Experience with geosynthetics in canal irrigation projects supported by the world bank

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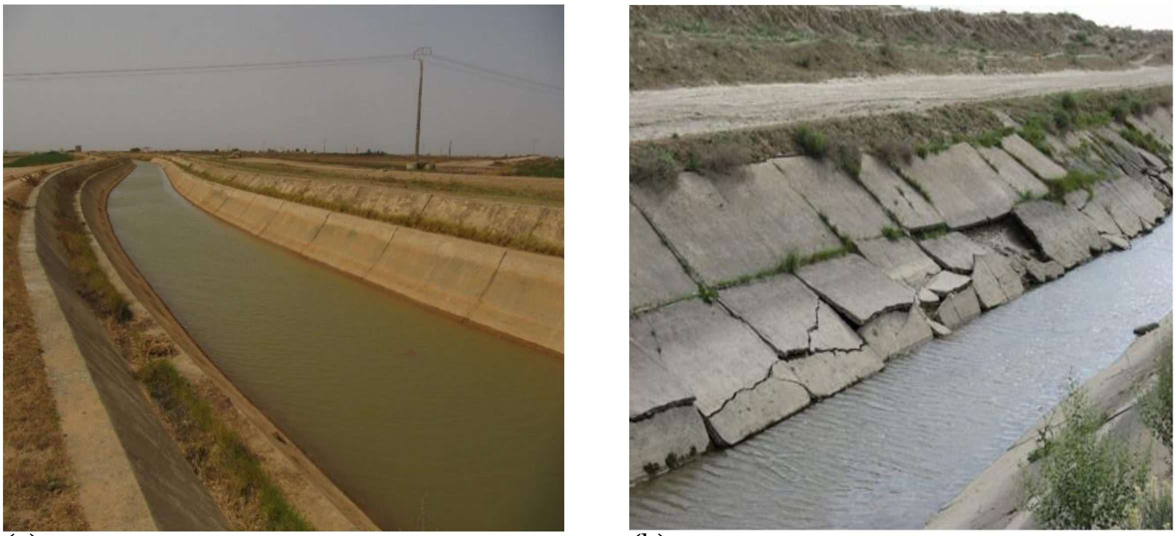
ABSTRACT: The first significant applications of geosynthetics in civil engineering date back about 60 years ago. However the acceptance of geosynthetics as sealants for canals in irrigation projects has been slow in comparison to other civil engineering applications. There is a strong adherence of irrigation agencies to old design standards for canal lining using rigid materials, mainly concrete, despite the evidence of rapid deterioration of these materials and the failure of functionality. The paper discusses the reasons for the slow adoption of geomembranes in canal irrigation projects. The paper then presents the application of geosynthetics in canal irrigation projects financed by the World Bank. In most cases the adoption of geomembranes was dictated by the local conditions such as the presence of gypsum soils in Syria, the water logging and poor sanitation conditions of the villages along the canals in Pakistan, the freezing and thawing destructive impact on concrete lining in the Tarim Basin, China and in Central Asia countries. Use of protected polymeric geomembranes remains the main application of geosynthetics for lining of irrigation canals. However other technical options such as application of bituminous or EPDM geomembranes or Geosynthetics Clay Liner ((GCL) are now under consideration.

Keywords: Geosynthetics, geomembranes, irrigation, canals, gypsum, frost, World Bank

1 INTRODUCTION

1.1 *General*

A considerable volume of water is lost for the irrigators through seepage to groundwater in irrigation canals. Lining of canals with impervious materials is used to reduce seepage losses. The most typical solution has been to line canals with rigid materials such as masonry, brick, cast-in-situ concrete or concrete panels. Some rigid canal linings built with high quality standards of construction still perform well decades later. However experience has demonstrated that rigid lining may lose its waterproofing functionality under certain conditions within a short period and in the most serious cases loses its structural integrity. Despite the poor performance of rigid lining, irrigation agencies and their consulting firms have adhered to the design standards for canal lining and are adverse to the adoption of modern advanced canal lining using flexible materials available with the progress in the geosynthetics industry. This paper discusses the experience in lining canals with protected geomembranes under irrigation projects financed by the World Bank over the last 50 years and the recent trend to use exposed geomembranes.



