PEAT - STRENGTH AND STABILITY OF EXISTING RAILWAY EMBANKMENTS

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KEYWORDS

Peat, strength, field, laboratory, testing, anisotropy, undrained, stability calculations, embankments, railway

ABSTRACT

In the paper some selected results are presented from an on-going research project about strength of fibrous peat below embankments and stability of existing embankments on peat. Field and laboratory tests, and stability calculations of the railway embankment at site Missenträsk, are presented. The field case high light some important aspects when dealing with the task of calculating and determining the stability of an existing embankment on peat. The peat below the embankment shows significant undrained strength anisotropy and strength increase with time, and considering this clearly affects the calculated factor of safety of the embankment. A "new" way is compared with the "traditional" way of considering strength for stability calculations of embankments. The developed field sounding method CYPT shows the variation of strength with depth both in the peat below the embankment and in the peat at the bog beside the embankment.

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1. INTRODUCTION

Experiences in Sweden and e.g. the Netherlands often show low calculated safety factors of existing embankments on fibrous peat (low and medium decomposed peat). However, failure of embankments on fibrous peat rarely occurs. Fibrous peat most likely has a higher strength than what we measure and evaluate with present experimental methods [1], and thus there is a need for new knowledge and methods for strength determination.

In the paper is presented some results from an on-going research project conducted at SGI, in cooperation with the Swedish Transport Administration (Trafikverket), regarding undrained shear strength of fibrous peat and stability of embankments [2]. The study focuses on strength increase with time (long term) in vertical/active direction below existing embankments. Field and laboratory tests are conducted to study strength properties and a new peat probe and a new peat sampler have been developed and used in field in the project. Three sites with old and not any more used railway embankments overlaying fibrous peat, have been investigated in situ with the new developed peat probe called CYPT and for comparison also with the tests T-bar, CPT and field vane. The compressed peat below the embankment as well as the peat of the bog at the side of the embankment have been investigated. In the laboratory, triaxial tests, direct simple shear tests and different compression tests have been performed. The main objective of the project is to develop and bring forth a new working procedure to determine undrained shear strength of fibrous peat for stability calculations of embankments.

In this paper some selected results from field and laboratory tests, and stability calculations of the railway embankment at site Missenträsk, are presented.

2. TEST SITE

The test site at Missenträsk is a part of the no longer used railway between the villages of Jörn and Arvidsjaur in the north of Sweden, figure 1. The railway was built 95-100 years ago and traffic stopped around the year 1990.

The embankment at the site is 1,5 m thick and lays directly on the peat. The compressed peat layer below the embankment is about 2,0 m and overlays a till. At the bog at the side of the embankment the (natural, not compressed) peat layer is about 2,5-2,8 m thick.

The peat at the bog is generally classified as H2 according to the von Post scale, with the water content varying between 600-900 %. The peat below the embankment is classified as H2 and has a water content varying between 450-650 %.

Figure 1 Investigations of peat at the (no longer used) railway at the test site Missenträsk.

