

CANAL LINING THROUGH GEOMEMBRANES : A CASE STUDY OF SARDAR SAROVAR PROJECT

Vivek P. Kapadia

*Superintending Engineer, Sardar Sarovar Narmada Nigam Limited,
Gandhinagar, Gujarat, INDIA*

B. L. Deopura

*Department of Textile Technology
Indian Institute of Technology, Delhi*

B. R. Chahar

*Department of Civil Engineering
Indian Institute of Technology, Delhi*

ABSTRACT

Canals are a major source of water for irrigation, particularly in the Indian subcontinent due to limited number of days with rainfall. However, canals can lose its water to a large extent, say between 10 to 40% due to seepage. This huge resource of water could be made available, if proper water conservation measures are adopted. Concrete linings cannot suitably be applied in all canal situations as their success is dependent on the soil type, temperature and operative period. Large areas of the Indian subcontinent have expansive soils which can cause the concrete lining to crack due to repeated swelling/contracting. On the other hand, unlined canals lose large quantum of water due to seepage, particularly in sandy soil.

Geomembranes are water impermeable sheets used worldwide for water seepage control in canals and other water bodies. There are a large number of geomembrane types i.e. HDPE, LLDPE, PVC, RPP etc. HDPE geomembranes of 1.5 mm thickness have been adopted in many canals as they provide reasonably good puncture resistance. However, because of their high thickness, these sheets have high bending rigidity and require elaborate arrangements for transportation and installation. These issues can make project execution prohibitively expensive. Aside of economic issues, HDPE also suffers from certain inherent limitations such as stress cracking. Other alternative materials like LLDPE have limited UV resistance. Another option which has been tested is to reduce thickness of the HDPE sheets. However, this approach severely compromises the puncture resistance.

Recently, IITD has developed certain novel textured geomembranes¹ with thickness of 0.6 mm. The puncture resistance of these novel geomembranes measures comparable to 1.5 mm HDPE sheets. Due to lower thicknesses and a built-in textured design, these sheets are very flexible. This property allows the sheets to be easily rolled and installed as well as allows them to conform to the terrain. Since these sheets come in large sizes, the requirement for field welding is also reduced. Many trials have been successfully conducted using these geomembranes to control water seepage in ponds.

Comparative field trials of IITD geomembrane and 0.3 mm HDPE sheets having similar weight per unit area are reported in this paper. The selected canal was a part of Sardar Sarovar Narmada Nigam canal system - "Tanchha Distributary", near the village Anor of Amod Taluka, Bharuch District of Gujarat. The canal section of ~3.2 km length was found to have been suffering very high seepage loss and surrounding farms were waterlogged. This water loss was associated with and ascribed to the expansive soil types (CH), referred to as black cotton soil. To compare the working with and effectiveness of different geomembranes, three materials - 0.3 mm HDPE, 0.3 mm LDPE and IITD geomembrane were chosen. Observations during execution and during post implementation period of six months are that there are installation limitations of 0.3 mm HDPE while the

¹Supported by Ministry of Water Resources, Govt. of India.

IITD geomembranes were easy to install due to their high flexibility; 0.3 mm HDPE sheets have inherently poor puncture resistance and as such do not provide confidence for large scale installation; and, LDPE sheets of 0.3 mm have similar limitation.

OVERVIEW OF THE PROBLEM

In Gujarat there are vast areas that have soil quality, which is not suitable for construction of canals. Bharuch district is one such example. There is no availability of good quality soil in near vicinity. The soil here is predominantly of the type “Clay of high plasticity (CH)”. This CH type of soil has a very high swelling pressure. It is typical that during water flow through a canal constructed from CH type soil, the water ingresses through the lining into the embankment and leads to swelling of the soil. During the subsequent dry period, when canal water flow activity is not present, the soil shrinks. These repeated cycles of swelling and shrinkage, which are differential, cause severe water piping through the canals into the neighboring terrain. This process may eventually lead to catastrophic bank failure. In several cases, heavy piping from the embankment leads to inundation of the surrounding areas and therefore leads to curtailing of cultivation activities.

