Pile Installation in Calcareous Clays

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ABSTRACT

Through the later years, the authors have been involved with pile driveability predictions, installation and dynamic monitoring of driven open-ended steel piles installed in the Arabian Gulf. This experience has been gathered into a database containing over 150 back-calculated offshore pile installation records and that is continuously updated with new inputs. It includes numerous pile installation in slightly over consolidated calcareous clays. Based on selected extracts from this database, a new and improved guidance to better characterize calcareous clays is proposed in this paper to provide an optimized and site-specific pile installation prediction. The developed guidance was used to optimize installation of new pile foundations of platform X installed in calcareous Clays. This paper also elaborates how the use of the Dynamic Monitoring System (DMS) and Signal matching analyses from past experience helps to develop a site-specific approach and minimize uncertainties related to Soil Resistance to Driving, set-up effect and soil dynamic parameters.

Keywords: calcareous clay, offshore pile installation, pile driveability, driving interruption, soil dynamic parameters, shaft friction degradation, set-up, soil damping.

1 INTRODUCTION

Offshore pile installation is a costly operation due to the specific conditions of the marine environment. The consideration of a suitable Soil Resistance to Driving (SRD) model, combined with soil dynamic parameters and soil set-up effect, significantly affects the hammer selection, the duration of the driving operations and limits the risk of unexpected situation during pile installation. This is particularly true for soil types with a high degree of uncertainty such as calcareous clays. Limited understanding of pile behaviour during installation in calcareous soils exposes the project to events such as early refusal or unexpected low resistance at final penetration. Such situations may cause delays and possibly the need of remedial installation operations, ultimately leading to significant costs overruns for the project. This paper presents guidelines for the assessment of pile installation in calcareous and carbonate clays that can help geotechnical engineers in a more accurate prediction of pile installation by driving. The guidelines are based on analyses of a selected set of pile monitoring data as well as geotechnical experience of the authors in offshore pile foundation engineering assessments and installation.

2 PROBLEM AND PURPOSE OF THE PAPER

Predicting the behavior of pile foundations in calcareous soils during offshore installation is challenging from the design stage to the installation stage. The uncertainty of driving long open-ended steel pipes in calcareous soils can lead to un-necessary operation measures and un-efficient sequence of piling operations which can increase the project risks and cost.

The authors have used a selected set of pile monitoring data in calcareous clays to derive specific parameters and support the driveability assessment to reduce technical uncertainties and financial risks attributable to the pile installation for the new offshore jacket (the new jacket is referred as X in this paper).

3 DEVELOPEMNT OF THE SITE-SPECIFIC GUIDLINES

The model has been developed based on a review and analyses of a pile monitoring dataset. The sections below present the data analyses of the selected available dataset.

3.1 Summary of the available Pile Dynamic Monitoring data

The available pile monitoring data in offshore fields, where calcareous clays are encountered, were selected for further analysis. The criteria that were used to select the relevant dataset are the following:

- Data with calcareous clays.
- Range of pile penetration as close as possible to penetrations expected for jacket X.
- Large pile diameters (as close as possible to X jacket's piles).
- Distance from the location X.
- Quality of the data.

The Table 1 below presents a summary of the selected dataset for the purpose of pile driveability at platform X. The platforms listed below are referred to as "selected dataset" in this paper.

Table 1. Summary of selected dataset

Test ID	Water Depth (m)	Final pile Penetration (m)	Pile Diameter (in)
A	20-25	90-95	66 – 84
B	30-35	70-75	66 – 84
C	30-35	55-60	66 – 84
D	20-25	75-80	66 – 84
E	60-65	110-115	66 – 84
F	65-70	110-115	66 – 84
G	50-55	115-120	66 – 84
N	50 - 55	125- 135	66 – 84

Note:
The range of values are provided to ensure anonymity of the data

3.2 Soil Conditions at location X

The stratigraphy is composed mainly of firm to very stiff calcareous clay and relatively thin layers of carbonate sand. Pile resistance to driving in this case is governed by the clay layers as carbonate sands contribution in shaft friction is very limited. Hence, the comparison of soil conditions between location X and nearby locations referred in the papers by letters from A to G is limited to clay layers only. The Figure 1 below presents the clay layers units and range of pile tip depth for platform X and the selected dataset.

