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Bituminous geomembrane: Successful alternative of distressed concrete canal lining built over expansive clays

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ABSTRACT: This paper focuses on the application of Bituminous Geomembrane (BGM) for the waterproofing of new and existing earthen canals. The start of its application is about half-century back when USBR first time applied BGM in canal waterproofing and the first time BGM was used in waterproofing of a large dam by Coletanche in 1978 in France. In India, the first application of BGM has been done in one kilometer stretch of Pench Canal in Nagpur, Maharashtra which was given as a pilot project to Yooil Infra to arrest the seepage and enhance the stability of the canal. The area comprises expansive soil which has been problematic for canal banks stability, concrete lining failures, heavy seepage through banks and breaching of banks at different reaches of canal. The BGM application resulted in a complete stoppage of seepage through that section of the canal and no stability related problem was observed due to the elimination of drawdown conditions while and after the full flow of canal during monsoon. BGM is unique due to its properties of being flexible, high puncture resistance, practically impermeable, resistant to thermal expansion, UV resistant, non-biodegradable, low maintenance cost and overall exceptional durability. This paper gives the technical assessment of slopes of the canal with the existing concrete lining, outlining possible reasons for the failure of concrete lining and remedy with the impervious bituminous geomembrane.

1 INTRODUCTION

The Pench Left bank and Right bank canals were built in 1970s as a part of Totladoh project on Pench river. Their total length is 84 km. It is being operated un-der Vidarbha Irrigation Development Corporation (VIDC), Maharashtra, India.

Under the prevailing situation of reduced rainfall coupled with reduced reservoir capacity followed by canal seepages and breaches, the only option left to meet the drinking and irrigation requirements is water conservation by increasing the stability of canal, minimizing the seepage loss, reducing the canal friction loss and thus ensure the maximum utilization of available water.

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2 PROJECT LOCATION AND SALIENT FEATURES

The site is about 3.4 km from National Highway 44 and is on state highway 249 (see Figure 1). The project is 1km from Gundhari Village in Nagpur district, Maharashtra, India.

Figure 1. Project location map of Pench Canal.

The salient features of canal selected for BGM lining are as follows:

Table 1. Salient features of Pench LB Canal.

Length	1000	m
Bed width	13	m
Full Supply Depth	3.8	m
Design Discharge	90	Cumecs
Mean Velocity	2	m/s
Bed Slope	1 (V):7000 (H)	
Side slopes	1(V):1.5 (H)	

3 CANAL BEHAVIOR WITH PLAIN CEMENT CONCRETE LINING

During the site inspection of left bank Pench canal, it is observed that concrete lining of canal is severely damaged (see Figure 2). Root causes behind the cracking of concrete lining of canal can be summarized as below:

Figure 2. Original condition of canal stretch.

Lining has joints at regular interval, through which seepage was taking place into the banks of the canal. General soil type along the canal alignment is expansive soil which is popularly known as “Black Cotton Soil”. Expansive soil exert pressure on the concrete lining due to volume expansion. As plain cement concrete is weak in tension, the expansion joint crack become wider, and sometimes new cracks develops in concrete lining.

Flowing water cause internal erosion below the lining of canal when enter in these cracks. During drawdown condition, situation becomes even worse when uplift force due to pore water pressure along with the swell pressure exerted by bank soil causing cracking of lining and sometime sliding of the whole soil mass into the canal.

A distinct disadvantage of Concrete lining is its brittleness. Thus, concrete lining frequently cracks due to contraction taking place from temperature change, drying and shrinkage and settlement of sub-grade.

4 ALTERNATIVE LINING - BITUMINOUS GEOMEMBRANE

Bituminous geomembranes (BGM) have been developed 40 years ago. This durable Geocomposite is an effective waterproofing layer with significant properties, such as UV resistance, workability at temperatures -40°C to 55°C, mechanical / puncture resistance, harsh chemical resistance, dimensional stability, and mechanical workability, easily installed, welded, and repaired by local crews or maintenance people of any client.

