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Experimental Investigation of Joint Filling Materials Performance on Preventing Seepage in Lined Open Concrete Canal (Laboratory and Field Model)

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Abstract

Seepage is one of the most serious problems of water loss in the irrigation canals. In Iraq, most projects of concrete lining irrigation canals suffer from seepage losses phenomena through joints. The loss of water due to seepage from irrigation canals constitutes a substantial part of the usable water. The aim of this study is to reduce or prevent the seepage by using new alternative joints filling materials. The methodology in this study follows two main categories for calculating and studying the seepage and efficiency of some alternative materials, hoping to apply a new filling joint material, and assessing their performance to prevent seepage. The first category was done by constructing a trapezoidal concrete canal model. The joints filling materials used in this research were : cement-sand mortar, cement-sand mortar with Styrene Butadiene Rubber (SBR), cement-sand with Krystol Internal Membrane (KIM), and Setseal B (liquid polymer with powder). The average percentage of seepage losses was reduced to about 11.3, 29, and 89% when using cement-sand mortar and SBR, cement-sand mortar and KIM, and Setseal B respectively, as joints filling material instead of cement-sand mortar (the initial filling material). While when using Setseal B as a coating material for 9 months duration give no seepage (zero seepage). The second category was carried out by field study, which was done on a branch of irrigation concrete Setseal B as a coating layer was applied on the existing cement-sand joints of the canal (based on the results of the laboratory model tests). It has been tested for 3 weeks. The average reduction percentage in water losses was about 62.5%, by comparing it with using cement-sand mortar only as joints filling material.

Keywords: *Seepage, joint filling materials, concrete canal, setseal B, Krystol Internal Membrane (KIM), Styrene Butadiene Rubber (SBR)*

1. Introduction

Life is tied to water as it is tied to air and food, and there is a growing demand for vast amount of water in agricultural areas, where water does not naturally exist at the level needed. To mitigate this problem, irrigation canals have been constructed to transport water from the source to where it is needed.

Water losses take place from several thousand kilometer length of irrigation canals traversing irrigation system. These losses constitute a substantial percentage of total utilizable water and lead to waterlogging and salinization of adjacent areas causing gross environmental degradation.

The seepage in an irrigation canal refers to the water that percolates into the soil through the wetted perimeter of a canal. Seepage is one of the most serious problems of water loss in the irrigation canals. The excessive seepage losses can cause low-lying areas of land to become unworkable. Seepage losses affect the operation and maintenance of the canals, in the sense that part of the water diverted for users is lost from the conveyance system, and at the same time this water might produce piping, erode the bank of the canals whether they are lined or not, produce excessive saturation, uplift pressure, which might produce failures of the canal and other structures (Rushton and Redshaw, 1979).

Agriculture represents an important component among many others, and is essential to the economy. It is largely practiced by rural citizens relying on traditional irrigation method, whose livelihoods depend on agriculture production. In Iraq, about 8 million hector (m ha) of the total area are irrigated and the remaining 4 m ha is rain-fed, In 1997 the total irrigated areas is estimated to be 3.4 m ha; of which 87.5% received water from irrigation projects, 9.2% from rivers using irrigation pumps, 3.1% from wells and 1.2% from the spring sources (FAO, 2003). It is within this context losses and seepage from irrigation canals has become an important issue over the world.

The aim of this study is to reduce or prevent the seepage by using new alternative joints filling materials in the open channel concrete lining, as well as to investigate the performance of those

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materials. The methodology in this study follows two main categories for calculating and studying the seepage and efficiency of some alternative materials, the first one is laboratory model, and the second is actual field channel, hoping to apply a new filling joint material, and assessing their performance to prevent seepage.

2. Seepage Measurements Methods

Due to many parameters involved and their variability, studies of the seepage and the seepage measurement have been yet few, and the results are somewhat inconclusive. No entirely satisfactory method for measuring seepage has yet been developed. At best, the methods are more indicators of the magnitude of the seepage rather than precise quantitative measures. These methods can be divided into three main groups: analytical methods, empirical methods and physical methods.

Hotes *et al.* (1985) reported that tests using both ponding and inflow-outflow methods have shown considerable variations, although not as much as do seepage meters. However, they suggested that these variations should be considered normal as evidenced from United State Agricultural Research Services (USARS) studies cited previously.

2.1 Ponding Method

According to different authors (Blackwell, 1951; Israelsen and Hansen, 1962; and United States Geological Survey, 1977; Alam and Butha, 2004), the ponding method is the most accurate method to measure seepage, but does not reflect the usual operating conditions of the irrigation system (e.g., this test is usually conducted during the non-irrigation season under non-flow conditions, the suspended material in the water can settle on the walls and the bed of the canal, reducing the seepage rate). Robinson (1981) and Hotes *et al.* (1985), considering that the ponding method is the most accurate means of the measuring seepage losses, and especially suitable for small canals, for this reason it was preferred to use ponding method in this study.

In this method, a selected canal reach is physically isolated by constructing temporary waterproof dikes at the head and tail ends of the reach. The reach of canal is selected so as to have the minimum variation in the cross-sectional area of the canal. The canal is ponded with water, and the drop in water surface with time is measured at different points along the length. The seepage rate is then computed according to the following formula:

$$qav = W(d1-d2)L/pL \quad (1)$$

Where,

- d1-d2 = Change in depth of water in the canal in 24 hours (m)
- L = Length of selected reach (m)
- P = Average wetted perimeter (m)
- *qav* = Average seepage m/day over distance L
- W = Average width of water surface of the ponded reach (m)

A modification to the above procedure is to add water to the pond to maintain a constant surface stage. The accurately measured volume of added water is considered to be equal to the total average loss rate in the elapsed time. This is the most accurate method of seepage determination, and is especially suitable when seepage loss rate is very small. Since the complete test takes a considerable time, evaporation and rainfall must be measured and taken into consideration in calculating seepage losses.

2.2 Joints in Concrete-lined Canals

The joints may be either transverse or longitudinal to the canal direction. There are also construction joints. The transverse joints may be either contraction or expansion joints. The purpose of the former is to prevent cracking caused by concrete shrinkage or contraction due to reductions in temperature. Transverse expansion joints are employed to prevent the problems caused by heat expansion of lining. While longitudinal joints are intended to provide the canal with a type of articulation which, to a certain extent, will allow it to deform with the ground movement due to changes in humidity levels of soil stratum beneath canal bed in nearby areas of different compaction (Neville and Brooks, 2010).

