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Aspects of Design and Benefits of Alternative Lining Systems

M. Riaz[1] and Z. Şen[2]
[1] *Assistant Director/Research Student, Irrigation Research Institute, Irrigation Secretariat Lahore – Pakistan aizariaz@hotmail.com*
[2] *Istanbul Technical University, Civil Engineering Faculty, Hydraulics Department. Maslak 34469, Istanbul, Turkey, zsen@itu.edu.tr*

Abstract: Seepage losses from irrigation channels have widely been identified as environmentally critical for the resulting groundwater accessions and associated drainage problems. Seepage from irrigation distribution system causes waterlogging in the area adjacent to channels while simultaneously reducing the amount of water available for safe and productive use. In case of saline groundwater conditions, water lost to seepage ultimately turns as irretrievable loss of valuable fresh water resource. Fordwah Eastern Sadiqia South (FESS) project area is located approximately 300 km South of Lahore in Bahawalnagar District in three places, namely, Bahawalnagar, Chishtian and Haroonabad. The original design water duty was 1.21 cms (42.7 cfs) per 1000 acres, implying a cropping intensity of about 80 percent (40 percent in each season). With the improved supplies supplemented by sub-irrigation from shallow ground water, the cropping intensity has increased to over 130 percent. This has resulted in significant salinity and water logging problems in the area. The objective of the canal lining project is to reduce waterlogging and salinity through the reduction of seepage losses from the irrigation channels. The project targeted the minor channels with discharges of less than 3.85 cumec (100 cusec), and a total length of approximately 160 Km (100 miles) is lined during the two year construction period. This paper describes the proposed canal lining systems to be installed in the project area both for the main production component and for experimental purposes. An outline of the evaluation criteria is also given with discussion on the difficulties in lining of the existing canal systems. The use of geosynthetic lining materials is also presented including the expected benefits.

Key words: Seepage, measurement, ground water, water logging and salinity, construction techniques, and benefits

1. INTRODUCTION

The Fordwah Eastern Sadiqia South (FESS) Irrigation and Drainage Project consists of approximately 105,000 hectares of land in Bahawalnagar, Pakistan. The area is underlain by saline groundwater. The project was designed to remove severe water supply constraints by increasing delivery efficiency of canals and water courses and to control excessive seepage.

A significant irrigation and drainage research component was also planned to refine the critical elements in the planning and implementation of the project. The research components were considered of i) evaluation of the impact of water logging and salinity on the crop production ii) introduction of improved technologies for planning and monitoring of irrigation and drainage projects, land and water conditions in general iii) assessing performance of different types of canal lining iv) improvement of the irrigation management with a view to much irrigation supplies with crop water demand i.e. integrated irrigated agricultural management and agriculture extension support. The research component on assessing performance of different types of canal lining is the main focus of this paper.

Canal lining can be carried out with different materials/types, specifications and construction methods. However, a little work on suitability of different lining materials/types and construction methodologies for conditions in Pakistan has been carried out. In order to provide definite recommendation about the use of different materials/types for canal lining with respect to the parameters like effectiveness towards seepage control, life expectancy, construction techniques and economic viability etc. It was considered important to experiment with various lining innovations under FESS canal lining programme.

A sheet of flexible material known as geomembrane, typically 0.2 to 3 mm thick, is used for canal lining. There are many materials and alloys of various types used for geomembrane. Mostly these materials are polymers formed by the chemical combination of monomers. These materials can be further distinguished as elastomers (rubbers) and thermoplastic materials. Another useful distinction can be made within the thermoplastic materials, i.e. Polyolefins like varieties of polypropylenes and polyethylenes and non Polyolefins like PVC (Polyvinyl chloride). Polyolefin contain carbons and hydrogen only and are chemically inert so that seams can be made by heat (welding methods) only. Non Polyolefins are chemically reactive to extent that solvents can be used for seaming. Elastomers can also be joined by solvents/adhesives. Properties of various geomembranes differ widely between types according to their chemical composition. (Koerner, 1989 and 1990).

