SUBSIDENCE OF PEATLAND CAUSED BY DRAINAGE, EVAPORATION, AND OXIDATION

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Abstract

Drainage, reclamation, and agricultural using of peatlands change their natural conditions, because the layers have originally a high pore volume and high water content. The subsidence of peatland is caused by three main effects, which are (1) compression of peat layers below the groundwater table, if it is lowered, (2) shrinkage of peat layer upon the groundwater table by desiccation, caused by evaporation, (3) oxidation/mineralization of the organic matter in the top layer, especially at arable land, depends on pH-value.

For the predicting of peatland subsidence we have to notice the following points: (1) type, decomposition and density of peat, (2) thickness of peat layer, (3) groundwater lowering, (4) reclamation and using, (5) climate condition.

Two formulae had been given to predict subsidence for predrainage and second drainage. The shrinkage of the peat top layers depends on the soil moisture tension (pF) and on the climatic and drainage conditions.

For several peatlands in Europe, Northern America and Asia the oxidation rates are correlated with climate dates.

Résumé (in French) see at the end.

Introduction

In Northwestern Germany the peatlands are soils, which man has occupied at last for agricultural use. Every utilization of peatlands (peat cutting, agriculture, horticulture, forestry) requires an adequate water management. Many peatlands of Northwestern Germany lie in lowlands along the bank of rivers near or below the main sea level. These peatland polders, mostly used as grassland, demand pumping stations.

Climate

Northwestern Germany belongs to the humid climate zone of Europe. Perennial winds from west and southwest cause a maritime climate with mild winter and relative cool summer. Table 1 shows the main climate dates.

Table 1. Mean dates of climate of Northwestern Germany

<table>
<thead>
<tr>
<th>Year</th>
<th>Mean or sum</th>
<th>Air temp. °C</th>
<th>Rel. air humidity %</th>
<th>Rainfall mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>January resp. winter</td>
<td>0.3</td>
<td>84</td>
<td>350</td>
<td></td>
</tr>
<tr>
<td>July resp. summer</td>
<td>16.7</td>
<td>78</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>Mean or sum Year</td>
<td>8.5</td>
<td>84</td>
<td>750</td>
<td></td>
</tr>
</tbody>
</table>
The climate diagram (figure 1) shows the annual course of temperature, rainfall, and potential evaporation for a normal year.

Figure 1.
Climate diagram for peatland pasture in Northwestern Germany

Soil types
A great portion of soils in Northwestern Germany is influenced by high ground-water level or generally by high rainfall. The proportion of peatlands is considerably great (table 2).

Table 2. Soil types in Northwestern Germany

<table>
<thead>
<tr>
<th>Soil types</th>
<th>Area</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gley-, river-, and marsh-soils</td>
<td>1,00</td>
<td>15.6</td>
</tr>
<tr>
<td>Peat-soils (peaty, fen, and highbog)</td>
<td>0.93</td>
<td>14.5</td>
</tr>
<tr>
<td>Sum</td>
<td>1.93</td>
<td>30.1</td>
</tr>
</tbody>
</table>

About 20 - 25% of these soil types lie in polder areas near the sea coast resp. in the river lowlands.

Peat soil structure
The soil structure is particularly important for the planning of soil meliorative (drainage) measures, because it influences the water storage as well as the air and thermal conditions of the soil. Soil structure is the three-dimensional arrangement of solid soil particles amongst and in relation to each other. The soil volume is subdivided into solid volume and pore volume and the latter is filled to varying degrees by water and air (Fig. 2.9.).
Peat soils do not have — contrary to mineral soils — a solid supporting structure. All types of peat have an unstable, fibrous, fungilike structure. The high pore space of 97 - 80 Vol.-% is nearly totally filled with water.

Drainage
Every modern utilization of peat soils in the humid, temperate zone needs an adequate drainage. This is attained, if in spring the ground-water level lies about 50 to 60 cm below surface. The experiences of the last decades have shown, that this drainage target is adequate. To calculate the proper drain spacing we need the formula of HOOGHOUDT (van BEERS, 1965).

For peatland drainage we have to respect the consequences of subsidence etc.

Subsidence
Drainage and reclamation of peat mean a disturbance of the natural conditions. This affects the typical properties of peat — high pore volume, high water content — and stops the accumulation of organic matter. Improved drainage and reclamation have three main effects, as:
- subsidence (compression) of the peat layers;
- shrinkage of the top layers;
- oxidation (mineralization) of the organic matter.

Subsidence (compression)
In peat soil the drainage releases physical effects, which never end. The macropore space and the hydraulic conductivity decrease, the bulk density and the subsidence increase.
Figure 3 shows the schematic connection for the whole time of drainage between solid matter content, macropore space, subsidence, and hydraulic conductivity. This phenomenon was found in many peatlands in Western Europe and other parts of the world.

If bogland is drained, the structure of the peat is modified. The coarse pores which, up till now, were filled with water, are emptied and later compressed. Consequently the air and water permeability is reduced (Figure 3). The soil dynamics set in motion by drainage, are practically unending and have been known for a long time as peat subsidence.