The procedure of construction concrete canals are as follows; alternate slabs are first constructed, as shown in Fig. 1, and once they have set and undergone most concrete shrinkage, then the intermediate closure slabs are casted by concrete. The use of this system reduces the shrinkage effects to almost half, so that the joint apertures are much smaller (Montanés, 2006). The construction of canal bed is executed first, and followed by sides. A longitudinal construction joint is required in between them. In fact, this joint should be impermeabilized, whereas in many cases and since concrete of sides does not unite with the concrete canal bed, it becomes the location of significant leaks, because it is exposed to maximum pressure head of the canal. Moreover, the longitudinal joint between the bottom and sides of the canal is usually defective due to the resulting angle formed by these concrete plains.

2.3 Joints Filling Materials of Concrete-lined Canals

The concrete irrigation canals in Iraq are designed by Ministry of Water Resources and depending on the design manual that

Fig. 1. Construction of Alternate Slabs in Al-Dora Project at Iraq

Table 1. The Details of Concrete Mix Properties used in this Study

Index	Cement content kg/m^3	Fine Aggregate kg/m^3	Coarse Aggregate kg/m^3	Water kg/m^3	W/C	Slump (mm)	Compressive Strength MPa		
							3 days	7 days	28 days
Mix Properties	322.147	644.295	1288.59	144.966	0.45	100	16	20.5	26

was composed by Pencol Engineering Consultants (1983). The Pencol manual recommends using polysulphide or asphalt mastic as joints filling materials. Due to high cost of polysulphide by comparing it with a concrete lining cost, asphalt mastic is preferred for joints filling.

Local observation evidences recommend that asphalt mastic filling material is unfavorable because of segregation, toxic, and short life. The ministry of water resources suggested two alternatives for joints filling materials; they are:

1. Cement-sand mortar and SBR with a mixing proportions of (1:3:0.2) and (1:3:0.1),
2. Cement-sand mortar.

These alternatives are applied at some locations inside Iraq. The first alternative is found costly with respect to the second one. Accordingly, cement-sand mortar as joints filling material becomes of a wide use in Iraq (Al-Furat general company for studies and design of irrigation projects, 2001). Latterly, it is found that these alternative materials are not so efficient in preventing seepage and there is a need for better and long life durability materials.

3. Experimental Work

A trapezoidal concrete canal model was constructed in the laboratory of fluid at the Building and Construction Engineering Department-University of Technology seeking three purposes: for good understanding and for studying the efficiency of some alternative materials to be applied as a filling joint material into concrete lining, calculating the seepage, and assessing the performance of new joints filling materials. The following materials were prepared and tested as joints filling materials:

1. Cement-sand mortar.
2. Cement-sand mortar with Styrene Butadiene Rubber (SBR).
3. Cement-sand with Krystol Internal Membrane (KIM).
4. Setseal B (Liquid polymer with Powder).

Moreover, a selected joint filling material was applied and tested on site field trapezoidal concrete lined irrigation canal (Hurriya-Dagh'ara project) to find out the efficiency and durability on real field situation.

The concrete mixes were designed according to the British standard method (1986). The compressive strength, maximum size of aggregate, type of aggregate, and workability were considered the principal concrete mix designed to have a 28 day compressive strength of about (20) MPa and slump 100±5 mm. The maximum size of the used aggregate was 20 mm. According to the mix design procedure, a concrete mix with a weight proportions of 1:2:4 and water/cement ratio of 0.45 was used as a reference concrete (Table 1).

Table 2. Laboratory Model Characteristics

Bed width	0.25 m
Top width	1 m
Canal side slope	1:1.5
Longitudinal slope (S)	10 cm/km
Panel length	0.75 m
Panel thickness	0.065 m
Joint width	0.025 m

3.1 Laboratory Model Description

Laboratory model scale was chosen as a simulation to actual watercourse canal branch. The canal model characteristics are listed in Table 2. It consists of three panels with longitudinal and transverse joints length of 9.3 m, the total length of the three panels is 2.25 m, the inlet and outlet panels length are 0.42 m each. The dimensions of the model are shown in Fig. 2.

The model has been built above a steel structure to be easily observed and monitored, as shown in Fig. 3. The steel structure

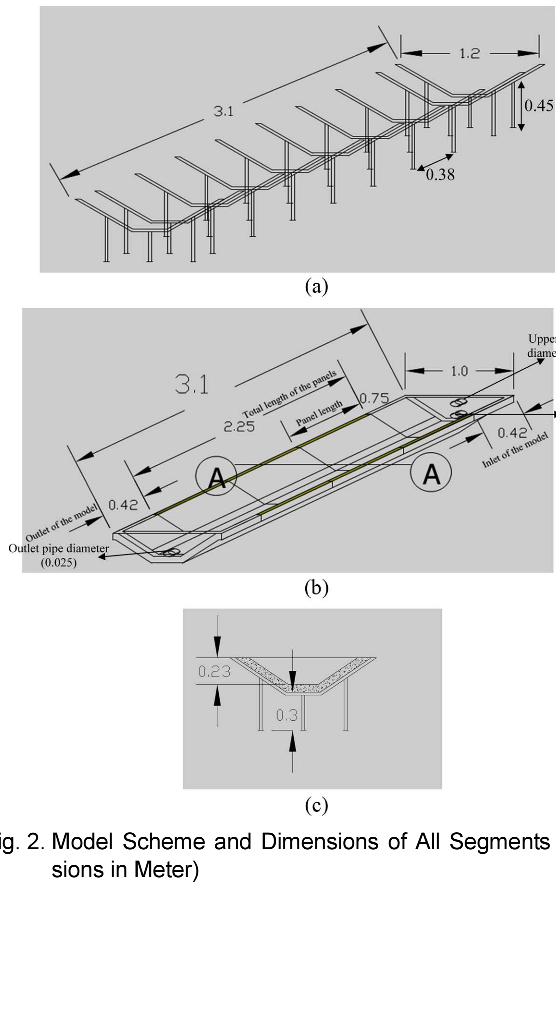

Fig. 2. Model Scheme and Dimensions of All Segments (Dimensions in Meter)

