Material behaviour and constitutive modelling of organic soils

François Mathijssen, Noel Boylan, Frans Molenkamp, Serge Leroueil & Michael Long

Dredging tools for the future - Academic session

CEDA dredging days 2009 - 6 November 2009
What is organic soil?

Scanning Electron Microscope image of: a) Slight to moderate (H4-H5) decomposed Loughrea peat. b) Strong to very strong (H7-H8) decomposed Loughrea peat (Fig. 1 – Boylan & Long, 2006b).

Phase diagram for typical peat from Escuminac, New Brunswick – Canada (Fig. 33 – Landva & Pheeney, 1980).

Introduction  Classification  In-situ testing  Laboratory testing  Field data  Modelling  Closure
### Classification

**Degree of humification according to Von Post & Granlund (1926).**

<table>
<thead>
<tr>
<th>Degree of humification</th>
<th>Decomposition</th>
<th>Plant structure</th>
<th>Content of amorphous material</th>
<th>Material extruded on squeezing (passing between fingers)</th>
<th>Nature of residue</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>None</td>
<td>Easily identified</td>
<td>None</td>
<td>Clear, colourless water</td>
<td></td>
</tr>
<tr>
<td>H2</td>
<td>Insignificant</td>
<td>Easily identified</td>
<td>None</td>
<td>Yellowish water</td>
<td></td>
</tr>
<tr>
<td>H3</td>
<td>Very slight</td>
<td>Still identifiable</td>
<td>Slight</td>
<td>Brown, muddy water; no peat</td>
<td>Not pasty</td>
</tr>
<tr>
<td>H4</td>
<td>Slight</td>
<td>Not easily identified</td>
<td>Some</td>
<td>Dark brown, muddy water; no peat</td>
<td>Somewhat pasty</td>
</tr>
<tr>
<td>H5</td>
<td>Moderate</td>
<td>Recognizable, but vague</td>
<td>Considerable</td>
<td>Muddy water and some peat</td>
<td>Strongly pasty</td>
</tr>
<tr>
<td>H6</td>
<td>Moderately strong</td>
<td>Indistinct (more distinct after squeezing)</td>
<td>Considerable</td>
<td>About one third of peat squeezed out; water dark brown</td>
<td></td>
</tr>
<tr>
<td>H7</td>
<td>Strong</td>
<td>Faintly recognizable</td>
<td>High</td>
<td>About one half of peat squeezed out; any water very dark brown</td>
<td></td>
</tr>
<tr>
<td>H8</td>
<td>Very strong</td>
<td>Very indistinct</td>
<td>High</td>
<td>About two thirds of peat squeezed out; also some pasty water</td>
<td>Plant tissue capable of resisting decomposition (roots, fibres)</td>
</tr>
<tr>
<td>H9</td>
<td>Nearly complete</td>
<td>Almost not recognizable</td>
<td>Nearly all the peat squeezed out as a fairly uniform paste</td>
<td>All the peat passes between the fingers; no free water visible</td>
<td></td>
</tr>
<tr>
<td>H10</td>
<td>Complete</td>
<td>Not discernible</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Material behaviour and constitutive modelling of organic soils**

CEDA dredging days 2009 - 6 November 2009
Field vane testing

In-situ measured vane shear deformation in Spagnum peat – Escuminac
N.B. (Fig. 8 – Landva, 1980).

Material behaviour and constitutive modelling of organic soils

CEDA dredging days 2009 - 6 November 2009
CPT testing

Soil description and cone resistance resulting from 28 soundings with the large tip (Fig. 5 – Viergever, 1985).

Table: Average success rates for both original and extended CPT classification rules (Table 9.14 – Mollé, 2005).

<table>
<thead>
<tr>
<th>Material</th>
<th>Average decision rules-based success rates (%)</th>
<th>Average main constituent-based success rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peat</td>
<td>26-33</td>
<td>24-37</td>
</tr>
<tr>
<td>Organic clay</td>
<td>45-59</td>
<td>64-70</td>
</tr>
<tr>
<td>Inorganic clay</td>
<td>27-58</td>
<td>46-67</td>
</tr>
</tbody>
</table>
**CPTU testing**

*Figure 1: Temperature calibration during in-situ testing. a) Cone equilibration to ground temperature. b) Comparison of cone and sleeve resistance results from piezocone testing on Vinkeveen peat – Netherlands. (Fig. 5 & 6, Boylan et al. 2008).* 

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Corrected Resistance, $q_c$ (MPa)</th>
<th>Sleeve Resistance, $f_s$ (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.005</td>
<td>0.05</td>
<td>0.005</td>
</tr>
<tr>
<td>0.01</td>
<td>0.1</td>
<td>0.01</td>
</tr>
<tr>
<td>0.015</td>
<td>0.15</td>
<td>0.015</td>
</tr>
<tr>
<td>0.02</td>
<td>0.2</td>
<td>0.02</td>
</tr>
</tbody>
</table>

**Introduction**  
**Classification**  
**In-situ testing**  
**Laboratory testing**  
**Field data**  
**Modelling**  
**Closure**

**Material behaviour and constitutive modelling of organic soils**

CEDA dredging days 2009 - 6 November 2009
CPTU testing

Strain rate dependency of cone penetration resistance using a 10cm² piezocone in peat near Vinkeveen, the Netherlands (Slow = 0.2cm/s; Normal = 2.0 cm/s; Fast = 8cm/s).

