GEOSYNTHETICS ENGINEERING: IN THEORY AND PRACTICE

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Module - 9
LECTURE - 44
Geosynthetics for ground improvement
Recap of previous lecture.....

- Introduction
- Ground improvement techniques
  - Consolidation technique
    - Properties of marine clay and natural prefabricated vertical drains (NPVDs)
Filtration Characteristics of Jute and Polymer Geotextile Filters

Requirements of geotextile Filters:

- Ability to retain soil
- Adequate permeability
- Ability to resist self clogging

Types of woven and non-woven jute and polymer geotextile filters.

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Apparent Opening Size (AOS or $O_{95}$) of geotextiles by dry sieving method

<table>
<thead>
<tr>
<th>Filter type</th>
<th>Filter opening size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$O_{95}$ (AOS)</td>
</tr>
<tr>
<td>WJT$_{550}$</td>
<td>0.8</td>
</tr>
<tr>
<td>WJT$_{700}$</td>
<td>0.25</td>
</tr>
<tr>
<td>WJT$_{775}$</td>
<td>0.16</td>
</tr>
<tr>
<td>NWJT$_{680}$</td>
<td>0.14</td>
</tr>
<tr>
<td>Non-woven polymer</td>
<td>&lt; 0.075</td>
</tr>
</tbody>
</table>

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## Permeability of geotextile filters

<table>
<thead>
<tr>
<th>Test property/Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Geotextile filter type</td>
</tr>
<tr>
<td></td>
<td>WJT\textsubscript{775}</td>
</tr>
<tr>
<td>Permeability (m/s)</td>
<td>1.7E-04</td>
</tr>
</tbody>
</table>

Widely recommended criteria (Rixner et al., 1984; Bergado et al., 1996(a); Rawes, 1997; Bo et al., 2003): Permeability of geotextile filters used in PVDs > 10 times the permeability of soil

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Compatibility of jute geotextile filters with marine clay

- Long Term Filtration Tests
- Hydraulic Conductivity Ratio (HCR) tests

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Long term filtration tests

Schematic diagram of fabricated filtration test apparatus.

Filtration test in progress.

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Long term flow behaviour in marine clay - geotextile filter systems

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Hydraulic conductivity ratio test

Hydraulic conductivity ratio (HCR) test

Three stages of HCR test: 1. Saturation of marine clay–geotextile filter system
2. Primary consolidation of marine clay
3. Initialization of flow

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Variation of hydraulic conductivity ratio with pore volumes

Results of HCR tests

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Variation of hydraulic conductivity of marine clay-geotextile filter system with time

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Soil retention criteria relationship:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Values from present study</th>
<th>Filter type</th>
<th>Christopher and Holtz (1984) for polymer filters</th>
<th>Bergado et al. (1996) for PPVD</th>
<th>Bo et al. (2003) for PPVD</th>
</tr>
</thead>
<tbody>
<tr>
<td>$O_{95}/D_{85}$</td>
<td>2.7</td>
<td>4.2</td>
<td>13</td>
<td>2.3</td>
<td>$&lt; 1.25$</td>
</tr>
<tr>
<td>$O_{50}/D_{50}$</td>
<td>58</td>
<td>94.7</td>
<td>315</td>
<td>$&lt; 39.5$</td>
<td>$&lt; 39.5$</td>
</tr>
</tbody>
</table>

$D_{85}$ of marine clay = 0.06 mm
$D_{50}$ of marine clay = 0.0019 mm

Retention criteria from present study $= \frac{O_{95}}{D_{85}} \leq 4.5$

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Summary and conclusions

- The AOS testing of non-woven jute geotextile from dry sieving is time consuming. From the tests conducted on non-woven jute geotextiles, it is concluded that dry sieving may not be a suitable method to find the AOS of non-woven jute geotextile.

- The permeability of all the jute and polymer geotextile filters is ten times more than the permeability of the marine clay and thus satisfies the generally recommended criteria used for filters used in PVDs installed in clay.

- From the long term filtration tests, for the given soil and hydraulic condition, the maximum system permeability is almost same in all the five systems measuring $1.4 \times 10^{-8}$ m/s. Multiple increase and decrease pattern in system permeability with time are observed before reaching the stable flow condition in all the systems.
Contd…

- All the marine clay-geotextile filter systems reached stable flow condition but at different time intervals. The loss of clay particles during filtration process is more in marine clay-WJT\textsubscript{550} filter system compared to other systems.