3. FIELD TESTS

Development of new probe CYPT and interpretation of results

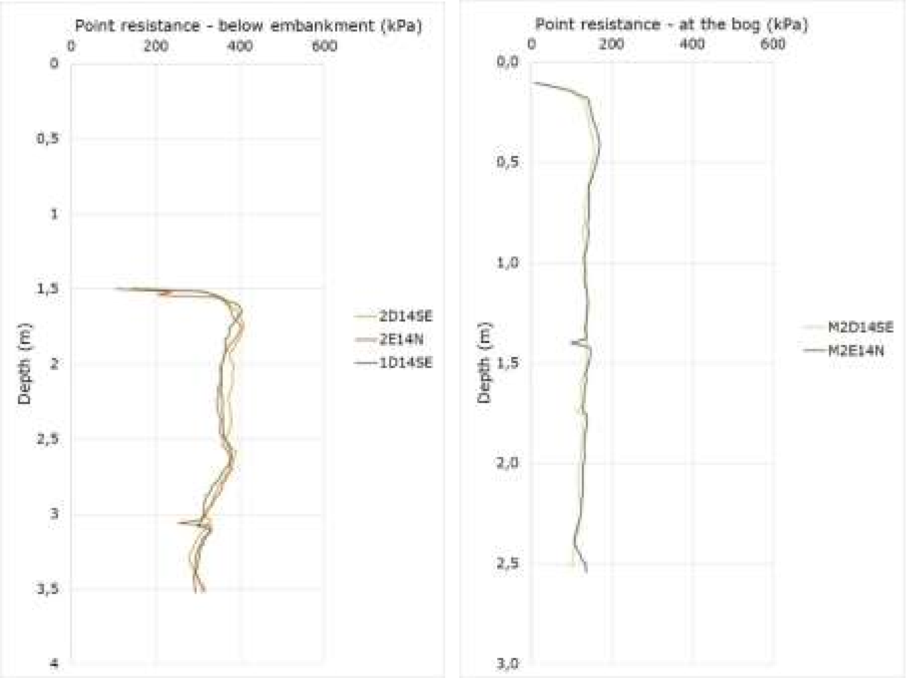
In the research project a new testing device for sounding in peat in situ has been developed, called CYPT (CYlindrical Penetration Test), [2]. Actually, five different variants of CYPT have been developed: one large with diameter 140 mm (research probe) and a small with diameter 70 mm (production probe), and with possibilities to either have the end surface (the point surface) attached with pins or being smooth (to evaluate effects of interface friction), and possibilities to have a single plate or double plates end (140 mm diameter). In figure 2 is shown two variants, CYPT 140 mm diameter with pins and CYPT 140 mm diameter double plates (inner and outer plate). The CYPT probe is connected to a standard CPT system and corresponding point pressure, sleeve friction, and pore pressure are registered, and the same penetration rate as in standard CPT was used. Using the double plate CYPT, the pressure on the outer plate is measured through the sleeve friction sensor and the inner plate through point pressure sensor (both plates have the same area). The idea of introducing two plates, and thus separating the inner and outer pressure, is to study the possible effects on the sounding resistance of tension forces in the fibrous peat.

a) b)

Figure 2 Two variants of the, in the research project, developed field sounding device CYPT, a) 140 mm diameter point surface attached with pins and a filter in the middle to measure the pore pressure, b) double plate (outer, inner) 140 mm diameter point surface with filter in the middle, (CYPT held upside down in the pictures).

In figure 3 some selected results from testing with CYPT in peat below embankment and peat beside embankment at the bog at site Missenträsk are presented. The variation of point resistance with depth is similar below the embankment and at the bog, there is a maximum point resistance after about 0,2-0,3 m and after that the resistance decrease with depth. The point resistance is, however, much higher below the embankment compared to at the bog, indicating a much higher strength of the peat below the embankment. Furthermore, as expected the point resistance decreases with depth and thus the strength of the peat below the embankment decreases with depth (significant reduction of point resistance at 1,1-1,2 m depth of the peat layer below the embankment).

In the research project the results of the CYPT have been compared with results from the field methods T-bar and CPT, and all three sounding methods show in general the same variation with depth of point resistance, both for (natural, not loaded) peat at the bog and for peat below the embankment. This suggests that the data received from the CYPT correspond to the variation of strength with depth. In the on-going research project the possibilities of using results from CYPT to also evaluate undrained shear strength of peat is investigated. Comparisons with and possible correlations to triaxial test data are searched for.



a) b)

Figure 3 Field testing with the new sounding method, CYPT, point resistance versus depth (note different depth scales and depth references in figure a and b), a) in peat below the embankment (starting 1,5 m below the upper surface of the embankment), b) in peat at the bog beside the embankment.

4. LABORATORY TESTS

Mechanical behaviour of peat and strength evaluation

Triaxial tests have been conducted to study the undrained behaviour and to evaluate strength of the peat. In figure 4 the stress-strain, pore pressure change and effective stress path responses from some of the triaxial compression (active) undrained tests conducted on peat at site Missenträsk are presented. Samples of peat taken from below the embankment (i.e. peat in situ loaded and compressed by the embankment during many years) and from the bog beside the embankment (i.e. peat natural in situ not loaded) have been investigated.