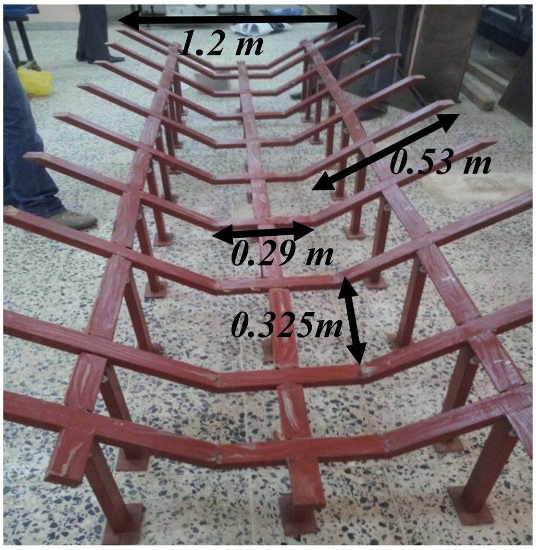

Fig. 3. The Steel Structures of the Open Canal

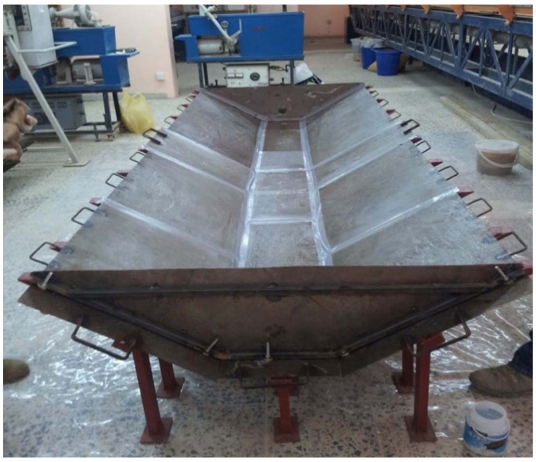

Fig. 4. Steel Structure (Base Steel) Sheets as Mold for the Concrete Open Canal

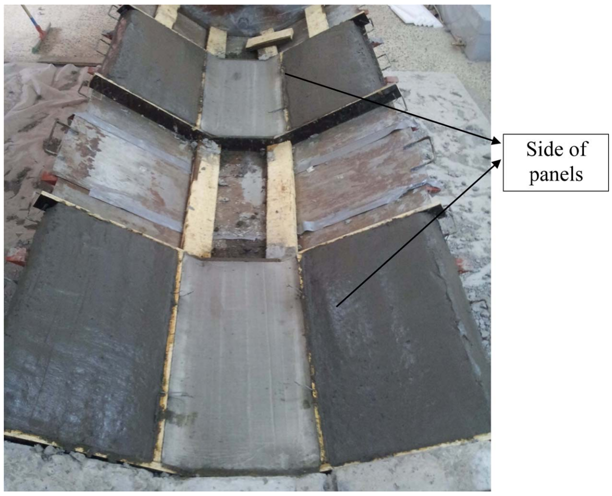

Fig. 5. Side and Base Panels Concrete Casting Procedure

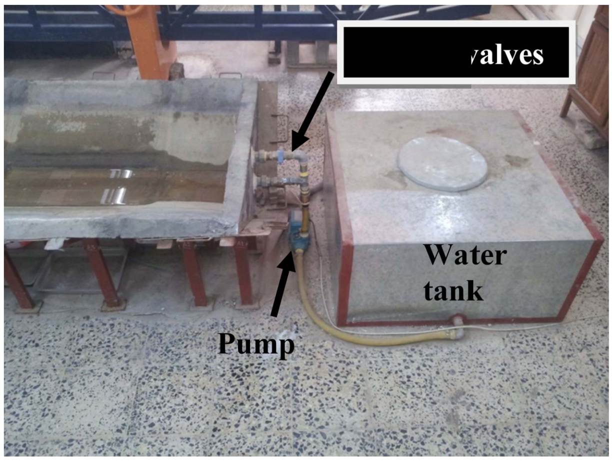

Fig. 6. Water Supply System in the Concrete Canal Lab. Model

was covered by a steel sheet to hold the artificial concrete canal panels, as shown in Fig. 4, 5, and 6.

All the used and tested joints materials in this study were selected according to their cost, availability at the local market, efficiency, environmental impact and suitability for arid and semi- arid region as shown in Table 3. In Iraq, the Ministry of Water Resources has been using cement-sand mortar as joints filling material in all the projects of concrete canal lining. A comparative study is carried out between four types of filling materials used in the lining of concrete canals as follows:

Table 3. Characteristics and Availability of Different Joint Filling Materials

Filling materials	Main composition	Cost (US$/1 m length)	Toxicity	Ease of application
Cement-sand mortar	Cement and sand	0.125 $	Non	Easy
Cement-sand mortar and SBR	Cement, sand and styrene butadiene rubber (liquid polymer bonding agent)	0.4 $	Non	Easy
Cement-sand mortar and KIM	Cement, sand and krystol internal membrane (cement-admixture powder)	0.16 $	Non	Easy
Setseal B (as filling material)	Liquid polymer with cementitious Powder	0.625 $	Non	Medium
Setseal B (as coating material)	Liquid polymer with cementitious Powder	0.15 $	Non	Easy
Bituproof 12	Dark brown emulsified bitumen liquid reinforced with rubber	0.9 $	Toxic to water	Medium
Polysulfide sealant	Grey paste compound	4 $	Non	Medium

*Note: that all the information listed in table are based on the technical data sheet of each material.

3.2 Cement-sand Mortar

Cement-sand mortar consists of sulfate-resisting Portland cement with fine aggregate of mix proportion 1:2 and water/cement ratio of 0.45. The mixture was mixed well to be homogenous cement paste which was used to fill the model joints. The lined concrete model with this mixing proportion of filling material was tested under steady state condition (constant seepage) which is obtained after 7 days under a heads of 0.17 m, 0.18 m and 0.19 m, and water temperature 310°C.

3.3 Cement-sand Mortar and Styrene Butadiene Rubber (SBR)

A mixture of sulfate-resisting Portland cement, fine aggregate (sand) and SBR with a proportion of 1 cement: 1.5 sand: 0.16 SBR, and water/cement ratio of 0.45. They were mixed well to form as cement paste used to fill the model joints. The system was tested for 7 days (till steady seepage is obtained) with applied head of 0.17 m, 0.18 m and 0.19 m, and water temperature 310°C. The initial and final setting time for (cement-sand mortar and SBR) was found to be 260 minutes, and 420 minutes respectively.

