APPLCATION OF GEOSYNTHETICS IN RESTORATION OF CANALS : CASE STUDIES OF SARDAR SAROVAR PROJECT

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ABSTRACT

Canals require regular maintenance and repairs during their operational life span. Repairs require the identification of problem and strategic devising of solution. When there is some construction flaw like selection of wrong materials or non-compliance with the technical specifications, the canal can not perform as per design and manifests serious problems during operation. In Sardar Sarovar Project, the command area is 1.8 million hectare and the canal network is very long, approximately 76000 Kilometer, and hence some issues related to defects in the construction had been encountered during the operation. Two case studies discussed here shed light on what kind of defects were found and how the solutions were worked out using geosynthetics in a very innovative way. Prima facie irreparable looking canals were restored in a very short period with cost effective, still permanent solutions which prove that geosythetics can effectively address the constriction defects in some cases and in some cases help restore already failed canals.

CASE STUDY – 1
RESTORATION OF BREACHED SECTION OF NARMADA MAIN CANAL

1. INTRODUCTION OF NARMADA MAIN CANAL

The Narmada Min Canal (NMC) is 476 Kilometer long out of which 458 Kilometer length is in Gujarat state and the rest in the Rajasthan state. 42 Branch Canals off-take at different locations from it in Gujarat. At the off-take of the Narmada Main Canal, its capacity is 3300 cumec. Figure 1 shows the command area of the Sardar Sarovar Project, the alignments of Narmada Main Canals and its branch canals.

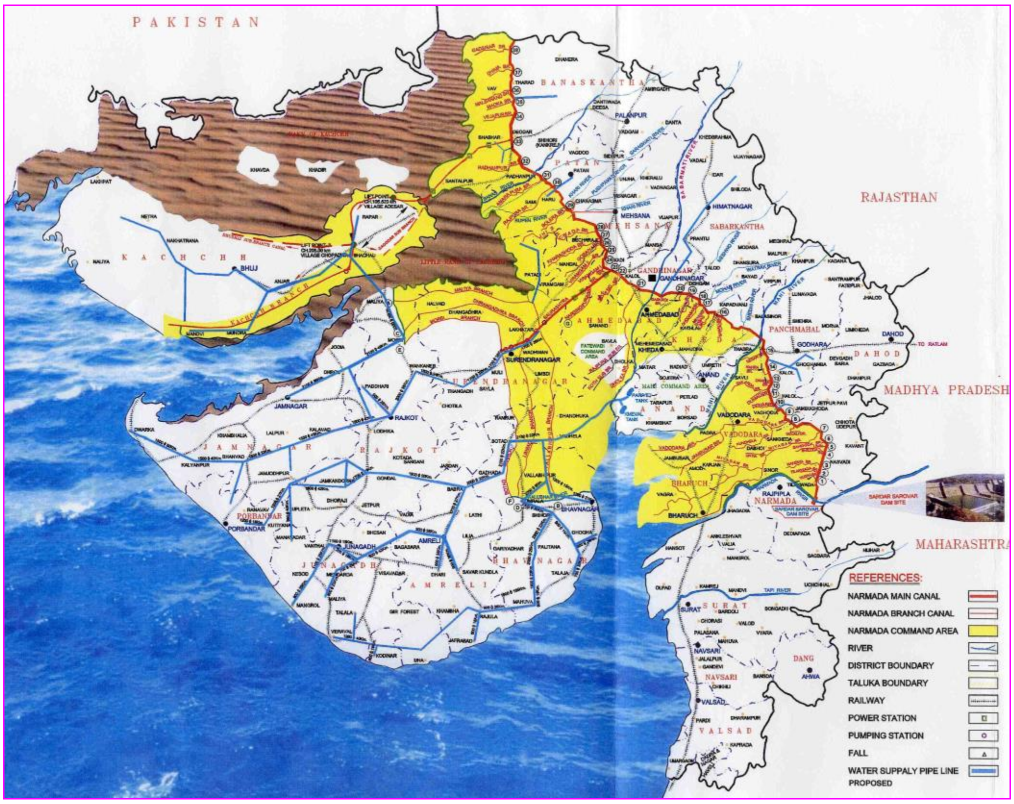

Figure 1. Alignments of the Narmada Main Canal and branch canals

2. OVERVIEW OF THE PROBLEM

The NMC crosses the river Sabarmati at Ch. 230 km through a siphon structure. In between are many river crossings and aqueducts or canal siphons have been provided as per requirements. The full supply level (FSL) downstream of the structure is about 64.75 m R.L. and the canal flows with a design gradient of 1 in 15000.

The canal reach from Ch. 269 km to Ch. 271.5 km is in full bank with bed banking of 1 to 1.5 m. The total bank height above the ground level is about 9 m. Beyond Ch. 278 km it is almost in full cutting of 8 to 9 m, the maximum cutting being about 18 m at Ch.280.5 km. The canal bed is 53.70 m wide here and the full supply depth (FSD) is 6.5 m. The designed discharge capacity is 583.57 m^3/ s (20,608 cfs). The canal side slopes are 2 (H) : 1 (V).

The embankment design had been done according to the standard procedure laid down in IS-7894 (or IS 8826: 1978). For the stability of the canal side slope for the sudden draw-down condition, only 50% of the original undrained head of water has been considered for pore-pressures. This is on consideration that the lining is effectively impervious and that the horizontal filter blankets and the strip drains as well as Pressure Release Valves (PRVs) are adequately functional. As this is not the case now in most of the situations, because the lining gets damaged due to various reasons and allows leakage, it would be advisable to check the slope stability considering full 100% pore pressures in the sudden draw-down condition. Of course, the breach in the present case cannot be attributed to this aspect as the canal had been flowing only partially and no sudden draw-down condition had been created. Zoned embankment designed to suit the codal provisions, design practices and material availability is shown in Figure 2.