(a) (b)

Figure 1. (a) Morocco: concrete lining 50 years old; (b) Central Asia: Frost effect

1.2 *Worldwide use of geosynthetics in hydraulic works*

Geotextiles and geomembranes dominate the worldwide sales of geosynthetics with 1400 and 300 million m2 per year respectively out of a total sales of 2230 million m2 per year (Wikipedia)

Few applications to large irrigation canals during the last 15 years are reported with the exception of Tekapo hydro-power project in New Zealand and Toshka Irrigation Main Canal in Upper Egypt.

The author has experimented himself with a pilot project using thin plastic film in 1965 and two years later with bituminous geomembranes in Morocco

1.3 *Irrigation canal systems*

Out of the 325 million hectares presently equipped for irrigation worldwide, it is estimated that about 150 million hectares are supplied with surface water, and the remaining through use of groundwater or small traditional irrigation systems developed by local communities or recently by private entrepreneurs.

A surface-water irrigation system consists in a hierarchical network of canals to convey water from a large reservoir or a river to a large number of farms within an irrigation district. Main and branch canals deliver water to primary canals which in turn feed secondary and tertiary canals. By contrast with navigation or hydro-electric canals which have a constant section over their lengths, irrigation canals are telescopic meaning that their transit capacity decreases from upstream to downstream as long as water is delivered to canals of next order. Standard side slopes of canals is 1.5/1. However side slopes of 2/1 or even 2.5/1 are adopted where crossing non-cohesive soils.

Typically large irrigation main canals have a capacity ranging from 10 to 100 m3/s serving irrigation projects of up to 100 000 ha. Bed widths range from 4 to 9 m with depths of water up to 4 meters. Ratios of depths of water to bottom widths is about one to two. Primary and secondary canals have a capacity of up to 10-15 m3/s with bottom widths of up to 3 meters. Tertiary canals are the smallest in the hierarchy of distribution canals deliver water at individual farm gate.

There are exceptional large canals such as the Central Arizona canal in the U.S.A, the Narmada canal in India with a capacity of 1133 m3/s at headworks which is the largest lined canal in the world and the 1375 km long Karakum canal in Turkmenistan with a capacity of 630 m3/s, the most important hydraulic engineering worldwide.

2 TO LINE OT NOT TO LINE IRRIGATION CANALS

There are many reasons for the lining of irrigation canals: I) Reduction of water lost by seepage, ii) Increase of canal discharge and higher velocity, iii) Limitation of weed growth, iv) Reduction of maintenance costs, v) Reduction of damages to land adjacent to canals through soil saturation and salinization, vi) More equitable water distribution between upstream and downstream farms along a canal. Of the above, reduction of water losses is the most frequent justification given by irrigation agencies and consulting firms. A considerable volume of water is lost in the vast network of irrigation canals. It is estimated that about 30-35 percent of the water released at the head of an irrigation system is lost through operational and seepage losses through conveyance and distribution systems. Of the volume of water delivered to the farms about 40 percent is lost through percolation to groundwater.

Lining or not lining irrigation canals has ignited a debate between irrigation and water resources experts. Opponents and advocates of canal lining have very strong opinions on the subject. Opponents of canal lining argue that overall water saving could be marginal since seepage losses contribute to the recharge of aquifers and losses from a project can be recovered further downstream. Advocates of canal lining respond that water quality may decline in the recycling process, lands adjacent to canals may be affected by water saturation, and an important volume of water can be lost through non-beneficial use from waste lands. Farmers have to support the cost of pumping groundwater. This debate is beyond the scope of this paper. The decision to line or not to line canals serving an irrigation system or part of it is not a trivial consideration at design stage, as it will have an impact of the cost of the project and ultimately on its economic feasibility. Canal lining may increase the cost of a new irrigation project by 40 percent compared to the cost of an unlined system and even more in the case of a rehabilitation/ modernization project.

