Geosynthetics Engineering: In Theory & Practice

Prof. J. N. Mandal
Department of Civil Engineering, IIT Bombay

Lecture No - 43
GEOSYNTHETICS ENGINEERING: IN THEORY AND PRACTICE

Prof. J. N. Mandal

Department of civil engineering, IIT Bombay, Powai, Mumbai 400076, India.
Tel. 022-25767328
email: cejnm@civil.iitb.ac.in
Module - 9
LECTURE - 43
Geosynthetics for ground improvement
OUTLINE

- Introduction
- Ground improvement techniques
- Consolidation technique
- Bearing capacity and settlement
- Principles of prefabricated vertical drains
- Design charts without and with smear effect
- Design chart with smear effect and well resistance
- Ground instrumentation and monitoring
- Ground improvement using geocell
- Ground improvement using geofoam

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INTRODUCTION

- Over the last 40 years the use of geosynthetic is growing rapidly worldwide

- Increasing demand for land reclamation and utilization of soft soils for ground improvement using geosynthetics
India has coastal area more than 4000 km long
Major Cities along the coastline – congested
Development is difficult due to
✓ Land
✓ Quality of land
Scarcity of good quality land for future development
With the rapid dwindling of good sites for construction activity of challenging infrastructure projects, the need is being increasingly felt for utilizing very low and marginal load bearing sites.

The need is even greater in high cost metropolitan and coastal areas where demand for the construction outstrips the land availability.

Consequently, many important and major projects such as airways, highways, railway embankments, large buildings, container yards and transport terminals have necessarily to be located on areas with soft alluvial and marine clay deposits of considerable thickness.

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Due to the very low shearing strength and high compressibility of soil deposits, the safe bearing capacity is very low and the settlements under nominal structural loads tend to be excessive.

Hence, it is required to improve the ground by technically feasible and economically viable methods for wider applications in various projects. It is required to achieve one or more of the following objectives:

- Reduction of post-construction settlement to a tolerable value
- Enhancement of shearing strength (and hence, bearing capacity) of soft soils
- Control on rate of loading consistent with the rate of gain in shear strength
Geosynthetics are recognized in civil engineering community as cost effective, proven and reliable materials to carry out civil engineering jobs in better, faster and economical way.

The applications of geosynthetics are vast because they have versatility in functioning, majorly as reinforcements, separators, filters, drains and liquid barriers in soil.

With the advent of geosynthetics, the revolution of utilizing them in different ground improvement systems for weak or soft soils is picking up at an unprecedented pace.

With the technical and economic feasibility as the major priority in any upcoming projects, geosynthetics in ground improvement methods are the norm of the day.

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GROUND IMPROVEMENT TECHNIQUES

What happens if ground improvement is not done?

• Excessive/differential settlement in structures
• Decrease in structures life
• Increase in maintenance cost

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The ground improvement techniques can generally be categorized as,

- **Removal and Replacement**
- **Consolidation techniques:** Sand drains, stone columns, encased sand and stone columns, PPVDs with full surcharge, PPVDs and vacuum consolidation with partial surcharge, NPVDs with full surcharge, NPVDs combined with stone column or sand column, Thermo-PVD, solar powered drain, electro-osmotic consolidation, vacuum dewatering and dynamic compaction
- **Geosynthetics reinforcement techniques:** Encased sand column, encased stone column, mechanically stabilized reinforced soil wall, geocell or geoweb, geofoam
- Densification: Piles (RCC, wooden, steel, and composite), dynamic compaction, vibro compaction, compaction grouting

- Chemical stabilizations: Lime column, deep soil mixing, jet grouting, injection grouting

- Electro kinetic stabilizations
Battered column provided to load transfer platform (After Han, 2003)

CSE with geosynthetic reinforcement to prevent lateral spreading (After Han, 2003)

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The application of geosynthetics can be perceived in a typical embankment construction. A canal is constructed on the embankment with a layer of geosynthetics clay liner or Geomembrane.

- Geosynthetic acts for filtration and drainage.
- Embankment fill can also be replaced with light weight geofoam.

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Correct choice of techniques for ground improvement

- The choice of appropriate technique for ground improvement depends on several factors such as the type of soil and type of improvement required i.e., increase in bearing capacity or decrease in settlement or both needs to be considered.

- Time and cost are also very important factors. Consolidation and installation/construction for long time is not suitable for any project.

- Application of huge and heavy equipments may increase the cost. The risk of non-performance or cost of time leads to expensive solutions.

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Sometimes, the advantage of area of application of the technique can be taken to reduce cost and time.