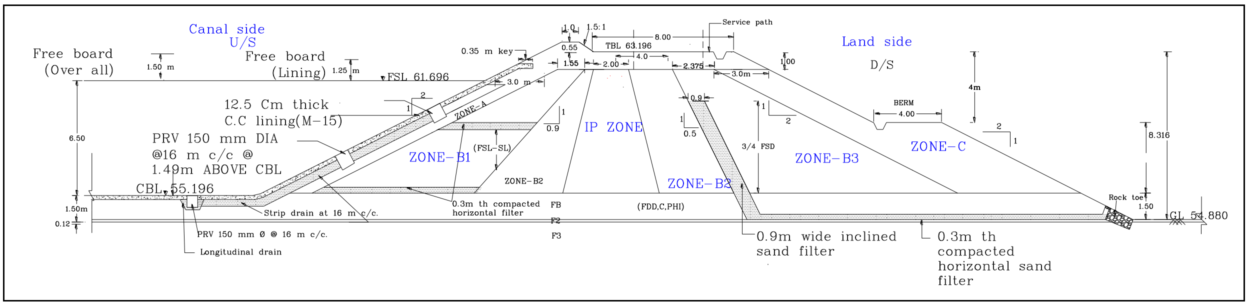

Figure 2. Designed section of canal embankment

However, on the 11th of June, 2008, a breach occurred in the canal near Kadi at Ch. 272.6 km inundating nearby villages and disrupting the water supply to the downstream area. Prior to that from 2005 i.e. soon after completion of the construction of the canal in this reach breaches had started taking place and many piping locations had been observed which are summarized in Table 1.

Table 1. List of noteworthy failures in the specific problematic reach

Date of Occurrence	Chainage in km	Side of the Bank
30-08-2005	272.500	Left
08-09-2005	271.300	Left
17-09-2005	269.700	Left (Huge Breach)
17-09-2005	270.900	Left (Huge Breach)
13-01-2006	271.180	Left
13-01-2006	271.450	Right
11-03-2006	270.300	Right

Failure of concrete lining of the canal at a particular height for a noticeable length was also observed as shown in Photograph 1. Snapshot of the very instance of occurrence of the breach in the embankment in September, 2005 is shown in Photograph 2. It clearly shows how piping enlarged to result in to a breach. Devastation in vicinity of the canal is shown in Photograph 3 and Photograph 4. The breach of 11th June, 2008 was about 65 meter in width and the embankment was found cut in a chiselled fashion as shown in Photograph 5 and Photograph 6.

Photograph 1 and Photograph 2. Defects in lining and breach in initial stage

Photograph 3 and Photograph 4. Devastation in vicinity of the canal

Photo – 5 and 6 Chiselled embankment

3. ANALYSIS OF AS BUILT SECTION AND DIAGNOSIS OF THE PROBLEM

Detailed investigation led to the conclusion that the soils in this reach are predominantly silty sands and clayey sands. There are some clayey strata also but generally less prevalent. The silty sands tend to be more uniform in grain size and have less cohesion with less resistance to erodability. According to the standard soil classification the soils can be classified as SM, SM-ML, ML, CL and CI. The clay horizons show clays of low to medium plasticity (CL and CI) and occasionally high plasticity (CH). These soils, if properly utilized in the construction of the embankment in appropriate zones with strict adherence to the specifications for the moisture content, laying and compaction would not pose any problem for the stability of a properly designed embankment incorporating necessary protective filters and toe protection. However, the actual state of canal bank as per investigation was constructed with some serious defects given below.

I. No zones with specific soil properties as per design were actually provided in the embankments.

II. Obligatory technical specifications for laying and compacting the soils in accordance with their types and properties as well as locations were totally neglected with the result that there were numerous locations and bands of loose or inadequately compacted soil zones.
III. No chimney filter or horizontal filter blankets were provided to protect the soil and prevent migration of particles outside.
IV. Due to very loose soil bands, particularly in the lower portion of the embankment, there was substantial subsidence of the earthwork causing loss of support for the plain cement concrete lining. The lining, as a result, cracked irregularly at several places creating even big hollows at some locations. The cracks and openings provided direct entry points for the canal water.
V. The canal water entering the embankment with relatively high pressure caused dislodgment of particles in the inadequately compacted soil due to high seepage forces resulting into piping and progressive failure ultimately.

Many defects narrated above in construction of canal embankment are clearly seen from Photograph 7.

Photograph 7. Stratified strata of soil with no zoning or filters

The behaviour of the embankment narrated above was tried to be understood by Finite Element Analysis of the as built section. Properties were obtained during investigation as time was sufficient (failures started taking place in 2005) and size of the problem was large enough to find it worth to make detailed study and come to proper conclusions. Slip circle modelling can not be taken as a reliable way in a problem in which stratification of soil is there and variations in density and material are many and therefore Finite Element modelling as steady unconfined seepage type problem[1] was done using four noded element in the self developed program. Steady unconfined seepage problem is shown in Figure 3. This type of problem is characterized by unique free surface which does involve variations with time. The analysis suggested that the embankment with as built section property was unstable with the designed head in the canal. However, this is possible when the lining failure is there which is due to crumbling of poorly compacted material due to its own weight at certain depth within embankment itself. And exactly this was observed during the investigation.

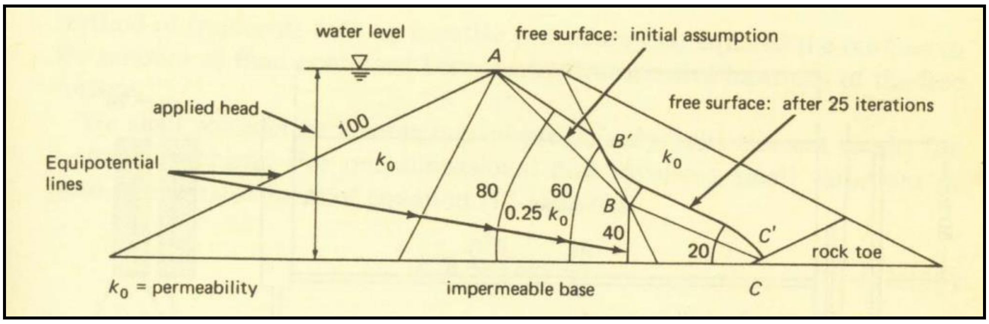

Figure 3. Steady unconfined seepage problem[1]

If there is zoned embankment, modelling as per Figure 3 is valid but in this case, there was no zoning but stratified layers were to be modelled and therefore conceptual mesh generation as shown in Figure 4 was followed. The actual mesh was much finer but conceptual basis with two different permeability values alternately varying vertically was adopted to go close to the reality.