3 HARD LINING VERSUS FLEXIBLE LINING

Once the decision to line has been taken, the key point is the choice of the method of canal lining. The standard method has been to line canals with rigid materials such as concrete, cast-in-situ or precast, masonry or brick. Traditionally rigid lining has been the preference of designers and irrigation agencies. However the experience has demonstrated that the efficiency of rigid lining could decrease over a few years, especially under certain conditions of soil and severe climatic conditions.

Cement concrete used for canal lining was generally unreinforced until recently. Standard designs developed by the U.S. Bureau of Reclamation provide for a thickness of 4 inches (10 cm) for large canals assuming a high level of quality of construction and strict adherence to rules of operation limiting variations of water level to avoid back-pressure on concrete panels. European design standards are more conservative. Thickness of unreinforced concrete lining can reach 12 or even 15 cm.

Construction joints in cast-in-situ concrete lining are provided at about 4 to 6 meters interval. In addition dilatation joints filled with polystyrene covered with sealant, about 2 cm thick, are provided to avoid buckling of the lining in case of high air temperatures.

The reasons for the slow adoption of modern innovative canal lining techniques are both administrative and behavioral:

- Resistance to change by irrigation departments; risk aversion and adherence to outdated designs;
- Lack of motivation by planners;
- Lack of contractual motivation for consultants to introduce new technology;
- Lack of sufficient information about proven new technologies by the consultants;
- Lack of training at all levels from the university to the field;
- And in some cases, failures of pilot projects resulting in a long delay before attempting to adopt innovative techniques.

There is considerable evidence of the failures of concrete rigid canal lining. Hard surface linings could deteriorate within a few years until seepage returns to that from an unlined canal. The cause of ineffectiveness of concrete canal lining over time is related to the quality of construction and to the physics of seepage flow lines. Saturation of the soils caused by inevitable seepages through joints causes some settlement of the canal base of side slopes resulting in a separation of the sub-base and concrete. The concrete slabs eventually would rest on few points resulting in development of cracks in the slab.

Many irrigation projects worldwide located around the latitudes of about 45-55 degrees in the Northern hemisphere are affected by the effect of freezing and thawing resulting in dislocation of concrete panels and ultimately in their slide into the bottom of canal and by the disintegration of concrete. The effect of cold climate is further aggravated by the silty nature of the soils. Regions most affected are the Inner Mongolia and Xinjiang Provinces in China, the central Asia countries, the Caucasian region (for example Armenia). Rigid linings are also badly affected in areas with swelling soils, such as in large parts of Peninsular India and in areas with the presence of gypsum such as in the Middle East region and Northern Spain.

Numerical models have demonstrated that linings with small imperfections result in a small reduction of seepage losses compared to an unlined canal. A modeling study has indicated that the losses from a canal with 0.01 percent of cracks would have seepage losses of about 70 percent of losses from an unlined canal

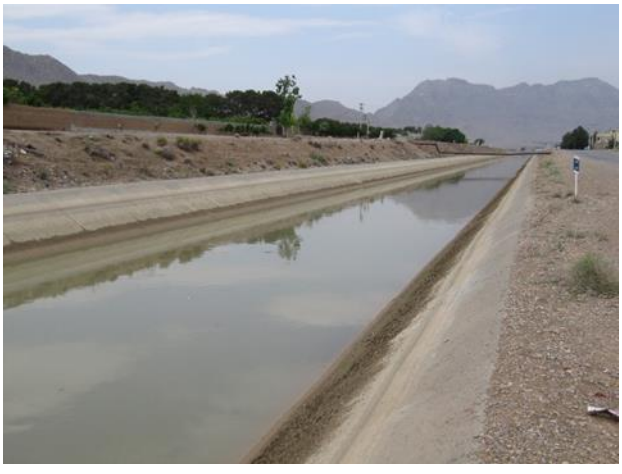
4 APPLICATION OF GEOMEMBRANES IN COMPLETED IRRIGATION PROJECTS FINANCED BY THE WORLD BANK