Material behaviour and constitutive modelling of organic soils

Introduction  Classification  In-situ testing  Laboratory testing  Field data  Modelling  Closure

CEDA dredging days 2009 - 6 November 2009
Ball cone & T-bar testing

T-bar and ball cone which can be fitted on the location of a conventional CPTU cone tip (Fig. 2 – Boylan & Long, 2006a); b) Comparison of different cone response results of Limerick peat plotted vs. below ground level (Fig. 1 & 8a – Boylan & Long, 2006a).

Material behaviour and constitutive modelling of organic soils

Introduction Classification In-situ testing Laboratory testing Field data Modelling Closure
Correlation In-situ vs. laboratory values

Test results between undrained shear strength and cone resistance for Flevopolder, the Netherlands (Fig. 7 – Viergever, 1985).
Field investigation campaign

Sherbrooke block sampling of peat at Motorway A2, Vinkeveen – the Netherlands. a) Retrieved block sample with expert drill team (Fig. 4 – Mathijssen et al., 2008); b) Conservation block sample with bee wax before placement in water bath at 5 °C.

Material behaviour and constitutive modelling of organic soils

Introduction  | Classification  | In-situ testing  | Laboratory testing  | Field data  | Modelling  | Closure
Early results
Vinkeveen site (2-2.5m – GS)

CAUC triaxial tests, D = 70mm

Boylan (2008)

Material behaviour and constitutive modelling of organic soils

CEDA dredging days 2009 - 6 November 2009
Anisotropy in strength & deformation

Global equilibrium of a uniformly shearing sample of an anisotropic soil with an inclined bedding plane and lateral load control of the bottom platen (Fig. 3 – Molenkamp, 1998); b) Calibration DSS/AS device.
Anisotropy in strength & deformation

Cross section test fill at Escuminac after construction and 4 years after construction (Fig. 19 – Landva & La Rochelle, 1983).

Material behaviour and constitutive modelling of organic soils

Introduction  Classification  In-situ testing  Laboratory testing  Field data  Modelling  Closure

CEDA dredging days 2009 - 6 November 2009
Critical State Soil Model

$M = \frac{6 \sin \phi_{TC}}{3 - \sin \phi_{TC}} = \frac{q}{p'}$

$R = \frac{p'_c}{p''_R} = OCR$

$r = \frac{p'_c}{p'_X}$

$\frac{c_{u,TC}}{p''_R} = M \left( \frac{R}{r} \right)^{\kappa}$

$\frac{c_{u,TC}}{\sigma'_v} R^\kappa = \left( \frac{c_{u,TC}}{\sigma'_v} \right)_{OCR^\kappa}$

Specific volume $v = 1 + e$

Idealised undrained triaxial test results in CSSM using associative flow rule (after Wroth 1984).

Material behaviour and constitutive modelling of organic soils

CEDA dredging days 2009 - 6 November 2009
Isotache approach

Timeline concept (Bjerrum, 1967)

Strain rate (a) and temperature dependent behaviour of isotache surface of Berthierville clay (Fig. 32 Leroueil 2006, after Boudali 1995).

Material behaviour and constitutive modelling of organic soils

Introduction   Classification   In-situ testing   Laboratory testing   Field data   Modelling   Closure
Closure
Some concluding remarks

- Heterogeneous nature requires thorough classification
- Advanced CPTU/ full flow penetrometer testing
- Consider sampling induced disturbance
- State of the art & novel anisotropic lab testing
- Constitutive coupled model incorporating viscosity and fibre reinforcement in CSSM framework
- Validation at various Dutch test sites with ranging organic content
Acknowledgements to:

The main research sponsors are:

Cambridge In-Situ
Consortium Holendrecht-Maarssen
Consortium N11
Delft University of Technology CiTG
ETH Zurich
Fugro
Deltares
GDS instruments Ltd.
Hydronamic
Lankelma UK
Loughborough University (UK)
Norwegian Geotechnical Institute
Public works depart. of Rotterdam
Royal Boskalis Westminster nv
SenterNovem
University College Dublin
Université Laval
Utrecht University of Technology

Material behaviour and constitutive modelling of organic soils

CEDA dredging days 2009 - 6 November 2009