- There exists good filtration compatibility between marine clay-polymer/ WJT\textsubscript{775}/ WJT\textsubscript{700}/ NWJT\textsubscript{680} filters for the given hydraulic and soil conditions. Whereas, marine clay-WJT\textsubscript{550} filter system is not a better filtration system.

- From apparent opening size (AOS) and filtration tests, the empirical ratio of O\textsubscript{95}/ D\textsubscript{85} ≤ 4.5 and O\textsubscript{50}/ D\textsubscript{50} ≤ 100 are suggested as marine clay retention criteria for jute geotextile.

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Absorption and Discharge Capacity Tests on NPVDs:

Graph of absorption capacity vs. time for NPVDs 1, 2, 3, 4 and PPVD (After Asha and Mandal, 2012)

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Rubber Membrane Confined Discharge Capacity Tests:

Schematic diagrams of discharge capacity test apparatus:
(a) longitudinal section and (b) transverse section

Test apparatus with loading plate

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Variation of discharge capacity of NPVDs and PPVD at normal compressive stresses at different hydraulic gradients

Results of rubber membrane confined discharge capacity tests:

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Discharge capacity variation in PPVD and NPVDs under different hydraulic gradients, $i$ and compressive stresses, $\sigma$

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Variation in discharge capacity of NPVDs and PPVD confined in marine clay with compressive stress at different hydraulic gradients.

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Discharge capacity comparison between rubber membrane and marine clay confined NPVD 1, 4 and PPVD at different compressive stresses for hydraulic gradients: (a) $i = 1$ and (b) $i = 0.1$.

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Comparison of the present study results at 0.5 hydraulic gradient between NPVD 1, 4 and PVDs made from natural geotextiles of other researchers.

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Summary and conclusions

- NPVD 2, made from nonwoven jute geotextile filter wrapped around coir ropes, has the greatest water absorption capacity, and the PPVD has the lowest absorption capacity. All the PVDs reached almost their maximum absorption after 2 hours of soaking in water; beyond 2 hours, there is a negligible increase in the absorption capacity.

- The discharge capacity is greater in the PPVD than in the NPVDs. Also, the discharge capacity reduction rate is greater in the NPVDs than in the PPVD when the compressive stress is increased at a specific hydraulic gradient.

- By confining the PVD in marine clay during discharge capacity tests, the discharge capacity of PPVD reduced by 40 %, NPVD 3, 4 by 50 % and NPVD 1, 2 by 60 % compared to rubber membrane confined discharge capacity tests.
Summary and conclusions

- NPVD 4, which is made of woven jute filter and a corrugated coir mat core, has a greater discharge capacity than NPVDs 1, 2 and 3 at the normal stresses and hydraulic gradients studied.

- The lowest discharge capacity is observed in NPVD 2, which is made from non-woven jute filter wrapped around coir ropes.

- Flow conditions through all the NPVDs are linear at all the hydraulic gradients, satisfying the theoretical requirement of PVDs.

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Large Scale Laboratory Consolidation Tests

Schematic diagram of developed and fabricated large scale consolidation test setup.

Consolidation test in progress.

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Results of consolidation tests

(a) Stages of loading in first set of tests and (b) graph of measured settlement vs. time in marine clay without and with different PVDs.

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(a) Stages of loading in second set tests and (b) graph of settlement vs. time in marine clay without PVD and with NPVDs and PPVD obtained from experiment.

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Numerical simulations of consolidation tests using software PLAXIS 2D 2010

Typical geometry for numerical simulation of large scale consolidation tests; (a) model for marine clay without PVD and (b) model for marine clay with PVD.

Equivalent diameter of band shaped PVD, $d$ (after, Rixner, 1986)

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## Soil properties and drain parameters used in numerical simulations