The properties of geomembrane can be measured by standard tests (ASTM, 1995 and Rollin and Rigo, 1991). Only those geomembranes are used for lining that withstand the puncturing, tearing, aging and ultraviolet radiation. These properties are tested in Engineer's Geosynthetics Laboratory Bahawalnagar, Pakistan. This paper specially addresses the design and construction aspects of the lining works which have been done in the FESS project.

2. FIELD EXPERIMENTS ON CANAL LINING

2.1 Constructional Aspects

The experiments were aimed at finding more cost effective ways of lining existing canals in the future, primarily to reduce water loss by seepage, under typical Punjab conditions and with special emphasis on methods that could be used without diversion channels. The experimental linings are intended to explore ways of lining canals more effectively or more cheaply in the future than is possible now. This experimental plan was designed in 1995 (Mott Macdonald, 1995).

2.2 Nature of the Canals to be Lined

The existing canals of the FESS area are alluvial canals typical of irrigation schemes in the flatter parts of Punjab. The range of sizes tested here extended from small canals about 1.83 m (6 ft) wide and carrying 0.11 cms (4 cfs) to larger ones about 18.28 m (60 ft) wide and carrying about 11.32 cms (400 cfs). Their longitudinal slopes vary generally from 1 in 10,000 to 1 in 2,000, the larger canals usually having the flatter slopes. Mostly the experiments were done in canal reaches carrying less than 0.28 cms (10 cfs), but some were done in one particular canal carrying about 11.32 cms (400 cfs) [Figure 2.1 to 2.4].

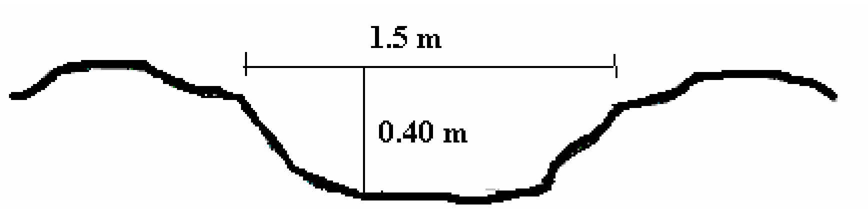


Figure 2.1 A typical small canal 0.17 cms slope 1 in 2500 B/D around 4

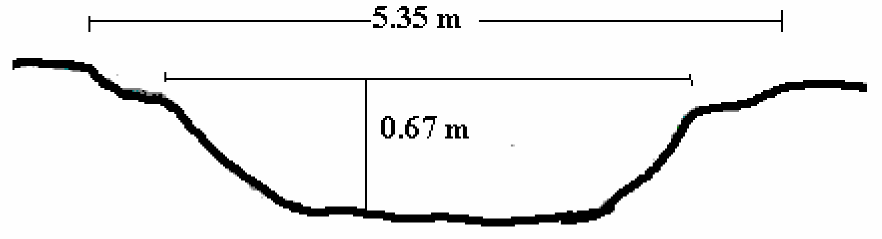


Figure 2.2 A typical canal carrying discharge 0.70 cms, slope 1 in 5000, B/D around 5

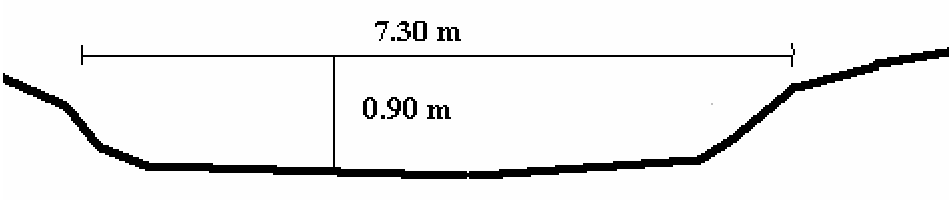


Figure 2.3 A typical canal carrying discharge 2.83cms, slope 1 in 8000, B/D 6-8

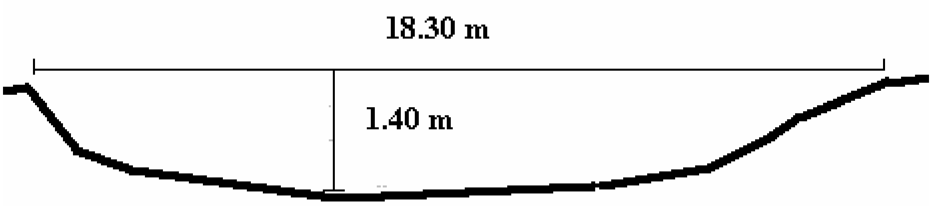


Figure 2.4 A particular large canal (head reach 3R/Hakra), carrying about 11.40 cms at slope of 1 in 6800,A more typical discharge of this cross section would be 8.5 cms at slope of 1 in 12000.

