SOIL-STRUCTURE INTERACTION

SESSION LEAD MONICA PREZZI/BARRY LEHANE

Presented papers:

Evaluation of monopile embedment using frequency, damping and modal shape analysis. Presented by : M. Maron

ABSTRACT

The design of monopiles foundation for Offshore Wind Farms requires the characterisation of the rigidity between the soil and the shaft of the pile. While soil investigation methods are normally used, return of experience with measured data is rarely available. This paper presents a series of simple dynamic tests, performed on two 1:6 scaled monopiles foundation installed in rock as part of a lateral pile test campaign. Results of the dynamic tests can be compared with the theoretical fixed beam using frequency, damping and modal shape parameters with the aim of assessing to rigidity of the soil-structure interaction. The tests were carried out onshore France in 2016 by FUGRO and EDF-RE for offshore wind farms development projects as an add-on to a large-scale pile testing program. Two foundation piles of 1.2 m diameter, partially installed into Calcarenite, received a range of lateral dynamic strokes. The dynamic response of each pile was recorded at high frequency by accelerometers installed along the stick-up length of piles. The results were analysed to identify the lowest resonant frequency and subsequent vibration patterns. In addition, logarithmic decrement analyses and modal deformation analyses were performed to better understand the piles dynamic response. Comparing those results to the theoretical values of a fixed beam provides valuable information and help to assess the as-built connection between the rock and the piles. Such information can be used at design stage to quantify the rigidity of interaction between the soil and the pile. It can also be used during the lifetime of the foundation to monitor the time evolution of this connexion.

Experimental and numerical study on behaviour of three types of model pile foundations subjected to vertical and horizontal loading. Presented by : Xiong

ABSTRACT

In recent years, efficient installation methods of piles have been developed. Nowadays, a challenge in piling engineering is to reduce costs including transportation and construction costs, and at the same time to keep safety of foundation structures. Hence, a target in this research is to show a possibility to use steel sheet piles for permanent piled raft foundations, because time and cost of construction of sheet piles could accurately be lower than those of pipe piles. In this study, a series of model tests were conducted first to investigate the load transfer behaviours of model foundations supported by three different types piles in dry sand ground subjected to vertical and horizontal loading. Then, corresponding numerical analyses of model tests on sheet piles were conducted using a three-dimensional finite element program PLAXIS 3D. According to the test and calculated results, a sheet pile foundation would be a promising alternative to conventional pipe pile foundation, especially in high-seismic areas.

Flaw detection threshold of thermal integrity testing. Presented by : Amir

ABSTRACT

The thermal method, based on measuring the hydration temperatures of fresh concrete, is the latest one devoted to testing the integrity of bored cast in situ piles (drilled shafts). Unlike other methods, it is claimed to cover the whole volume of the piles, both inside and outside of the rebar cage. The flaw detection capabilities of the method are still undecided, having been established by a small number of controlled site tests. This document describes a new numerical method that can simulate the thermal behavior of newly-cast piles of any shape and under any boundary conditions. The results of a few situations modeled prove that under worst-case scenarios the thermal method is unable to establish the integrity of the pile skin and may even totally miss a complete discontinuity. It is shown that the method still requires extensive improvements to qualify as a dependable, user-friendly tool for testing the integrity of concrete piles.

T-BAGS seismic base isolation system for earthquake energy dissipation. Presented by : A. Vakilazadsarabi

ABSTRACT

The seismic base isolation system has been known as a practical approach to mitigate building damages in high seismic risk areas. T-BAGS is a seismic base isolation system based on sliding two stacked layers of sandbags developed by Takeuchi Construction Inc. in Japan. In this research, the static and dynamic behavior of the T-BAGS is investigated first through laboratory tests, including simple shear tests of a sandbag, shaking table tests on one set, or six sets of stacked layers of two sandbags with slip sheet between them. Then the dynamic analysis of the T-BAGS system is conducted using mass-spring modeling. The friction behavior of the interface between the sandbags is assumed to follow the force-dependent non-linear spring laws. The analysis results show that the dynamic behavior of the T-BAGS system depends on the slip material and normal force between sandbags, and input acceleration. Also, the experiment and numerical results demonstrate that the T-BAGS system has a high performance of seismic base isolation.