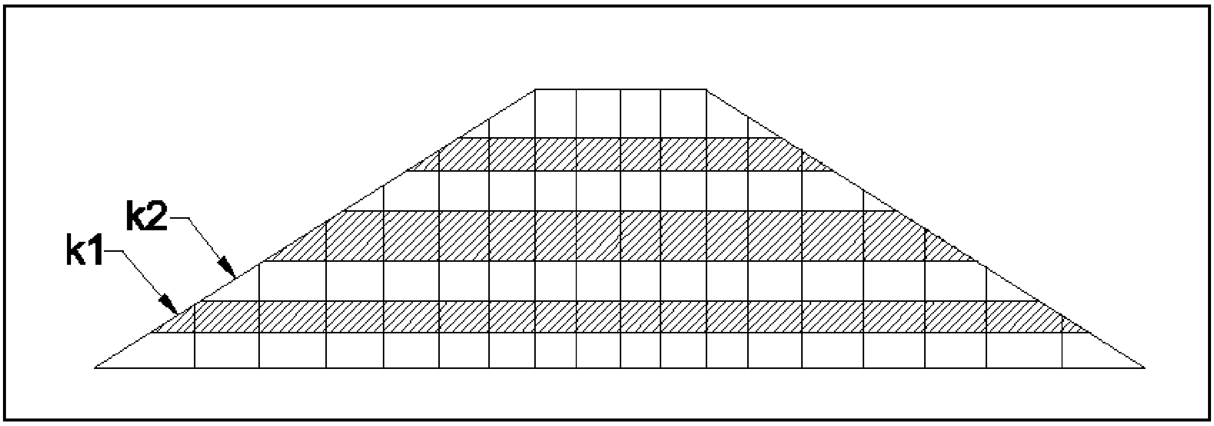

Figure 4 Conceptual modeling of stratified embankment

4. ISSUES WITH RESTORATION OF CANAL EMBANKMENT

The gravity of the problem can be understood from the above discussion. But restoration was not just a matter of borrowing good soil and reconstruction of the embankment as per designed section. Some issues are listed below.

- Time of only 10 days was there to restore the canal as drinking water for many towns and villages was depending up on the main canal and they had hardly 10 day standby arrangement.
- Because rainfall had already occurred once, borrow areas were not available and the soil available was predominantly sand with small amount of clay. For zoning and for filters suitable material was not available.
- In given time and small length proper compaction was a matter of doubt.
- Bonding with the surrounding parts of the canal was difficult.
- Other than technical issues like people's wrath, political intervention, movement of media, etc. were adding fuel to fire.

5. GEOREINFORCED EMBANKMENT AS A SOLUTION AND ITS IMPLEMENTATION

Considering above issues in the restoration work, obviously with permeable soil the embankment was to be reconstructed; zoning was impossible; compaction to limited level was to be put up with and yet long lasting a solution was to be worked out. In this situation, the performance of the embankment needed that pore pressure be released, little movement within embankment be permitted especially the service road and lining are concerned and bond with existing embankment is ensured. All these constraints led to the application of geosynthetic to construct the embankment as the right solution. Considering the constraints involved, geosynthetic material with properties as shown in Table 2 was chosen and the designed section of georeinforced embankment was as shown in Figure 5. The material was woven with reasonably good flow rate.

Table 2. Material Properties

Property	Unit	Value
Weight	g/m^2	270
Wide Width Tensile	kN/m^2	50
Wide Width Elongation	%	15
Trapezoidal Tear Strength	kN	0.50
CBR Puncture resistance	kN	6.0
Flow Rate	$l/ m^2/min$	260
UV Resistance	%/hrs	70 / 500

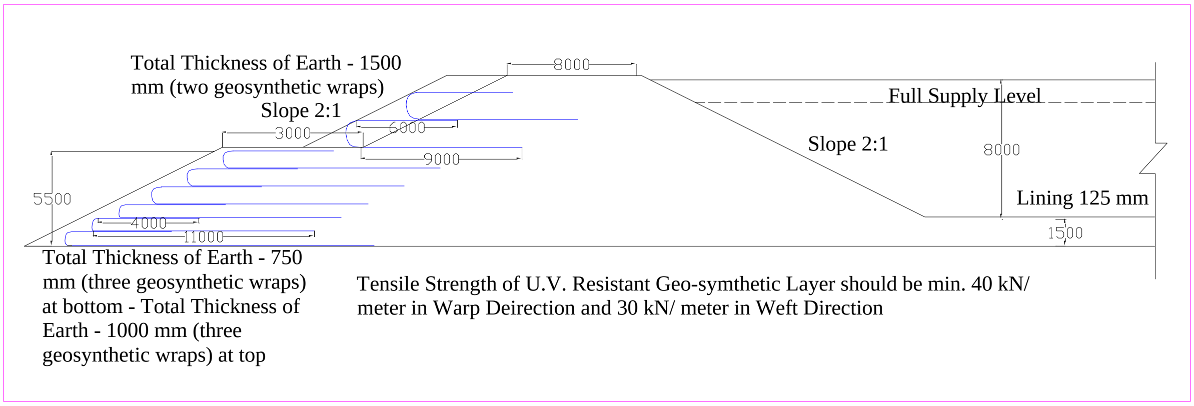

Figure 5. Section for Restoration of Main Canal Embankment

Finite Element Analysis was also done in addition to the conventional design procedure[2] to ensure the safety of the embankment. Implementation is shown in Photograph 8 and Photograph 9. Completed work is shown in Photograph 10 and Photograph 11. To accommodate adjustments within embankment due to probability of lack of proper compaction, Reinforced Concrete lining was done in 80 meter length of the canal so that flexibility is added to concrete.