The surface subsidence to be expected in peat soils, after drainage at a normal drainage depth, may be calculated beforehand according to the empiric subsidence formula evolved by HALLAKOPRI - SEGBERG (1966).

The subsidence formula runs: \( S = a(0.080 \ T + 0.066) \);
where \( S \) = subsidence, \( T \) = peat depth (both in m) and \( a \) = factor of compacting density, which can be analytically determined via the solids volume. Figure 4 shows the nomogram of the subsidence formula and table 3 the relation between initial drainage, compactness, solid volume and subsidence formula.

Figure 4. Nomogram of the empirical subsidence formula.
Table 3. Relation between initial drainage, compactness, solids volume and subsidence formula for peat drainage.

<table>
<thead>
<tr>
<th>Evaluation according to initial drainage (in situ)</th>
<th>Relative compactness</th>
<th>Solids a in volume formula</th>
<th>Subsidence formula %</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>nearly floating</td>
<td>&lt; 3</td>
<td>4.0</td>
</tr>
<tr>
<td>Very reduced</td>
<td>loose</td>
<td>3 - 5</td>
<td>2.85</td>
</tr>
<tr>
<td>Reduced-moderate</td>
<td>rather loose</td>
<td>5 - 7.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Moderate-good</td>
<td>rather compact</td>
<td>7.5 - 12</td>
<td>1.4</td>
</tr>
<tr>
<td>Intensive + long</td>
<td>compact</td>
<td>&gt;12</td>
<td>1.0</td>
</tr>
</tbody>
</table>

For several peat sites we have compared the measured subsidence with the predicted subsidence. The results of predictions and measurements correspond rather well.

SEGEBERG (1960) has adapted in the subsidence formula the depth to which the ground-water is lowered. This approximation gives the following subsidence formula after SEGEREN (1974):

\[ S = \xi D_0 D_f 0.707 \]

where \( S \) = subsidence (m), \( D_0 \) = initial thickness of peat (m), \( D_f \) = final depth of drainage (m), \( \xi \) = coefficient.

The coefficient depends on the pore volume (P) as follows:

\[ \xi = 0.05 + \frac{1}{100 - P} \]

The rates of first surface subsidence after drainage vary between 0.5 m up to more than 3 m. New drainage causes new subsidence. For second or third drainage period the subsidence can be predicted by the following subsidence time formulae (table 4).

Table 4. Subsidence time formulae for second or third drainage periods by ILNICKI (1974).

<table>
<thead>
<tr>
<th>Relative compactness</th>
<th>Formula*</th>
<th>( t )</th>
<th>( S )</th>
</tr>
</thead>
<tbody>
<tr>
<td>loose</td>
<td>( S = 14.3 \cdot t )</td>
<td>0.412</td>
<td></td>
</tr>
<tr>
<td>rather loose</td>
<td>( S = 7.35 \cdot t )</td>
<td>0.476</td>
<td></td>
</tr>
<tr>
<td>rather compact</td>
<td>( S = 5.14 \cdot t )</td>
<td>0.485</td>
<td></td>
</tr>
</tbody>
</table>

*Where is \( S \) = subsidence in cm and \( t \) = time in year.

The subsidence after second (third) drainage varies between 10 cm and 50 cm for a period of about 30 years.

Peat surface oscillation

In natural peatlands the surface subsides in summer and rises in winter. This phenomenon is caused on the one hand by an evaporation surplus (in summer) and on the other hand by rainfall surplus (in winter) (compare climate diagram in figure 1).
The amplitude is influenced by the evapotranspiration of the different vegetations of fen or highbog. The annual oscillation amplitudes differ between 4 cm (for grassland), 6 - 10 cm (for moss vegetation), and 10 - 20 cm (for reeds); groundwater inflow from a river or lake reduces the oscillation.

**Shrinkage**
Shrinkage occurs in the topsoil above the phreatic level due to highly negative soil water pressure heads caused by an evaporation surplus. The degree of shrinkage depends on the thickness of the layers liable to shrinkage and on climatic and drainage conditions. Shrinkage causes crack formation and a considerable increase in hydraulic conductivity; the higher the peats are decomposed, the greater the shrinkage phenomenon will be. The rates of shrinkage vary between 10 mm up to 35 mm (SCHOTHRST, 1982).

**Oxidation/mineralization**
The oxidation resp. mineralization is a microbiological and chemical process in the top organic layer. It is influenced firstly by climate and type of peat, furthermore by chemical and physical soil conditions, soil moisture and depth of ground-water table, reclamation and cultivation, tillage and plant cover, etc.

On peat grasslands and forests the rate of oxidation is very small and may be compensated by the litter of leaves and/or remains of roots. Therefore the peat oxidation of arable and horticultural lands will be discussed here only.

