Geosynthetic reinforcement in distressed canal embankment in Gujarat, India : a case study

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ABSTRACT: Large canals in embankment generally face the issues of stability. Phreatic line and pore water pressure are the important aspects to focus on. In case of usage of improper material or non-compliance with the technical specifications, the canal can not perform as per design and manifests serious problems during operation. The paper discusses such a case study of a huge canal with 583.57 cubic meters per second as the designed discharge and embankment height of more than 9 meter that manifested serious distress immediately after construction. The paper includes details as to how and why the canal breached and how it was restored using geosynthetics as reinforcement. Main thrust is on the fact that an impossible-looking problem could be effectively solved using geosynthetics. Gujarat state of India is known for its pioneering role in applications of geosynthetics in canals. An innovative way of working out solution of a very complex problem and, that too, amongst many constraints as described in the paper categorically underlines the importance of applying geosynthetics in addressing the real world problems of the present time.

Keywords: canal, embankment, geosynthetics, phreatic line, pore water pressure, reinforcement

1 INTRODUCTION

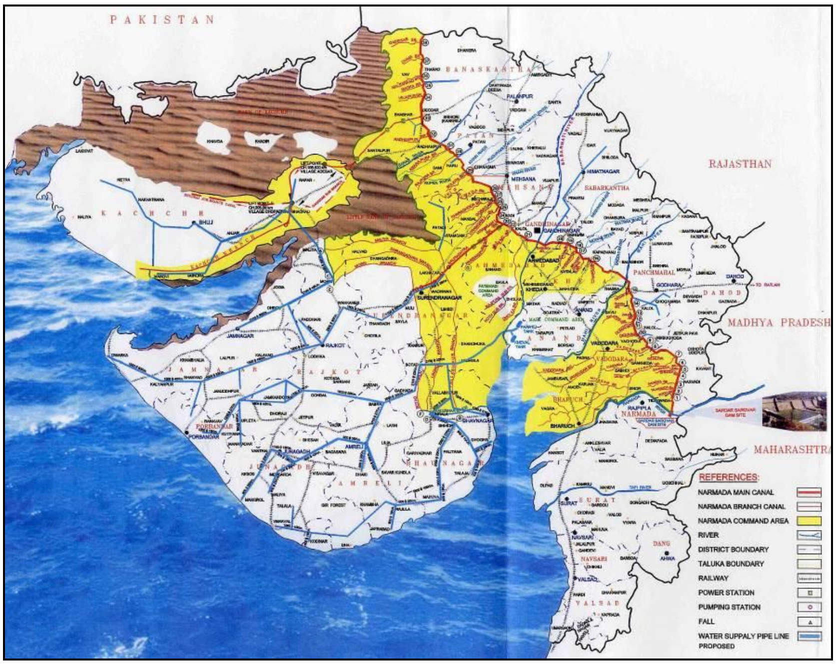

Figure 1. Alignments of the Narmada Main Canal and branch canals

Sardar Sarovar Project, one of the largest projects of the world with 1.8 million hectare of command area and 75,000 km long canal network provides domestic water to 9600 villages and 135 towns. The main canal i.e. Narmada Main Canal is the largest in the world having carrying capacity of 1133 cubic meter per second at the off-take point. It 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.

Figure 1 shows the command area of the Sardar Sarovar Project, the alignments of Narmada Main Canals and its branch canals.

2 OVERVIEW OF THE PROBLEM

The canal reach from Chainage (Ch.) 269 Kilometer (Km) to Ch. 271.5 Km is in full bank with bed banking of 1 to 1.5 meter (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 cubic meters per second. 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.