During January 2010, the engineers of the SSNNL surveyed “Tanchha Distributary”. This distributary passes by close to the village of “Anor” of Amod Taluka. It was observed that it was leaking very heavily and the agricultural fields in the surrounding areas were found to get inundated with water. This situation has been occurring for the last three years. The overall condition of the canal was very bad; the bed of the canal was highly uneven; the brick lining was significantly disturbed. This is schematically shown in Figure-1.

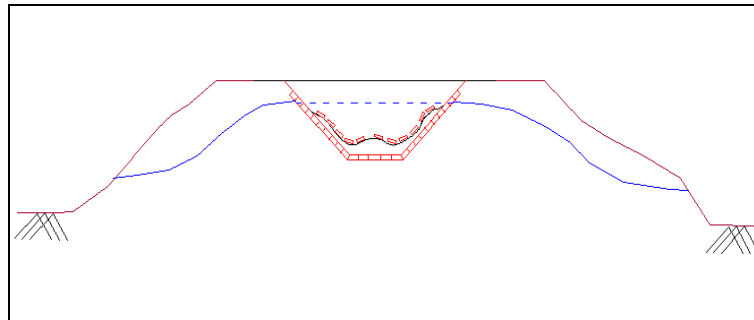


Figure-1 Disturbed Profile of Canal Due to Swelling of Embankment Soil

The deteriorated condition of the canal can be viewed in Photos-1 and 2. The bed of the canal was also unusually swollen. There were several other issues. The banks were disbursed and scattered. The canal section at one location was found to be much wider in comparison to what it was originally. The embankments had also been dislocated. At several locations, cracks and breaches were patched up by cement mortar or through plastering to restrict water seepage. The local farmers were forced to construct bunds on either sides of the canal to patch up the failure of the embankment. However, this solution was not satisfactory because of the propensity of the canal embankment to break repeatedly and suddenly.



Photos - 1 and 2 Bad Condition of Tanchha Distributary

Piping from canal banks and leakage from canal siphons both contributed to the seepage. Photos-3 and 4 show the seepage from the canal siphon and a through hole in the embankment. These occurrences used to result in water inundation of the surrounding areas.

The farmers always had a sense of insecurity because of this propensity for sudden embankment destruction which had the potential to destroy crops being grown. In these areas, for the purpose of irrigation, the only alternative of canal water has been tube well water. However, the ground water quality being poor and inappropriate for agricultural uses, canal water irrigation was and is critical to sustain cultivation within the area.



Photos – 3 and 4 Leakage and Identification of Piping through Banks

In the Tanchha Distributary, three patches (Ch 5.65 to 7.17 km, 7.17 to 7.92 km and 7.92 to 8.67 km) were identified where severe water seepage was observed. Since these three patches were adjacent to each other, they formed a continuous length of 3.02 km. This entire length of canal was required to be attended to urgently. Average perimeter of the canal section was 5.7 meters (m); bottom width was 1.1 m; inner slope of the canal was 1.5:1; outer slope was 2:1; full supply depth of the canal was 1 m; and the bed gradient was 1 in 6000 as per original design. The designed discharge, in the middle of the length of the canal was $1.51 \text{ m}^3/\text{sec}$ and was $0.76 \text{ m}^3/\text{sec}$ at the tail. The total command area of the distributary was a huge 2384 hectare.

GAMUT OF SOLUTIONS

Preliminary engineering work was carried out to examine possible solutions. Several alternatives were considered and benefits and shortcomings of the respective methodologies were examined prior to deciding on the option of utilizing geomembranes. Some of the options considered are discussed in brief. This will allow the reader some measure of understanding of the comprehensive nature of the analysis carried out. While, in the long-run, it is possible that multiple alternatives may be used synergistically and in conjunction at the same site or at adjacent sites within the canal, the discussion below is primarily geared towards understanding and evaluating the merits of each of the possible alternatives, when utilized independently.