2.3 Basic Canal Lining Types

Under experimental component, the different lining types were selected using different combination of geomembrane and geotextile with hard and soil cover. Its objective was to search for more cost effective ways of canal lining in existing canals in future. One way to make lining more cost-effective is to make it cheaper without undue loss of effectiveness and one of the main costs, both in direct financial terms and in terms of disruption to other activities, is the use of diversion channels.

All the experimental lining types in canals carrying less than 2.86 cms (100 cfs) were carried out using a relatively thin but good quality geomembrane namely a Flexible Polypropylene Alloy (FPA) manufactured by the blown film technique in a thickness of 0.5 mm and a roll width of about 5.79 m (19 feet) and welded where necessary by the double wedge method or by extrusion welding. This was in contrast to production lining component and the experiment in large canal, where mostly used a Very Low Density Polyethylene (VLDPE), 0.75 mm thick and made in slightly wider rolls. (FESS, 1995)

2.3.1 Geomembrane under Soil Cover

This group of lining types can be in practice only be used for canals deep enough to prevent contact between buffalo hooves and the canal bed when the canal is full, i.e. deeper than 1.22 m (4 ft) and even then only with special precautions near the banks where wallowing buffaloes will always have access. On the bed, geomembrane needs to be covered with soil (normally the fine sand which collects on canal beds anyway) cover to sufficient nominal or design depth to protect it in the long term from occasional traffic and buffaloes during annual closures, from people who extract sand for construction purposes during closures and from future changes in the bed level due to hydraulic and sediment transport condition. Experiment includes design sand cover depth of 0.30, 0.45 and 0.61 m (1, 1.5 and 2 ft). There are two basic types in this group. (Snell, 1999)

Type A: Geomembrane on the bed and in the bank, with geomembrane in the bank protected by geotextile and several feet thickness of compacted cohesive soil. [Figure 2.5]

Type B: Geomembrane on the bed only, under sand cover no geotextile [Figure 2.6]

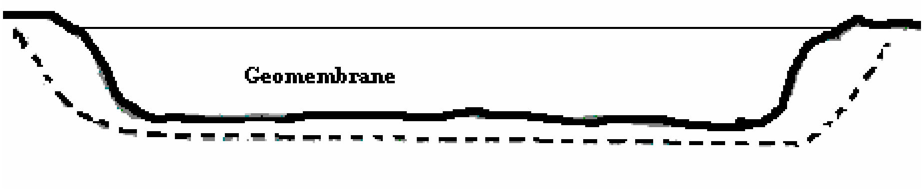


Figure 2.5 Geomembrane on the bed and banks and protected by geotextile

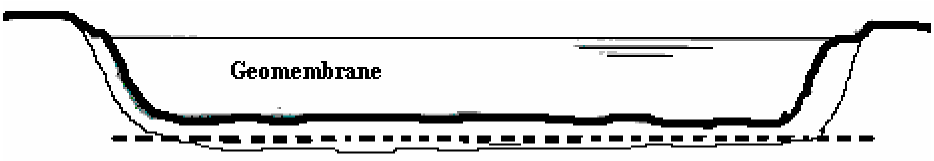


Figure 2.6 Geomembrane on the bed only under soil cover with no geotextile

2.3.2 Geomembrane under Hard Cover

The smaller canals are so shallow (0.4 m to 1.22 m (roughly 1.3 to 4 ft) water depth) that it is not realistic to expect a soil cover to survive as effective protection to a geomembrane layer, primary because of wallowing buffaloes. Therefore a hard cover is needed if a geomembrane is to be used, and in this group the experiments consisted of trails of various sorts of hard cover, plus a few lining types with no geomembrane and the water tightness is provided by making well sealed joints in the hard cover. In canals carrying discharge less than 2.83 cms (100 cfs), most of the experiments involved a geomembrane as the watertight element with concrete cover to protect it from damage, but some variants have no geomembrane and one has bricks lining instead of concrete. In some variants the geotextile is provided between geomembrane and concrete, to protect the geomembrane during construction and or to prevent wet concrete sliding on slopes. Seven basic lining types were tested, five of them involving precast concrete (some concrete joints have no sealants).