Photograph 8 and 9. Spreading, stitching and placing geosynthetic sheet

Photograph 10 and 11. Restored Main Canal embankment

Implementation was done in only 10 days and canal flow was allowed. Regular observation was made for a considerable time thereafter and it was observed that the performance of the embankment was well.

CASE STUDY – 2
ADDRESSING FAILURE OF CANAL EMBANKMENTS IN SWELLING SOILS

6.0 OVERVIEW OF A PROBLEMATIC CANAL

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.

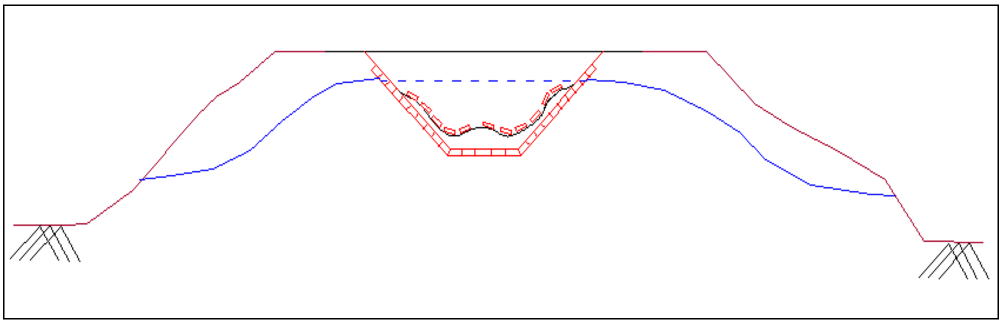

Figure 6. Disturbed profile of canal due to swelling of embankment soil

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 6.

The deteriorated condition of the canal was visible. The bed of the canal was also unusually swollen as shown in Photograph 12. There were several other issues. The banks were disbursed and scattered.

Photograph 12. Swelling of bed and sides of canal

Photograph 13. Leakage from canal

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.

Piping from canal banks i.e. sides of the canal and leakage from canal siphons both contributed to the seepage. These occurrences used to result in water inundation of the surrounding areas.

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.

Photograph 14. Pipings from sides of the canal

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 m^3/sec and was 0.76 m^3/sec at the tail. The total command area of the distributary was a huge 2384 hectare. The said canal was constructed some 10 years back but unfortunately every season it was tried to be operated, it used to give more and more troubles in the form of various kinds of failures.

7.0 DIAGNOSTIC ANALYSIS

How canal embankments in swelling soil fail is interesting to understand. Soil of canal embankments made up of swelling soils tends to swell when comes in to contact of water. Because concrete or brick lining becomes saturated or some fine cracks give way to water, soil of embankment can not remain dry for a long time after commissioning of the canal. When the soil comes in contact of water, it swells. During the initial stage of swelling, hogging tendency in lining dominates and concrete or brick lining undergoes cracks as it has only little flexural and shear strength and then more water seeps through and further wetting the soil of embankment takes place. Then swelling aggravates gradually. It causes further upheaval of lining.