4.1 *Syria: balikh irrigation project*

The Balikh irrigation project in Northern Syria approved in 1974 was the first World Bank Project where geomembranes were used for lining irrigation canals. An earlier pilot project in the Balikh River Basin supported by United Nations Development Plan (UNDP) covering about 19 600 ha revealed the importance of damages to canals if some special measures were not taken to manage seepage losses from the canals. Marl and gypsum are the predominant rock types in the Balikh river basin. Aeolian activity during the quaternary period has resulted in widespread deposition of powder gypsum all over a large part of the project area. Consequently very severe damages occurred to the concrete- lined canals where crossing soils with powder gypsum dissolved by leaking water and resulting in severe cracks in concrete slabs. In other places where rock gypsum was found the bottom of the canals collapsed into wide open cavities.

The World Bank project consisted in continuation of a reach of the 148 km long Main canal and the distribution system for serving an area of 41 300 ha. Original design provided the installation of a 0.5 mm thin PVC plastic film protected with precast concrete panels. However during implementation of the project, the design was revised using the experience of an irrigation project located around Esfahan in Iran where gypsum soil conditions were also found, however with less content. The design of canal lining in the Balikh area was upgraded with the assistance of Prof. Giroud who had provided technical assistance in Iran. He recommended adopting a double canal lining consisting in a 0.75 mm butyl rubber and a concrete protection with a geotextile placed between these two materials to drain the eventual seepage losses through the concrete. However the details of construction could not be found in available reports from the World Bank. PVC was not considered a reliable sustainable material given the local conditions in the late 1970s. In addition, during execution of the works, the gypsum soils were replaced down to a depth of 2 meters by soils without gypsum content. As a result of these provisions, the cost of the project was quadrupled and only 20 000 ha were completed by 1987.

The author of this paper did not have the opportunity to visit the project located around the city of Raqqa. However he visited the main canal serving the Esfahan area in April 2016, about 45 years after the installation of the geomembranes. No damages was reported by the management office of the canal with only a case of buckling of the concrete panels due to exposure to very high temperatures during a closure of the canal.



4.2 *Pakistan: fordwah sadiqia project*

The Fordwah-Sadiqia project is located in the Punjab Province near the Indian border. Seepage from canals and inefficient use of water and deficient drainage systems led to intolerable rise of groundwater level in the project area. The project approved by the World Bank in 1992 involved the lining of almost 173 kilometers of existing canals of which 34 km were devoted to about 20 experimental types. The production canals with 1: 1.5 side slopes were lined with geotextile and geomembrane protected with cast-in-situ concrete. The material used for the production canals was a 0.75 mm Very low Density Polyethylene (VLDPE), and the material used for the smaller canals was a relatively thin 0.5 mm flexible polypropylenes (PP) manufactured by the air -blown technique. Dual-track welding was used for the two materials.

A research program was associated with this project:

- Testing of the physical characteristics of the geomembranes used in the project and samples provided by other manufacturers;
- Testing of the seepage losses through the inflow/outflow and ponding methods;
- Experimentation with several design and materials for canal lining.

Most measurements were done in canals carrying less than 2.8 m3/s.

Seepage losses before and after lining:

The project included a systematic measurement of canal seepage before and after lining. Twenty-five ponding tests were carried out on unlined canal reaches. For each test a length of canal, about 300 meters long, was closed off with two earth bunds waterproofed with geomembranes. The results indicate losses ranging from 25 to 116 mm/day with a mean value of 53mm/day, far below the standard rate of 210 mm/day (8 cfs/million sf2). Thirteen ponding tests were also conducted on reaches of canals which have been lined under the project.

