Peat in Sweden

Some notes from studying peat for 35 years

Peter Carlsten
Inventory of the peat resources in southern Sweden, 1917-24
The engineer, his assistant and all the necessary equipment
## Common peatland soils

### A. Sediment
- Clay gyttja
- Lime gyttja
- Marl (bleke)
- Plankton gyttja (fine detritus gyttja)
- Detritus gyttja (coarse detritus gyttja)
- Laky dy
- Diatomaceous earth (kieselguhr)
- Alluvial peat

### A. Sedentary formations (peat)
- Limnic peat
- Marsh peat - telmatic
- Marsh peat - terrestric
- Moss peat (sphagnum peat)
Classification of peat according to von Post

- Degree of humification, H1-H10
- Wetness, B1-B5
- Sedge fibres, F1-F3
- Root threads, R0-R3
- Wood remnants, V0-V3
Inventory of the peat resources in southern Sweden, 1917-24

von Post – Presentation of survey
Dalarövägen, 1979

Carlsten, P., Förbelastning av torvmosse i samband med byggnation av Dalarövägen, Stockholm. Swedish Geotechnical Intitute, Varia No. 151, Linköping (In swedish), 1985

Dalarövägen – follow-up

The purpose of the follow-up was to
- evaluate and describe the method “preloading with surcharge” over peat,
- give guidance during construction of the road,
- develop a method for taken “undisturbed” samples of peat,
- compare field measurements and results from calculations,
- Suggest geotechnical investigations, calculation methods and practical guidance for future objects
Instrumentation Dalarövägen
Case history: Dalarövägen, Stockholm
Dalarövägen – follow-up of settlements
Dalarövägen – follow-up of horizontal movements

The figure shows vertical and horizontal movements in the top layer of the peat.
Dalarövägen: Rebound and settlements
The SGI Peat sampler
Geotechnical properties of some Swedish peats. Database at Swedish Geotechnical Institute (SGI)

Carlsten, P. & Lindahl, A. Torvs geotekniska egenskaper – Sammanställning av erfarenheter från laboratorieförsök på torv, Swedish Geotechnical Institute, Varia 519, 2002

Consolidation tests

- Consolidation tests were mainly performed in compressiometers with a diameter of 100 mm and a height of about 45 mm.
- Incremental loading starting at 2.5 kPa. The load is doubled to 5, 10, 20, 40 and finally 80 kPa.
- Duration 24 hours. Time-settlement relation is recorded during the entire loading sequence.
- $\sigma'_c, M_L, \sigma'_L, M', k_{v0}, \beta$ and $\alpha_s$ have been evaluated.
- The database contains geographic position, dates for sampling and laboratory tests, degree of decomposition, bulk density, dry density, water content, assumed gas content and void ratio.
Geotechnical properties of peat: Dry density vs. water content

Source: Muskeg Engineering Handbook, University of Toronto Press, Ottawa, 1969
Geotechnical properties of peat: Dry density vs. water content

Geotechnical properties of peat: Initial void ratio, $e_0$, vs. water content

Source: Muskeg Engineering Handbook, University of Toronto Press, Ottawa, 1969
Geotechnical properties of peat: Initial void ratio, $e_0$, vs. water content

Laboratory investigations: Relation Tangent modulus vs. effective pressure

\[ M' = \frac{\Delta M}{\Delta \sigma} = 7.1 \]
Geotechnical properties of peat: Compression index, $c_c$, vs. water content

Geotechnical properties of peat: Initial void ratio, $e_0$, vs. water content

Lefebvre et al. Laboratory testing and in situ behaviour of peat as embankment foundation, Canadian Geotechnical Journal, 21, 2, pp. 322-337, 1984.

Kogure, K. Yamagushi, H., Ohira, Y. & Ishoroshi, H. Physical and engineering properties of a peat ground, Advances in Peatland Engineering, proceedings, Ottawa, pp. 95-100. 1986
Laboratory investigations: The coefficient of secondary consolidation, $\alpha_s$, vs. deformation
Relation deformation vs. water content (Swedish Transport Administration)
Valid for fibrous peat and medium decayed peat
Permeability vs. relative compression

E.T. Hanrahan Memorial Symposium 2013-09-11
Laboratory investigations: Void ratio vs log k, SGI 1998, Lea & Brawner (Muskeg Eng.)