Residual stress measurement of driven precast piles using distributed fibre optic sensors. Presented by : K. Duffy

ABSTRACT
Stresses generated from pile installation are a critical component in understanding pile behaviour. These are known as residual stresses and in Delft, the Netherlands, the response of three driven precast piles founded in sand was measured using distributed fibre optic sensing as part of a series of full-scale static load tests. The instrumentation set-up and analysis is discussed in this paper, highlighting the uncertainties with developing an appropriate residual stress distribution and in particular, how instrumentation selection, positioning and calibration can influence the interpretation of the residual stress profiles. The resulting profiles shows a substantial development of residual stress in the pile, an important consideration to take into account when preparing and analysing full-scale load tests on driven precast piles.

Environmental vibrations due to installation at high frequency. Presented by : P. Hölscher

ABSTRACT
Traditional vibrators sheet piles and foundation piles work at 25-40 Hz, but recently vibrators with very high frequency are developed; A so-called resonator has frequency about 120-150 Hz. The paper presents field measurement and the modelling of the environmental vibrations. Two cases will be discussed: installation of wooden piles with a traditional vibrator in clay layer over sand and installation of sheet piles with a resonator in a sandy soil. For both cases vibrations are measured at the surface at several distances. The measurements are presented with focus on the decay of amplitude with distance. Empirical decay curves are derived and compared. A numerical model for the source and wave propagation is discussed. The source model is based on the CPT-results (shaft friction and cone resistance) together with a dynamical factor. The wave propagation in the surrounding soil is based on a semi-analytical method for layered soil, with integration over the embedded length of the element. The results are compared with the results of the measurements. The model will be used to analyze the consequences of the vibration frequency on environmental vibrations. The importance of pile length and toe resistance can be derived. The strength of the vibrations with depth might be differ strongly from the vibrations at surface. The question whether the regulations for vibrations in structures must be extended is raised.

Laboratory study on vertical and horizontal resistance of the pile installed by various displacement pile installation methods. Presented by : S. Moriyasu

ABSTRACT
In the regions where earthquakes occur frequently, to properly design the pile foundation, both the vertical and horizontal resistance of the pile should be considered. The objective of this study was to investigate the influence of pile installation methods on vertical and horizontal pile resistances. In a series of laboratory experiments, four types of pile installation methods were used: monotonic push-in, surging (repetitive push-in and pull-out), vibratory pile driving, and bored pile (non-displacement) methods. Additionally, two types of model piles with different flexural rigidities were used. Moreover, vertical and horizontal load tests were conducted, successively, on the model piles. Though the pile installed using the displacement pile methods showed higher vertical resistance than that of the pile installed using the bored pile method, their horizontal resistance was found to be almost the same.

Independent assessment of toe and skin capacities in near real-time using top and toe instrumentation.

Presented by : P. Arumughan

ABSTRACT
The conventional practice of estimating the capacity of deep foundations using dynamic load testing is done by obtaining data from external sensors that are bolted near the top of the pile. The toe and skin components are extracted from the total estimated capacity using signal matching analysis with several assumptions. The results of signal matching analysis are highly dependent on the user performing the analysis and the program utilized. Therefore, the estimated toe and skin capacities are not known with certainty. Also, in top only instrumentation the actual condition of pile toe is only approximately deduced from the top instrumentation data. To overcome these uncertainties, Florida Department of Transportation sponsored research with University of Florida led to the development of EDC (Embedded Data Collector) with sensors embedded at the pile top and pile toe. Using state-of-the-art FDOT (Florida Department of Transportation) method of analysis of the top and toe instrumentation data collected, it is now possible to independently determine the toe and skin capacity accurately in near real-time. In the FDOT method Toe capacity is calculated using ‘Energy Conservation’ principle with toe gauge data and, Skin capacity is calculated using ‘Segmental Skin Friction’ approach with top and toe gauge data as boundary condition. The benefits of FDOT method analysis using top and toe EDC instrumentations includes a more efficient design, improved quality, faster construction process. FDOT method of analysis results along with superposition principle to determine the optimum capacity of piles were demonstrated for a bascule bridge built over the Miami River on state road 968, Florida, USA where uplift was a critical design aspect of the bridge.