5 CANAL BEHAVIOR WITH BGM LINING

The installation of BGM layer forms an impermeable barrier all around the inner surface of canal and along the top width of embankment up to half of embankment top width. This layer prevents the seepage of canal water to enter the embankment fill. Thus, the moisture variation almost ceases to take place in the canal embankment and hence no excess pore pressure develops during drawdown condition. Thus, the critical failure surface is on the slope of embankment opposite to the canal side. But in actual practice, there is no failure anywhere at the site on outside slope of canal. Hence the system is completely safe with BGM layer.

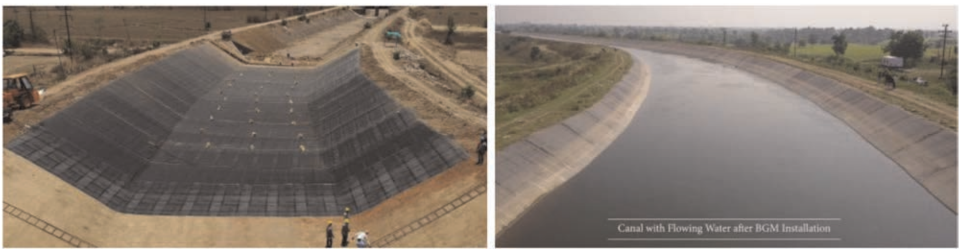

Figure 3. Canal during BGM installation and after 4 years of flowing condition.

6 METHOD OF ANALYSIS & SOFTWARE USED

To access the actual cause of failure based on the in-situ strength and deformation characteristics of embankment, stability analysis of the embankment is performed using Limit Equilibrium method using “Slide” as well as through FEM analysis using “Phase2” from Rocscience Inc.

7 DESIGN INPUT PARAMETERS

Following are the input parameters adopted for the slope stability analysis based on the lab test results of embankment fill material.

Table 2. Salient features of canal embankment (in Filling).

Properties of Slope	
Total Height	5 m
Water Table Location	At ground level, Full Supply level (FSL) and Drawdown condition
Embankment Slope	1.5H:1V

Table 3. Geotechnical design parameters for embankment fill and foundation.

S.n	Description	Unit	Value
1	Bulk Density	g/cc	1.83
2	Liquid Limit	%	41
3	Plastic Limit	%	19
4	Shrinkage Limit	%	12
5	IS Classification	-	C I
6	Free Swell Index	%	25
7	Peak Cohesion	KPa	23
8	Peak Friction Angle	Φ	13
9	Residual Cohesion	KPa	20
10	Residual Friction angle	Φ	5
11	Permeability	m/s	3×10^{-7}
12	Swelling Pressure	KPa	51.2
13	Young's Modulus	MPa	23

The above parameters were obtained by testing the actual soil samples extracted from the canal embankment and canal bed level (foundation) and conservative value is considered in design.

7.1 *Loading condition*

As per Indian road congress, IRC 75-2015 (Guidelines for the design of high embankments), following are the loading conditions to be used for the stability analysis of embankment.

Live Load (External Traffic Load): 24 KPa to be considered across the width of carriageway.

Dead Load: Self weight of embankment and any other structure resting on the embankment.

Static Condition: Deal Load + Live Load

Table 4. Summary of recommended min Factor of Safety (FOS) required for stability.

Loading Condition	Factor of Safety under static load
Static Load	1.4 (at the end of construction), 1.2 (*Initial factor of Safety)
Sudden Drawdown	1.3
Steady Seepage	1.3

During the canal site visit, it was observed that no failure has occurred in the base of the canal, and the concrete at base remained intact all throughout. Accordingly, in the analysis, the parameters of the foundation layer were increased considerably to avoid the failure slip circle passing through the base of embankment. Only slip circles passing through the slope of embankment were considered to evaluate the FOS during analysis.

8 SIMULATION OF VARIOUS CONDITIONS IN SOFTWARE

8.1 *With Cohesive Non-Swelling (CNS) layer and concrete lining as conventional technology*

8.1.1 *Normal operating condition*

The normal operating level is 3.8m. Accordingly piezometric head of 3.8m is applied in the embankment. In the canal portion, additional Uniformly distributed load (UDL) corresponding to head of 3.8m is applied on the bed as well as canal slopes to simulate the water head in canal, since piezometric lines action in some material only and not in open space.