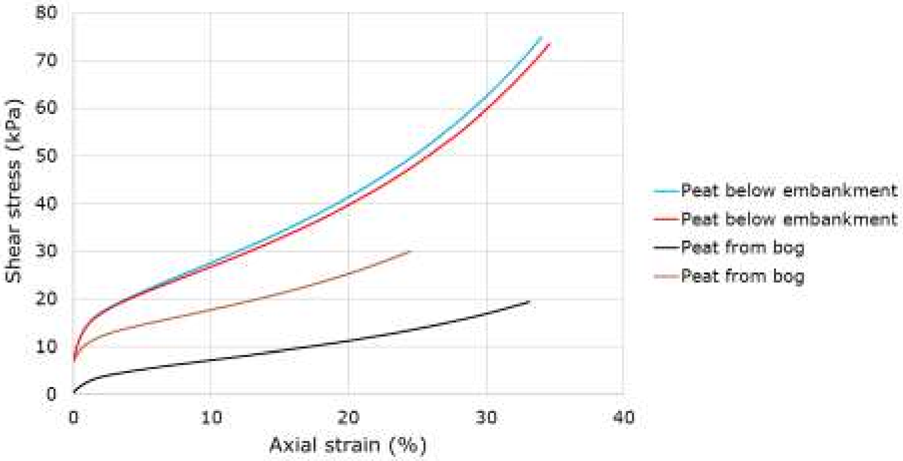
For the samples taken below the embankment, at small axial strains, about 0.5 to 1.5 %, there is a bend in the shear stress – axial strain curve, figure 4 a. The high initial stiffness significantly decreases after the bend and between about 2-3 % to about 15 % axial strain the stiffness is close to constant, i.e. there is a almost a linear stress-strain relation. For axial strains larger than about 15 %

the stiffness increases during the rest of the shear, i.e. the curve bends (weakly) upwards. The stress-strain response of samples from the bog is qualitatively the same as for the samples from below the embankment. The differences being lower stiffness and lower shear stress for the samples from the bog. The peat samples from below the embankment, and one of the peat samples from the bog, were consolidated (stresses applied before the shear phase shown in figure 4) in the triaxial test for a pressure corresponding to the (long term) load of the embankment (i.e. about 28 kPa effective vertical stress) and one of the samples from the bog consolidated for low stresses (here 7 kPa effective vertical stress).

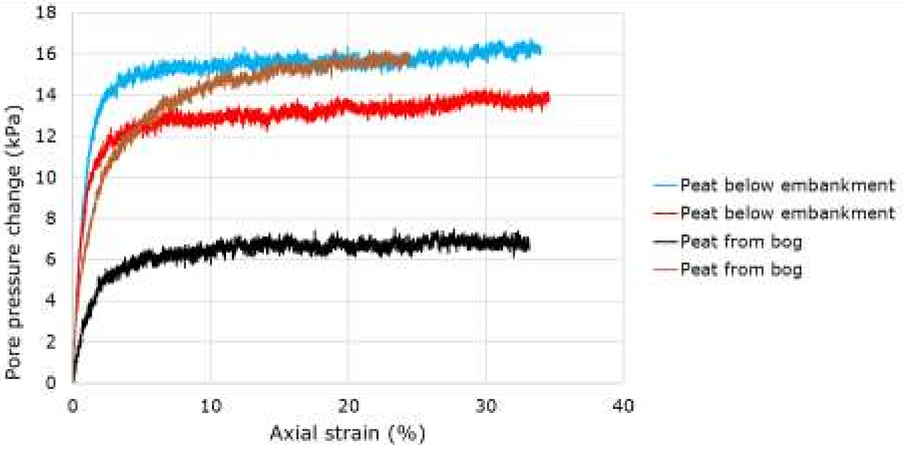
The effective stress paths first go upwards to the left, i.e. the mean effective stress decrease during an increase in shear stress, after which the stress paths turn upwards to the right, i.e. the mean effective stress increase and the shear increase during the rest of the shear, figure 4 c. During the first part of the shear there is a high pore pressure increase, which significantly contributes to the stress path going to the left, after which the pore pressure increase is small, figure 4 b. The response is principally the same for samples from below the embankment as from the bog.

In the triaxial compression tests on peat from both below the embankment and from the bog the shear stress increase with increasing strain, i.e. no peak value of shear stress is achieved. This strain-hardening behaviour is typical of most fibrous peat independent if drained or undrained triaxial tests are conducted [3]. Strengths used as input for stability calculations of the embankment in Missenträsk (Chapter 5) has been chosen to be evaluated as the shear stress at 15 % axial strain in the triaxial tests (and at the shear stress at 0,225 radians in the direct shear tests).

