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Centrifuge modelling of sand and sawdust embankments on peat for sustainable infrastructure development

Modélisation par centrifugation de remblais de sable et de sciure sur tourbe

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ABSTRACT: Previously accepted methods to develop infrastructure across peatlands such as roads or railways typically excavated out the peat and substituted it with granular material. Such solutions, especially the alteration to drainage, can disturb peatlands and emit large amounts of greenhouses gases. The work on the GEOLAB / CLARIFIER (Centrifuge modeLling of peat embAnkments foR critical inFrastructure In EuRope) project explores the use of an innovative combination of sawdust and sand as embankments for rural roads, a technique which has previously been used in Norway. Although this previous work shed light on the deformation behaviour, very little is currently known about the performance during traffic loading and about the failure mechanisms of such embankments. A series of centrifuge tests were performed as plate loading tests and on sawdust and sand embankments at Deltares. The testing was carried out on intact peat using large block samples which were recovered from a site in Trondheim, Norway. In addition to extensive instrumentation, two colour cameras were used to capture images throughout the centrifuge tests to allow image-based deformation analysis. This paper provides an overview of the project as well as some preliminary results.

RÉSUMÉ: Les méthodes précédemment acceptées pour développer des infrastructures à travers les tourbières, telles que des routes ou des voies ferrées, consistaient généralement à extraire la tourbe et à la remplacer par des matériaux granulaires. De telles solutions, notamment la modification du drainage, peuvent perturber les tourbières et émettre de grandes quantités de gaz à effet de serre. Les travaux du projet GEOLAB / CLARIFIER (Centrifuge modelling of peat emAnkments for crucial inFrastructure In EuRope) explorent l'utilisation d'une combinaison innovante de sciure de bois et de sable comme remblais pour les routes rurales, une technique qui a déjà été utilisée en Norvège. Bien que ces travaux antérieurs aient mis en lumière le comportement en déformation, on sait actuellement très peu de choses sur les performances lors du chargement du trafic ucialet sur les mécanismes de rupture de tels remblais. Une série d'essais de centrifugation ont été réalisés sous forme d'essais de chargement de plaques et sur des remblais de sciure et de sable à Deltares. Les tests ont été effectués sur de la tourbe intacte à l'aide de gros blocs d'échantillons récupérés sur un site de Trondheim, en Norvège. En plus d'une instrumentation étendue, deux caméras couleur ont été utilisées pour capturer des images tout au long des tests de centrifugation afin de permettre une analyse de déformation basée sur l'image. Cet article fournit un aperçu du projet ainsi que quelques résultats préliminaires.

Keywords: Peat; embankments; centrifuge; soil characterisation; DIC: digital image correlation.

1 INTRODUCTION

There is an increasing need to develop roads and other critical infrastructure across peatlands, e.g. for low trafficked roads in rural areas, housing estates and for upland renewable energy projects. In the past the peat would have been dug out and replaced by imported

granular material. This type of solution is no longer acceptable for environmental and cost reasons. This project investigates the use of innovative, low cost and sustainable road construction in peatland using a combination of sawdust and sand to form the road embankments. The main knowledge gap is that the failure mechanism of such a construction on natural fibrous peat is unknown. There are no methods available to design such systems against bearing capacity failures or to assess whether the structure remains within serviceability limits. To address this some centrifuge testing of model embankments was carried out over 1 month at the facilities of Deltares in The Netherlands as part of the project CLARIFIER, funded by the EU GEOLAB scheme. This paper gives an overview of the project and some preliminary results.

2 ABOUT GEOLAB

GEOLAB is a European network of renowned institutes bringing together eleven unique installations in Europe aimed to study subsurface behaviour and the interaction with structural elements, and the environment. Critical Infrastructures (CI) and their service in the water, energy, urban and transport sectors are at risk due to climate change, extreme weather, geohazards, and aging. The overarching aim of GEOLAB is to integrate and advance these key national research infrastructures for performing ground-breaking research and innovation that enhances the resilience of Europe's CI. GEOLAB is led by Deltares and has received funding from the European Union's Horizon 2020 Research and Innovation program under grant agreement No. 101006512 (https://project-geolab.eu/).

3 THE DELTARES CENTRIFUGE

The GeoCentrifuge at Deltares is a beam centrifuge with a 260 g-tonne capacity and a platform radius of 5.0 m. The device is produced by Actidyn and the model designation is C72-31. The platform of the centrifuge can house test subjects with dimensions up to 1.2 m × 1.2 m × 1.2 m. The data-acquisition system is supplied by HBM and has 56 channels with a simultaneous sampling rate of 100 kHz. Beyond conventional sensors, the centrifuge is equipped with two 4K cameras and two high-speed cameras which are routinely used for digital image correlation (DIC) applications. While the 4K cameras can capture images with 31 MP (megapixel) resolution at 26 fps frame rate, the high-speed cameras can capture images with a resolution of 2 MP at 2500 fps frame rate for a period of 4 s. Figure 1 illustrates the CLARIFIER test setup onboard the platform of the Deltares GeoCentrifuge.

