WAVE MECHANICS APPLICATIONS

SESSION LEAD ANDREI METRIKINE / EVANGELOS KEMENTZETDIS

Presented papers:

A case study of using VCPTu for drivability analysis of vibratory pile driving.   Presented by : M. Fetrati

ABSTRACT

Impact pile driving is the conventional method for the installation of monopiles in the offshore wind industry; however, this installation method is environmentally unfriendly and can induce high fatigue in piles. To overcome these issues, the vibratory pile driving method was introduced. However, one major obstacle to utilizing the vibratory pile driving method, is the lack of a well-established drivability analysis method. So far, the most reliable approach for drivability analysis of vibratory pile driving is based on the back-analysis of instrumented test piles in the same soil condition, which is highly costly and time-consuming. The inability to develop a robust drivability analysis method is due to uncertainties related to the cyclic soil resistance during vibratory penetration. The one possible approach explored here is to investigate the cyclic soil resistance during vibratory penetration is the use of Vibratory CPTu (VCPTu). VCPTu is an in-situ soil investigation device that penetrates the ground while inducing cyclic strains with different vibration modes. The collected data can be post-processed to determine a reduction in cyclic soil resistance due to the vibratory mode of penetration. In this study, we adopted wave equation analysis and back analyzed the installation data of a monopile, obtained from the VIBRO project at Cuxhaven-Germany, where three monopiles have been installed using the vibratory pile driving method, and several VCPTus have already been performed there. The reduction in the cyclic soil resistance to vibratory driving, known as degradation factor i.e., Beta Factor, was then calculated and compared with the Beta Factor values obtained from the VCPTu tool. Results showed that the VCPTu data are promising, to some extent and that the results can be considered as roughly representative for the installation of piles. VCPTu is a potential investigation method for challenging sites in the future.

Enhanced Stress Wave Analysis of Scaled Monopiles in Glacial Till at Cowden.   Presented by : S. Martin

ABSTRACT

Conventional stress wave analysis for pile driving involves a subjective signal matching process using pile driving analyser (PDA) measurements. The PICASO (PIle Cyclic AnalySis: Oxford and Ørsted) research project provided an opportunity to collect high frequency strain measurements using optical fibre Bragg grating (FBG) sensors over the embedded length of the pile, in addition to conventional PDA data. This paper reports the application of a novel hybrid approach incorporating FBG data into the signal matching process, as developed by Buckley et al. (2020a), to an overconsolidated glacial till site in Cowden, Hull, UK. The additional information on stress wave propagation, obtained through FBG measurements, provides insights into the development of soil resistance to driving (SRD) in stiff clays. The results obtained using the new framework are compared to the resistance predicted using a widely-adopted empirical method.

IMPACT: cloud-based software for stress-wave and drivability analysis of driven piles.   Presented by : J. Doherty

ABSTRACT

The dynamic analysis software, IMPACT, was originally developed some 30 years ago for drivability assessment and stress-wave matching of driven piles. The software has recently been launched as a web-based application, which brings major advantages in terms of speed of analysis and the potential to run the app remotely in batch mode from appropriate code. Dynamic pile-soil interaction is implemented using a continuum approach, although the traditional Smith models are retained as an option, with the internal soil plug treated independently from the external soil. Pile-soil interaction parameters may be derived from CPT data, either from in-built published recommendations or from user-input algebraic expressions for a range of different soil behaviour types. For drivability analysis, friction degradation is allowed for automatically using in-built or user-supplied relationships. The paper illustrates application of the web-app to an example field study, showing how measurements of hammer energy and blowcount data may be combined with intermittent stress-wave analysis of specific blows in order to refine pile-soil interaction parameters and their relation to CPT data.

The use of pile velocity in verification of untested piles – a sensitivity study.   Presented by : Denes

ABSTRACT

Pile testing is undertaken to confirm that a pile has sufficient geotechnical strength, as per the design intention. In practice, it is common to test only a proportion of the piles. For untested piles, geotechnical strength is usually assessed using bearing graphs or dynamic driving formula based on a combination of energy and movement. The pile set, as an expression of permanent pile movement, can be measured in a number of ways, such as using traditional pile markings on the pile, survey, or even non-contact high frequency displacement monitoring devices. For untested piles, the energy is generally assumed to be a function of drop height and hammer size, reduced by an energy transfer ratio. Hammer performance, cushion properties, and accuracy of hammer drop height readings are examples of factors that can influence the energy transfer ratio. In turn, this impacts the reliability of the capacity estimate. As an alternative approach, pile velocity can be used to infer applied force into the pile. Thus, a relationship between geotechnical strength, pile force and static movement (set) can be determined for site-specific verification of untested piles. This paper investigates the sensitivity of this relationship to dynamic ground parameters (quake and damping), pile impedance and cushion stiffness, using wave equation analyses. It draws on earlier papers discussing the theoretical framework and case study data from high strain dynamic testing.