Solutions Without Geomembrane

One option considered was that existing canal banks could be scrapped and CNS soil be brought in to provide a good internal layer. A brick lining would be redone over it. Locating CNS soil and transporting would be costly and utilizing this option would almost be equivalent to redoing the entire canal section, making it prohibitively expensive. Additional considerations are that utilization of this methodology would eventually be prone to weed growth and deterioration of bricks. In all likelihood, regular maintenance would be required to account for the weakening of joineries due to constant submergence.

A second option considered was strengthening of the canal bank with additional berm and then re-doing the lining. The soil of the embankment is clay which is a major contributor for the cause of piping. By providing additional berms one could increase the length of the seepage path. Since the existing brick lining is highly disturbed, it is required to be redone with either brick or concrete. One of the issues with this approach is that even if there was some seepage that took place, which is very likely, swelling of the soil would occur, which consequently would lead to shear cracks in the lining. Therefore, with passage of time, some stray panels of the concrete lining would need to be replaced. One of the major issues is the perception of the individuals and authorities involved. Given that the banks are currently in a state of deterioration, it is anticipated that once a major construction is carried out, which requires a substantial expense upfront, there be status quo for a long time and the canal bed is visually elegant with no appearance of cracks. Appearance of cracks, even minimally, could be very damaging, not only due to actual water seepage which may occur but also due to the perception of inefficacy it creates, which would lead to everything being viewed with a skeptical eye.

A third option was to provide a concrete lining with an embedded welded wire mesh as a possible alternative. This alternative seems to be a promising one as the concrete lining is quite dense. In addition, through this alternative, a high shear and flexural strength would be imparted to the system, which would allow for resistance to scattered spot stresses due to swelling. The cost associated with this option was somewhat high, but it seemed to be a very promising solution.

Solutions with Geomembrane

The function of geomembrane would be to form an impervious curtain behind the brick lining, which will not allow the water to come into contact with the soil of the embankment. Brick lining, on its own, allows the water to seep through because of the porous nature of bricks and the consequent soaking property of bricks. Deterioration of bricks and weakening of joineries are issues which will clearly be encountered with passage of time, if bricks are left unprotected. In such an unprotected environment, water will seep through the brick lining and would come into contact with the soil of embankment. Since it is the inherent nature of the soil to swell, it absorbs the moisture and takes uneven shape.

With the introduction of a geomembrane which does not let the water penetrate through, the profile of the canal would remain undisturbed. Figure-2 illustrates the function of geomembrane in canal lining. The contact of seepage water with the embankment would be avoided and therefore soil swelling will not take place. This methodology would work with the existing soils and thus execution could be carried out quickly. There could be different types of geomembranes such as HDPE, Polypropylene, Polyolefin, LDPE, etc.; with specific advantages/ disadvantages. However, the fact that no additional berm would be required for slope stability is the biggest advantage of this solution.

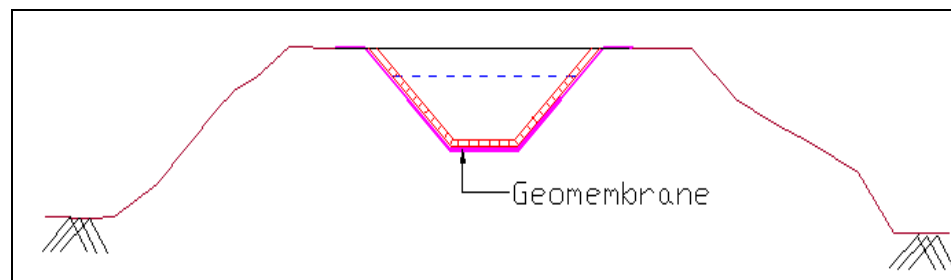


Figure-2 Application of Geomembrane

CONVERGENCE TO FINAL SHAPE OF SOLUTION

After a systematic and comprehensive consideration of all possible alternatives, the option of utilizing geomembranes was finally selected. For three different patches of the canal i.e. Ch 5.65 to 7.17 km, Ch. 7.17 to 7.92 km and Ch. 7.92 to 8.67 km it was decided to use three different geomembranes - HDPE, LDPE, Polyolefin (IIT Delhi innovation). The purpose of going for three materials in three patches of the same canal was to have a comparative study and apply the right material in different situations in other canals. These three geomembranes needed to be benchmarked for the following issues in order to arrive at a suitable techno-commercial comparison :