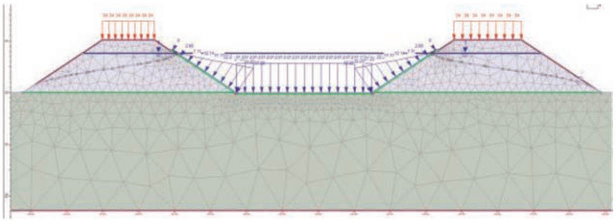

Figure 4. Model of stage-1 under normal condition of conventional canal lining.

8.1.2 *Sudden drawdown condition*

First FEM analysis with groundwater and stress condition is considered with Normal water levels.

Phreatic line in the embankment body under steady state condition is generated.

To simulate the Sudden drawdown condition, in the analysis, groundwater type is changed to piezometric, and phreatic line obtained from step "b" is imported for water levels in the dam body under drawdown condition, and piezometric water level at canal bed level is modelled for remaining portion.

SRF (strength reduction factor) is computed for sudden drawdown condition.

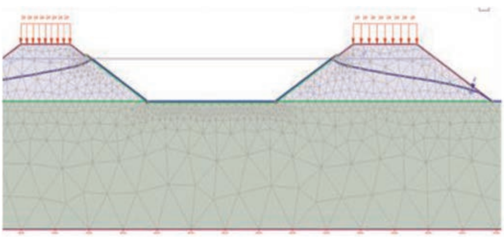

Figure 5. Model of stage-2 under drawdown condition (Conventional canal lining).

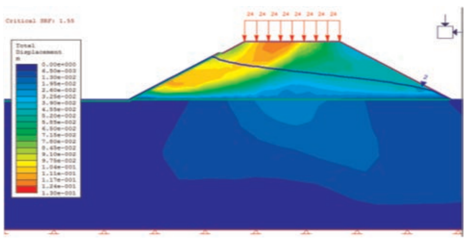

Figure 6. Output: Failure surface with displacement contours.

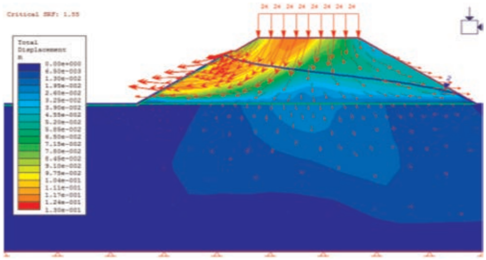

Figure 7. Output: Deformation Vectors showing the potential failure direction.

8.2 *With BGM layer*

8.2.1 *Normal operating condition*

The normal operating level is 3.8m. Since permeability of BGM is of order of 10^{-14} m/s, which is practically impermeable, membrane applied on the canal surface.

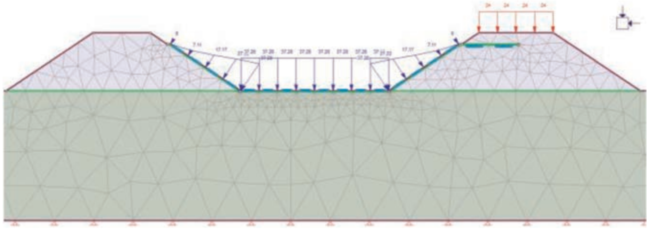

Figure 8. Model of stage-1: BGM layer installed as liner under normal condition.

Hence no water level is considered in the embankment body and additional UDL corresponding to head of 3.8m is applied on the bed as well as canal slopes to simulate the water head in canal.

8.2.2 *Sudden drawdown condition*

Due to impermeability of BGM layer, the water will not enter the embankment before drawdown. So, no water table is considered in the model before and during drawdown condition.

SRF (strength reduction factor) is computed for sudden drawdown condition.