2.4 Comments on the Experimental Programme

The nine basic lining types and their variants bring the number of combinations tested to twenty nine. Some types, included in the list of basic types, were only developed towards the end of the programme in the light of experience with other types which were treated as variants: for the sake of clarity the above description follows as logical rather than a historical order. For instance, Types 1b and 3 were included from start and after more than a year Type 9 was developed to exploit the best features of both the earlier ones. The experimental reach ranges from 14.63 m (48 ft) to several hundred meters in length, and total some 32 km.

The experimental lining programme deliberately included some innovative and untried lining methods, and it was expected at the planning stage that some of them would fail. In the event some types proved unsuccessfully or impractical, at least under local physical conditions, and some others were not successful under the prevailing contractual arrangements and scale although they might still have potential in other contractual circumstances; for instance in a large enough project to use modern precasting methods. Some methods proved successful and could be recommended for future projects wherever they would be appropriate to the circumstances.

3. RESULTS OF EXPERIMENTS

3.1 Aspects and Criteria

There are four main aspects under which lining types are judged;

- Ease of construction,
- Water tightness (likelihood of achieving good water tightness at the time of construction)
- Durability (likelihood of maintaining initial degree of water tightness in the long term)
- Relative cost

The basic lining types tested and their variants are discussed in respect of the above criteria. The assessment also uses the pre and post lining seepage measurements where they are available. But, in many cases, this is based on subjective and on observations supported by discussion with contractors and consultant’s staff and others. The comparison is primary in terms of conditions in FESS area, but some remarks on likely performance under other conditions are also included in this paper.

3.2 Summary of Experimental Results

The conclusions are based on observation of the lining trials conducted on FESS lining project, but are extended by some reference to experience elsewhere and by some informed speculation about what would happened if particular lining types were used on a larger scale or with other contractual arrangements [Table 3.1].

4. SEEPAGE INVESTIGATIONS

4.1 Comparison of Pre and Post Lining Seepage Rate

Seepage loss estimation from post lining ponding tests on the diverse test lining types over hard cover in channels 1R/3R Qaziwala, 3R/ Hakra, 1R/Bahadarwala, Najibwah, Shadab and 2L/3R along with pertinent seepage reduction levels are presented as in Table 4.1 and Graph 4.1.

4.1.1 Lining with Hard Cover

Brief summary about seepage performance of variants:

a) Type 1b and 1c in which precast interlocking slabs over geomembrane, with and without geotextile, showed considerable residual seepage. The sharp precast slab edges had punctured the underlying geomembrane in these types as reported by the team who had installed these tests by lifting a few protective slabs for secure placement of pond dikes.
b) A high degree of seepage reduction (91%) was observed in type 2c (T shaped precast slabs with joint sealants and without geomembrane and geotextile). Type 2b (T shape precast slabs with geomembrane and geotextile without joint sealant) exhibited a poor seepage control efficiency. Test on another variant 2a (T-shape precast sides with joint sealant on wall and geomembrane on bed) remained inconclusive as the post lining seepage losses on this section showed a rise in water loss quantities compared to the pre-lining seepage.