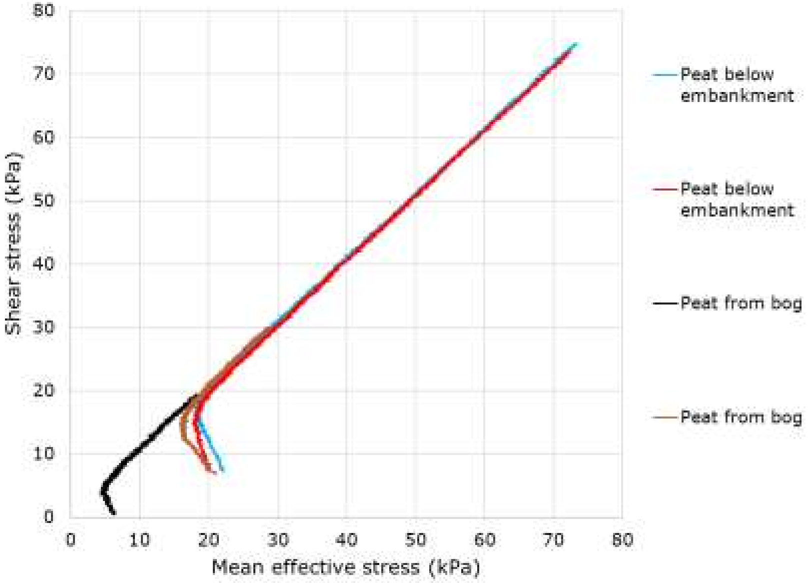
Triaxial extension (passive) undrained test and undrained direct simple shear tests have also been conducted on peat samples from the site Missenträsk (not showed in this paper).


Shear stress (kPa)
80
70
60
50
40
30
20
10
0
0
10
20
30
40
Axial strain (%)
Peat below embankment
Peat below embankment
Peat from bog
Peat from bog

a)


Pore pressure change (kPa)
18
16
14
12
10
8
6
4
2
0
0
10
20
30
40
Axial strain (%)
Peat below embankment
Peat below embankment
Peat from bog
Peat from bog

b)



c)

Figure 4 Triaxial undrained compression (active) tests conducted on peat from below embankment and from the bog, test site Missenträsk, a) shear stress (axial – radial stress) versus axial strain, b) pore pressure change versus axial strain, c) effective stress paths with shear stress (axial stress – radial stress) versus mean effective stress ((effective axial stress + effective radial stress)/2).

5. STABILITY CALCULATIONS

Calculations of embankment stability according to “new” and “traditional” methodology

For the studied section of the railway embankment at Missenträsk stability calculations have been performed. Stability has been studied for two different ways of applying the undrained shear strength. In the first case, “new” methodology, suggested in the research project, strength anisotropy and strength increase with time of peat below embankment is considered. In the second case, “traditional” methodology, strength anisotropy is not considered, and strength is based on investigations of peat at the side of the embankment. The stability calculations are used mainly to show the differences in calculated safety factor comparing the “new” and the “traditional” way. The calculations do not claim to e.g. capture a true failure mechanism.

In the calculations undrained conditions in the peat are assumed and thus the strength of the peat can be described by undrained shear strength. Here is presented results from using the traffic load 32 kN/m^2, refers to soil conditions of the embankment after about 95 years of construction. The calculations are conducted using Morgenstern-Price's method of slices and according to and using the stability calculation software Slope/w (GeoStudio version 2021.4) [4].

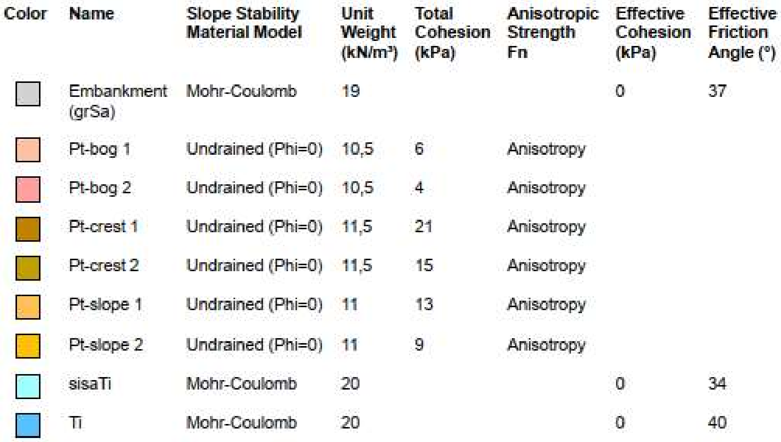
For the "new" methodology considering strength anisotropy, the undrained shear strength values of the peat below and beside the embankment are based on undrained triaxial tests (active, passive) and undrained direct simple shear tests conducted on samples taken from below the embankment and from the bog beside the embankment. The variation of strength with depth, for both "new" and "traditional" methodology, is based on in situ tests using the new probe CYPT (and T-bar and CPT).