Friction fatigue in soft rock and soft, non-cohesive soils: a physical model for the role of abrasive wear in skin friction reduction. Presented by : J. van Wijk

ABSTRACT
Friction fatigue, the progressive reduction in shaft resistance at a certain soil horizon upon penetration of the pile, for sandy soils is related to the relative penetration and the cyclic nature of pile driving. Friction fatigue is also known in weak rock (e.g. chalk) or cemented soils with soft grains. Contrary to steel-sand interfaces, steel-chalk interfaces are reported to produce a low strength putty under cyclic loading and shearing. In this article we present a physical model for friction fatigue in weak rock based on abrasive wear theory, including the development of an intermediate interface layer and the mechanical/rheological properties of the interface layer. The model is verified with experimental data from literature (interface shear tests with chalk and calcareous sands). The model describes the reduction in interface friction well. Validation with well-documented cases of pile driving will be part of future work.

RLT on prefab concrete piles of wind turbine foundations in tidal sands in the Netherlands . Presented by : F. van Dijck

ABSTRACT
During pile driving for wind turbine foundations in pre-dominantly tidal sands, unexpected low blow counts as low as one blow per 0.25 m were observed. To restore confidence in the foundation various aspects were investigated. Within the scope of this investigation several rapid load tests (RLT) have been executed in accordance with NPR7201:2017 and ISO22477-10:2016. From these tests it was concluded that the pile bearing capacity was sufficient. The maximum applied test loads, without geotechnical failure occurring, exceeded the maximum pile bearing capacity predicted by the calculation methods of the Dutch geotechnical standard NEN9997-1. Alongside bearing capacity, the dynamic axial stiffness of the pile in unloading – reloading is of great importance in the design of piled wind turbine foundations. A new simple method has been proposed to directly extract the unloading-reloading stiffness from the RLT test.

PDA measurements, fact or fiction. Presented by : Orlando

ABSTRACT
Pile Driving Analyzer (PDA) measurements have been used since the 1970's to monitor the pile driving process, driving stresses in the pile, pile integrity, as well as the soil resistance magnitude and resistance distribution and to judge the hammer performance in relation to pile driveability predictions carried out by 1-D simulation programs. Pile strains and axial pile accelerations are in general measured at 1 or 2 location along the pile 180° divided over the circumference, with each location composed of 2 or 4 pairs of sensors, or at 4 locations, 90° divided over the circumference. In general, for each hammer blow, these strain and acceleration measurements are recorded by special devices mounted to the outside of the pile wall. The results of the measured strains and accelerations are averaged and the final result gives indications about the behaviour of the whole pile. Although the assumption of a 1D system may in the past have been more or less accurate for small hammers and small diameter piles, for the present hammers with higher rated energies, and for current monopiles for wind energy farms with top pile diameters ranging from 6 m to 8 m this is certainly not the case anymore. In these conditions, an attempt to determine the behaviour of these piles during pile driving by measuring just at 2 or 4 local points over the circumference can lead to errors in the interpretation of the results. PDA measurements can be affected by the bending of the pile wall introduced by the deformation of the pile driving equipment, the unevenness of the pile top resulting in insufficient contact between pile top and anvil, not perfectly aligned impact of the ram onto the pile due to eccentricity offsets or inclinations, etc., as well as by assumptions made during the post-processing of the PDA measurement results. In this paper, an analysis of PDA measurements executed for a recently installed offshore windfarm is performed and a comparison with finite element results is made to determine the effect of the parameters mentioned above on the measurement accuracy. It will be shown that these effects can be quite considerable and can lead to for example a large spreading in the ENTHRU energy following from the PDA measurements.