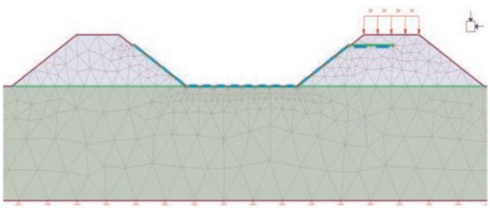

Figure 9. Model of stage-2: BGM layer installed as liner under drawdown condition.

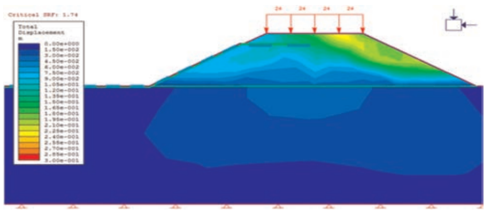

Figure 10. Output: Failure surface with displacement contours under drawdown condition. (FOS=1.74).

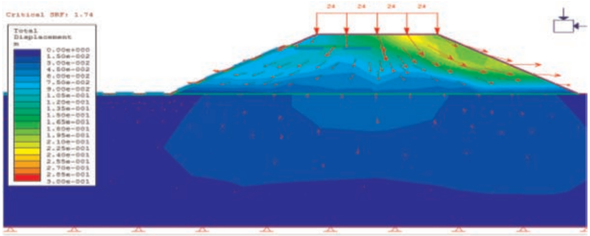

Figure 11. Output: Deformation vectors showing the potential failure direction.

9 RESULTS AND DISCUSSION

Following are the output of stability analysis in terms of Factor of safety obtained under various conditions of analysis.

Table 5. Factor of safety against various loading conditions.

Condition	Factor of Safety	
	With CNS Layer & concrete lining	With BGM Layer
Sudden Drawdown	1.55	1.74

The embankment soil is high to medium plastic clay, hence the value of Skempton's pore pressure parameter, "B" was kept as 1 in the software to simulate the rise in pore pressure actually taking place during drawdown in the canal. The routine lowering of water taking place in the canal can be considered as sudden drawdown keeping in view the rate of lowering of water vs the slow dissipation of pore pressure due to low permeability of soil.

9.1 *Analysis of embankment with CNS layer*

It can be clearly seen from the results that in case of normal condition, the embankment has found to be safe in slope stability, whereas under drawdown condition, the Factor of Safety (FOS) reduces further due to reduction of effective stress in embankment soil. Further, the erosion of embankment soil due to flowing water led to removal of "toe" material and the seepage of water into the soil lead to loosening of soil, and these two phenomenon combinedly lead to failure of canal slope. This phenomenon of seepage through concrete lining joints, erosion of CNS layer, swelling of expansive clay and cracking of concrete lining thereof has already been explained in 3 Canal Behavior with Plain Cement Concrete lining.

9.2 *Analysis of embankment with BGM layer installed*

The installation of BGM layer forms an impermeable barrier (all around the inner surface of canal and along the top width of embankment up to half of embankment top width. This layer prevents the seepage of canal water to enter the embankment fill and at the same time during rains, the rainwater is also prevented to percolate into the half width of the embankment top. Thus, the moisture variation almost ceases to take place in the canal embankment and hence no excess pore pressure develops during drawdown condition. Also, the provision of BGM layer rules out any possibility of soil erosion by flowing water. These rules out the major failure causing factors due to provision of BGM layer in the canal. Thus, as expected, software analysis gives the critical failure surface on the slope of embankment opposite to the canal side, but with FOS more than minimum required. In actual practice also, these is no failure anywhere at the site on outside slope of canal. Hence the system is completely safe with BGM layer.

10 CONCLUSION

This type of embankment having swelling characteristics with provision of CNS layer also are not able to prevent the erosion of CNS layer and embankment fill from flowing water in canal after cracking of rigid concrete slab. A flexible, impermeable membrane having tensile strength is required to be installed to take care of all the issues like seepage into embankment fill, concrete slab cracking, surface erosion, moisture variation etc. Bituminous Geomembrane meets all the technical requirement to address the adversities in the stability of embankment along the canal.

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