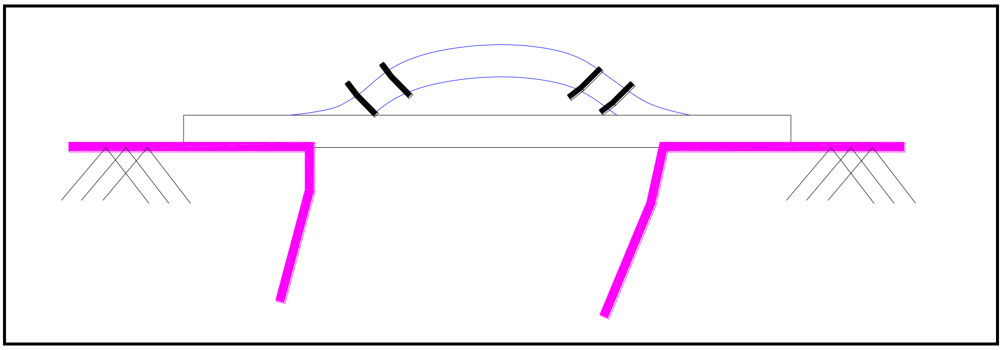

Figure 7. Hogging of lining due to swelling of soil

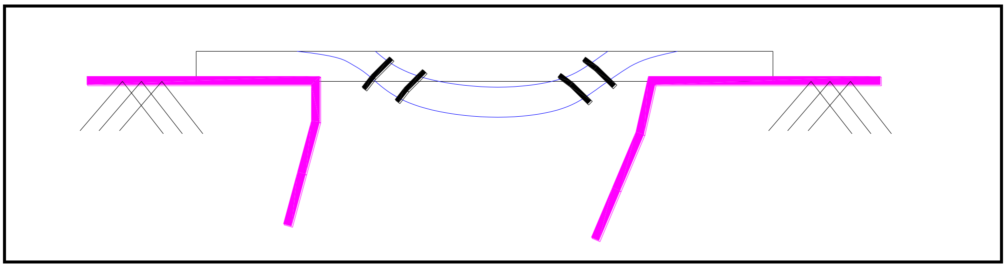

Figure 8. Sagging of lining under load of water mouth of piping

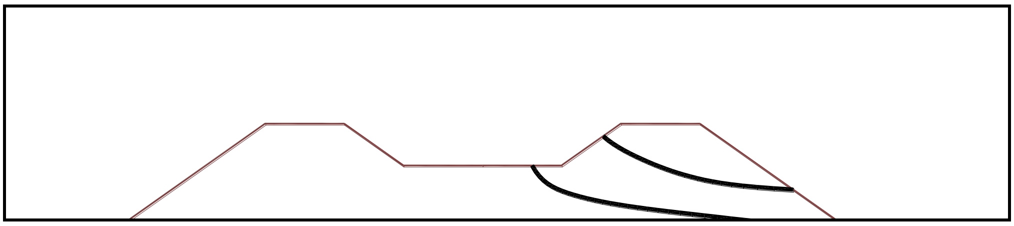

Figure 9. Paths of piping through embankment

When the canal is closed as per schedule, drying of the soil of the embankment results in to shrinking which causes wide cracks and gaps in the embankment. Subsequent operational phase of the canal, along with aggravating the swelling phenomenon, obviously signals piping as the passage to water through cracked lining and gaps in the embankment as well, is unobstructed and many such paths are created after some time in the embankment which not only saturate the embankment very soon but also raise the position of the phreatic line.

Moreover, at the entry point of piping which is really as hollow tubular way through the embankment as visibly shown in Figure 8, the lining behaves as if an unsupported slab under heavy load due to water and sagging occurs and the lining undergoes failure due to bending and shear. Brick lining is more vulnerable than concrete lining due to poor bending strength. This phenomenon finally forms a continuous pipe like mechanism within the embankment.

If the embankment does not have any internal drainage arrangement, raised phreatic line becomes a major reason for embankment failure. Heavy pore pressure in addition to several pipings make the embankment unstable and it becomes difficult to judge as to whether disintegration or dispersion of embankment under pore pressure first takes place or soil erosion through piping followed by crumble or subsidence happens prior to that or both the kinds of failures are mixed.

8.0 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.

8.1 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.

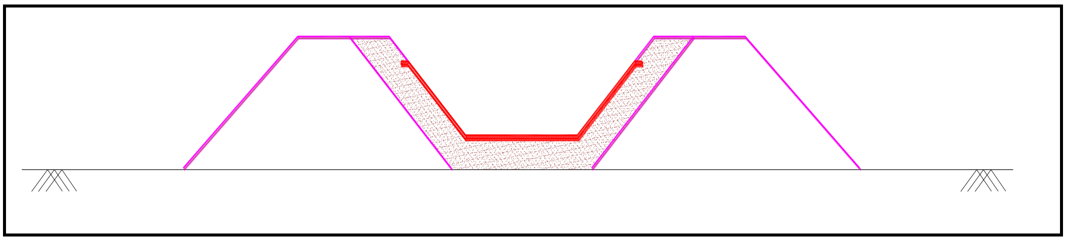

Figure 10. Scrapping the canal bank and redoing with CNS layer and lining redone

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.

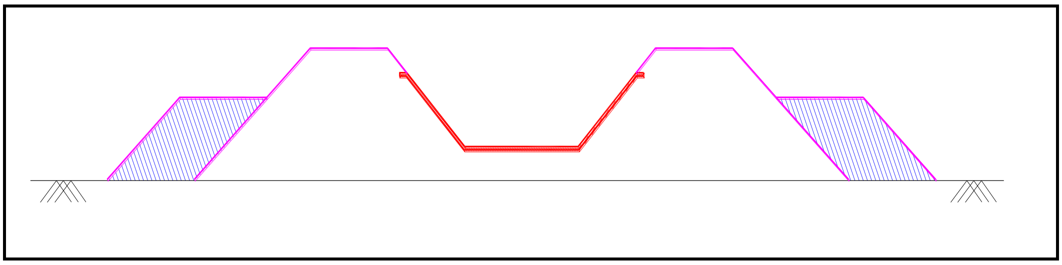

Figure 11. Strengthening of canal bank with additional berm and lining redone

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.

Third option was to provide a concrete lining with an embedded welded wire mesh as a possible alternative. This alternative ever seems to be a promising one as the concrete lining becomes 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 and shrinkage. The cost associated with this option was somewhat high, but it seemed to be a very promising solution.

8.2 Solution 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. Therefore, main function of geomembrane would be to protect the soil from water.

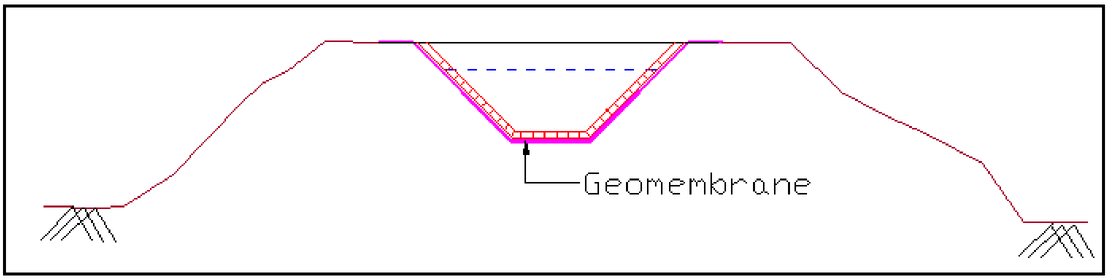

Figure 12. Application of geomembrane

With the introduction of a geomembrane which does not let the water penetrate through, the profile of the canal would remain undisturbed. Figure 12 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. However, the fact that no additional berm would be required for slope stability is the biggest advantage of this solution. In the new canal, the role of geomembrane would be to check the entry of water i.e. seepage and prevent swelling and shrinkage.