Probing the cause for the discrepancy through digging out soil under the canal berm on external sides revealed the poor lining installation with the joint sealant missing between a numbers of lining profiles. Seepage tests were repeated at higher discharge of above types during the canal closure 2003. The reduction in seepage of type 2a (25%), 2b (68%) and 2c (67%) were observed.

c) Tests on Types 3a and 3b i.e. geomembrane with precast 50.8 mm (2 inches) plain slab concrete covers with and without the intermediate geotextile protection showed fairly high seepage control as 81% and 86% respectively.
d) Type 41g the parabolic geomembrane partially geotextile without joint sealant showed fair success of seepage reduction of 73%.
e) A moderate degree of seepage reduction (72%) was observed in type 4I that represents parabolic sealed joints without geomembrane and geotextile.
f) Type 4 , the parabolic precast channel with sealed joints but no geomembrane showed fair success with a residual seepage of the order of 11 mm/day in place of prelining seepage rate of 69 mm/day. This seepage control was achieved after the removal of mortar from the wet surface of the joint and place joint sealant in contact with both precast units at each joint.
g) Type 5a i.e. geomembrane with geotextile underlying 76 mm (3 inches) in-situ concrete with joint sealant showed a higher degree of seepage control i.e. 97%.
h) A moderate degree of seepage reduction (73%) was observed in the type 5b that represents the conventional in-situ concrete linings without geomembrane.
i) The geomembrane under in-situ experiment, type 5c showed as nearly zero seepage as can be measured. As this type replicates the production lining with a thinner geomembrane, it is the most probable that the production lining would generally provide a high degree of seepage control.
j) A higher degree of seepage reduction (99%) is observed in type 5cd that represents the geo-texture without geotextile overlain by 76.2 mm (3 inches) in-situ concrete without joint sealant
k) A higher degree of seepage reduction 99% is also observed in type 5n that represents the geomembrane overlain by 50.8 mm (2 inches) in-situ concrete with geomembrane and geotextile without joint sealant.
l) The type 6 has 97% reduction in seepage. The post lining seepage is negligible.
m) A moderate degree of seepage reduction (76%) was observed in type 7 that represents tongued and grooved precast slab, 76.2 mm (3 inches) bed in one piece, over geomembrane protected with geotextile layer.
n) A higher degree of seepage reduction (98%) was observed in type 8 which is 76.2 mm (2 inches) precast small channels without geomembrane, geotextile and joint sealant.
o) Test on type 9, geomembrane overlain by 50.8 mm (2 inches) precast slabs edge beam, mortar joined, with and without geotextile showed a high seepage control in the order of 3.05 mm/day in a place that showed 39.5 mm/day before lining. This represents a fair degree of success of 50.8 mm (2 inches) precast slabs with loss reduction up to 92%.
p) Option 3 on 3R-Hakra i.e. geomembrane under concrete filled mattress showed a high degree of seepage control (97%).

4.1.1 Lining with Soil Cover

Seepage loss estimates from post lining ponding test on the lining types with soil cover experimental in the channel 3R distributation. The seepage reduction levels are given in table 4.1 and graph 4.2.

a) Option 1 on 3R-Hakra, only bed lined with geomembrane with 457 mm (1.5 ft) nominal soil cover showed an approximately seepage rate of 15.5 mm/day. This represents a fair degree (49%) of success for lining of bed only.

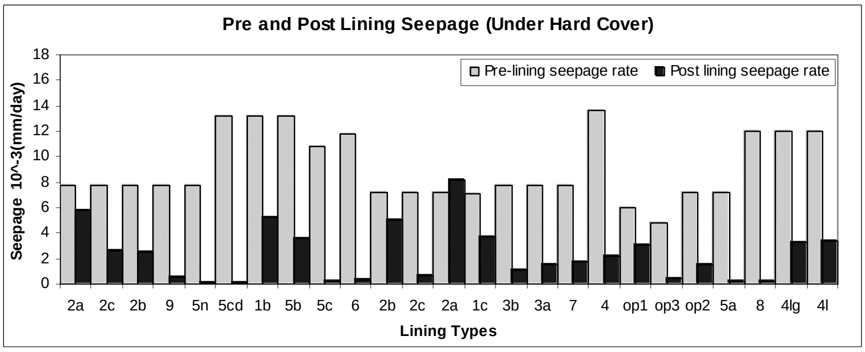
b) Option 2 on 3R-Hakra i.e. geomembrane lining on both bed and sides with 457 mm (1.5 ft) of soil cover showed a moderate seepage control exceeding 78%.