The embankment can be designed for achieving 80% consolidation and the remaining 20% consolidation can take place during the construction of different pavement layers. The availability of labour and materials also affect the time and cost.

The suitability of technology depends on the availability of resources of the country. Countries such as India, Bangladesh, Pakistan, Myanmar, Thailand, China etc. have abundant natural materials like jute, coir, sisal and bamboo.

The geotextiles made from such natural materials are called as limited life geotextiles (LLGS) by Sarsby (1997).
Many of the polymer based geosynthetics can be replaced with degradable and ecofriendly natural geotextiles depending on the areas of application.

Mandal (1987) recommended the use of jute and coir for ground improvement systems. They have many good technical properties:

- Strength
- Extensibility or stiffness
- Flexibility
- Durability
Natural fibers have been used in the construction industry since fifth or fourth millennia BC. The villagers used mud-clay reinforced with straw to build the dwelling units for their shelter. Some vegetable natural fibers have low tensile strength and poor durability.

The tamarisk branches were used with clay and gravel for the construction of the Great Wall of China in 200 BC.

The ropes were used for many centuries to lift the heavy loads at dock sides and mine industries.

Currently, renewed natural fibers can be used by automobile industry. The weight reduction of the door panels of cars is about 20 % using flax-sisal fiber mat embedded in an epoxy resin matrix.
Natural fibers can be utilized in several applications:

- Used for short period of time
- The unpaved temporary access road (Separation)
- The embankment constructed on soft clay (Basal reinforcement)
- Ground improvement (Time dependent due to consolidation and drainage)

- Currently, jute and coir are the most promising economically viable and vegetable fiber fabrics. Those have high water absorption capacity as well as lower impact on environment than manmade fiber does.
Indigenous natural geotextiles have certain major advantages and play significant role in developing countries like India,

- The raw materials are environment friendly, renewable resources and available abundantly (India is the second largest jute producer in the world), thus making sustainable construction industry
- Natural, bio-degradable, nourishes soil and return to the ground without pollution
- Low unit cost (Production and conversion cost low), provides competitive cost and economical
- Create new market to agricultural products (supports agro industry) and jobs for local people

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- Increase range of crops
- Farmers can cultivate and sell
- New markets are primarily close to the production point
- Money is attracted to rural areas and region without incurring major expenditure on transportation
- Helps in bringing down costly imports

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CONSOLIDATION TECHNIQUE

Since 1930, sand drains are used in various projects. They are typically 200 mm to 600 mm diameter vertical drains and spaced at 1.5 m to 6 m interval.

The conventional vertical sand drain technique is time consuming and very costly. The availability of good quality sand is becoming scarce in current years.

Sand drain

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Recently, prefabricated vertical band drains are replacing the sand drains.

Compared to sand drain, the polymer based prefabricated vertical drain (PPVD) is 100 mm in width and 3-5 mm in thickness.

Different types of prefabricated vertical drains

Drainage core wrapped with the geotextile
The prefabricated vertical drains have many advantages with respect to the sand drains.

The band shaped prefabricated vertical drains are easy to install in the soil as well as causes least disturbance to the soil during installation.

The discharge capacity of band drain is more and consolidation rate is higher than that of sand drain. It also decreases the required surcharge for the compression of the soil.
The PVDs are generally placed at 1 m to 2 m spacing.
Outline

- Properties of Marine Clay and Natural Prefabricated Vertical Drains (NPVDs)
- Filtration Characteristics of Jute and Polymer Geotextile Filter

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Prefabricated vertical drains (PVDS) have various application areas including:

- Soft soil storage tank
- Embankment with PVDS (After, Rixner, 1986)
- Polymer based Prefabricated Vertical Drain (PPVD)

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Common application areas of Prefabricated Vertical Drains (PVDs):

- Highways (roadways, structure approach fills, etc.)
- Airfields (runways, taxiways, cargo aprons and buildings)
- Earth dams (foundations)
- Embankments and levees
- Storage tanks
- Excavations (steepen allowable slopes)
- Waste ponds and mine tailing ponds
- Buildings (industrial plants, warehouses, wastewater treatment plants, apartments, shopping centers)
Natural Prefabricated Vertical Drains (NPVDs)

- Made from natural materials; jute and coir
- Eco-friendly
- Hygroscopic
- Indigenous and economical when available abundantly

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Aims and Objectives of Present Study

To study some of the major properties such as tensile strength and discharge capacity of the NPVDs, and soil retention ability and clogging potential of natural geotextile filter materials which are essential to ascertain their efficiency and utility.