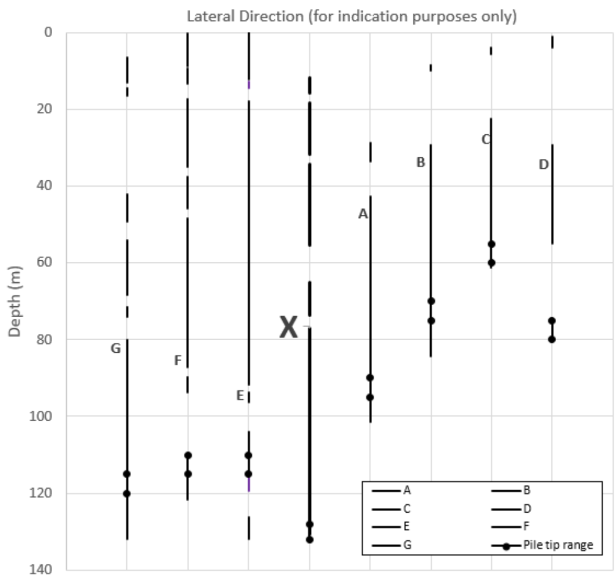

Fig. 1. Calcareous clay layers at different platform locations

The main geotechnical parameters of the clay layers are summarized in Table 2.

Table 2. Geotechnical parameters of the clay layers

Unit Weight	18 to 20 kN/m3
Fine content	95 to 100%
Carbonate Content	50-70 %
Plasticity Index	25-45 %
N_k	15-25
Sensitivity	2
Over Consolidation Ratio (Slightly over-consolidated)	0 to 15 m depth: 10 to 2 Below 15 m depth: 2 to 1.5

4 ANALYSES OF EXISTING DATA

4.1 Shaft Damping from CAPWAP

The shaft damping parameters concluded from the signal matching analyses performed with CAPWAP (Case Pile Wave Analysis Program) software (PDI, 2006; Smith, 1960) using selected data at end of driving (following continuous driving) and restrike are shown in Figure 2. The data from platforms A to E has been used by the authors to assess the driveability at platform X. The piles at platform X have been successfully and efficiently installed based on those recommendations, data from platform X is plotted on the same Figure 2.

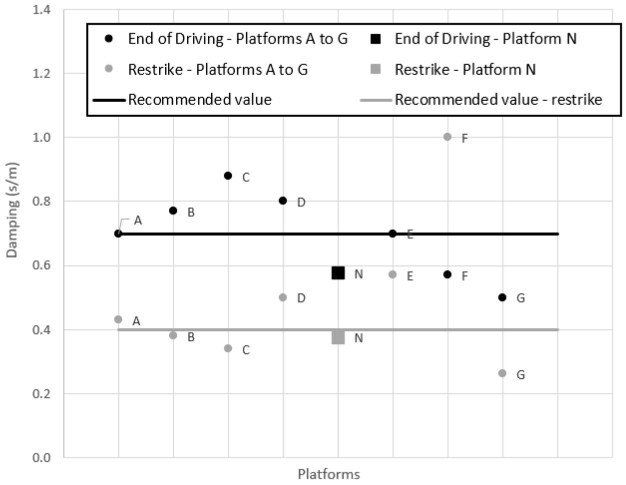

Fig. 2. Damping at different platforms locations and recommended values for calcareous Clays

Compared to data at end of the driving, the shaft damping at restrike tests has decreased for all platforms except for one. The CAPWAP analyses are user dependent and values out of general range shall not be considered, typically values higher than 1.0 s/m shall be ruled out as recommended by Maron (2021). From the selected experience, it is advised to consider a shaft damping of 0.7 s/m for continuous driving and 0.4 s/m for restart of driving. It should be noted that other authors reported similar range of damping for calcareous Clays such as Tagaya (1979) and Raushe (2008) papers where a range of 0.5 to 0.65 m/s was reported.

4.2 Set-up effect from the selected dataset

For an optimum measurement of set-up it is recommended that hammer performance reaches high level as quickly as possible directly following the restart of driving. Hussein et al (1988) reported that restrike tests conducted on main piles of North Rankin A indicated a set-up value that decreases quickly with subsequent blows as indicated in Figure 3 below.

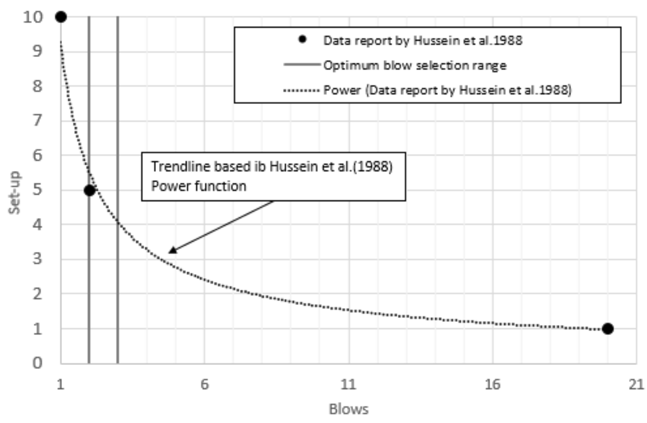

Fig. 3. Set-up versus restrike blows

It is recommended to select one of the first good quality blows of sufficient energy after resumption of driving for CAPWAP before the soil degradation occurs.