Source: Muskeg Engineering Handbook, University of Toronto Press, Ottawa, 1969
Consolidation in peat (Swedish Transport Administration)

Valid for fibrous peat and medium decayed peat

\[ \bar{u} = 1 - 0.6 \cdot e^{-\left(\frac{0.52 \cdot w^{0.75}}{H^2 q^{0.5}}\right) t} \]
Consolidation in peat

\[ U = 1 - 0.6 \cdot e^{-\left(\frac{0.52 \cdot w^{0.75}}{H^2 \cdot q^{0.5}}\right) t} \]

**STEP 2**
Depth of peat = 4.4 m
Load 22 kPa

Consolidation in peat

\[ U = 1 - 0.6 \cdot e^{-\frac{0.5 \cdot W^{0.75}}{H^2 \cdot q^{0.5}}} t \]

Consolidation in peat

\[ U = 1 - 0.6 \cdot e^{-\left(0.52 \cdot w^{0.75} \right) \left(\frac{H^2}{q^{0.5}}\right)t} \]

*THE DIAGRAM SHOWS THE SOLUTION FOR FREE DRAINAGE AT THE TOP AND BOTTOM LAYERS OF THE PEAT. IF THE LAYER IS IMPERMEABLE THE PEAT THICKNESS SHOULD BE MULTIPLIED BY 2

E.T. Hanrahan Memorial Symposium 2013-09-11
Consolidation in peat

\[ U = 1 - 0.6 \cdot e^{-\frac{0.52 \cdot W^{0.75}}{H^2 \cdot q^{0.5}}} \cdot t \]

*The diagram shows the solution for free drainage at the top and bottom layers of the peat. If the layer is impermeable the peat thickness should be multiplied by 2.*

E.T. Hanrahan Memorial Symposium 2013-09-11
Consolidation in peat

\[ U = 1 - 0.6 \cdot e^{-\frac{0.52 \cdot W^{0.75}}{H^2 \cdot q^{0.5}} \cdot t} \]

Consolidation in peat

**Equation**: \[ U = 1 - 0.6 \cdot e^{-\frac{0.52 \cdot W^{0.75}}{H^2 \cdot q^{0.5}} \cdot t} \]

**Diagram Notes**: The diagram shows the solution for free drainage at the top and bottom layers of the peat. If the layer is impermeable, the peat thickness should be multiplied by 2.

**Legend**:
- \( W \) - Water content (%)
- \( H \) - Thickness of peat, m
- \( q \) - Applied load (kPa)
- \( t \) - Time (days)
Consolidation in peat

\[ \Psi = 1 - 0.6 \cdot \left[ \frac{0.52 \cdot \Psi^0.75}{\Psi^2 \cdot \Psi^{0.5}} \right] \]

\[ \Psi = - \left[ \ln \left( \frac{1 - \Psi}{0.6} \right) \right] \cdot \left[ \frac{\Psi^2 \cdot \Psi^{0.5}}{0.52 \cdot \Psi^{0.75}} \right] \]

<table>
<thead>
<tr>
<th>w</th>
<th>water content</th>
<th>12</th>
<th>12</th>
<th>12</th>
<th>12</th>
<th>12</th>
<th>12</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>Peat depth</td>
<td>m</td>
<td>4.4</td>
<td>4.4</td>
<td>4.4</td>
<td>4.4</td>
<td>4.4</td>
<td>4.4</td>
</tr>
<tr>
<td>q</td>
<td>load</td>
<td>kPa</td>
<td>22.8</td>
<td>47.5</td>
<td>47.5</td>
<td>47.5</td>
<td>47.5</td>
<td>47.5</td>
</tr>
<tr>
<td>U</td>
<td>Degree of consolidation</td>
<td>0.7</td>
<td>0.7</td>
<td>0.8</td>
<td>0.85</td>
<td>0.9</td>
<td>0.95</td>
<td>0.99</td>
</tr>
<tr>
<td>t</td>
<td>time</td>
<td>days</td>
<td>19</td>
<td>28</td>
<td>44</td>
<td>55</td>
<td>71</td>
<td>99</td>
</tr>
</tbody>
</table>

E.T. Hanrahan Memorial Symposium 2013-09-11
Laboratory investigations: Direct shear tests

The sample is mounted in the direct shear apparatus

The direct shear test is concluded

The quotient $c_u/\sigma_N$ is normally 0.4 when the tests are evaluated at 0.15 rad deformation and 0.55 when the tests are evaluated at 0.35 rad deformation.
Ring shear test results on sphagnum peat from Escumanic, Landva, 1980

Landva A.O., Geotechnical behaviour and testing of peat, Ph. D. thesis, Laval University, Quebec, 1980
Model tests (Landva 1980)

