Irshad, A. C. Bashir, N. H. Butt. Study on the Performance of Various Lining Materials, Proceedings Workshop on Canal Lining And Seepage, Lahore, Pakistan: 301-321, 1993.

[vi] D. B. Karaat. Irrigation Canal Lining; Irrigation and Drainage Paper. FAO, Food and agriculture Organization of the United Nations, Rome, 1977.

[vii] M. B. Rollins, and A. S. Dyll. Field experiment on sealing permeable fine sand with bentonite: soil science. American society of civil Engineers, 268-271, 1964. Project monitors (jan-2008) www.projectsmonitor.com/detanews.asp