- (1) Critical material properties
- (2) Ease of application
- (3) Cost of materials

A market survey was carried out prior to materials procurement. In the process of searching for an effective geomembrane based solution, many manufacturers of different materials were explored. In this process, the IIT, Delhi novel geomembrane also came into prominence. It was found that HDPE and LDPE geomembrane sheets with a thickness more than 0.3 mm were very difficult to handle due to weight and bending difficulty. Therefore, 0.3 mm HDPE and LDPE geomembranes were selected. The IITD Polyolefin was felt easy to handle - both weight-wise as well as in its ability to bend and conform to all surfaces.

(1) Critical Material Properties

In evaluating these geomembranes, a comparison of the critical material properties which govern their water seepage prevention characteristics is of primary importance. Clearly, it is critical to compare performance in

order to ensure that the sought after objective of attaining a leak free canal is eventually met, both for the short term as well as the long term. This comparative exercise sheds light on various aspects of the performance of the respective materials.

**Table-1 Parametric Comparison of Various Geomembranes
(Testing by I.I.T., Delhi)**

Polymer Type			Polyolefin	HDPE	LDPE
Property	Test Method	Units	Performance (SI)		
Thickness	ASTM D5199	mm	0.6	0.5	0.25
Weight		gm/m ²	260	470	230
Puncture Strength	ASTM D4833	kN	0.5	0.2	0.06
UV Resistance	EN277 For 200 hours	----	Pass	Pass	Pass
Breaking Strength	ASTM D638 Type IV	kN/m	36	10	2
Breaking Elongation	ASTM D638 Type IV	%	20	500	100
Tear Resistance	ASTM D5884	kN	0.20	0.22	0.08
Water Permeability	ASTM D1499	cm/sec	10 ⁻⁶	10 ⁻⁶	Variable

**Table-2 Parametric Comparisons of HDPE and LDPE
(Testing by CIPET, Ahmedabad)**

Polymer Type		HDPE (As per IS : 10889-2004)	LDPE (As per IS : 2508-1984)
Property	Units	Performance	
Thickness	mm	0.3	0.3
Weight	gm/m ²	283	279
UV Resistance	----	Pass	Pass
Tensile Strength at Break (A) Machine Direction (B) Transverse Direction	Kg/cm ²	(A) 332 (B) 272	(A) 212 (B) 189
Elongation at Break (A) Machine Direction (B) Transverse Direction	%	(A) 505 (B) 543	(A) 564 (B) 696
Tear Resistance (A) Machine Direction (B) Transverse Direction	N/ mm	Not Provided	(A) 138 (B) 161

An appropriate method to carry out comparison of different geomembranes is to select one critical use parameter and keep the value of that parameter as a constant. Then, other parameters can be compared against each other. In this case, it made sense to keep the weight per unit area as the parameter of choice and maintain it

as a constant. Weight per unit area was selected because this property governed the total amount of material used for the project. It also automatically brought to light the inherent intrinsic properties of the material, which included the most important property of puncture resistance in case of geomembranes. Also, it allowed for a direct comparison for other related properties such as breaking strength and tear resistance. Furthermore, from an implementation standpoint, the weight per unit area was a good determinant of the overall costs associated with transportation.

The three materials selected viz. IITD polyolefin, HDPE and LDPE had a nearly similar weight per unit area of 260, 283 and 279 gm/m² respectively. The respective thicknesses for these three chosen materials were 0.6, 0.3 and 0.3 mm. Table-1 provides performance comparison of materials properties for the above described Polyolefin, HDPE and LDPE geomembranes based on the testing performed at I.I.T. Delhi. It is also important to note that the comparative data is for a 0.5 mm HDPE which has puncture resistance of 0.2 and tensile strength of 10 kN/m. The puncture resistance for a 0.3 mm HDPE (which was the one which was used) may be approximately 0.12 while the tensile strength may be 7 kN/m. Additional testing was also carried out at CIPET, Ahmedabad for which the results are shown in Table-2. The measured values of Puncture Strength and Breaking Strength both indicate that Polyolefin is a much superior material to HDPE as well as the LDPE.