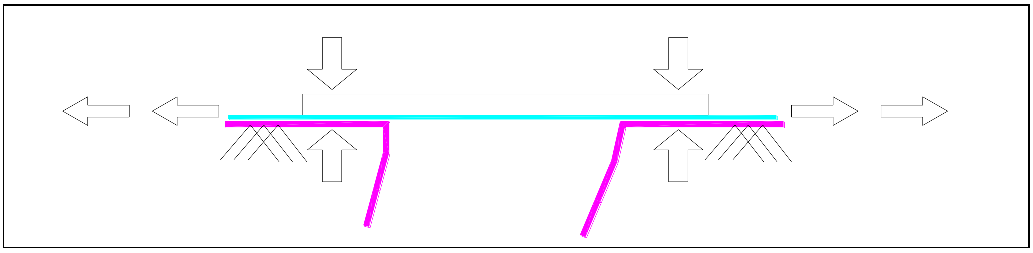

Figure 13. Bending of slab converted to tension in geomembrane

But in the existing canal in swelling soil wherein there are many piping paths in the embankment all of which are not visible during restoration, the role of geomembrane can not be limited to check the seepage. During swelling, hogging of lining takes place at the mouth of the piping and during shrinkage, sagging. The geomembrane is gripped all around the mouth of the piping under the load of the lining and water also and hence the uniformly distributed load occurred by swelling or shrinkage (due to residual water content) of soil beneath is taken by it in the form of tension which relieves the slab from bending. Thus, tension mechanism replaces bending mechanism due to geomembrane. Therefore, geomembrane should possess sufficient tensile strength. Moreover, cropping of weed from the soil would tend to puncture the geomembrane and hence it should possess sufficient puncture resistance. The most critical aspect is that, failure of geomembrane in any case either by tension or by puncture or by failure of joinery would give way to all the problems related to swelling and shrinkage and the entire solution worked out would be almost of no use. Therefore, right choice of geomembrane and workmanship as per site situation becomes very important.

9.0 CONVERGENCE TO FINAL SHAPE OF SOLUTION OF THE CANAL

After a systematic and comprehensive consideration of all possible alternatives, the option of utilizing geomembranes was finally selected. All the options discussed above had been actually explored on different canals and hence sufficient experience and data of working of each were there. The canal under consideration i.e. Tanchha Distributary was however, somewhat different in a sense that so many pipings had already taken place and all of them were not visible even after removal of lining. Moreover, the canal embankment had been badly disturbed and was not proper to allow direct lining in to the canal section. These were the reasons why solution with geomembrane was felt more promising as compared to others.

There was a specific stretch of canal which needed some treatment. This problematic length was divided in to three different patches specifically 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 geombranes specifically polyolefins - HDPE, LDPE, modified polyolefin (IIT Delhi innovation) referenced as IITD Polyolefin here onwards. 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 material procurement. In the process of searching for an effective geomembrane based solution, many manufacturers of different materials were explored. 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 for the width required. 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. HDPE and LDPE were available with flat surface whereas IITD Polyolefin was having a textured surface. HDPE and LDPE with textured surface could be availed in sandwiched form but were found exorbitant during market survey.

(1) Critical Material Properties
In evaluating all the geomembranes, a comparison of the critical material properties which govern their water seepage prevention characteristics is of primary importance. This comparative exercise was carried out by IIT, Delhi which sheds light on performance of the respective materials.

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.

Table 3. Comparison of various geomembranes (Testing by IIT, Delhi)

Property (Test Method)	**Units**	**IITD Poly-olefin**	**HDPE**	**LDPE**
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

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/m^2 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 IITD Polyolefin, HDPE and LDPE geomembranes based on the testing performed at I.I.T. Delhi. Results for very low thickness of LDPE in the said comparison in Table 3 can be made comparable with other two materials but the difference is large though the weight is almost equal.

Table 4. Parametric comparisons of HDPE and LDPE (Testing by CIPET, Ahmedabad)

Polymer Type		**HDPE (IS : 10889- 2004)**	**LDPE (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

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 actually 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 4. 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

Ease of application is a critical parameter in geomembrane selection. From an application standpoint, aspects such as handling ease, efforts in making joinery, grip of geomembrane with soil and lining, life of the project, workability, etc. are the issues which need to be allowed serious and proper consideration because engineering aspects of such practical projects are of as much importance as 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 IITD Polyolefin material, the required thicknesses for those would increase several fold. Materials with higher thickness are not practical because of several reasons. First, LDPE with higher thickness is not typically manufactured but is required to be ordered for and the manufacturers prepare specially. Second, the cost of such a material would be prohibitively higher. Moreover, weight of the roll of such material would make it unwieldy and after spreading, positioning it as per profile would be very difficult and in case there is any gap between the sheet and the sub-base, it would not be possible to locate and correct the same. 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 test results that LDPE does not meet the requirement as a geomembrane material for the projects having long life span and large quantity of work.

(3) Costs

Detailed costing was prepared so as to form a basis of comparison of different solutions and also to have an idea as to how the total costs could change when the scale is large and the cost difference between the solutions be reduced. Table 5 provides a summary of detailed cost calculations per kilometer length of the canal under consideration.

Table 5. Cost comparison of different solutions

Different Solutions	Total Cost Per Kilometer Length
(1) Scrapping the Canal Bank and Redoing with CNS Layer and Lining Redone	Rs. 28,28,905
(2) Strengthening of Canal Bank with Additional Berm and Lining Redone	Rs. 23,63,480
(3) Providing C.C. Lining with Welded Wiremesh without Berm	Rs. 26,30,280
(4) Geomembrane with Brick Lining without Berm • Polyolefin 0.6 mm (including consultation cost) • HDPE 0.3 mm • LDPE 0.3 mm	 • Rs. 41,09,420 • Rs. 26,61,620 • Rs. 25,98,920

Total costs of canal re-lining with HDPE and LDPE geomembrane were almost identical. The cost of canal re-lining with IITD Polyolefin was higher for a small quantity of work, yet it was not worth to be ruled out considering its other benefits.

