CASE STUDY – 1
Restoration of Main Canal of Sardar Sarovar Project
DESIGN FEATURES OF MAIN CANAL

• Largest in the world having carrying capacity of 1133 cubic meter per second at the off-take point.

• From Ch. 269 km to Ch. 271.5 km is in full bank with bed banking of 1 to 1.5 m - total bank height above the ground level is about 9 m

• Canal bed is 53.70 m wide and the full supply depth (FSD) is 6.5 m

• Designed discharge is 583.57 m$^3$/s (20,608 cfs)

• Canal side slopes are 2 (H) : 1 (V)

DESIGN FEATURES OF MAIN CANAL

• Zoned embankment designed to suit the codal provisions, design practices and material availability
## HISTORY OF CANAL EMBANKMENT FAILURE

<table>
<thead>
<tr>
<th>Date of Occurrence</th>
<th>Chainage in km</th>
<th>Side of the Bank</th>
</tr>
</thead>
<tbody>
<tr>
<td>30-08-2005</td>
<td>272.500</td>
<td>Left</td>
</tr>
<tr>
<td>08-09-2005</td>
<td>271.300</td>
<td>Left</td>
</tr>
<tr>
<td>17-09-2005</td>
<td>269.700</td>
<td>Left (Huge Breach)</td>
</tr>
<tr>
<td>17-09-2005</td>
<td>270.900</td>
<td>Left (Huge Breach)</td>
</tr>
<tr>
<td>13-01-2006</td>
<td>271.180</td>
<td>Left</td>
</tr>
<tr>
<td>13-01-2006</td>
<td>271.450</td>
<td>Right</td>
</tr>
<tr>
<td>11-03-2006</td>
<td>270.300</td>
<td>Right</td>
</tr>
</tbody>
</table>

**Defects in lining**
HISTORY OF CANAL EMBANKMENT FAILURE

Defects in lining

HISTORY OF CANAL EMBANKMENT FAILURE

Defects in lining
HISTORY OF CANAL EMBANKMENT FAILURE

Devastation in Vicinity of Canal

HISTORY OF CANAL EMBANKMENT FAILURE

Devastation in Vicinity of Canal
HISTORY OF CANAL EMBANKMENT FAILURE

Chiselled Embankment

HISTORY OF CANAL EMBANKMENT FAILURE

Chiselled Embankment
ANALYSIS OF AS BUILT SECTION AND SHORTCOMINGS FOUND IN THE EMBANKMENT

- No zones with specific soil properties as per design

- Obligatory technical specifications for laying and compacting the soils totally neglected - numerous locations and bands of loose or inadequately compacted soil zones

- No chimney filter or horizontal filter blankets to protect the soil and prevent migration of particles outside.

- Due to very loose soil bands there was substantial subsidence of the earthwork - lining, as a result, cracked irregularly, even big hollows at some locations

- 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
ANALYSIS OF AS BUILT SECTION AND SHORTCOMINGS FOUND IN THE EMBANKMENT

Stratified Strata of Soil with No Zoning or Filters

• Slip circle modelling can not be taken as stratification of soil and therefore Finite Element modelling as steady unconfined seepage type problem was done using four noded element in the self developed program.

• Analysis suggested that the embankment with as built section property was unstable with the designed head in the canal
ANALYSIS OF AS BUILT SECTION AND SHORTCOMINGS FOUND IN THE EMBANKMENT

Steady Unconfined Seepage Problem

Conceptual modeling of stratified embankment
ISSUES WITH RESTORATION OF CANAL EMBANKMENT

• Time of only 10 days was there - drinking water for many towns and villages depending up on the main canal

• 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

ISSUES WITH RESTORATION OF CANAL EMBANKMENT

• 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.
GEOREINFORCED EMBANKMENT AS A SOLUTION

• 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.

• All these constraints led to the application of geosynthetic to construct the embankment as the right solution.

GEOREINFORCED EMBANKMENT AS A SOLUTION

<table>
<thead>
<tr>
<th>Material Properties</th>
<th>Property</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>g/m²</td>
<td></td>
<td>270</td>
</tr>
<tr>
<td>Wide Width Tensile</td>
<td>kN/m²</td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>Wide Width Elongation</td>
<td>%</td>
<td></td>
<td>15</td>
</tr>
<tr>
<td>Trapezoidal Tear Strength</td>
<td>kN</td>
<td></td>
<td>0.50</td>
</tr>
<tr>
<td>CBR Puncture resistance</td>
<td>kN</td>
<td></td>
<td>6.0</td>
</tr>
<tr>
<td>Flow Rate</td>
<td>l/m²/min</td>
<td></td>
<td>260</td>
</tr>
<tr>
<td>UV Resistance</td>
<td>%/hrs</td>
<td></td>
<td>70 / 500</td>
</tr>
</tbody>
</table>
GEOREINFORCED EMBANKMENT AS A SOLUTION