Over the last 20 years, HDPE has been preferred over LDPE as a geomembrane material. To understand this issue, a test comparison for the as used 0.3 mm thickness HDPE and LDPE materials was also carried out at a CIPET laboratory, Ahmedabad. The results presented in Table-2 indicate that HDPE outperforms LDPE on all relevant comparative parameters.

(2) Ease of Application

The ease of application is a critical parameter in geomembrane selection. From an application standpoint, aspects such as handling ease, life of the project, workability amongst other such issues need to be allowed serious and proper consideration because engineering aspects of such practical projects may outweigh the importance of other measurable parameters.

If an attempt were made to obtain HDPE or LDPE materials having comparable puncture strength and breaking strength with respect to the polyolefin material, the required thicknesses for those would increase several fold. Higher thickness materials for LDPE and HDPE are not practical, because of several reasons. First, higher thickness materials for LDPE are not typically manufactured. Second, the cost of such a material would be prohibitively higher. Finally, such thick materials (both HDPE and LDPE) would be extremely rigid, making it unworkable because of extreme difficulty in bending of such sheets. Bending is a summary requirement and very important to allow the geomembrane to conform to canal edges. In fact, it is clear from the data, that LDPE can summarily be discarded as a geomembrane material for the projects having long life span and large quantity of work.

(3) Costs

The total costs of canal re-lining with HDPE and LDPE geomembrane were almost identical. The cost of canal re-lining with Polyolefin is higher for a small quantity of work, yet it is also competitive considering its other benefits.

Since this project is a test evaluation for only a short canal section, the costs incurred per unit length are not representative of the costs that would be incurred in large scale commissioning. Transportation costs and other overheads would vary drastically and would approach the realistic cost for actual commissioning of the large projects. As discussed previously, handling of HDPE of thickness greater than 0.3 mm is extremely difficult and not practical. Therefore, the 0.3 mm thickness was chosen. LDPE of the same thickness of 0.3 mm was chosen because of similar costing as the HDPE and in order to compare the difference between the HDPE and LDPE. However, in large quantum work the difference between HDPE and polyolefin is bound to come down.

Cost balance, though important consideration in deployment of similar large scale projects, is outweighed by the vast difference in the materials properties (Polyolefin is an engineered material with 0.6 mm apparent thickness, HDPE and LDPE have a 0.3 mm thickness) and their long term suitability for canal lining projects. A leveling exercise is, therefore, impossible.

In order to validate a detailed comparative analysis of different geomembrane materials, the pilot project was decided to be commissioned to have a direct firsthand experience of all the activities required to be carried out in a large project. The longer term results and data of how effectively each geomembrane allows for water

seepage prevention can only be studied through a practical test. Therefore, importance of both - analysis as well as validation through a pilot project is of immense benefit.

EXPERIENCES OF EXECUTION, OBSERVATIONS AND FINDINGS

Execution of the pilot project in the year 2011 provided rich and diverse experience as narrated below.

(A) Material Vulnerability

One of the advantages of the IITD polyolefin geomembrane was that handling was significantly easier since the materials inherent properties do not make it vulnerable to tearing and breakage. In comparison, handling of LDPE and HDPE was difficult. LDPE, in fact, was quite prone to tearing.

(B) Brick Laying

Furthermore, since the IIT polyolefin is designed to have a rough surface on one side, laying of bricks atop this was accomplished easily. HDPE and LDPE, on the other hand, have very smooth surfaces on both sides. Therefore, brick laying atop them was difficult.

(C) Geomembrane bending ease

Bending ease i.e. ease in folding of geomembrane is an important criterion as was experienced during practical application. Figures-3(A) and 3(B) illustrate this phenomenon geometrically. There are two possibilities – formation of proper corners or formation of curved surfaces near the corner edges. The polyolefin bends easily and was found to be extremely good.