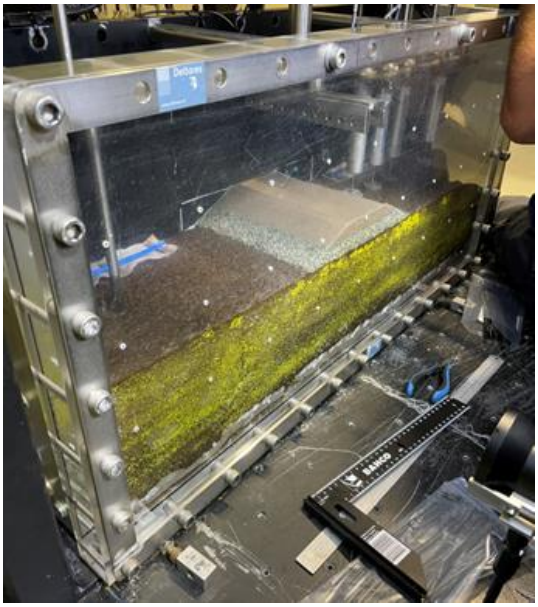

Figure 1. Deltares centrifuge with the test setup (notice the green tracers/speckles for DIC).

4 MOTIVATION AND AIMS OF PROJECT

The motivation for this project was the availability of construction records and long term settlement data from four trial embankments constructed of sawdust and sand which were placed directly on peat by NGI and NPRA in 1963 and 1964. These embankments are still accessible. Their purpose was to investigate the use of sawdust for low cost lightly trafficked roads and railway lines in rural areas. The embankments were constructed in Kongsvinger in south-eastern Norway and at Slåttemyra in Nordmark just north of Oslo. A summary of the experience gained from these embankments is given by Long et al. (2023).

5 SOIL SAMPLING

Large block samples of natural peat were extracted from a site at Tiller-Flotten some 11 km south of Trondheim city centre (Figure 2). The peat research area is located immediately adjacent to the Norwegian Geo-Test Site (NGTS) quick clay area (L'Heureux et al., 2019). Sampling was carried out to ISSMFE (1981). The block samples were cut using a serrated knife and subsequently sealed with cling film to avoid drying. Wooden boxes with dimensions of 930 (length) x 280 (width) x 215 (height) mm and 930 x 280 x 315 mm were used for transport. Eight of these samples were successfully transported to Delft from Trondheim via car and ferry.

Figure 2. Block sampling at Tiller-Flotten site.

6 PEAT CHARACTERISATION

The peat from Tiller-Flotten is characteristic of other peats in the Trondheim area and in Norway in general (Long et al., 2022). It is a very soft highly compressible fibrous peat. It has an average water content of 1150%, a density of 1.05 Mg/m^3 and its loss on ignition (LOI) is between 95% and 98%. Its von Post degree of decomposition (H) is equal to 3.

7 OVERVIEW OF CENTRIFUGE TESTS

An overview of the seven centrifuge tests carried out is given on Table 1. Three of the tests involved plate loading tests to investigate failure mechanisms during loading with different g levels being used. The remaining four tests involved a model embankment made of sand and sawdust. The test layout, for the tests where a model embankment was included, is shown in Figure 3. The intention was to test a prototype peat layer of 7.5 m in thickness. Therefore, for the plate loading tests the samples were trimmed to between 150 mm and 250 mm in height. For the embankment tests a uniform g level of 50 was assumed, giving a 150 mm peat height and a total embankment height of 40 mm in model scale. Water level was maintained at the top of the peat.

Data obtained during the testing included vertical displacement of the surface of the peat using displacement transducers (LVDT in Figure 3), pore water pressures, total pressures as well as the load versus displacement of the loading piston. A mini cone penetration test (CPT) with a diameter of 11 mm was conducted on each test specimen. In addition to the instruments in the strongbox, soil deformations on the front window of the strongbox were derived using the open-source DIC software GeoPIV (Stanier et al., 2015) from pictures taken with two cameras.

Table 1. Overview of centrifuge tests.

No.	g-level	Plate (P) or embankment (E)	Peat water content (%)	von Post H
1	50	P	1423	3
2	30	P	1314	4
3	75	P	788	3
4	50	E	1137	4
5	50	E	695	3
6	50	E	639	3 to 4
7	50	E	663	3

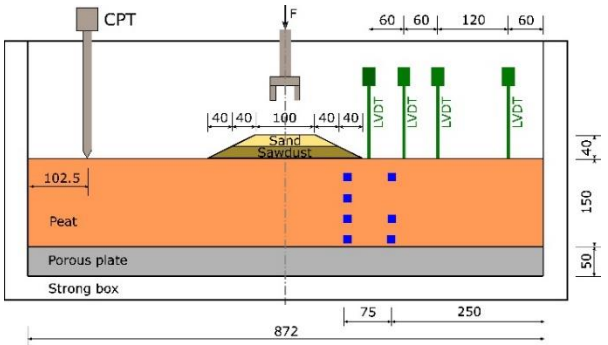

Figure 3. Test layout. CPT = mini cone penetrometer test, F = load cell, LVDT = linear variable differential transformers and P = pore pressure transducers. Dimensions in mm and model scale.