<table>
<thead>
<tr>
<th>Parameter / Unit</th>
<th>Marine clay</th>
<th>Gravel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unsaturated unit weight (kN/m³)</td>
<td>14.5</td>
<td>17</td>
</tr>
<tr>
<td>Saturated unit weight (kN/m³)</td>
<td>14.5</td>
<td>18</td>
</tr>
<tr>
<td>Initial horizontal Permeability of the soil (m/day)</td>
<td>0.60x10⁻³</td>
<td>1</td>
</tr>
<tr>
<td>Initial vertical permeability of the soil (m/day)</td>
<td>0.60x10⁻³</td>
<td>1</td>
</tr>
<tr>
<td>Modified compression index</td>
<td>0.085</td>
<td>-</td>
</tr>
<tr>
<td>Modified swelling index</td>
<td>0.02</td>
<td>-</td>
</tr>
<tr>
<td>Initial void ratio</td>
<td>2.75</td>
<td>-</td>
</tr>
<tr>
<td>Effective cohesion (kPa)</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Effective angle of internal friction (degree)</td>
<td>25</td>
<td>35</td>
</tr>
<tr>
<td>Elastic modulus (kPa)</td>
<td>-</td>
<td>21000</td>
</tr>
<tr>
<td>Permeability change index</td>
<td>-</td>
<td>1.3</td>
</tr>
<tr>
<td>Diameter of the cylinder of influence of the drain (mm)</td>
<td>480</td>
<td></td>
</tr>
<tr>
<td>Length of the drain (mm)</td>
<td>650</td>
<td></td>
</tr>
<tr>
<td>Type of PVD</td>
<td>NPVD 1</td>
<td>NPVD 2</td>
</tr>
<tr>
<td>Equivalent diameter of the PVD (mm)</td>
<td>61</td>
<td>62</td>
</tr>
</tbody>
</table>
Comparison of numerical (Num.) and experimental (Expt.) results obtained for marine clay model with and without NPVD.

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Excess pore water pressure development and dissipation showing the effect of drain in numerical simulations.

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Excess pore water pressure dissipation patterns in numerical simulations (a) marine clay alone model and  (b) marine clay with NPVD model.

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Summary and conclusions

- The large scale consolidation tests have showed that all the NPVDs and PPVD aided in acceleration of the primary consolidation process in marine clay soil.

- The rate of settlement in all the marine clay installed NPVDs and PPVD is almost same. The effects of different PVDs in terms of well resistance and hence, its effect on settlement rate could not be compared distinctly.

- Clogging of the core of NPVDs and PPVD are not observed after the 65 days period of consolidation tests.
Summary and conclusions

- The numerical simulation of experimental consolidation behaviour of marine clay with and without NPVDs and PPVD can be made reasonably well through ‘drain element’ option and ‘permeability change index’ soil parameter.

- The developed and fabricated NPVDs are eco-friendly, easy to fabricate and low cost material which can be used to accelerate the primary consolidation process in marine clay.
Major Contributions

- Development and fabrication of four types of band shaped PVDs made from single layer woven and non-woven jute geotextile as filter and coir ropes or coir mats as core (designated as Natural Prefabricated Vertical Drains: NPVD 1, 2, 3 and 4).
- NPVD 4 made from woven jute filter and corrugated coir mat core has a higher discharge capacity and better drainage characteristics.
- Application of long term filtration and hydraulic conductivity ratio tests on marine clay-jute geotextile systems. The filtration tests are viable method to evaluate compatibility of jute filter with soil.
- All the NPVDs aid in acceleration of the primary consolidation of marine clay soil.

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The NPVDs are more appropriate, low cost, alternative choice to PPVDs, especially in developing countries like India, because of following salient factors:

- Technically feasible
- More economical
- Low energy utilization

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Improvement in the consolidation behaviour of soil due to NPVD can be predicted numerically based on theories of radial consolidation originally derived by Barron (1948) with subsequent modifications by Hansbo (1979, 1981).

The equivalent vertical permeability ($k_{ve}$) was derived based on one dimensional vertical consolidation theory and Hansbo’s (1981) unit cell radial theory,

$$k_{ve} = \left\{1 + \frac{2.26H^2}{\mu D^2} \frac{k_h}{k_v}\right\}k_v$$

$$\mu = \frac{n^2}{n^2-1} \left[\ln(n) - \frac{3}{4} + \frac{1}{n^2} - \frac{1}{4n^4}\right]$$

$k_v$ = vertical permeability of soil  
$k_h$ = horizontal permeability of soil  
$D$ = diameter of the cylinder of influence of the drain,  
$\mu$ = shape factor without smear and well resistance effect  
$n = D/d$; $d$ = equivalent diameter of the band shaped drain
The band shaped PVDs can be converted into equivalent circular drain based on Hansbo’s (1981) expression.

\[ d_w = \frac{2(a + b)}{\pi} \]

a = Width of the drain, and b = Thickness of the drain.

Equivalent diameter of the PVD

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Adopting equivalent vertical permeability concept, Asha and Mandal (2011) numerically simulated the laboratory models with finite element analysis.

Comparison of settlement obtained from experimental (EXPT) and finite element analysis (FEA)

- Predicted settlement from the finite element analysis is closely matched to the laboratory consolidation test.

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Please let us hear from you

Any question?
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THANKS FOR LISTENING