Seepage losses are negligible after lining with a geomembrane protected with a hard protection either cast-in-situ concrete, concrete mattress or brick. Seepage rates are somewhat higher for canals lined with geomembranes protected with precast concrete panels, which was expected: The damages to the geomembranes by puncturing are not carefully plugged as when using cast-in -situ concrete. The test with a soil cover failed because of the large tear of the geomembranes and local slide of the cover. Holes at the end of installation of geomembranes is typically 1 to 5 holes per 10 000 m2 with high quality geomembrane with strict construction quality assurance (Giroud 2016). However the number of holes could reach 20 holes per 10 000 m2 depending on the amount of care during installation of the geomembranes and placement of the protection.

4.3 *China: tarim I and II projects*

The Tarim river basin in the Province of Xinjiang, China, suffers from very low and prolonged temperatures in winter which require the adoption of innovative technologies to avoid damages to canal lining caused by frost heave.

The World Bank financed two irrigation projects in the Tarim river basin in the Western Province of Xinjiang in China. The Tarim I project in the late 1980s involved lining 860 kilometers of canals consisting in overlapping thin plastic films (0.2 mm) protected with concrete or local materials such as cobble or gravel. This method was substantially improved for the Tarim II project implemented 10 years later through the use of 0.5 mm of geomembrane panels which were fabricated in factory and then assembled on site through double welding. Under Tarim II project about 5.8 million m2 of geomembranes were installed which is still the largest application in irrigation.

The supplier of the geomembranes for Tarim II project imported an air blown factory from Italy. In an attempt to meet all the technical specifications, the supplier mixed granulates of three varieties of polyethylene (HDPE, LDPE and LLDPE) hoping to make an ideal geomembrane meeting all contract specifications. The final product passed all the mechanical tests included in the technical specifications with the exception of the hydrostatic test which is the most severe one reflecting the relative rigidness of this mix product.

Several designs were adopted for the lining of 37 trunk and main canals totaling about 740 kilometers with or without geomembranes: Cast-in-situ concrete, pre-cast panels, cobble with mortar, dry cobble, earth and grass turf. About 435 kilometers were lined with geomembranes totaling 5.5 million m2. In addition 305 000 m2 of 0.75 mm thick geomembrane of same quality were used for lining the upstream face of a medium size earth Xining dam.

Seepage tests carried out under the Tarim I and II projects provide reliable data on the efficiency of canal lining with the use of geomembranes. Daily seepage rates of about 140 mm were measured from a canal lined with plastic film and of 300 mm from a canal lined with concrete slabs without plastic under Tarim I project. Seepage tests from a canal lined with welded geomembrane under the Tarim II Project were reduced to a remarkable value of 4 to 6 liters/ m2/day. It was roughly estimated that the seepage losses from the 57 canals lined under Tarim I project were reduced from 1375 to 400 million m3 /year and the volume of water saved in the Tarim II project may be in the order of about 600 to 800 million m3. These results clearly indicate the low performance of concrete lining alone in adverse climatic conditions and the higher performance of welded geomembranes. The remaining loss of 4 to 6 mm per day reflects the quality of workmanship of the geomembranes and its protection during installation. The author has no information on the performance of canal lining under these two project during the last 15 years, and especially the stability of the thin prefabricated panels placed over the geomembranes.

5 USE OF GEOMEMBRANES IN ON-GOING WORLD BANK PROJECTS

Use of geomembranes has been adopted or is under consideration for the lining of canals of World Bank supported projects which are under implementation indicating an increasing interest for this technology. The reasons for this gain of interest are likely the evidence of the weaknesses of concrete lined canals in areas suffering from freezing temperatures and to some extend the promotion of the technical options with use of geomembranes through events organized by the International Geosynthetics Society (IGS) at regional level, and modestly by the author during preparation of projects with the invaluable cooperation of J.P. Giroud on numerous occasions. The diversity of proven geomembranes available commercially has encouraged the author to explore further materials that the polymeric ones conventionally adopted in earlier projects. Because of the cost of lining using protected geomembranes, irrigation departments are now expressing interest for exposed geomembranes. The challenge is then the selection of geomembranes which can resist to ultra-violet and oxidation and importantly cannot be removed from the canals by the local population for personal usage such as water proofing of house roofs.