Table 3.1 Summery of Technical Conclusions on Lining Types

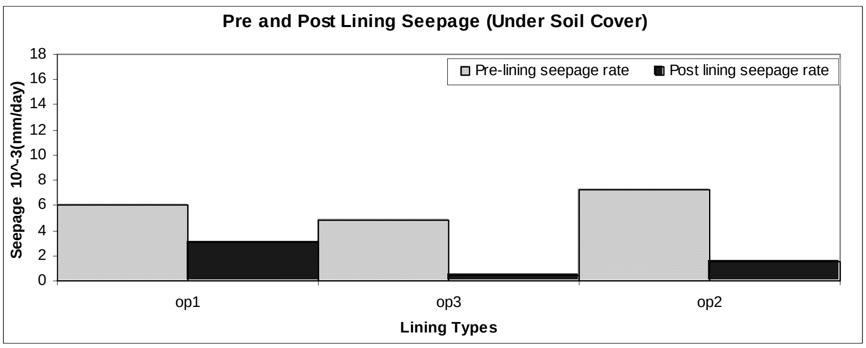
Basic Lining Types	Ease of construction	Water tightness	Durability
Geomembrane on bed only, under soil cover (Type B)	Fair, difficult to avoid occasional tearing when replacing sand. High groundwater can make problems	Poor: even a perfect bed only lining is unlikely to reduce seepage by more than about 60 %	Probably good if sand cover is at least 50 mm (2 ft), doubtful with less cover
Geomembrane under soil cover on bed and banks (Type A)	Bed as above Banks time consuming problems arise if existing canal banks are narrow. Stability doubtful, needed careful refilling	Would probably be good if soil cover on banks remain intact	Doubtful. Probably fair if first two years survived and natural berm deposits re-established
Geomembrane under concrete filled mattress (Type I)	Fair, after initial learning period. Minimal earthworks needed, adoptable to regular shapes	Good. Serious damage to geomembrane during installation unlikely	Doubtful. Probably fair to good. Mattress could be damaged by heavy animal traffic near bank top.
Geomembrane under sand on bed and mattress on banks (Type N, not tested)	Fair, mattress on banks can be placed during closure but filled underwater in flowing canal	Probably good if ways found to avoid damaging geomembrane on bed during installation.	Probably fair to good; as Type I
Trapezoidal insitu concrete without geomembrane (Type 5b)	Fair. Requires extensive earthwork preparation, both compaction and trimming	Fair, depends on quality of joint sealant and its installation.	Poor, joint sealant vulnerable and needs good maintenance.
Geomembrane under insitu concrete (Type 5c)	Fair. Require extensive earthwork preparation, both compaction and trimming. Placing of Geosynthetics not difficult if geomembrane sufficiently flexible	Good, Geotextile provided to prevent slipping of concrete, but also protects geomembrane during installation	Good water tightness provided by geomembrane which is not exposed, no reliance on joint sealing
Geomembrane under precast concrete trapezoidal (Type 9)	Fair. Require extensive earthwork preparation, both compaction and trimming. Precasting of plain slabs easy. Placing of slabs needs care. Variant Type I (interlocking pieces) difficult. Requires large scale to make good precasting economic	Potentially good if enough care taken to avoid puncturing geomembrane during installation use of geotextile helps this.	Fair to good; some chance of damage to geomembrane by vandalism via cracks between slabs (danger reduced if joints mortared) Variant Type 3b vulnerable to theft because no edge beam.
Geomembrane under mortared brickwork (Type 6)	Fair. Requires extensive earthwork preparation, both compaction and trimming. Placing of bricks very slow.	Good. Geotextile not needed.	Probably good. Bricks on edge difficult to remove and easy to replace or repair. Alternative tiles not so good.
Vertical precast walls, insitu bed (Type 2b)	In principle easy; needs little earthwork preparation, and no bank trimming. Like some other types, needs a learning process for installation. Has advantage where access is restricted.	Expected to be good (with geomembrane to bank top level in, Type 2b: poor for Type 2a, fair for Type 2c)	Probably good. High resistance to theft or tempering, geomembrane very well covered.
Geomembrane under precast parabolic channel (Type 4g)	Precasting and handling difficult, except when scale permits factory type precasting as, in Mediterranean countries. Installation fairly easy, even with limited	Good, with geomembrane. Fair for variant Type 4 with no geomembrane because of reliance on numerous scaled joints.	Fair to poor. Geomembrane may be vulnerable to objects poked through joints. Type 4, with no geomembrane, vulnerable to loss of joint sealant.