Probability theory applied to pile driveability predictions based on the wave equation. Presented by : J. Sinke

ABSTRACT
Accurate driveability predictionsassist in decision-making on pile installation aspects, like hammer choice.These decisions involve significant risks and costs. Thispaper is aproof of concept which showsthat probability theory can be applied to driveability predictions based on the wave equation modelto quantify refusal risk.Ten soil parameters are turned into stochastic variables. The variability of these stochastic variables consists of spatial and transformational variability. The former is caused by soil heterogeneity, whilst the latter is caused by uncertainty in the relationship between measurement and soil model parameter. Spatial variability is incorporated in the one-dimensional profile of each parameter by means of a random field. This random field is a function of the vertical scale of fluctuation which is derived from Cone Penetration Test (CPT)data. The horizontalcorrelation is assumed to be zero. In practice, there will be horizontal correlation, but this cannot be derived fromcommon soil research. Soil stratification(arrangement of soil layers) is assumed to be deterministic.The transformation variability of the stochastic variables is determined by gathering experimental datafrom previous research. Based on the variability of the parameters,Monte Carlo simulations are done to quantify the risk of refusal.Case studies show that predictions of the refusal risk give outcomes which are of thesame order of magnitude as measurements.

A novel anvil modelling approach for pile driveability prediction, validated with PDA measurements. Presented by : J. Ligthart

ABSTRACT
The growth of offshore wind turbines pushes the size of monopile foundations and with that the size of anvils that are used to install monopiles. The current simulation programs that are used to predict the pile driveability rely on simple models to represent the anvils. Those models are shown to be inaccurate, especially for anvils > 5.5 m, which reflects directly on the accuracy of the driveability prediction result. Also for pile driving noise emission predictions the force wave that travels through the pile must be estimated accurately, including its high-frequency content, which is not possible with the currently available impact pile driving simulation programs. To overcome this shortcoming, a novel anvil modelling approach is proposed, based on the Mode Displacement Method, which is a Reduced Order Modelling approach. The resulting anvil models are robust and universally applicable since the methodology relies only on a FE model and just a single parameter to defines the model frequency content. A comparison of the simulation results with the novel anvil model to FEA results shows that all relevant behaviour during impact is caught very accurately by the application of the proposed anvil model. Instead the former lumped-mass anvil model results in a large overestimation of the impact force in the impact simulation with an 8 meter anvil, and also relevant high-frequency effects in the force wave are not captured with that model. A validation of the new anvil model based on PDA measurement data from the installation of a wind turbine monopile in the North Sea shows a good match between simulation and reality.

Post Driveability Study for Caesar's Rhine Bridge 55 B.C. Presented by : P. Middendorp

ABSTRACT
As the story goes, in the early summer of 55 BC the Roman general Julius Caesar had a 400 m long bridge built over the Rhine within just 10 days and then demolished again after a few days. According to Caesar, the bridge was built in order to be able to carry out a punitive expedition against the Germans on the right bank of the Rhine. The bridge was undoubtedly a beam or yoke bridge. The distances between the yokes were at most 12 m, so that a total of 30 - 35 yokes were required. The piles consisted of tree trunks pointed at the bottom, most likely without the iron pile shoes that were otherwise common among the Romans. The piles were driven into the riverbed with specially designed pile driver, which means that there must have been experience with taking pile driving conditions into account and understanding of those conditions at the job site. Nowadays a pile driveability study would have been part of the bridge design process. The authors took up the challenge to perform a post driveability study for this bridge based on the limited data available and the results are presented in this paper. The predictions were performed with the wave equation program AllWave-PDP.

What happens in the soil during pile driving? - G. DE JOSSELIN DE JONG. Presented by : G. Verbeek

ABSTRACT
A. A graphical method is used to determine stress and velocity in rods under dynamic loading conditions. Application to a sample of dry sand gives regions of permanent deformation and dissipation of energy into friction. Penetration of the energy into the interior of the sample is deeper for longer duration of impact. Experiments confirm this theoretical result.
B. The way sand saturated with water reacts on dynamic load is studied by separating stresses and velocities of the two phases. It is shown that water bears nearly total dilatation stress, while the granular skeleton is affected by rotation for high frequency loading.
C. Impedance of rigid sphere in infinite, elastic medium is computed in order to obtain information about the impedance of a pile-toe in soil. It is shown that for high frequencies the load is mostly affecting the water stresses. The different effects of these phenomena on the reaction of a pile while driven into the soil are considered.

The rebirth of traditional SIT interpretation methods to incorporate engineering judgement in present day data analysis. Presented by : M. van Delft

ABSTRACT

The method of Sonic Integrity Testing (SIT) was developed many decades ago, at a time when the only pile testing method available was Static Load Testing. SIT was designed to test cast-in situ piles or bored deep foundations, and because of this test method cast in-situ piles (including Continuous Flight Auger (CFA) -piles) became popular in Western Europe. As the main QA method for this pile type, the application of cast in-situ piles increased the popularity of SIT and vice versa. SIT became even more popular when digital testing equipment was developed. Easy to operate hardware and user-friendly software started to become available in the 1960s. But while the testing engineers of the first hours were used to dealing with the uncertainties associated with this test method, newer generations of engineers became increasingly just operators, relying more and more on automated interpretation algorithms. However, engineering judgement is still required from the testing engineers, as pile testing is more than simply operating a test kit and pushing the right buttons at the right moment. This paper provides some examples of how 'old school' experience with this test method is still very relevant for the interpretation of 'modern' signals, such as the use of a site average to eliminate the soil impact (shaft friction and toe resistance) on the signals, as well as the pile signature to minimize false negative and false positive interpretations. In addition, advanced signal matching techniques for SIT data will be described as a useful method to quantify and visualize test results.