**Peat Consumption in Different Climates**
For this analysis we collected many data on the loss of height of peatlands in Northern, Western, Eastern, and Southeastern Europe, in Northern America, and in Asia. We examined these data from soil science reviews. Then we compared these data with the climate conditions.

For this report we returned on the rain factor by LANG (1915) cited by EGGELSMANN (1976).

\[ f = \frac{R}{t} \]

where is \( R \) = the annual rainfall (mm) and \( t \) = the annual mean temperature (°C). LANG has used this factor to explain the main climate influence on the soil types in the different regions of the world.

For our analysis we must take the data of the main climate stations, but we know, that the climate in peat areas is generally influenced by the peat soil itself. There exists many investigations on the peat micro climate. But for this general survey the rain factor by LANG may be sufficient.

For 20 low moor peatlands the annual loss caused by oxidation is graphically plotted in fig. 5 together with the rain factor. A correlation of the logarithm data shows a very high significant correlation (\( r = 0.729^{***} \)). The curve shows the relation between the annual loss of height by oxidation and the climate expressed as rain factor. The smaller the rain factor, the higher will be the peat soil oxidation. The listed
six regions demonstrate the climate. in semiarid climate the
annual loss caused by oxidation increases up to 50 mm/a. Maxi-
mum values are 70 mm/a.

Figure 5. Annual loss of height caused by oxidation of the
organic matter in low moor soils (fens).

In fig. 6 the oxidation data of 14 reclaimed high-bog soils
are plotted versus the rain factor. High-bogs will be found
only in humid climate regions. But fig. 6 shows that first of
all the annual loss of height increases with decreasing rain
factor until a maximum with a rain factor of about 80 will be
reached, then the loss decreases too. This rain factor char-
acterizes as region with a rainfall of 560 to 640 mm and an
annual main temperature of 7 to 8 °C.

Figure 6. Annual loss of height caused by oxidation of the
organic matter in highbog soils.
For peatlands in Indonesia with oligotrophic wood peats the annual peat consumption caused by oxidation is rather small. The short vertical lines in fig. 6 show the fluctuation of the oxidation rate caused by groundwater depth, lime content (pH), kind of crops, and others. For low moor peatlands we have only plotted the means. The variance is larger than in high bog soils.

The rates of height loss caused by oxidation over a period of 30 years vary between 30 cm in (oligotrophic) highbogs and about 60 cm in (eutrophic) fens in humid climate resp. much more than 120 cm in warm climates.

Peatland protection
In the last decade in Northwestern Germany the peatlands without agricultural using got under peat protection, nature conservation or landscape reservation. Many protection areas got a hydrological protection zone.

by the drain spacing formula of HOOGHOUDET (van BEERS, 1969), the results of nearly peatland protection areas show table 5 (by KUNTZE & EGGELSMANN, 1981).

<table>
<thead>
<tr>
<th>Peat type</th>
<th>Width m</th>
</tr>
</thead>
<tbody>
<tr>
<td>deep high bog</td>
<td>30 - 80</td>
</tr>
<tr>
<td>shallow high bog above fine sand</td>
<td>120 - 150</td>
</tr>
<tr>
<td>shallow low moor above sand</td>
<td>200 - 350</td>
</tr>
<tr>
<td>spring-water bog, wooded swamp</td>
<td>&gt; 350</td>
</tr>
</tbody>
</table>

Final remarks
The period of peatland drainage for reclamation ended at about 1965. Only grasslands on peat, which are agriculturally used since several decades, require at some places a better subdrainage or a thin sand cover for an intensive using as pasture. These problems of the agricultural engineering are equivalent to that of nature conservation.

References
Affaissement du sol marnégeux
Suite au drainage, à l'évaporation et à l'oxydation

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Résumé

Le drainage, le défrichage et l'exploitation agricole des sols marécageux en changent l'état naturel, car, à l'origine, les couches possèdent un volume élevé de pores et une importante teneur en eau. L'affaissement d'un sol marécageux est le résultat de trois phénomènes principaux qui sont : (1) la compression des couches de tourbe en-dessous de la nappe phréatique si celle-ci baisse, (2) le tassement de couches de tourbe au-dessus de la nappe phréatique faisant suite à une dessiccation, elle-même causée par l'évaporation, (3) l'oxydation ou la minéralisation de substances organiques dans la couche supérieure, notamment dans les terres cultivées, dépend du pH.

Pour prédire l'affaissement d'un sol marécageux, il nous faut noter les points suivants : (1) nature, décomposition et densité de la tourbe, (2) épaisseur de la couche de tourbe, (3) baisse de la nappe phréatique, (4) défrichage et utilisation, (5) conditions climatiques. Il a été donné deux formules permettant de prévoir un affaissement pour un prédrainage et un second drainage.

Le tassement des couches supérieures de tourbe dépend de la tension d'humidité du sol (picofarad) et des conditions climatiques et de drainage.

Pour plusieurs sols marécageux d'Europe, d'Amérique du Nord et d'Asie, on a établi un rapport entre les taux d'oxydation et les données climatiques.