Landva A.O., Geotechnical behaviour and testing of peat, Ph. D. thesis, Laval University, Quebec, 1980
Increased shear strength, Dalarövägen

Uncorrected shear strength, kPa

E.T. Hanrahan Memorial Symposium 2013-09-11
Increased shear strength, Canada

Road 50 Mjölby-Motala

Johansson, B, NCC Construction Sverige AB, Föreblastning av torv, kalkgyttja och bleke, In Swedish, SBUF, Project 12399, Report

E.T. Hanrahan Memorial Symposium 2013-09-11
Compressiometer test

Compressiometer test φ 100 mm
Sample 04 - 2,4-2,6 Medium decayed peat

Load (kPa)

Relative deformation

Water content 793 %
Density 1,03 t/m³

- $\sigma'_c = 0$
- $M_L = 19$ kPa
- $M' = 8,2$
- $\sigma'_L = 2,4$ kPa
- $k_0 = 3,2 \times 10^{-6}$ m/s
- $\beta = 3,9$

- Derived values
- Calculated values
- Unloading 120-80 kPa
- Reloading 80-90 kPa

E.T. Hanrahan Memorial Symposium 2013-09-11
## Road 50 Mjölby-Motala

<table>
<thead>
<tr>
<th>Soil</th>
<th>Effective stress (kPa)</th>
<th>Shear stress (kPa) at different deformation angles (rad)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0,15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peat</td>
<td>100</td>
<td>37,0</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>14,0</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>15,5</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>13,5</td>
</tr>
<tr>
<td>Calcareous soil</td>
<td>100</td>
<td>23,0</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>21,2</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>7,0</td>
</tr>
<tr>
<td>Clay</td>
<td>65</td>
<td>16,0</td>
</tr>
<tr>
<td></td>
<td>95</td>
<td>22,5</td>
</tr>
<tr>
<td></td>
<td>125</td>
<td>26,0</td>
</tr>
<tr>
<td>Marl (bleke)</td>
<td>40</td>
<td>8,0</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>10,2</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>15,0</td>
</tr>
</tbody>
</table>
### Road 50 Mjölby-Motala

<table>
<thead>
<tr>
<th>Soil</th>
<th>Effective stress (kPa)</th>
<th>Shear stress (kPa) at different deformation angles (rad)</th>
<th>Shear strength (kPa) calculated with different values of the parameter a (a=(c_u/\sigma'))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0,15</td>
<td>0,35</td>
</tr>
<tr>
<td>Peat</td>
<td>100</td>
<td>37,0</td>
<td>48,0</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>14,0</td>
<td>17,0</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>15,5</td>
<td>18,0</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>13,5</td>
<td>15,0</td>
</tr>
<tr>
<td>Calcareous soil</td>
<td>100</td>
<td>23,0</td>
<td>28,0</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>21,2</td>
<td>24,0</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>7,0</td>
<td>9,0</td>
</tr>
<tr>
<td>Clay</td>
<td>65</td>
<td>16,0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>95</td>
<td>22,5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>125</td>
<td>26,0</td>
<td></td>
</tr>
<tr>
<td>Marl (bleke)</td>
<td>40</td>
<td>8,0</td>
<td>12,0</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>10,2</td>
<td>17,0</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>15,0</td>
<td>21,0</td>
</tr>
</tbody>
</table>
Staged construction

- Instrumentation
- Stage 1 – Geogrid, vertical drains, 1,2 m fill over the total breadth of the embankment and pressure berm - Follow-up; settlements, pore pressure, increase in shear strength
- Stage 2a – 0,5 m fill over the total breadth of the embankment and pressure berm
- Stage 2b – Remaining fill up to the level of “Road ready for use”. Follow-up; settlements, pore pressure, increase in shear strength
- Stage 3 - Surcharge - Extra fill up to the level 1,5 m above “Road ready for use”. Follow-up; settlements, pore pressure, increase in shear strength
- Stage 4 Unloading to sub base
- Base coarse material
Instrumentation Road 50

- Hose settlement gauge
- Plastic casing, vane testing
- Plastic casing, CPT
- Plastic casing, Samples
- Settlement plate
- Profile with soil screws
- Piezometers

Crest of future road

V6 V1 H1 Crest of future road

H8 H9

23/982 23/981 23/980
23/979 23/978

E.T. Hanrahan Memorial Symposium 2013-09-11
Profile – soil screws
Road 50 - Pore pressure gauges
Soil profiles