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### Properties of remoulded Marine clay

<table>
<thead>
<tr>
<th>Properties</th>
<th>Test method</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>IS : 2720 part 3/sec 1</td>
<td>2.60</td>
</tr>
<tr>
<td>Liquid limit (%)</td>
<td>IS : 2720 part 5</td>
<td>82</td>
</tr>
<tr>
<td>Plastic limit (%)</td>
<td>IS : 2720 part 5</td>
<td>40</td>
</tr>
<tr>
<td>Shrinkage limit (%)</td>
<td>IS : 2720 part 6</td>
<td>10</td>
</tr>
<tr>
<td>Plasticity index</td>
<td>-</td>
<td>42</td>
</tr>
<tr>
<td>Silt content (%)</td>
<td>IS : 2720 part 4</td>
<td>33.7</td>
</tr>
<tr>
<td>Clay content (%)</td>
<td>IS : 2720 part 4</td>
<td>51.0</td>
</tr>
<tr>
<td>Compression index, $C_c$</td>
<td>IS : 2720 part 15</td>
<td>0.75</td>
</tr>
<tr>
<td>Swelling index, $C_s$</td>
<td>IS : 2720 part 15</td>
<td>0.11</td>
</tr>
</tbody>
</table>

Classified as ‘Clay of high plasticity (CH)’ as per Indian Standard classification system (IS: 1498).

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Natural prefabricated vertical drains (NPVDs) can also be developed using natural geotextiles such as jute and coir, especially in countries like India, where they are available in abundance.

Newly developed natural prefabricated vertical drains made of jute and coir geotextiles (After Asha and Mandal, 2012)

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### Physical description of NPVDs and PPVD

| Type of PVD | Filter                                | Core                                              | Size of PVD          |
|------------|---------------------------------------|                                                  | Width (mm) | Thickness (mm) |
| NPVD 1     | Single layer woven jute geotextile    | Five number of 5 mm diameter coir strands        | 85 – 90    | 9              |
| NPVD 2     | Single layer non-woven jute geotextile | Five number of 5 mm diameter coir strands        | 85 – 90    | 11             |
| NPVD 3     | Single layer woven jute geotextile    | 10 mm thick flat coir mat                        | 85 – 90    | 12-12.5        |
| NPVD 4     | Single layer woven jute geotextile    | 13 mm thick corrugated coir mat                  | 85 – 90    | 16-16.5        |
| PPVD       | Single layer non-woven poly-propylene | 4.5 mm thick corrugated and studded poly-propylene sheet | 100        | 5              |
## Properties of filter and core

<table>
<thead>
<tr>
<th>Structure</th>
<th>Test property/Unit</th>
<th>Test method</th>
<th>Woven jute</th>
<th>Non – woven jute</th>
<th>Non – woven polypropylene</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Filter Type</strong></td>
<td>Mass per unit area (g/m²)</td>
<td>ASTM D5261</td>
<td>700</td>
<td>680</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Thickness (mm)</td>
<td>ASTM D5199</td>
<td>1.8</td>
<td>6</td>
<td>0.5*</td>
</tr>
<tr>
<td></td>
<td>Tensile strength (kN/m)</td>
<td>ASTM D4595</td>
<td>29</td>
<td>5</td>
<td>50*</td>
</tr>
<tr>
<td></td>
<td>Elongation at break (%)</td>
<td>ASTM D4595</td>
<td>8.4</td>
<td>25</td>
<td>25*</td>
</tr>
<tr>
<td></td>
<td>Puncture strength (kN)</td>
<td>ASTM D6241</td>
<td>0.62</td>
<td>0.46</td>
<td>1*</td>
</tr>
<tr>
<td></td>
<td>Trapezoid tearing strength (kN)</td>
<td>ASTM D4533</td>
<td>0.53</td>
<td>0.12</td>
<td>0.8*</td>
</tr>
<tr>
<td><strong>Core type</strong></td>
<td>Diameter (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thickness (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tensile load (kN)</td>
<td>IS 1671</td>
<td>0.25 kN</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tensile strength (kN/m)</td>
<td>ASTM D4595</td>
<td>48 kN/m</td>
<td>12 kN/m</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Elongation at break (%)</td>
<td>IS 1671</td>
<td>23</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>ASTM D4595</td>
<td>40</td>
<td></td>
<td>19</td>
</tr>
</tbody>
</table>

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## Physical properties of NPVDs and PPVD

