Benchmarking of three penetrometers for identification of fluid mud layers

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Introduction

Fluid mud, a highly concentrated suspension of solids and organic matter, is a known phenomenon which occurs in harbours and waterways worldwide. The nautical bottom lies within the fluid mud layer and is defined by the density or rheological properties of the mud (Wurpts, 2005). Fluid mud is navigable under certain conditions, but consolidating mud layers have to be dredged to ensure a deep enough navigation depth. PIANC defined the critical density for the transition from navigable to non-navigable mud at 1200kg/m³ (PIANC, 1997). To keep dredging volumes and costs to a minimum it thus is important to distinguish navigable from non-navigable mud layer.

Acoustic echo sounders are commonly used to determine fluid mud deposits but they are not suitable for a detailed resolution of the nautical bottom depth (Wurpts, 2005). Seifert and Kopf (2012) have shown that dynamic cone penetration testing with pore pressure measurements can be a supplementary method for *in-situ* identification, characterization and quantification of fluid and soft mud layers.

Aim of this survey was to deepen the knowledge on penetrometer performance upon impact into fluid mud layers and to compare and correlate the results.

Method

In order to not have to deal with tidal currents and be restricted to the short time span during slack tides for measurements, an artificial environment, provided at a test facility by dotOcean, was chosen for this survey. The test facility is located at Zeebrugge Harbour (Belgium) and consists of a hollow pile filled with water, into which two exchangeable buckets filled with controlled layers of fluid to consolidating mud of two sources were placed consecutively. A layer of sand as a security layer was added before filling one of the buckets with mud. Three differently shaped penetrometers were used during this survey: (i) GraviProbe (dotOcean), (ii) NIMROD (MARUM) and (iii) a dynamic CPTu lance (MARUM). GraviProbe was developed for the special purpose of assessing rheological and density conditions of sediment layers, NIMROD and the dynamic CPTu lance are penetrometers designed for investigation of sediment strength. The penetrometers were deployed into the test environment in various (geometrical) set-ups and in either free-fall mode or via a winch at various velocities.

During deployment and impact into the mud deceleration, pore pressure and tip resistance among other parameters were measured. These primary parameters were used to calculate secondary parameters such as impact velocity, penetration depth, density, sediment resistance force and (dynamic) undrained shear strength. For now the focus mainly lies on the pore pressure and deceleration measurements.

Results

First results show that the pore pressure signal and the density, which is based on pore pressure measurements as well as tip resistance as a function of tip sensitivity and geometry are the most reliable parameters for identifying the impact into the fluid mud layer. Significant deceleration mainly occurs when the penetrometers enter mud or sand layers which are stiff and/or rough enough to slow down the penetrating device.

GraviProbe data gave a good insight into the density of the mud layers. Density increased rapidly from 1020kg/m³ in the water column to values exceeding 1200kg/m³ in the first bucket, in the second bucket this increase was less rapid. This implied that in bucket 1 the fluid mud layer was less thick (approx. 0.15m) than in bucket 2 (approx. 0.9m). The underlying consolidating mud was about 1.30m and 2.20m thick, respectively. Maximum density was reached at 1350kg/m³.

NIMROD and CPTu data showed partly significantly differing deceleration and pore pressure signals, dependent on set-up geometry and/or deployment velocity.

In bucket 1, NIMROD data showed a distinct deceleration signal upon impact into the mud, especially when using a cylindrical tip on the device in free-fall mode. The overall penetration depth is in good agreement with the GraviProbe results for mud thickness. In bucket 2 the deceleration only occurred in the bottommost layers and is more pronounced in deployments in free-fall mode.

Regardless of tip geometry and deployment velocity, the pore pressure decreased to subhydrostatic values during impact into the mud, but the depth where this decrease sets in is not constant throughout all data sets.

When using the conical tip on the CPTu lance pore pressure decreased to subhydrostatic values as soon as the penetrometer impacts the fluid mud, but for a ball- or disk-shaped tip the pore pressure increased to suprahydrostatic values. The depth of this kink in pore pressure signal is in good agreement with the one for the increase of tip resistance when using a more sensitive tip and was also observed by Seifert and Kopf (2012) before. The deceleration signals only showed the impact into the bucket bottom.

Discussion

The penetrometer type, set-up, tip geometry and sensitivity have a major effect on how the data look. On one hand, pore pressure decreases with NIMROD and the CPTu lance upon impact in the mud if a tip geometry is chosen which displaces the sediment (cone, hemisphere, cylinder). On the other hand, it increases if a so called full-flow tip geometry (ball, disk) is chosen around which the sediment has to 'flow'.

We identified three factors which compromised the data quality: (i) unreliable pore pressure measurements, (ii) variable deployment velocity and (iii) a too slow deployment velocity.

As the pore pressure obviously is a very important parameter in such a study, the pore pressure sensor has to work impeccably. During several deployments in this survey the filter ring sitting in front of the pore pressure port on the MARUM devices got clogged by clayey material and hampered transmission of pressure transients to the sensor. While the absolute values are dampened, the relative evolution of pore pressure with depth was still valuable. To prevent unreliable pore pressure data, the filter ring has to be watched carefully and needs to be exchanged or cleaned even more frequently than usual. This problem does not transfer to GraviProbe, which does not have a filter of porous metal.

The pore pressure evolution is also a matter of deployment velocity. The faster the deployment velocity, the steeper is the gradient of the pore pressure signal. To guarantee that any change in (pore pressure) signal is due to a change of physical properties of the penetrated matter, the penetration velocity needs to be kept constant throughout a single deployment. However, a too slow deployment velocity (< 0.1m/s) is not advisable. At faster deployment velocities measurements get more pronounced due to the rate effect at dynamically operated cone penetration testing in cohesive sediments (Dayal and Allen, 1975).

In general the results of this survey show that penetrometer can be used to geotechnically characterise fluid and consolidating mud layers, but further refinement of the deployment method is needed for the MARUM devices in order to guarantee good results at the best possible vertical resolution, even in free fall. Moreover a correlation of pore pressure, deceleration and tip resistance values by NIMROD and the CPTu lance to density measurements of GraviProbe has to be set up.

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