8 SOME PRELIMINARY TEST RESULTS

Figure 4 shows preliminary results from the plate loading tests. The load was measured by a load cell while keeping the displacement rate constant. The peat displacements were analysed using GeoPIV and are shown as vertical and horizontal contours.

Typical images obtained during the centrifuge test series to subsequently perform the image-based measurement technique are shown in Figure 5. Figure 1 shows the sand and sawdust embankment on the natural peat before starting the centrifuge test. Peat and embankment deformation due to increase of the gravitational acceleration can be seen in Figure 5a. Figure 5b shows the deformed embankment and peat due to traffic loading.

An interesting observation from Figures 4 and 5b is that the peat deformations during loading are different to typical bearing capacity failures. This implies that design concepts for mineral soils may not apply for peat. The design of such embankments on peat may be governed by the serviceability limit state. Some impressions from the tests can be found on the movie: Deltares Clarifier Project – YouTube and the CLARIFIER data is available on the ZENODO platform; DOI: 10.5281/zenodo.8099793.

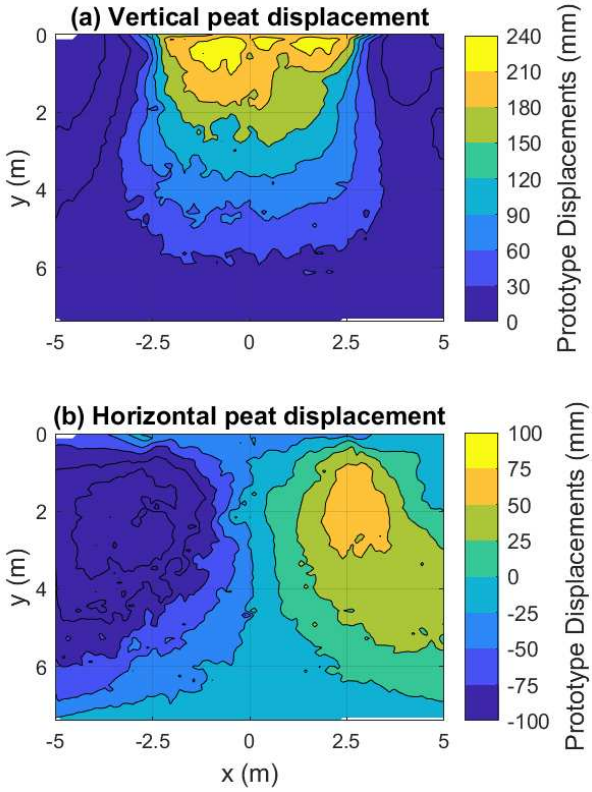

Figure 4. Example results from a plate loading test: (a) vertical displacement contours and (b) horizontal displacement contours.

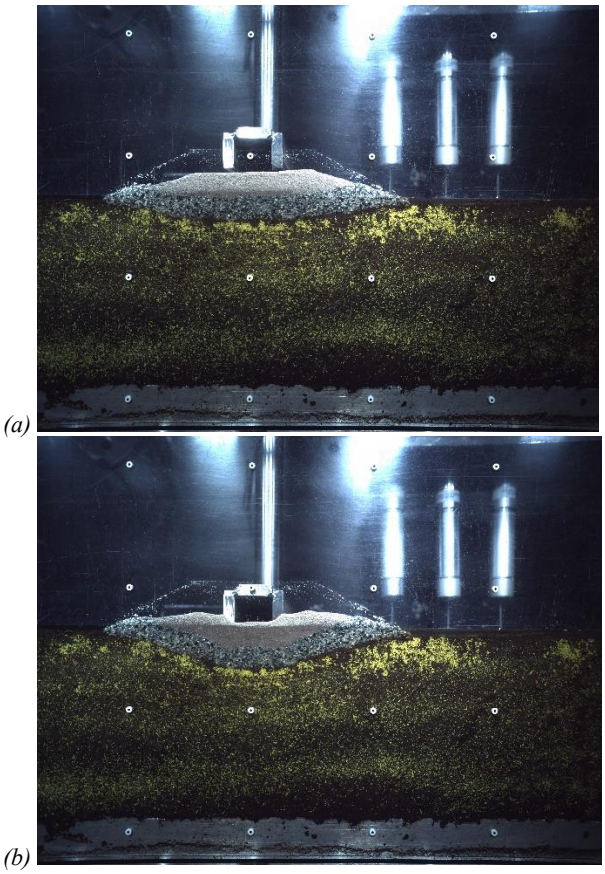

Figure 5. Observations during a sand and sawdust embankment test: (a) spin-up and (b) traffic loading.

9 CONCLUSIONS AND FUTURE WORK

This contribution introduces a centrifuge tests series which studies the performance of an intact peat during loading and its interaction with an embankment composed of sand and sawdust. Block samples of intact peat were obtained from Tiller-Flotten, Norway. The centrifuge tests of these samples were carried-out at Deltares and were part of the GEOLAB project. Preliminary results indicate that failure mechanism suggested for embankments on mineral soils may not apply for peat. Future work will focus on detailed analysis of the experimental data. In addition, the data will be explored to calibrate numerical models.

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