Use of exposed bituminous geomembranes for the lining of the existing secondary canals under a rehabilitation project in Kazakhstan has been accepted. Bidding for a first package is under way.

Use of Geosynthetics Clay Liners (GCL) has been considered for linings of large canals of two projects under preparation. These canals are found oversized because of conversion from rice to cotton cultivation which is less demanding in water. Therefore the placement of a ballast over the GCLs does not require an over-excavation to maintain the original transit capacity of these canals.

The design for the lining of a large main canal in Uzbekistan under an on-going project provides the installation of about 1.9 million m2 of protected geomembrane. A unique material-neutral performance type specifications was adopted for the supply of the geomembrane: The technical specifications do not impose the type of polymeric materials to avoid limiting the geomembrane to a specific material. Only a minimum thickness of 1.5 mm was imposed to limit the occurrence of damages during placement of the concrete over the geomembrane. It was specified that all materials proposed by the civil works contractors should meet the international standards for these materials. Given the differences in physical characteristics between geomembranes with regards to the conformity with the sub-grade at installation and ease of welding, limits on the Melting Flow Index and Oxidation Induction time of relatively rigid materials were introduced in the technical specifications.

6 OVERALL LESSONS FROM PROJECTS USING GEOMEMBRANES

Thin geomembranes of less than 1 mm were installed under the projects executed before 2005. It was difficult to convince the irrigation agencies to accept geomembranes of over 1 mm. Most civil engineers involved in irrigation projects were still believers that concrete is the main barrier to control seepage losses. Thicker geomembranes are now more easily accepted on the basis of longevity of the geomembrane and its inaccessibility for repair under the protection material.

However given the cost of a typical lining system combining geomembrane and concrete, there is some interest for geosynthetics which could be placed without protection. The solution of geomembrane protected with concrete for lining a 400 meters long section of a main canal in in the Office Du Niger, Mali was rejected in favor of replacement of sandy soils by compacted clay with low permeability because of the high price of concrete in that region (30 and 20 US $/m2 for the concrete and geomembrane respectively). Bituminous geomembranes have been extensively applied in hydraulic works for the mining industry. However application of this technique in irrigation canals is still limited at few examples for example the Yakima irrigation District in Washington State, USA and for repair works of the 60-year old concrete lining in the Canal-de-Provence, France. Lining of canals with bituminous geomembranes in Kazakhstan will start in 2018.

In Australia lining with exposed geomembrane was experimented in the 2000s using first HDPE which was later replaced by EPDM geomembranes which are not slippery for animals and people who fall in water. The Trangier Nevertire Irrigation District in Australia where a 110 km reach of the main canal was lined using 2.19 million m2 of EPDM geomembranes.

Out of the five projects with application of geomembranes, only one, the Pakistan case, has been associated with an intensive research component. Several important lessons came out from the research program in Pakistan:

- The need to conduct seepage tests before deciding on the sections of canals should be lined, if lining is not imposed by other considerations such as difficult soils, such as gypsum or loess or any collapsible soils;
- The better performance of lining system using geomembranes protected with cast-in-situ concrete over precast panels.

In the case of the Balikh project in Syria, a well performing waterproofing system was imposed by the gypsum nature of the soils. A well performing waterproofing system was also needed over a large part of the canals in the Tarim Basin running over highly permeable cobble materials found in the alluvial fans of the torrential rivers flowing down from the Himalayas and Karakorum mountains. Damages to rigid canal lining caused during winter is another justification for adoption of geomembranes in the design of canal lining in Western China and in Central Asia region.

7 RECOMMENDATIONS

Canal lining is a very costly component of development of irrigation and therefore should be applied selectively based on engineering soil surveys and estimates of seepage rates. Design of lining should take into consideration physical local conditions and explores alternative technical options such as unprotected geomembranes. Minimizing investment cost should not be the primary consideration. Longevity of geomembranes in civil engineering works, ease of installation are more important considerations.

To reduce investment costs in canal lining, options with exposed geomembranes should be considered.

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