In figure 5 is presented the soil profile, chosen parameter values and the failure surface corresponding to the calculated lowest factor of safety for the "new" calculation case. The peat is divided into an upper and lower layer below the embankment, below the slope and beside the embankment. Since the undrained shear strength decrease with depth below the embankment the peat is divided into an upper and lower layer with different strengths. The side boundaries of the layers are assumed to have a slope of about 3:1, and this is based on the deformation pattern obtained in previous laboratory model tests on fibrous peat conducted at SGI [3].

Based on the results of the undrained triaxial tests (active, passive) and undrained direct simple shear tests on peat from below the embankment, the active strength was set to 1.6, and the passive 0.7 times the direct shear strength. The same strength anisotropy relations were assumed for the peat beside the embankment.

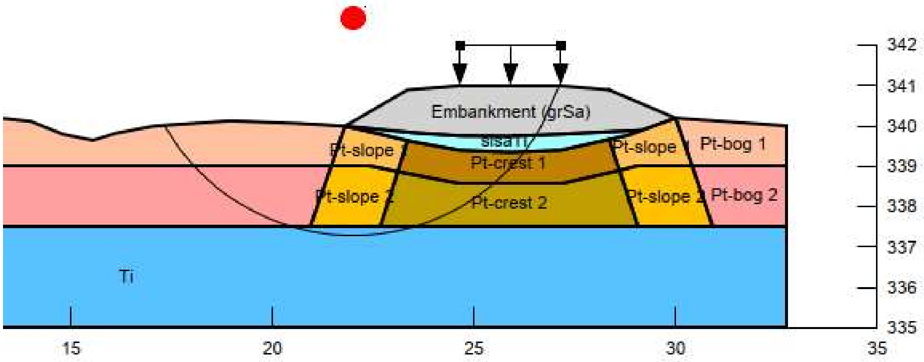
The evaluated undrained shear strength from the direct simple shear tests on peat from below embankment is 21 kPa, which is seen in figure 5 as input for the upper layer. Based on tests with CYPT (and other sounding methods) it is seen that the resistance (and undrained shear strength) is about 0.7 of that in the upper layer, giving direct shear strength 15 kPa in the lower layer, see figure 5. Thus, the strength of the upper layer of peat is in this case based on laboratory test results and the lower layer of peat based on the field sounding method results, by correcting the strength results from the upper layer. The values of peat below the embankment slope are assumed (interpolated) based on the values from below embankment and from beside of the embankment.

In figure 6 is presented the soil profile, chosen parameter values and the failure surface corresponding to the calculated lowest factor of safety for the "traditional" calculation case, where isotropic (same in all directions) strength conditions are assumed. The soil layers are similar but simplified as compared to "new" case (figure 5). The undrained strength (direct shear) is 5 kPa for the peat beside the embankment. In the upper layer below the embankment the strength is 13 kPa, evaluated from an undrained direct simple shear test conducted on peat from beside embankment and consolidated in the direct shear test for the load of the embankment, i.e. the load that is acting on the peat below the embankment. The strength of the lower layer is set to 0,7 times the upper layer, yielding 9 kPa.



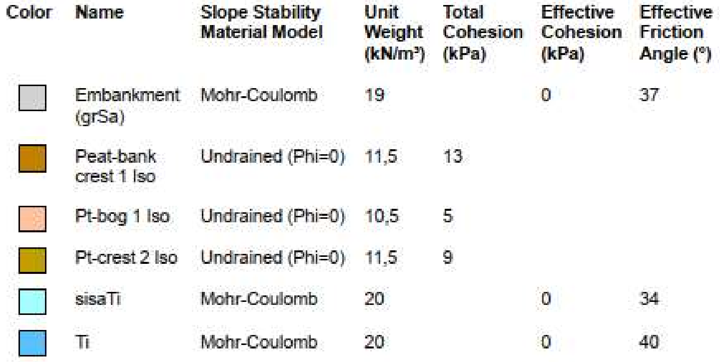
Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Total Cohesion (kPa)	Anisotropic Strength Fn	Effective Cohesion (kPa)	Effective Friction Angle (°)
⬜	Embankment (grSa)	Mohr-Coulomb	19			0	37
🟧	Pt-bog 1	Undrained (Phi=0)	10,5	6	Anisotropy		
🟥	Pt-bog 2	Undrained (Phi=0)	10,5	4	Anisotropy		
🟫	Pt-crest 1	Undrained (Phi=0)	11,5	21	Anisotropy		
🟫	Pt-crest 2	Undrained (Phi=0)	11,5	15	Anisotropy		
🟨	Pt-slope 1	Undrained (Phi=0)	11	13	Anisotropy		
🟨	Pt-slope 2	Undrained (Phi=0)	11	9	Anisotropy		
🟦	sisaTi	Mohr-Coulomb	20			0	34
🟦	Ti	Mohr-Coulomb	20			0	40