Table 4.1 Comparison for Pre and Post Seepage from Experimental Lining

Test No	Channel	Lining Type	Canal geometry Q(cms)	BW(m)	D(m)	Seepage rate (mm/day) Pre	Post	Reduction %
1	1R/3R	2a	2.6	4.5	1.2	39.62	29.57	25.38
2	1R/3R	2c	2.6	4.5	1.2	39.62	13.11	66.92
3	1R/3R	2b	2.6	4.6	1.2	39.62	12.50	68.46
4	1R/3R	9	2.6	3.3	1.3	39.62	3.05	92.31
5	1R/3R	5n	2.6	2.9	1.3	39.62	0.30	99.23
6	1R/3R	5cd	2.6	2.4	1.2	67.06	0.61	99.09
7	1R/3R	1b	2.6	2.8	1.2	67.06	26.82	60.00
8	1R/3R	5b	1.7	2.4	1.1	67.06	18.29	72.73
9	1R/3R	5c	1.7	2.4	1.1	54.86	1.37	97.50
10	1R/3R	6	1.1	2.1	0.8	60.05	1.62	97.31
11	1R/3R	2b	0.9	2.5	0.8	36.58	25.30	30.83
12	1R/3R	2c	0.9	2.5	0.8	36.58	3.35	90.83
13	1R/3R	2a	0.9	2.5	0.8	41.45	36.58	88.24
14	1R/3R	1c	0.9	1.8	0.8	35.97	18.59	48.31
15	1R/3R	3b	0.3	0.9	0.6	39.62	5.79	85.38
16	1R/3R	3a	0.3	0.9	0.6	39.62	7.62	80.77
17	1R/3R	7	0.3	0.9	0.6	39.62	8.84	77.69
18	1R/(Bah)	4	0.1	0.9	0.3	69.19	10.97	84.14
19	3R/Hakra	Op1	8.7	11.9	1.3	30.48	15.54	49.00
20	-	Op3	8.7	11.9	1.3	24.38	2.44	90.00
21	-	Op2	7.8	10.7	1.3	36.58	7.92	78.33
22	Najibwah	5a	1.2	4.3	0.8	36.58	1.22	96.67
23	Shadab	8	0.1	0.9	0.3	60.96	0.91	98.50
24	2L/3R)	4lg	0.3	1.5	0.4	60.96	16.46	73.00
25	2L/3R	4l	0.3	1.5	0.4	60.96	17.37	71.50



Graph 4.1 Graphical presentation of pre and post lining seepage



Graph 4.2 Graphical presentation of pre and post lining seepage

5. CONCLUSIONS AND RECOMMENDATIONS

Table 5.1 brings together the conclusions of the technical and cost comparisons between different lining types. No single lining type can be recommended for all conditions. Comparison with the conventional in-situ concrete lining method (Type 5b) indicates that the use of geomembranes is probably justified: when the need for sealed joints in the conventional lining is taken into account, and their poor long term durability, the simple in-situ type with geomembrane (Type 5c, similar to the production lining) is only slightly more costly and considerably better for water tightness and durability. For small canals this in-situ type with geomembrane is therefore favoured. For any lining project of sufficient size to justify modern precasting equipment, the use of plain precast slabs in place of in-situ concrete, as a protection to a geomembrane, is worth considering (Type 9), especially where it can be installed quick enough to make diversion channels unnecessary. The vertical sided hybrid design (Type 2) is too expensive to be attractive, except in special circumstance of restricted width.

For canals deep enough to enable a geomembrane to be buried under sand the bed, without danger of damage by animals, it is worth considering the use of sand cover in the bed and a hard cover on the banks only. The best kind of hard cover is probably a concrete filled mattress (Type N), preferably using locally manufactured fabric to reduce costs if the project's scale is big enough.