SBR is one component of styrene butadiene rubber latex bonding agent. It is used to improve the physical properties (like fineness, setting time, flexural strength and compressive strength) of cement mixes and slurries. The advantages of using SBR are as follows (DCP-SBR, 2012):

- Successfully increases the bonding/adhesion of cement mixes.
- Excellent waterproof additive which helps produce waterproof renders, screeds and toppings.
- Effective plasticizer giving a good workability and cohesion.
- Improves the mechanical and physical properties by increasing tensile, flexural and adhesive strengths.
- Reduces shrinkage and cracking in repair and screeding mixes.
- Good freeze/thaw resistance.
- To produce waterproof renders (Billmeyer, 1971).

The chemical and physical properties of SBR used are given in Table 4.

Table 4. Chemical and Physical Properties of SBR

Color	White
Shape and appearance	Emulsion
Solid in aqueous solution	45%
Mixing with water	Mix with water at any percent
Specific gravity	1.081 kg/lit
Butadiene	40 (by weight)
Styrene	60 (by weight)
Sodium alkyl sulfate	0
Sodium phosphate	0
(PH) value	9.5
Fire	Non - flammable

*(DCP-SBR, 2012).

3.4 Cement-sand Mortar and Krystol Iinternal Membrane (KIM)

This material is consist of sulfate-resisting Portland cement, fine aggregate (sand) and KIM with a mixing proportion of 1 cement: 2 sand: 0.02 KIM, and water/cement ratio of 0.45, they were mixed well to form of cement paste used to fill the model joints, it was also tested for 7 days (till the seepage was in a constant range) with a head of 0.17 m, 0.18 m and 0.19 m, and water temperature of 310°C. the initial and final setting time for (cement-sand mortar and KIM) was found to be 180 minutes, and 260 minutes respectively.

KIM is a chemical admixture in dry powdered form, and effective in creating waterproof concrete. It is used in places of externally applied surface membranes to protect against moisture transmission, chemical attack and corrosion of reinforcing steel. When combined with fresh concrete, Krystol technology reacts with un-hydrated cement particles to form millions of needle-like crystals. Over a period of weeks and months, these crystals grow, filling the naturally occurring pores and voids in concrete, and permanently blocking the pathways for water and waterborne contaminants. Later, if cracks form due to settling or shrinkage, incoming water triggers the crystallization process and additional crystals form, filling cracks and ensuring that the structure's waterproofing barrier is maintained and protected (Kryton, 2011).

3.5 Setseal B (Liquid polymer with powder)

Setseal B is consists of liquid polymer mixed with a cementitious material powder (DCP-Setseal B, 2012), they were mixed thoroughly to prepare two basic materials for the model, and they are:

i. *Filling materials*; with proportion of (1liquid polymer: 2.5 cementitious powder). The constituents are mixed well to be a form of cement paste to fill the model joints, this material is examined under steady seepage conditions for 7 days of a head 0.17 m, 0.18 m and 0.19 m, and water temperature of 310°C. The initial and final setting time tests are done for the Setseal B. The initial setting time was 420 minutes, and the final setting time was 720 minutes.

ii. *Coating layer*; with a mix proportion of 1 liquid polymer: 1.5 cementitious powder as it designed, they were mixed well to form an elastic cement coat used to coat the model joints (over cement-sand joints). This material was tested for more than 9 months (from July 2012 to March, 2013) with a head of 0.17 m, 0.18 m and 0.19 m. Water temperatures during the test were ranged from 450°C to 20°C. Moreover, there are 3 cycles of drying-filling the canal for 10 days, in each cycle the canal was put under observation to fix the effects of drying-filling process of the model.

Setseal B is regarded as a multi-use elastomeric polymer modified cementitious waterproof coating which is suitable for internal and external applications. Setseal B provides a hardwearing, seamless, waterproof membrane for potable water retaining structures, tanks, basements, foundations and culverts. Setseal B shows excellent crack accommodation and is suitable for use on concrete (DCP-Setseal B, 2012).

4. Test of Filling Material in Field Lining Canal

The field study was done on a branch irrigation concrete canal in Hurriya-Dagh'ara project, located at Al-Diwaniyah Province-southern part of Iraq, which is one of the major projects in irrigation and land reclamation field in Iraq. The characteristics canal are shown in Table 5. That project aims to irrigate and reclamation of 137000 acres (554.42 km^2) and consists of irrigation and drainage networks: 17500 km of main concrete lined canals, 18300 km of branch concrete lined canals and 1000 km of secondary concrete lined canals (Ministry of Water Resources, reports, 2012).

The ponding method was applied to calculate the losses of water (seepage rate) by closing part of the lined irrigation canal. Three segments of the branch canal were selected with a length of 9 m for each. The joints of the first segment are filled with cement-sand mortar to calculate the losses of the water in the joint material to simulate the projects of the Ministry of Water Resources. The second segment was to compare the losses for the same segment before and after applying the selected joint material for comparison purposes, and the third segment is to test the best joint filling material (based on the results of the model canal). Each segment consists of the three panels with longitudinal and transverse joints length of 30.8 m.

The main aspects under the selection and applying of Setseal B material as joints coating material on the field canal were: the ease of construction, water tightness (achieving good water tightness at the time of construction), durability (possibility of maintaining the initial degree of water tightness in the long term), and suitable cost. So, Setseal B as coating layer was applied on the field canal based on the laboratory model results. The scenario of the field study was done during January and February 2013, and it was carried out as follows:

1. Each segment was closed off with the two earthen cuts off which are compacted and surrounded by a thick nylon membrane as a core inside the cuts off, to prevent seepage (Fig. 7).
2. The joints of segments number one and two are filled (as designed) with cement-sand mortar. These two segments are filled with water, and the water level was at the designed level in ministry of irrigation design of 0.34 m.
3. The joints of segment number three were coated by Setseal B over the existing filling material (mortar cement and sand. After curing completed, the segment was filled with water. The water depth is at the designed level of 0.34 m.
4. All the segments in this study are filled with water at the same time with a water level of 0.34 m; water level is checked every 24 hours, and sufficient quantity of water was added to maintain its original level.
5. For all segments in this study, there are spaces between them, as shown in Fig. 7, to monitor and make sure if there was any seepage through the compacted embankments.
6. After 7 days from beginning the test, segment number two is closed and emptied from water for coating its joints with Setseal B and refilling the segment with water level of 0.34 m to measure the seepage difference before and after the joints coating with this material and compare the results with the other segments.
7. Water temperature during this test is taken and ranged from 120°C to 100°C (during January and February, 2013).