Numerical modelling of vibropiling at the test site Altenwalde. Presented by : T. Pein

ABSTRACT
This article describes characterization of a site for vibro-installation of large-diameter piles and estimation of soil parameters for the numerical code VibPile to simulate the vibratory pile installations. The code applies new computational models for the far field elastodynamic springs and accounts for the soil stiffness and damping outside and inside the pile. A minimum number of input soil parameters such as interface friction angle, shear wave velocity and soil density are required. Results of cone penetration test and shear wave velocity measurements in-situ were applied to estimate the input soil parameter and simulate the penetration of a large monopile with a diameter d=4.3m. The predicted optimum driving frequency is in good agreement with in-situ results.

Development of jet-gun and fluidization enhanced pile installation tools. Presented by : B. Arntz

ABSTRACT
Installation of large monopiles by impact hammering is becoming increasingly difficult. Partially because increasing pile sizes push the limits of the capacity of hammers and anvils; partially because restrictions regarding noise emission restrict the use of these hammers. Because of this there are many initiatives for developing alternative methods and tools for installation of monopiles. One concept that stands out is based on the temporary reduction of soil resistance on the inside of a monopile, using a water jetting gun technique, combined with vibro driving. Water jetting and soil fluidisation have been around since long, but this largely grew from empirical practice while the combination of theoretical knowledge with large scale offshore applications has been quite limited. Main research questions concerned the prediction of the required operational parameters for the jetgun (like pressure, flow rate, nozzle configuration, etc.) and the vibro tool (frequency, amplitude, etc.) for successful installation, as a function of soil and monopile parameters. For a pile installation to be successful it is essential that the soil integrity under the pile tip and next to the pile is preserved while the soil inside the pile is fluidised. This paper presents an overview of the desk research, scaled lab tests and scaled field tests that have been performed during the development of a new installation method, based on a vibro tool at the top of the monopile, in combination with a retrievable jetgun near the toe of the pile. The paper focusses on jetting and fluidisation installation aspects in a largely non-cohesive (i.e. a sandy, silty) seabed.

Parametric numerical study on deformation of the Tender Net Foundation subjected to vertical loading. Presented by : Vo Cong

ABSTRACT
Raft (footing) foundation on soft ground does not have enough bearing capacity, and often has excessive average and differential settlements. In that case, deep foundations (pile foundations) have been usually employed to minimize settlements of the foundation. Another solution is ground improvement. TNF (Tender Net Foundation) method is one of ground improvement methods for building foundations. The TNF has been developed by Takeuchi Construction Company Inc. in Japan since 1993, and it has been widely applied in more than 1600 projects as of Dec. 2021, including factories, workshops, schools, warehouses, and shopping malls in Japan. The TNF is a combination of grid-shaped soil improvement and shallow ground improvement, on which concrete slab and footings are constructed. In this paper, performances of various types of TNF are numerically investigated using the PLAXIS 3D FEM software. Influences of depth of grid-shaped improvement and thickness of shallow improvement on foundation settlements are estimated through the analyses. Furthermore, behaviors of TNFs on original grounds with various stiffness are analyzed for an appropriate design of TNF.

A proposed model for ground vibration induced by a Statnamic test. Presented by : Z. Eng

ABSTRACT
Statnamic Load Test (STN) is an economical alternative to a Static Load Test (SLT) for the determination of bearing capacity of piles. The shock impulse from STN test of about 150-250ms will induce vibration in the ground (in terms of Peak Particle Velocity, PPV). This vibration will then be damped and attenuated radially with distance from the test pile location. Lack of a reliable method in assessing the risk of ground vibration over distance limits the application of STN, especially if there is sensitive structures nearby. Middendrop (2011) and Chew et al. (2012) showed that PPV is proportional to the test load based on the compilation of a few sets of actual measured data, with test load up to about 16 MN, in Europe and Malaysia/Singapore respectively. However, over the last 10 years, there are many more number of STN tests conducted in Malaysia and Singapore with ground vibration measured, and at much higher test load level. It was observed that the maximum vibration induced by a STN test at much higher test load did not increase proportionally, but is seems to be capped at a maximum threshold value. It is noted that the piles in Malaysia and Singapore usually are terminated at competence soil (SPT'N >100) or hard rock. The data also suggest that the pile penetration length seems to have significant influence on the ground vibration. Massarch & Fellenius (2008) proposed a model to predict ground vibration induced by a hard driving of pre-cast pile, taking into account the effect of pile length. This paper aims to present a modified model to predict the ground vibration induced by a STN test at a higher test load (till 40 MN), with pile length effect included. A comparison between predicted and field measured PPV from a number of STN project sites is presented in this paper. The comparison shows a very good agreement between the measured and predicted PPV.