Since this project was a test evaluation for only a short canal section, the costs incurred per unit length were 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 was extremely difficult and not practical. Therefore, opting for more than 0.3 mm thickness was not thought wise and finally 0.3 mm thickness for HDPE was chosen. LDPE of the same thickness of 0.3 mm was chosen because of similar costing and almost similar weight and similar issues as the HDPE and because of objective of comparing the difference between the HDPE and LDPE. However, in large quantum work, the cost difference between HDPE and IITD Polyolefin could come down. Cost balance, though important consideration in deployment of similar large scale projects was outweighed by the vast difference in the properties of the materials (IITD Polyolefin was an engineered material with 0.6 mm apparent thickness, HDPE and LDPE had a 0.3 mm thickness) and their long term suitability for canal lining projects. A leveling exercise was, 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 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 and visual inspection of the canal after some long time. Therefore, importance of both - analysis as well as validation through a pilot project could be of immense benefit. Specific site situations may add to the experiences and provide different challenges which could lead to newer techniques and better solutions. Therefore, costing alone is not a consideration in such problems.

10. EXPERIENCES OF EXECUTION, OBSERVATIONS AND FINDINGS

Execution of the pilot project in the year 2011 provided rich and diverse experience as narrated below. Different practical aspects of restoring the canal were as important as the laboratory testing of materials and provided important points to be followed during commissioning of large scale projects in future.

(A) Preparation of Canal Section

In the stretch in which the restoration was to be made, old brick lining was removed. As the bricks had already been separated due to failure of bonds under swelling pressure, the process of removal of lining was very simple. But the major problem was of the disturbed profile of the canal which was to be corrected to precisely meet the design. Prepared canal section is shown in Photograph 15. It required manual trimming or earth filling at different locations and re-leveling of the entire bed.

Then was required to fill up the visible pipings. Cement-mud grout 1:10 was used to fill up the visible pipings knowingly that the gravity grout could creep up to certain length only and not through the entire length of the piping as pressure grout could further damage an already weakened earthen embankment. Some invisible pipings or internal cracks could not be addressed. But here, there was clarity that strengthening of the embankment was not the objective, mouths of the pipings were to be sealed so as to reduce the number of bending mechanisms to be generated in the lining. However, the sealed mouths of pipings could not be expected to avoid bending mechanism in lining for ever as the grout would tend to slide down in the piping with passage of time. Thus, constructing a new canal was found much different from restoring an existing canal with many pipings. This factor perhaps requires much higher tensile strength of the geomembrane.

Photograph 15. Preparation of canal section

(B) Material Vulnerability

Once the canal section was prepared with proper profile and longitudinal slope, placing geomembrane in position became important and needed to be done immediately as exposed canal prism was not safe for a long time. Placing of role on site and then putting it in to the canal section, spreading and placing as per the canal section needs some strength of the material itself. One of the advantages of the IITD polyolefin geomembrane was that handling was significantly easier since the material's inherent properties do not make it vulnerable to tearing and breakage. LDPE, in fact, was quite prone to tearing during laying itself. This phenomenon – ruggedness, was found not much with the LDPE and it needed careful handling. HDPE was better that way.

(C) Geomembrane bending ease

Placing of geomembrane in position in canal section proved that bending ease i.e. ease in folding of geomembrane was an important criterion. Figure 14 and Figure 15 illustrate this phenomenon geometrically.

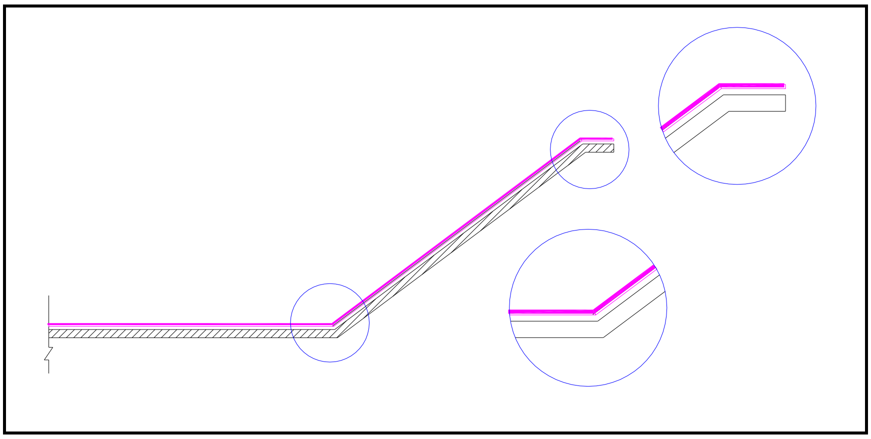

Figure 14. Handling aspect - bending ease of geomembrane (Preferred)

The geomembrane should be closely touching the sub-base so that there is no hollow between the geomembrane and the sub-base. On the flat surface this could be achieved without significant difficulties. Undulations and edges of the canal section put challenges against placing of geomembrane. At the edges of the canal section, there were two possibilities – formation of proper corners in geomembrane or formation of curved surfaces near the corner edges. The polyolefin could be bent easily and was found to be extremely good for bending ease. With HDPE, the experience was totally opposite. It was very difficult to place the HDPE in 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.

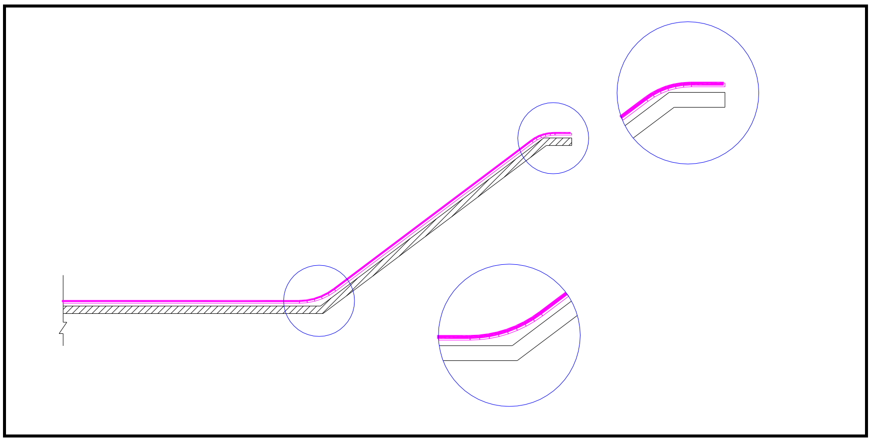

Figure 15. Handling aspect - bending ease of geomembrane (Not Preferred)

Where the geomembrane was properly placed on the sub-base, brick lining was not difficult as the surface of geomembrane did not have any play. The placement of brick lining over the geomembrane at the edges as well as the corners became a major difficultly where the geomembrane was rigid against folding which happened in the case of HDPE and LDPE. Rigid material was found to have created hinge like motion and the bricks tended to be displaced. For small canals, this limitation of HDPE in bending could be further amplified, since the respective edges and corners would be extremely close to each other.