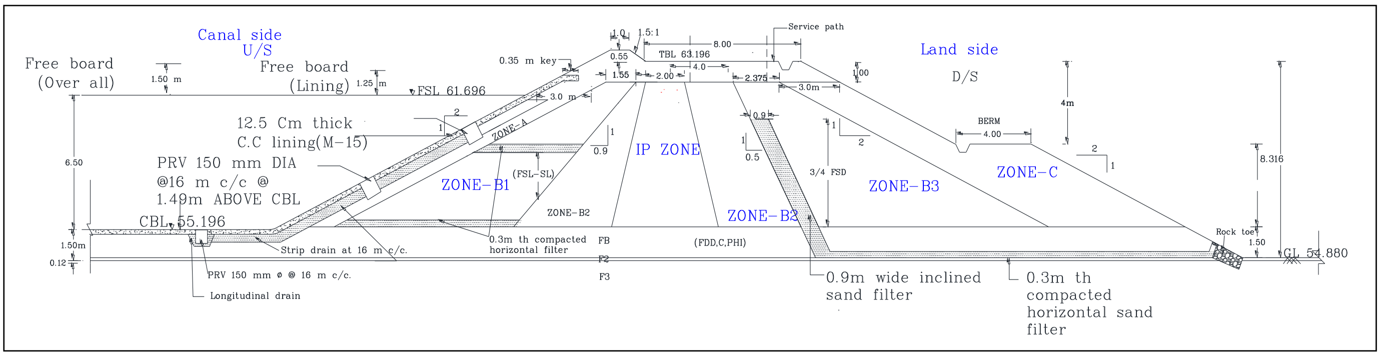

Figure 2. Designed section of canal embankment

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 viewed in 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 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. Continuous horizontal crack in the concrete lining was a sign of shear failure of concrete due to subsidence of soil mass behind it. Crumbling of soil behind the lining was due to presence of poorly compacted soil, which settled due to its own weight at certain depth within the embankment, which was observed during the investigation.

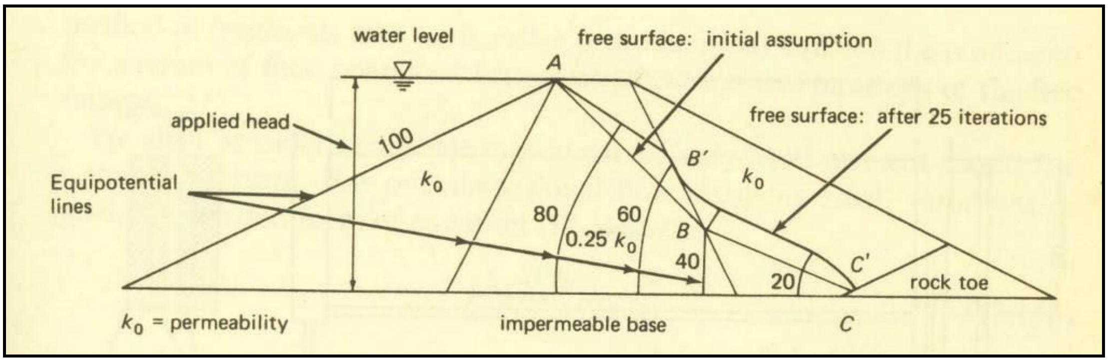

Figure 3. Steady unconfined seepage problem

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.

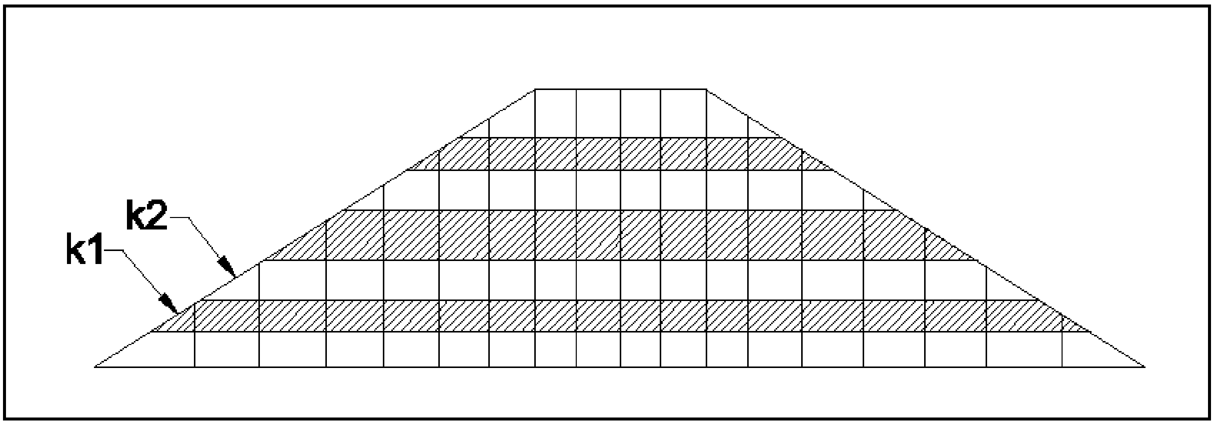

Figure 4 Conceptual modeling of stratified embankment

4 GEOTEXTILE REINFORCED EMBANKMENT AS A SOLUTION

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 as reinforcement in the embankment was thought of.

Table 2. Material properties

Property	Unit	Value
Weight	g/m^2	270
Wide Width Tensile Strength	kN/m	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

Availability of geosynthetic material in a short time was also an issue. Geotextile material with properties as shown in Table 2 was available. The designed section of geotextile reinforced embankment was worked out using wrap around mechanism as per principles discussed by Venkatapparao, G. and Suryanarayana Raju, G.V.S. (1990) as shown in Figure 5.