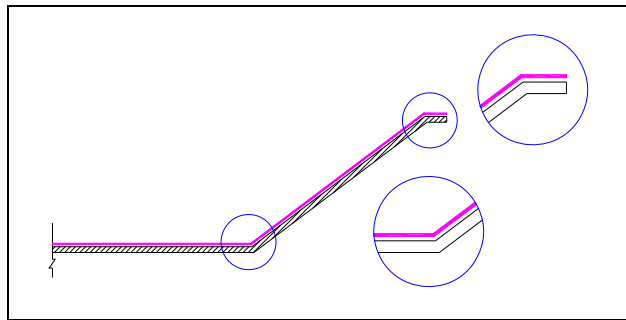


Figure-3(A) Handling Aspect - Bending Ease of Geomembrane (Preferred)

With HDPE, the experience was totally opposite. It was extremely difficult to apply the HDPE on top of the canal, as it made a chamfered surface at all the edges and corners in the bed as well as within the key of the canal. LDPE was largely unsuitable for this purpose too, since there was a great propensity for the LDPE material to tear. The placement of brick lining over the geomembrane at the edges as well as the corners becomes a major difficulty, if the geomembrane is rigid against folding, which happened in the case of HDPE and LDPE. For small canals, this limitation of HDPE in bending is further amplified, since the respective edges and corners would be extremely close to each other.

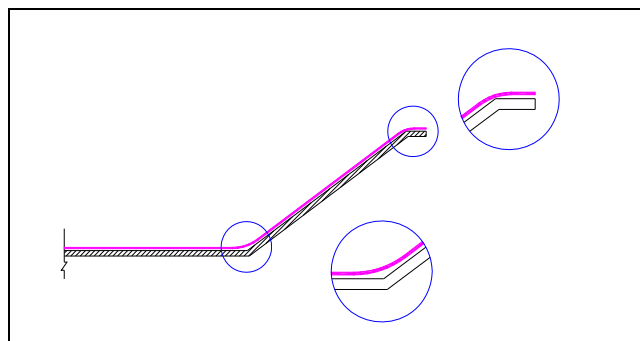


Figure-3(B) Handling Aspect - Bending Ease of Geomembrane (Not Preferred)

(D) Heat Resistance

During the day time, under the heat of the sun, behavior of Polyolefin and HDPE remains unchanged. The LDPE was found to become softer with an increase in heat.

(E) Heat Sealing

Rolls of 80 to 85 meter length were available for all three materials. Heat sealing was required to be carried out on site. Machine parameters were optimized for this process. For all three materials, heat sealing on site was a rather simple and straightforward process.



Photos – 5 and 6 Preparation of Canal Section and Heat Sealing of Geomembrane

(F) Difficulty in Brick Lining

Conventional brick lining requires a 12 mm thick cement mortar layer on the earthen slopes and bed of the canal up on which the bricks are laid with frog downward and then pointing is done. This provides a smooth surface for the water flow. Whereas here in this case, once the geomembrane was laid in the canal section, 12 mm thick cement mortar layer could not be placed up on it due to lack of bond. The solution to this issue was found in specifying the geometrical lay-out of the bricks. They were placed frog up i.e. right position; and were placed closely without joints to be filled in with cement mortar as pointing. Then 18 to 20 mm thick single mala cement plaster was applied on top of the brick layer. The function of the cement plaster was to keep proper positioning of the bricks as well as to provide a smooth surface. The inside surface of the canal is smoother than the conventional brick lining and the Roughness Co-efficient is close to 0.018.

(G) Physical Testing and Inspections of Canal

After completion of each of the three sections with the respective geomembrane materials, testing was carried out. This testing was carried out by filling water within the upstream and downstream bunds and was done for a period of over 60 days. In the forthcoming irrigation season i.e. beginning from 1-10-2011, water flow through the canal was initiated as is normally done through the canal. No seepage or leakage was observed for over a month on either side of the canal. Since the embankment section was not too wide, a comparative measurement of hydrostatic pressure in the pre-application and post-application scenario was not felt useful; only visual observation was resorted to in order to make assessment of the effectiveness of the solutions implemented.