Table 5. Field Irrigation Lined Canal Characteristics

Discharge (Q)	0.17 m^3/s
Bed width	0.6 m
Top width	1.62 m
Canal side slope	1:1.5
Longitudinal slope (S)	25 cm/km
Panel length	3 m
Panel thickness	65 mm
Joint width	25 mm
Water head	0.34 m

Fig. 7. Canal Segments no.1 and 2 Filled with Water

5. Results and Discussion

5.1 Concrete Flume Joints Material Tests Results

The seepage during the test of the selected joints material is calculated by two different procedures:

1. *Ponding laboratorial canal*; the head difference inside the canal between time 1 and time 2 is calculated in unit area for time difference (Δt) to obtain the volume of water that seeps, the volume was divided over the time difference (Δt) to obtain the seepage.
2. *Flowing laboratorial canal*; the head difference inside the water tank (source of flow system) from time 1 to time 2 is calculated and multiplied by surface area to obtain the volume of water losses (seeps), this volume is divided over the time difference Ät to obtain the seepage. Both procedures show the same results for all joints materials.

5.2 Cement-sand Mortar

The seepage values are calculated for three different heads of 0.17 m (designed head according to Ministry of Water Resources), 0.18 m and 0.19 m to assess the influence of the head variation on seepage value. The seepage rate becomes in a constant rate after 5 days of operating. Test duration of 7 days was adopted to be more convenient result for all tests. The seepage results are quantitatively taken as liter/day/1 m length and cm/day/1 m^2. The obtained experimental results are briefly included in Table 6.

Table 6. Seepage Rate from the Laboratory Model by using Cement Mortar-sand Material for the Three Heads

Day	Estimated Seepage Losses					
	H=0.17 m		H=0.18 m		H=0.19 m	
	(m^3/day)/1 m canal length	(cm/day)/1 m^2	(m^3/day)/1 m canal length	(cm/day)/1 m^2	(m^3/day)/1 m canal length	(cm/day)/1 m^2
1	400×10^{-4}	4.636	410×10^{-4}	4.751	420×10^{-4}	4.867
2	390×10^{-4}	4.520	400×10^{-4}	4.636	410×10^{-4}	4.751
3	380×10^{-4}	4.404	390×10^{-4}	4.520	400×10^{-4}	4.636
4	370×10^{-4}	4.288	385×10^{-4}	4.462	400×10^{-4}	4.636
5	365×10^{-4}	4.230	380×10^{-4}	4.404	390×10^{-4}	4.520
6	365×10^{-4}	4.230	380×10^{-4}	4.404	390×10^{-4}	4.520
7	365×10^{-4}	4.230	380×10^{-4}	4.404	390×10^{-4}	4.520

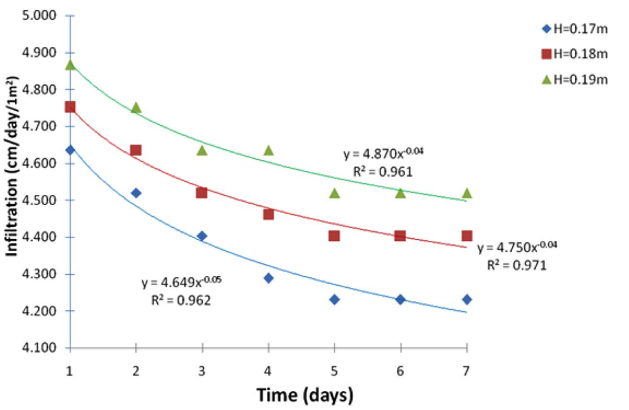

Fig. 8. The Infiltration Rate with Respect of Test Duration for Cement-sand Mortar as Joint Filling Material

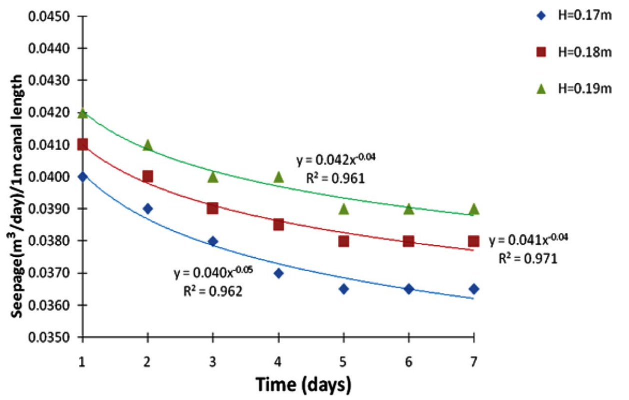

Fig. 9. The Seepage Rate with Respect to Test Duration for Cement-sand Mortar as Joint Filling Material

Table 7. Seepage Rate from the Laboratory Model by using Cement-sand Mortar and SBR Material for the Three Heads

Day	Estimated Seepage Losses					
	H=0.17 m		H=0.18 m		H=0.19 m	
	(m^3/day)/1 m canal length	(cm/day)/1m^2	(m^3/day)/1m canal length	(cm/day)/1 m^2	(m^3/day)/1 m canal length	(cm/day)/1 m^2
1	340×10^{-4}	3.940	342×10^{-4}	3.966	347×10^{-4}	4.017
2	338×10^{-4}	3.914	340×10^{-4}	3.940	344×10^{-4}	3.992
3	336×10^{-4}	3.889	338×10^{-4}	3.914	342×10^{-4}	3.966
4	333×10^{-4}	3.863	336×10^{-4}	3.894	340×10^{-4}	3.940
5	331×10^{-4}	3.837	333×10^{-4}	3.863	338×10^{-4}	3.914
6	329×10^{-4}	3.811	333×10^{-4}	3.863	338×10^{-4}	3.914
7	329×10^{-4}	3.811	333×10^{-4}	3.863	338×10^{-4}	3.914

The results showed that the reduction in seepage after 5 days, were 8.75, 7.32, and 7.14%, for heads of 0.17, 0.18, and 0.19 m respectively (Figs. 8 and 9).

5.3 Cement-Sand Mortar and SBR

The seepage rate calculated for three different heads of 0.17 m 0.18 m and 0.19 m to assess the influence of the head variation on seepage value when using Cement-Sand Mortar and SBR. The seepage rate becomes in a constant rate after 5 days of operating and the test duration was until 7 days. The obtained experimental results are included in Table 7 and shown graphically in Figs. 10 and 11. The results showed that the reduction in seepage after 6 days, were 3.27, 6, and 2.56%, for heads of 0.17, 0.18, and 0.19 m respectively.