a)



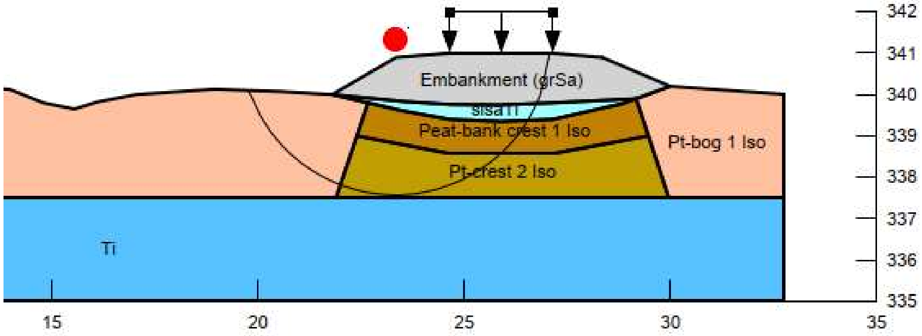
b)

Figure 5 Calculations of stability of railway embankment at Missenträsk according to "new" methodology, a) Parameter values chosen for stability calculations b) Soil model and the slip surface with lowest calculated factor of safety for a traffic load of 32 kN/m^2.



Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Total Cohesion (kPa)	Effective Cohesion (kPa)	Effective Friction Angle (°)
⬜	Embankment (grSa)	Mohr-Coulomb	19		0	37
🟫	Peat-bank crest 1 Iso	Undrained (Phi=0)	11,5	13		
🟧	Pt-bog 1 Iso	Undrained (Phi=0)	10,5	5		
🟨	Pt-crest 2 Iso	Undrained (Phi=0)	11,5	9		
🟦	sisaTi	Mohr-Coulomb	20		0	34
🟦	Ti	Mohr-Coulomb	20		0	40

a)



b)

Figure 6 Calculations of stability of railway embankment at Missenträsk according to “traditional” methodology, a) Parameter values chosen for stability calculations b) Soil model and the slip surface with lowest calculated factor of safety for a traffic load of 32 kN/m^2.

The lowest calculated factor of safety for undrained failure is 1,48 when considering strength anisotropy (“new” methodology) and 0,91 when assuming isotropic conditions (“traditional” methodology).

The failure surface (for lowest factor of safety) goes down slightly in the underlying till layer for the case considering anisotropy, because below the slope toe the effective stresses are very low and thus the shear strength low in the uppermost part of the till. However, in the isotropic case, the failure surface only touches the till layer because the undrained shear strength is lower in the peat than the drained shear strength in the uppermost part of the till.

6. CONCLUSIONS

The field case showed in this paper high light some important aspects when dealing with the task of calculating and determining the stability of an existing embankment on peat.

When considering strength anisotropy and strength increase with time and depth, of peat below an existing embankment according to the suggested "new" methodology, the calculated factor of safety becomes much higher than when conducting "traditional" analyses and calculations.

To not consider strength anisotropy and underestimating strength increase below an embankment, is probably a main explanation behind that existing embankments sometimes show calculated factors of safety that are low or below one, without that any failure having occurred.

Fibrous peat is in general a strain-hardening material, meaning that the peat may take more and more load without going to failure. This is something that should be considered when calculating stability and bearing capacity of embankments on peat, e.g. when choosing failure criteria for evaluation of experimental data or a constitutive model to simulate the behaviour of peat.

The field sounding method, CYPT, developed in the research project seems to be able to capture the variation of strength of peat with depth, both below an embankment and at a bog.

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