• Section for Restoration of Main Canal Embankment

![Diagram showing geosynthetic materials and thicknesses]

Tensile Strength of U V Resistant Geo-synthetic Layer should be min. 40 kN/meter in Warp Direction and 30 kN/meter in Weft Direction

Spreading Geosynthetic Sheet
GEOREINFORCED EMBANKMENT AS A SOLUTION

Stitching Geosynthetic Sheet

GEOREINFORCED EMBANKMENT AS A SOLUTION

Restored Main Canal Embankment
GEOREINFORCED EMBANKMENT AS A SOLUTION

Restored Main Canal Embankment

CASE STUDY – 3
Construction of Canal with Sandy Soil using Georeinforcement and Geomembrane
CONTEXTUAL BACKGROUND

OVERVIEW OF THE PROBLEM

• Tail Branch Canals of Sardar Sarovar Project passing through sandy soil and their command areas adjoining desert

• Capacity about 15 cumec and length about 20 Kilometer

• All the canals have cutting, partial banking and banking – banking up to 3.5 meter

• SM soil with almost uniform particles and hence compaction the biggest problem

Difficulty in compaction and high permeability, both required to be addressed
OVERVIEW OF THE PROBLEM

- Fluctuations in water levels – variations in pore pressure
- Sudden variations in pore pressure may cause spreading or dispersion failure of the embankment

High permeability means flatter hydrostatic line requiring much larger width of embankment - economic viability adversely affected

Lower compaction results in susceptibility to disintegration i.e. stability failure
OVERVIEW OF THE PROBLEM

GCL checks the seepage path
Geogrid checks the disintegration of sand particles

GEOGRID FOR REINFORCED EMBANKMENT

- Three levels of Geogrid
  1\textsuperscript{st} Layer at [CBL – 0.30] m level
  2\textsuperscript{nd} Layer at [CBL + 0.40] m level
  3\textsuperscript{rd} Layer at [FSL - 0.40] m level

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Method</th>
<th>Unit</th>
<th>TG U-60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate tensile strength</td>
<td>MD CD</td>
<td>kN/m</td>
<td>60</td>
</tr>
<tr>
<td>Reduction nfactor (RF) and machine direction long term design strength (LTDS)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Creep (RF\textsubscript{CR})</td>
<td>120 years life, 40\degree C temp</td>
<td>1.55</td>
<td></td>
</tr>
<tr>
<td>Installation damage (RF\textsubscript{ID})</td>
<td>Sand/Silt/Clay, &lt; 37.5 mm gravel</td>
<td>1.05</td>
<td></td>
</tr>
<tr>
<td>Durability (RF\textsubscript{D})</td>
<td>pH = 4 to 9</td>
<td>1.15</td>
<td></td>
</tr>
<tr>
<td>LTDS - 120 years, 40\degree C : Sand /Silt /Clay : pH = 4 - 9</td>
<td>kN/m</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>LTDS - 120 years, 40\degree C : Gravel &lt; 7.5 ; pH = 4 - 9</td>
<td>kN/m</td>
<td>29.3</td>
<td></td>
</tr>
<tr>
<td>Aperture size (+/- 2 mm)</td>
<td>mm</td>
<td>30 x 25</td>
<td></td>
</tr>
</tbody>
</table>
SOLUTION USING GEOGRID AND GEOMEMBRANE

Canal Bank in Sandy Soil

- Geogrid in 3 layers and GCL (HDPE Geomembrane 0.5 mm thick) - Geogrid as reinforcement for stability and GCL for checking seepage
- Rock toe to release pore pressure though minimum

SOLUTION USING GEOGRID AND GEOMEMBRANE

First Stage of Concrete Lining With Paver Machine

Second Stage of Lining With Paver Machine
GEOSYNTHETIC CLAY LINER

- Geosynthetic clay liners (GCLs) include a thin layer of finely-ground bentonite clay. When wetted, the clay swells and becomes a very effective hydraulic barrier.

- GCLs are manufactured by sandwiching the bentonite within or layering it on geotextiles and/or geomembranes, bonding the layers with needling, stitching and/or chemical adhesives.

SOLUTION USING GEOGRID AND GCL

Gadsisar Branch Canal
CONCLUSIONS

With limited choice about type of soil, focus on solution as a system is more required.

Geosynthetic itself is not the solution but the system whose part it is needs to be designed to take its maximum advantage.

Conventional solutions are not always more economical than innovative solutions.

Resource crunch has forced engineers to think out of box and to put up with available resources with corrections applied.
THANKS TO ALL