Under special circumstance unmortared brick may be feasible instead (Type M), which would reduce cost but can be difficult and slow to install.

On overall basis, taking into account of all criteria in the table, the three most favourable lining types are;

- Geomembrane under insitu concrete (Type 5c)
- Geomembrane under precast concrete, trapezoidal (Type 9)
- Geomembrane under sand on the bed and mattress on bank (Type N)

6. FUTURE WORK

There are some further methods for discussion for canal lining, which for reasons of timing and resource constraints have not been covered in this paper. One development of potential advantage is the use of Geosynthetics Clay Liners (GCLs). A GCL typically comprises of two geotextile layers with a layer of bentonite clay between them. The resulting lining material is laid in a canal with bentonite in unhydrated state, and when it hydrates on contract with canal water it forms a layer of very low permeability. The significant advantage relative to geomembrane is that the water proof layer is to a considerable extent self sealing after accidental or other damage. Cost and technical feasibility would depend on the supply of suitable bentonite could be found reasonably near a particular canal lining project. Techniques for rapid installation would need to be developed for a situation like this project, with only one month closure per year. Another possibility worth considering is the use of synthetics geocells or geogrids to stabilize either soil or concrete used as a protector cover over a geomembrane in a canal lining system. It is recommended that the designer of any future canal lining project should consider these modern products in addition to the more conventional ones covered in this report. The paper presented has not covered the underwater placing of linings in existing canals, although the people involved are aware of such experiments elsewhere and have from time to time discussed the potential application of techniques. The technical problems are considerable, and no easy methods have been developed yet.

This paper has presented some facts and ideas that should be of value in the planning and design of any future project for lining existing irrigation canals with minimal disruption to their operation. Any such projects must be planned with due regard to its specific and local conditions as well as its size (some processes are only worthwhile for large quantities, while others are applicable to large or small projects).

Table 5.1 Summery of Technical and Comparison of Lining Types

Basic Lining Types	Ease of construction	Water Tightness	Durability	Cost (US $)
Geomembrane on bed only, under soil cover (Type B)	Fair	Poor: is unlikely to reduce seepage by more than about 60 %	Probably good for deeper canals only.	Cheap, both per unit length and per unit area. (US$ 5 per m^2 of the bed area)
Geomembrane under soil cover on bed and banks (Type A)	Poor	Would probably be good if soil cover on banks remain intact	Doubtful.	Cheaper than Type N unless Type N uses cheap local fabric; around US$ 11/ m^2
Geomembrane under concrete filled mattress (Type I)	Fair	Good.	Probably fair to good. For deeper canals only	Very expensive, almost US$ 30/ m^2, unless using local fabric.
Geomembrane under sand on bed and mattress on banks (Type N, not tested)	Fair	Probably good	Probably fair to good for deeper canals only.	Fairly expensive, about US$ 18/ m^2, unless using local fabric.
Trapezoidal insitu concrete without geomembrane (Type 5b)	Fair. Extensive earth work preparation	Fair, depends on joint sealant.	Poor, sealed joint vulnerable and needs good maintenance.	20 % cheaper than Type 5c for 2.85 cms (100cfs); closer for small canals.
Geomembrane under insitu concrete (Type 5c)	Fair. Extensive earthwork preparation	Potentially Good.	Good.	Fairly expensive, US$ 16 to 18 / m^2 for small canals.
Geomembrane under precast concrete trapezoidal (Type 9)	Fair. Extensive earthwork preparation. Requires large scale to make good precasting economics	Good	Fair to good;	Slightly dearer than Type 5c, but just cheaper if diversion channel can be avoided.
Geomembrane under mortared brickwork (Type 6)	Fair. Placing of bricks very slow.	Good.	Probably good.	Similar cost to type 5c.
Vertical precast walls, insitu bed (Type 2b)	In principle easy; Has advantage where access is restricted.	Expected to be good	Probably good.	Much more expensive than trapezoidal types, about US$ 27 to 40/ m^2
Geomembrane under precast parabolic channel (Type 4g)	Precasting and handling difficult, Installation fairly easy, even with limited access.	Good, with geomembrane.	Fair to poor.	(Not analysed)

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