5.4 Cement-Sand Mortar and KIM

The seepage values were calculated for three different heads of 0.17 m 0.18 m and 0.19 for cement-sand mortar and KIM as joints filling material. The seepage rate becomes in a constant rate after 5 days of operating until 7 days. The seepage results are quantitatively taken. The obtained experimental results are listed in Table 8 and shown graphically in Figs. 12 and 13.

The result shows that the head difference had no effect on the amount of seepage, and for the first 5 days the seepage slightly

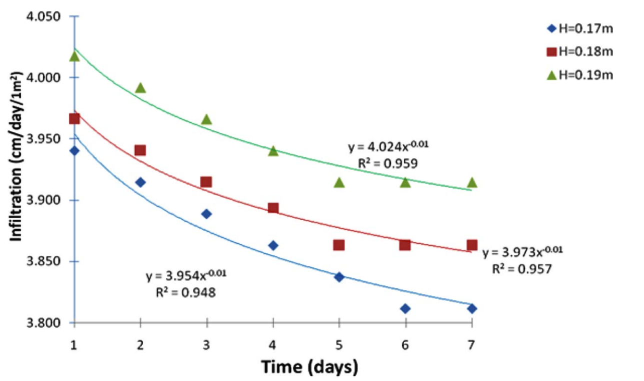

Fig. 11. The Seepage Rate with Respect to Test Duration for Cement-sand Mortar and SBR as Joint Filling

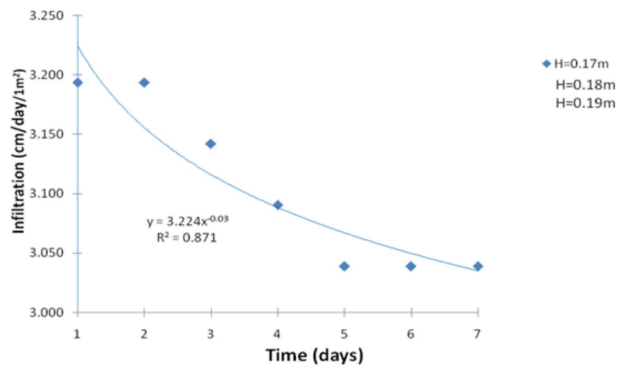

Fig. 12. The Infiltration Rate with Respect of Test Duration for Cement-sand Mortar and KIM

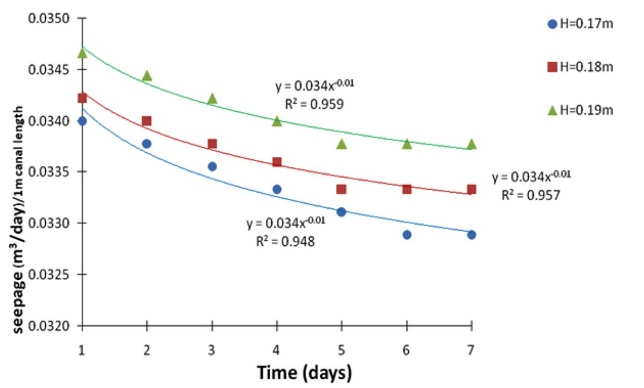

Fig. 12. The Infiltration Rate with Respect of Test Duration for Cement-sand Mortar and KIM

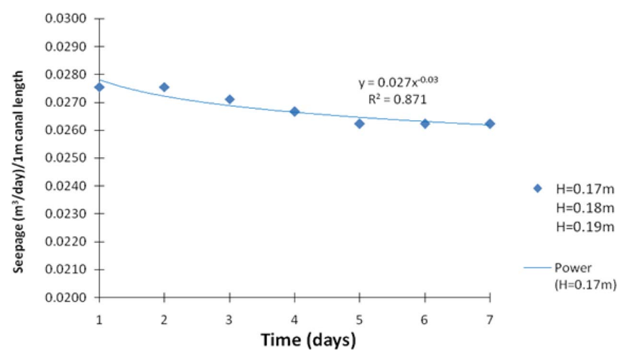

Fig. 13. The Seepage Rate with Respect to Test Duration for Cement-sand Mortar and KIM as Joint Filling Material

decreased about 5%, after that, the seepage was constant at 0.026 (m^3/day)/1 m canal length for the rest of the test duration (Fig. 13).

5.5 Setseal B (Liquid polymer with Powder)

This material consists of liquid polymer mixed with a cementitious material powder, they were mixed well with two different procedures of applications on the model as follows:

i. *As a filling material:* The seepage values were calculated for three different heads of 0.17 m, 0.18 m and 0.19 m to assess the influence of the head variation on seepage value. Tests duration of 7 days and the seepage rate becomes in a constant rate after 5 days of operating. The obtained experimental results are listed in Table 9 and shown graphically in Figs. 14 and 15.

The result shows that the head difference had no effect on the amount of seepage, and for the first 3 days the seepage was constant for all three heads, but in the fourth day the seepage slightly decreased for the three heads about 9%, after that the seepage was constant for all heads at 0.004 (m^3/day)/1 m canal length for the rest of the test duration (Fig. 15).

ii. *As coating layer:* This material is tested for 9 months (from July 2012 to March, 2013) as coating layer by using the trapezoidal concrete canal model. The test results showed that there is no seepage (seepage zero) during this duration under the considered heads and water temperature range from 450°C to 20°C depending

Table 8. Seepage Rate from the Laboratory Model by using Cement-sand Mortar and KIM Material for the Three Heads

Day	Estimated Seepage Losses					
	H=0.17 m		H=0.18 m		H=0.19 m	
	(m^3/day)/1 m canal length	(cm/day)/1 m^2	(m^3/day)/1 m canal length	(cm/day)/1 m^2	(m^3/day)/1 m canal length	(cm/day)/1 m^2
1	276×10^{-4}	3.193	276×10^{-4}	3.193	276×10^{-4}	3.193
2	276×10^{-4}	3.193	276×10^{-4}	3.193	276×10^{-4}	3.193
3	271×10^{-4}	3.142	271×10^{-4}	3.142	271×10^{-4}	3.142
4	267×10^{-4}	3.090	267×10^{-4}	3.090	267×10^{-4}	3.090
5	262×10^{-4}	3.039	262×10^{-4}	3.039	262×10^{-4}	3.039
6	262×10^{-4}	3.039	262×10^{-4}	3.039	262×10^{-4}	3.039
7	262×10^{-4}	3.039	262×10^{-4}	3.039	262×10^{-4}	3.039