Photos – 7 and 8 Completed Canal Section

The appropriate time-period to make a reliable assessment on comparison of actual performance of the three materials, used in the respective canal sections is three years. However, in this short term performance, the results are encouraging.

CONCLUSION

Application of geomembrane is a promising and viable solution to check the problem of swelling of soil and consequent problems leading to failures. For restoration of deteriorated condition of the canals, the above implementations have demonstrated that they afford potential to provide an effective solution. Furthermore, in construction of new canals, usage of geomembranes would be more economical than CNS treatment in most cases. Areas where availability of good soils is a problem, geomembrane for canal lining use can be a boon. In the present time, when large infrastructure projects have consumed most of the soil mass, canal engineers have hardly any choice for designing and constructing new canals; rather, in many cases soil specifications might lead to entanglement in work schedules and execution owing to issues like lead, extra, excess, etc. and hence the engineers would have to learn to work with locally available soil complemented with necessary corrections, such as geomembranes to be applied to get the proper performance of the canals.

Commissioning of a pilot project on a small stretch of canal has revealed that LDPE is not an attractive alternative, either from a cost standpoint or from a physical properties standpoint. Moreover, the government is discouraging the use of LDPE because of many issues. The IITD polyolefin material has a puncture resistance and breaking strength which is over 5 times as compared to the HDPE material and is not vulnerable to tearing and allows for easy brick laying up on it because it has a rough surface on one side. HDPE and LDPE are smooth on both the sides. Furthermore, since the IITD material is flexible, it allows for easy bending which is a critical attribute to allow the geomembrane to conform to the edges and corners within a canal. These properties of the IITD geomembrane make it a favorable material for use in canal applications.

The application of geomembrane would also be helpful in safeguarding canal banks from burrowing animals. These animals, as they burrow, prefer dampness in the embankment which zeroes out, if a geomembrane is applied.

The actual requirements of different projects could be different and therefore depending on the situation, an appropriate proposition for the geomembrane should be decided on. A thorough understanding of all the practical aspects of the problem at hand combined with intuitive abilities, a skillful consideration of all relevant attributes and judgmental strength of the designer or the solution provider are required and of greater use in such projects.

BRIEF PROFILE OF THE AUTHORS

Vivek P. Kapadia has been working at present as Superintending Engineer in Water Resources Dept. of the Government of Gujarat and is also the Director of Water Management Forum of The Institution of Engineers (India). He has obtained Master of Engineering, Master of Laws, Post Graduate Diploma in Personnel management (eq. to M.B.A.) and Post Diploma in Computer Applications. He joined the Government of Gujarat in the cadre of Executive Engineer in 1997. He has designed over 250 hydraulic structures and contributed to policy making in the water sector. He has over 50 papers and publications at national and international levels.

Dr. B.L.Deopura is Professor at Department of Textile Technology and at Centre for Polymer Science & Engineering at Indian Institute of Technology Delhi. Prof. Deopura did his doctorate from IIT Kanpur. He joined IIT Delhi as a faculty in 1974. He spent about a year at University of Massachusetts, Amherst in 1979 and also at US Air Force Materials Laboratory, Dayton Ohio in 1985. He has to his credit a large number of publications, conference presentations and chapters in books. His contributions on developments of water lining material are of major significance, with a major impact on water conservation.

B. R. Chahar, Asso Professor, Dept of Civil Engg, IIT Delhi. Earned PhD degree on “Optimal Design of Channel Sections considering Seepage and Evaporation Losses” from IIT Roorkee and MTech degree in Water Resources Engg from IIT Kharagpur. His current areas of research include Seepage, Subsurface drainage, Urban drainage, Groundwater modeling, Channel design and Numerical methods. He is recipient of several scholarships and awards including AICTE Career Award for Young Teachers. He is author of more than 70 articles in reputed journals and proceedings. He is Fellow/Life Member of seven Professional Bodies including Vice President, North India Chapter, EWRI of ASCE.