<table>
<thead>
<tr>
<th>Test property/Unit</th>
<th>NPVD 1</th>
<th>NPVD 2</th>
<th>NPVD 3</th>
<th>NPVD 4</th>
<th>PPVD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheath Type</td>
<td>Woven jute</td>
<td>Non-woven jute</td>
<td>Woven jute</td>
<td>Woven jute</td>
<td>Non-woven Polypropylene</td>
</tr>
<tr>
<td>Core type</td>
<td>Coir strands</td>
<td>Coir strands</td>
<td>Flat coir mat</td>
<td>Corrugated coir mat</td>
<td>Corrugated and studded polypropylene</td>
</tr>
<tr>
<td>Width (mm)</td>
<td>85 -90</td>
<td>85 -90</td>
<td>85 -90</td>
<td>85 -90</td>
<td>100</td>
</tr>
<tr>
<td>Thickness at 2 kPa (mm)</td>
<td>9</td>
<td>11</td>
<td>12 -12.5</td>
<td>16 – 16.5</td>
<td>5</td>
</tr>
<tr>
<td>Weight per metre (gm)</td>
<td>184-185</td>
<td>160-165</td>
<td>270-280</td>
<td>310-325</td>
<td>85</td>
</tr>
<tr>
<td>Tensile strength (kN/ 85mm wide drain)</td>
<td>6.2</td>
<td>2.25</td>
<td>5.75</td>
<td>5.75</td>
<td>8</td>
</tr>
<tr>
<td>Elongation at break (%)</td>
<td>10</td>
<td>25</td>
<td>10</td>
<td>10</td>
<td>35</td>
</tr>
<tr>
<td>Discharge capacity (m³/s) at hydraulic gradient, i=0.5 under 250 kPa stress</td>
<td>2.8E-06</td>
<td>0.9E-06</td>
<td>2.5E-06</td>
<td>4.25E-06</td>
<td>13.5E-06</td>
</tr>
</tbody>
</table>

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## Properties of NPVDs and PPVD

<table>
<thead>
<tr>
<th>Test property/Unit</th>
<th>Type of PVD</th>
<th>NPVD 1</th>
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<th>NPVD 4</th>
<th>PPVD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight per metre (g)</td>
<td></td>
<td>180-185</td>
<td>160-165</td>
<td>270-280</td>
<td>310-325</td>
<td>85</td>
</tr>
<tr>
<td>Tensile strength (kN)</td>
<td></td>
<td>6.2</td>
<td>2.25</td>
<td>5.90</td>
<td>5.60</td>
<td>23</td>
</tr>
<tr>
<td>Elongation at break (%)</td>
<td></td>
<td>10</td>
<td>25</td>
<td>10</td>
<td>10</td>
<td>22</td>
</tr>
<tr>
<td>Tensile strength at 10 % strain (kN)</td>
<td></td>
<td>6.2</td>
<td>1.25</td>
<td>5.90</td>
<td>5.60</td>
<td>15</td>
</tr>
</tbody>
</table>

Widely recommended criteria: Tensile strength of whole PVD > 1 kN at 10 % strain (Koerner, 1994; Rawes, 1997; Bo et al., 2003)

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### Standard deviation and coefficient of variation of tensile strength

<table>
<thead>
<tr>
<th>Material</th>
<th>Standard deviation</th>
<th>Coefficient of variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woven jute geotextile (filter)</td>
<td>2.69</td>
<td>0.09</td>
</tr>
<tr>
<td>Non-woven jute geotextile (filter)</td>
<td>2.24</td>
<td>0.434</td>
</tr>
<tr>
<td>Coir strands (core)</td>
<td>0.05</td>
<td>0.24</td>
</tr>
<tr>
<td>Flat coir mat (core)</td>
<td>9.13</td>
<td>0.186</td>
</tr>
<tr>
<td>Corrugated coir mat (core)</td>
<td>2.08</td>
<td>0.17</td>
</tr>
<tr>
<td>NPVD 1</td>
<td>0.46</td>
<td>0.07</td>
</tr>
<tr>
<td>NPVD 2</td>
<td>0.34</td>
<td>0.14</td>
</tr>
<tr>
<td>NPVD 3</td>
<td>0.87</td>
<td>0.14</td>
</tr>
<tr>
<td>NPVD 4</td>
<td>0.30</td>
<td>0.05</td>
</tr>
</tbody>
</table>
Summary and conclusions

- All the NPVDs have adequate tensile strength to resist the tensile force of 1 kN at a tensile strain of 10%.

- The highest average maximum tensile strength is obtained in NPVD 1 while the lowest in NPVD 2.
Please let us hear from you

Any question?
Prof. J. N. Mandal

Department of civil engineering, IIT Bombay, Powai, Mumbai 400076, India.
Tel. 022-25767328
email: cejnm@civil.iitb.ac.in

THANKS FOR LISTENING