- Torv – peat
- Bleke/kalkgyttja – Marl, calcareous soil
- Lera med siltskikt – Clay with silt layers
- Varvig lera – Varved clay
- Lera - Clay

E.T. Hanrahan Memorial Symposium 2013-09-11
Settlements, section 23/980

- Torv – peat
- Bleke/kalkgyttja – Marl, calcareous soil
- Lera med siltskikt – Clay with silt layers
- Varvig lera – Varved clay
- Lera - Clay
Excess pore pressure, section 23/980
Prognosis of settlements according to Asaoka

E.T. Hanrahan Memorial Symposium 2013-09-11
Results from CPT-soundings

23/980 Stages 1, 2 & 3

24/060 Stages 1, 2 & 3

24/420 Stages 1, 2 & 3
Road 50, Rate of settlement with time

![Graph showing the rate of settlement with time for Road 50, including data for different sections such as Sektion 23/980, Sektion 24/060, and Sektion 24/420. The graph represents the rate of settlements in mm/day over days ranging from 150 to 450.]
Recommended procedure for future objects – preloading on peat

- Economy – compare to other construction methods
- Technical considerations - compare to other construction methods
- Geotechnical investigation
- Design
- Description of performance
- Follow up
Conclusions

• The final settlement and the rate of settlement with time can be calculated with good accuracy
• The preloading shall be combined with a surcharge. Unloading should give a reduction in effective pressure of at least 20%
• A careful follow up is essential
• Staged construction
• Geometry of embankment – Description of each loading step in detail
Mass stabilisation: Experiences from Construction of Road 44 between Uddevalla and Trollhättan

Mass stabilisation: Section 8/390-8/700
Geotechnical conditions
Mass stabilisation: Section 8/390-8/700
Geotechnical conditions

- 5 m peat
- Mainly low degree of decomposition
- Water content 1200-2000 %
- "normally" consolidated and highly compressible
- Beneath the peat 1 m dry crust
- In total maximum 17 m clay, over consolidated by 40-60 kPa
Mass stabilisation: Section 8/390-8/700

Description

• Peat is stabilised with cement
• Width of stabilisation is 27 m
• No stabilisation of the clay
• 200 kg/m³ SH-Cement
• Preloading with surcharge
• 6 months of preloading
• Follow up on settlements
Mass stabilisation: Section 8/390-8/700

Description

- In total 3 m fill
- 3 stages; (1,0+1,0+1,0) m
- Times for stages; (30+30+120) dygn
- Unloading at the end of preloading: 0,3-0,9 m
- Extra unloading with light-weight aggregates ($\sigma' < 0,85 \sigma'_{c}$)
Mass stabilisation: Section 8/390-8/700

Design

- Road level 1 m above original ground level
- Density of fill - 1,9 t/m³
- Calculation of settlements 8/580

Deformation curing/consolidation = 25-35 %
Shear strength mass stabilisation 50 kPa

- Effective pressure in clay below 0,85 σ´c
Mass Stabilisation; Section 8/390-8/700
Loading step 1
Execution of mass stabilisation
Execution of mass stabilisation
Loading step 1
Preloading, Section 8/640

E.T. Hanrahan Memorial Symposium 2013-09-11
Follow-up; Settlements

Settlement vs time, Section 8/450

Stage 1
2002-04-08

Stage 2
2002-05-14

Stage 3
2002-08-12

8/450 H1

8/450 H8

E.T. Hanrahan Memorial Symposium 2013-09-11
Excavation down to top layer of mass stabilisation
Mass stabilisation – heave, settlement

- Peat
- Peat + cement before curing and consolidation
- Peat + cement after curing and consolidation
- Reference: Peat without stabilising agent after consolidation

Relative volume

Solids  □  Liquids  □  Gas

E.T. Hanrahan Memorial Symposium 2013-09-11
Mass stabilisation: For discussion

- Calculation model, settlements, magnitude and consolidation time
- Design, width of mass stabilisation, preloading
- Stability OK when unloading is used
- Choice of stabilising agents, characteristic values $c_{uk}$, correlation between properties in laboratory/field
- Good economy
- Other possible construction techniques
- Environmental aspects
Road 44 between Uddevalla and Trollhättan
Existental embankments on peat

BVS 1585.002 Stabilitet för befintliga järnvägar, version 1.0 (Stability for existent railroads)

E.T. Hanrahan Memorial Symposium 2013-09-11
Peat is a mysterious but friendly soil........
......but it could be in bad company
Thank you for listening