Table 9. Seepage Rate from the Laboratory Model by using Setseal B Material for the Three Heads

Day	Estimated Seepage Losses					
	H=0.17 m		H=0.18 m		H=0.19 m	
	$(m^3/day)/1$ m canal length	$(cm/day)/1\ m^2$	$(m^3/day)/1$ m canal length	$(cm/day)/1\ m^2$	$(m^3/day)/1$ m canal length	$(cm/day)/1\ m^2$
1	44×10^{-4}	0.515	44×10^{-4}	0.515	44×10^{-4}	0.515
2	44×10^{-4}	0.515	44×10^{-4}	0.515	44×10^{-4}	0.515
3	44×10^{-4}	0.515	44×10^{-4}	0.515	44×10^{-4}	0.515
4	40×10^{-4}	0.464	40×10^{-4}	0.464	40×10^{-4}	0.464
5	40×10^{-4}	0.464	40×10^{-4}	0.464	40×10^{-4}	0.464
6	40×10^{-4}	0.464	40×10^{-4}	0.464	40×10^{-4}	0.464
7	40×10^{-4}	0.464	40×10^{-4}	0.464	40×10^{-4}	0.464

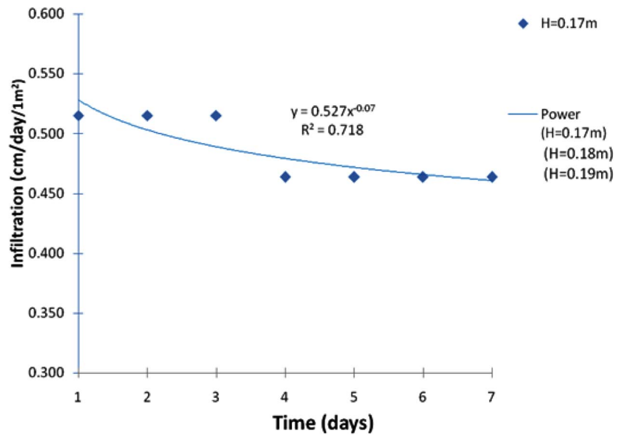

Fig. 14. The Infiltration Rate with Respect of Test Duration for Setseal B

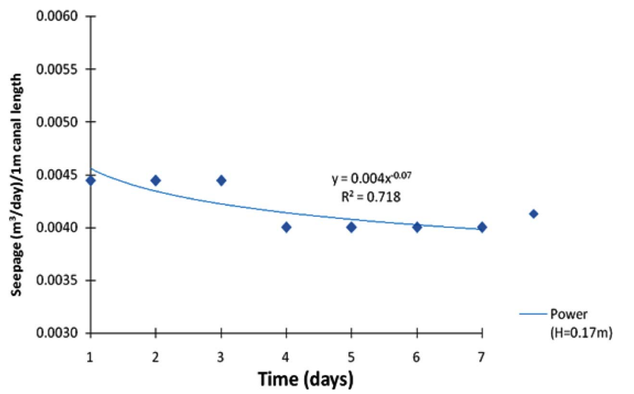

Fig. 15. The Seepage Rate with Respect to Test Duration for Setseal B as Joint Filling Material

on weather variations. Moreover, there are 3 cycles of drying and filling the canal with water for 10 days each one to observe the canal behavior under drying and filling conditions.

6. Comparison between the Different Joints Materials with Respect to Seepage

The comparison is made for the designed head of h = 0.17 m for all materials used in this laboratorial analysis for the concrete

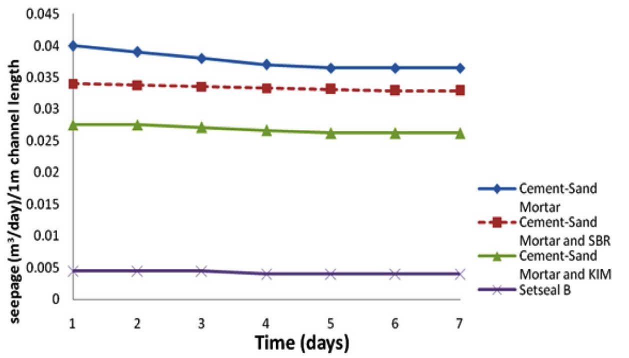

Fig. 16. Comparison of Seepage Values for the Laboratory Canal with a Head of 0.17 m for Different Joints Filling Materials

Table 10. Percentage of Seepage Reduction Compared with Cement-sand Mortar

Day	% of Seepage reduction (compared with cement-sand mortar)		
	Cement-sand mortar and SBR	Cement-sand mortar and KIM	Setseal B
1	15%	31.11%	88.89%
2	13.39%	29.34%	88.60%
3	11.70%	28.65%	88.30%
4	9.91%	27.93%	89.19%
5	9.28%	28.16%	89.04%
6	9.89%	28.16%	89.04%
7	9.89%	28.16%	89.04%

canal, the chosen head is to simulate an existing branch watercourse as open canal. The study revealed that the initial percentage of seepage losses is reduced to 15%, 31%, and 89% when using cement-sand mortar and SBR, cement-sand mortar and KIM, and cement-sand mortar and Setseal B (as coating layer) respectively, instead of pure cement-sand mortar (Fig. 16, Table 10).

7. Field Test For Filling Joint Materials Performance

Setseal B as a coating layer applied on an existing field concrete lined canal by using the laboratory model results as

Table 11. Water Head Reduction at Irrigation Lined Canal at the Field Site

Time (days)	Initial head (mm)	Segment no.1		Segment no.2		Segment no.3	
		Head level reading (mm).	Head reduction (%)	Head level reading (mm).	Head reduction (%)	Head level reading (mm).	Head reduction (%)
1	340	330	2.94	330	2.94	335	1.47
2	340	331	2.65	330	2.94	335	1.47
3	340	331	2.65	330	2.94	336	1.18
4	340	331	2.65	331	2.65	336	1.18
5	340	331	2.65	331	2.65	336	1.18
6	340	332	2.35	332	2.35	337	0.88
7	340	331	2.65	332	2.35	336	1.18
8	340	331	2.65	---[a]	---[a]	336	1.18
9	340	330	2.94	---[a]	---[a]	335	1.47
10	340	332	2.35	334	1.76	336	1.18
11	340	332	2.35	335	1.47	336	1.18
12	340	332	2.35	335	1.47	336	1.18
13	340	332	2.35	336	1.18	337	0.88
14	340	333	2.06	336	1.18	337	0.88
15	340	333	2.06	336	1.18	337	0.88
16	340	333	2.06	337	0.88	337	0.88
17	340	333	2.06	337	0.88	337	0.88
18	340	334	1.76	336	1.18	337	0.88
19	340	335	1.47	337	0.88	338	0.59
20	340	333	2.06	336	1.18	337	0.88

*Water temperature during the test was ranged from (12-8°C).
(---[a]) There was no reading during days no. 8 and 9 for segment no.2 because it was closed for coating its joints with Setseal B.