(D) Heat Resistance

During the day time, under the heat of the sun, behavior of Polyolefin and HDPE remained unchanged. The LDPE was found to become softer with increase in heat. Brick laying on the placed geomembrane gave different experiences for different materials.

(E) Heat Sealing

Photograph 16. Heat sealing of geomembrane

Rolls of 80 to 85 meter length were available for all the three materials. Heat sealing was required to be carried out on site. Machine parameters were optimized for this process. Different machines for heat sealing for different materials were used. Even the same machine can be used with different parameter settings foe different materials. For all three materials, heat sealing on site was a rather simple and straightforward process.

(F) Difficulty in Brick Lining

In the canal under consideration, originally there was a brick lining and only a small stretch of canal was to be repaired and therefore, brick lining was proper in the stretch to be restored so as to maintain consistency in hydraulic behavior of the canal. The IIT polyolefin was designed to have a rough surface on one side, laying of bricks atop this was accomplished easily. HDPE and LDPE, on the other hand, had very smooth surfaces on both the sides. Therefore, brick laying atop them was difficult.

Conventional brick lining generally 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 to fill up the joinery between adjoining bricks. 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 place closely without joints to be filled in with cement mortar as pointing. Bricks were placed to maintain weight balancing on the sides of the canal. 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 and as well as to provide a smooth surface. The inside surface of the canal was found smoother than the conventional brick lining.

(G) Physical Testing and Inspections of Canal

Photograph 17. Completed canal section

(H) Testing of Canal
After completion of each of the three sections with the respective geomembrane materials, testing was carried out.

Photograph 18. Testing of completed canal section

For testing, there were two walls constructed in the canal to create a pool inside as shown in Photograph 18. This testing was carried out by filling water within the upstream and downstream walls 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 about a period of two years on either side of the canal. Earlier to the restoration, weed growth inside the canal through brick lining was a severe problem and the bank used to remain saturated and hence outer sides of the canal banks remained covered with vegetation whereas after restoration with geomembrane weed growth inside the section and on the outer sides of the bank was also absent when observed after a year. 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.

Flow measurement showed that the roughocity Co-efficient of the canal was close to 0.018. This was a significant achievement because generally in the canals the roughocity co-efficient taken in the design consideration is not achieved practically and finally the performance of the canals is affected whereas in this case, it could be achieved and hence designed discharge could be flown without any encroachment in the freeboard.

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.

11. CONCLUSION

The Case Study – 1 shows that for a canal embankment with so many problems and constraints narrated above, as such there was no apparent solution in the given situation to restore the canal as per the original design. No precedence observed anywhere of restoring a canal embankment as reinforced earthen section and for the first time this kind of experimentation was done in absence of any other viable solution but it worked well; and, in case, in future any canal embankment has the problem of stability due to whatever reason, such design can be safely adopted.

The Case Study – 2 shows that application of geomembrane to canals is a promising and viable solution to check the problem of swelling of soil and consequent problems leading to failures of canals. For restoration of deteriorated condition of the canals, the above implementations have demonstrated that they afford potential to provide an effective solution. Further, in construction of new canals, usage of geomembranes would be more economical than conventional CNS treatment in most cases. Areas where availability of good soils is a problem, use of geomembrane for canal lining can be a boon. In the present time when large infrastructure projects have consumed most of the usable soil mass, canal engineers have hardly any choice for materials for designing and constructing new canals; rather, in many cases, only theoretically worked out specifications might lead to entanglement in work schedules and contract management 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.

The most important aspect for any civil engineering project is its performance. Canals and hydraulic structures are practically very difficult to bring to the required performance level as they involve multidisciplinary issues and need utmost care in design, selecting the materials and workmanship. Because the surface of the canal lining could obtain the desired value of roughocity co-efficient in the present project, it could attain success. That became actually a key factor for the improved hydraulic performance of the canal. Changes in conventional practice sometime lead to positive changes if introduced thoughtfully which could be learnt from this project.

Some engineering solutions can offer many benefits other than addressing the objective problem without any additional cost as compared to the conventional solutions and save large maintenance costs which otherwise would have been incurred on the project. Fact that problem of weed growth and subsequent damage to lining and vegetation on outer sides of the canal banks could be sorted out has proven this aspect. It was found that if cost of CNS was compared with the geomembrane based solution, conventional solution was not any economy. However, if other benefits and reduction in maintenance cost, etc. are properly counted in the life cycle cost analysis of the project, their value addition to the future propositions could be appreciated by the stakeholders. When there is a choice of introducing improvement in the material by modifying the production system, much better properties can be obtained which can contribute to performance enhancement of the project as a whole. IITD polyolefin as an engineered material has led to a conclusion that some innovation in material can bring out much better results. Some struggle for selecting or designing the right quality material pays a lot in long run.

Finer details about experiences while commissioning some engineering activities teach a lot as to what are the pros and cons of different materials used and how they trigger some changes in their application and they also define the need of reforms to be introduced. How little amendments could make the activity more efficient is learnt from the reforms introduced to brick lining in the said project. Application of geomembrane can 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 for resolution of complicated engineering problems arising out of non-availability of natural materials.

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(Case Study – 2) is hereby acknowledged.