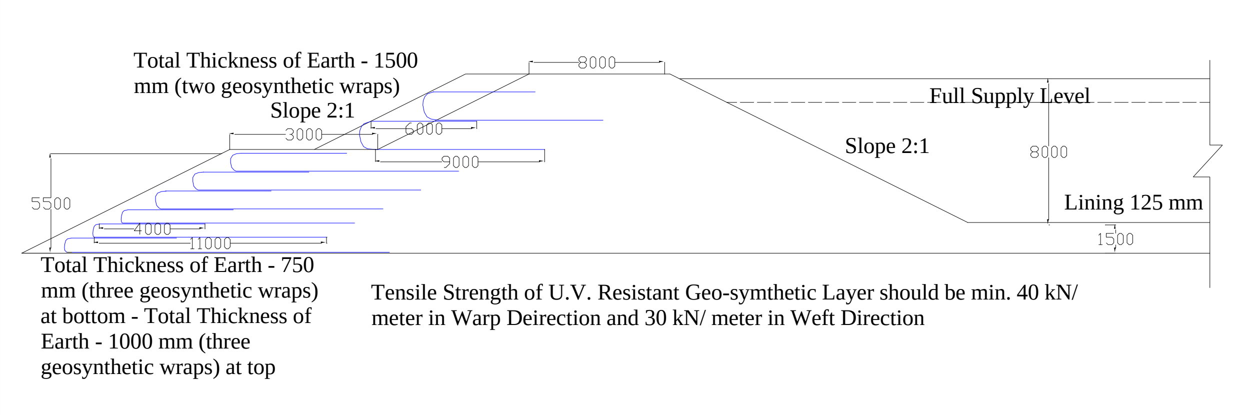

Figure 5. Section for Restoration of Main Canal Embankment

The geotextile material was woven with reasonably good flow rate. Controlled elongation in the geotextile was a selected property to ensure that deformation in the canal embankment is not very big. Filtration property was selected in such a way that the pore pressure would be released without soil particle migration. Portable stitching machine was used to join the width-wise pieces of the geotextile and polyester yarn threads were used for stitching.

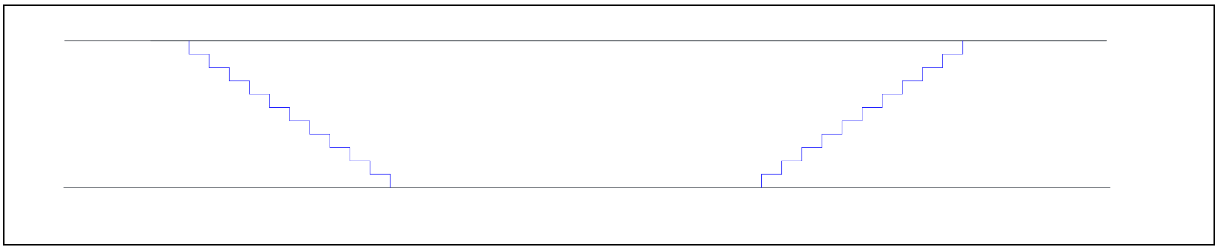

Figure 6. Step cutting for joining restored section and original construction (side view of embankment)

Proper connection between the restored section and original construction of the embankment was required to be done in order to ensure a congruent behaviour without any development of sign of behavioural difference between the two. As shown in Figure 6, stepping was done on both the sides of the breached length so as to provide grip in the earthwork. Grip was made stronger by providing geotextile material on bottom of the respective step such that as the height of the embankment increased, length of the geotextile reinforced section also increased.

 

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

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 shear and bending resistance are added to the concrete.

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. From the time of repair i.e. year 2008 the canal has been flowing without any problem. As it supplies domestic water to several towns and villages, it has not been possible to provide any closure but the performance in the repaired stretch has been quite satisfactory.

5 CONCLUSION

Some problems in geotechnical engineering are very complex and especially the soil of right quality is not easily available nowadays. Time permitted to execute the solution is as an added challenge. In canal embankment, such challenges are obvious when the height and size of the canal are very big. In order to work out the solutions of difficult problems, geosynthetic could help design a cost effective and viable solution with ease in construction as an additional feature. The case study has provided a time tested performance record for the geotextile reinforced embankment for huge canal.

REFERENCES

Venkatapparao, G. and Suryanarayana Raju, G.V.S. (1990) Engineering with Geosynthetics, Tata McGraw Hill, New Delhi