Influence of grout injection parameters on shaft bearing capacity of screw displacement piles. Presented by : P. IJnsen/Admiraal

ABSTRACT
This document describes the test program that was conducted in 2021 to investigate the influence of grout injection parameters on the shaft bearing capacity of screw displacement piles. Grout variants considered were water/cement ratio, blend composition and flow rate. This resulted in 5 groups of 3 test piles with more or less the same grout parameters. Other installation parameters were kept constant. Back flow grout was sampled to determine composition and properties. Static load tests in tension until failure were used to determine the shaft bearing capacity of the test piles. In total 7 out of 15 test piles were extracted afterwards to establish the pile diameter. Also the annulus of the extracted piles was cored with the purpose to obtain the shear properties of the grout/concrete interface of the piles. It can be concluded that the range of water/cement ratio's applied in the test program did not have a substantial influence on the bearing capacity of the test piles and that the applied highest grout flowrate seemed to be at the limit of becoming influential. Furthermore it was found that the empirical cone resistance factor for shaft resistance (αt according NEN 9997-1) is in compliance with the generic value of 0.009 for sand layers for this type of pile, provided that a limit value of 15 MPa for the cone resistance qc is not applied and provided that the shaft bearing capacity is computed based on the outer diameter of the screw tip.

Alternative facts in pile testing . Presented by : G. Verbeek

ABSTRACT
For many in the foundation testing industry it is not always clear which 'fact' is truly a fact, or merely an opinion (which could be classified as an alternative fact). This paper will discuss a number of 'facts' associated with high strain dynamic testing and review most of them using the stress wave theory. This stress wave theory applied to foundation piles is over 70 years old, and is a great tool to assess 'facts'. Some of the 'facts' have been debunked in the past, but remain popular because of they are easy to apply and because practitioners are simply unable to keep up with the sheer number of papers and articles about the subject. Instead they often limit themselves to reading what is in line with expectations, thereby perpetuating these alternative facts. By providing telling examples this paper hopes to break that cycle.

An alternative CPT averaging procedure to estimate pile base capacity. Presented by : M. Boorder

ABSTRACT
A wide variety of cone penetration test (CPT) based methods of estimating pile base capacity exist. These methods typically link the base resistance at some specified pile base settlement level to a representative value of cone resistance q_c through a correlation factor to account for pile installation effects. The representative or design q_c value is derived using procedures which typically average the cone resistance over a number of pile diameters above and below the pile tip. As the averaging procedure varies from region to region attempts to unify design methods are hampered by uncertainties related to the design value that should be adopted. In this paper two series of laboratory CPT tests on layered soil deposits are used to calibrate an alternative CPT averaging procedure that, when compared to existing procedures, can adequately capture the transition in q_c across a variety of soil conditions.

Soil resistance of steel pipe piles during vibratory hammer installation. Presented by : Shinji Nishimura

ABSTRACT
In this paper, we attempted to evaluate the soil resistance during the installation and the bearing capacity after curing time of the steel pipe piles by vibratory hammer installation. Four steel pipe piles with diameter of 114.3mm and length of 11m were constructed for the test. Three piles were installed by a vibratory hammer with different penetration rates. One pile was installed by a drop hammer. Dynamic measurement with axial pile head strain and acceleration were performed during installation. As the calculation method of the soil resistance for vibratory hammer installation, we adopted two methods, the single-mass model analysis method and the CASE method (Rausche et al., 1985) based on the one-dimensional wave theory. We attempted to separate the soil resistance into the shaft and the toe from the shape of the soil resistance – displacement curve. Static load tests were performed on all test piles with curing time of 1 day, 28 days and 180 days after installation.