Table 12. Losses Rate at the Field Irrigation Lined Canal

Time (days)	Initial head (mm)	Segment no.1 Head difference (mm).	Segment no.2 Head difference (mm).	Segment no.3 Head difference (mm).	% of losses reduction between Segment no.1 & 3
1	340	10	11	5	50%
2	340	9	10	5	44%
3	340	9	10	6	55%
4	340	9	9	4	55%
5	340	9	9	4	55%
6	340	8	8	3	62.5%
7	340	9	8	4	55%
8	340	9	------	4	55%
9	340	10	------	5	50%
10	340	8	6	4	50%
11	340	8	5	4	50%
12	340	8	5	4	50%
13	340	8	4	3	62.5%
14	340	7	4	3	57.14%
15	340	7	4	3	57.14%
16	340	7	3	3	57.14%
17	340	7	3	3	57.14%
18	340	6	4	3	50%
19	340	5	3	2	60%
20	340	7	4	3	57.14%

preliminary data to deal with. The Setseal B gives zero seepage when it was applied as a coating layer in laboratory model, and small seepage amount when applied as joint filling material.

The scenario of testing methodology by ponding method is by selecting three segments of the branch canal along Hurriya-Dagh'ara canal with a length of 9 m for each segment. After that, water heads have been applied in the three segments. The observed heads are recorded and included in Table 11.

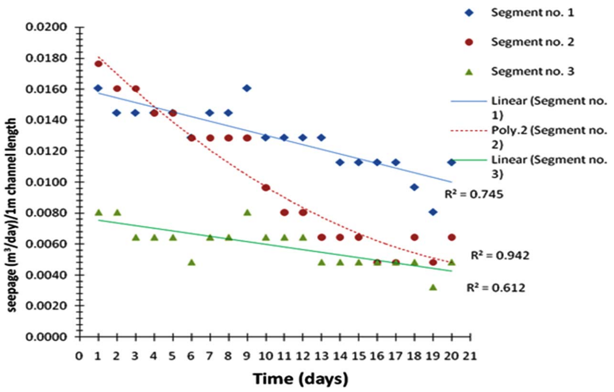

Fig. 17. Losses of Seepage with Respect to Time for the Field Lined Canal (Hurriya-Dagh'ara project)

Table 13. Losses Amount Obtained from the Field Site

Day	(m^3/day)/1 m canal length.	(m^3/day)/ 1 m canal length.	(m^3/day)/ 1 m canal length.	Segment no.1&3 (m^3/day)/1 m canal length.
1	0.0161	0.0176	0.0081	0.0080
2	0.0145	0.0161	0.0081	0.0064
3	0.0145	0.0161	0.0065	0.0080
4	0.0145	0.0145	0.0065	0.0080
5	0.0145	0.0145	0.0065	0.0080
6	0.0129	0.0129	0.0048	0.0080
7	0.0145	0.0129	0.0065	0.0080
8	0.0145	------	0.0065	0.0080
9	0.0161	------	0.0081	0.0080
10	0.0129	0.0097	0.0065	0.0064
11	0.0129	0.0081	0.0065	0.0064
12	0.0129	0.0081	0.0065	0.0064
13	0.0129	0.0065	0.0048	0.0080
14	0.0113	0.0065	0.0048	0.0064
15	0.0113	0.0065	0.0048	0.0064
16	0.0113	0.0048	0.0048	0.0064
17	0.0113	0.0048	0.0048	0.0064
18	0.0097	0.0065	0.0048	0.0048
19	0.0081	0.0048	0.0032	0.0048
20	0.0113	0.0065	0.0048	0.0064
Average	0.0139		0.00659	0.0073

The first segment was considered to record the losses of the existing project joint material, the second segment was to compare the losses for the same segment before and after applying the selected joint material, and the third segment was to check the selected joint material.

The losses reach a steady state condition (constant losses) after day no. 13, so the percentage of losses reduction between segment no. 1 and segment no. 3 is about 62.5%, and the percentage of losses reduction for segment no. 2 after coating its joints is about 50%, as shown in Table 12.

The amount of average losses reduction between segment no.1 and segment no. 3 is 0.0073 m^3/day per 1 meter of the canal length, as shown in Fig. 17 and Table 13. So, for the total length of Hurriya-Dagh'ara branch canal 18300 km, it can be estimated that the storage water equals to 128100 m^3/day.

In this study, a laboratorial concrete open canal was constructed to evaluate the efficiency of some filling material to resist seepage through their joints. After the amount of seepage were measured and evaluated, the best filling material was chosen to be applied later on an existing open canal to evaluate its efficiency in the field. The hereinafter points concluded under the light of the study:

1. Seepage amount is directly proportional with ponding of hydraulic head.
2. In all cases (laboratory canal and field canal), seepage amount reduces gradually with ponding time to reach a constant values after 5 days since starting. Seepage reaches a constant value of 0.0365 m^3/day/1 m length, 0.0329 m^3/day/ 1 m length, 0.026 m^3/day/1 m length, and 0.004 m^3/day/1 m length for cement-sand, cement-sand with SBR, cement-sand with KIM, Setseal B as mortar respectively.
3. Whereas Setseal B gives no seepage (zero seepage) when it is used as a coating joint material for both laboratory canal and field canal.
4. Setseal B as a coating layer represents a good and significant solution for maintenance and curing the weak joints of the executed concrete irrigation canals. Setseal B as a coating joint material reduces the field losses to about 54.5%, this coating material can be used for the existing irrigation canals in Iraq.
5. Further studies of the factors affecting seepage in open canals are required in order to improve the understanding of the seepage behavior, such as soil swelling effect, and the effects of plants growth through joints and cracks.

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