Figure 4 presents the set-up values from the selected dataset. The set-up is calculated as the ratio of shaft resistances at restart of driving over end of driving. Values are ranging between 2 and 4.2 and increasing with the duration of driving interruption. A tentative logarithmic trendline is presented in the graph to reflect the evolution of set-up effect with time. The validity of the logarithmic trend is supported by Bullock (2008) but limited to the period of 1 day to 5 days. The trend was used to estimate the set-up values at deep penetrations for different interruptions scenarios (sections welding, maintenance downtime, weather standby …etc.).

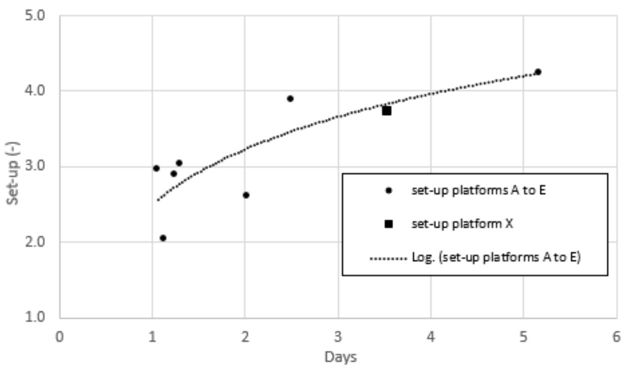

Fig. 4. Set-up values versus time

By Considering the set-up versus time trend of the dataset as well as the recommendation of damping at restart of driving in the driveability model for Platform X, the authors were able to reduce the uncertainty about risk of refusal under different scenarios and allowed the installation contractor to adopt an efficient sequence of pile driving which saved the barge time and cost.

4.3 SRD degradation effect from the selected dataset

Figure 5 presents the global degradation factor at end of driving for the selected dataset. The degradation factor is defined as the ratio of CAPWAP SRD at end of continuous driving to the predicted long-term axial static capacity at the same pile penetration. It should be noted that the shaft friction is limited to 150 kPa for stiff and hard calcareous clays based on previous experience in similar soil conditions. The degradation is plotted versus depth as it is a continuous process, which increase with depth (higher degradation at deeper pile penetration). Linear trendlines to cover both low estimate and high estimate based on available data and pile installation experience in similar soil conditions are presented in Figure 5 to reflect the evolution of the degradation factors with depth. The proposed range of degradation factors are based on data ranging from 60 m to 130 m of pile penetration. The degradation above this penetration range can be conservatively assumed constant. This guidance can be used to adjust different methods of Soil Resistance to Driving to match the global degradation factors obtained from recent experience.

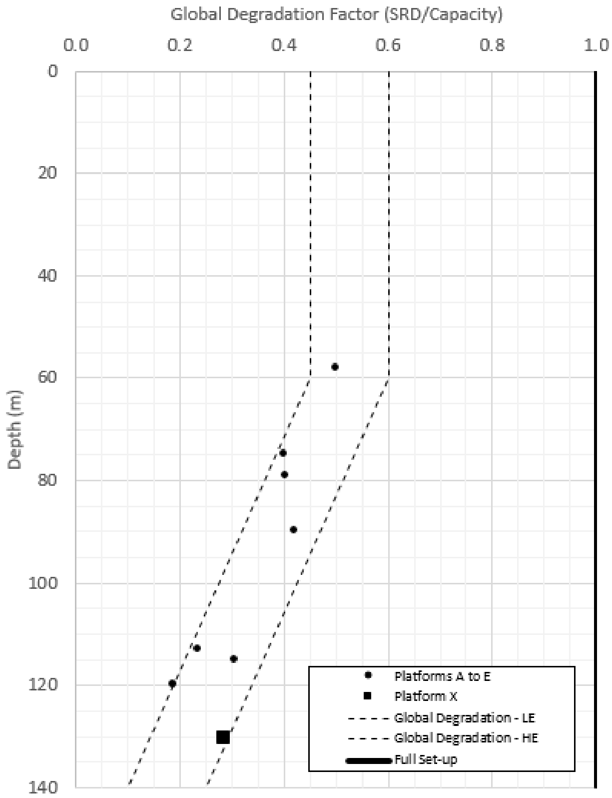

Fig. 5. Global degradation factor versus depth – continuous driving

5 CONCLUSIONS

The site-specific assessment consisted in extracting from the database seven good quality records of pile monitoring data and signal matching analyses from piles driven into firm to very stiff calcareous clay. A detailed evaluation of the records helped to conclude on general trends of key parameters related to pile installation resistance such as shaft friction degradation, set-up effect as well as damping and its evolution with time. The global degradation factor is defined as the ratio of shaft resistance from SRD at end of driving evaluated by signal matching to the static shaft resistance predicted by API RP 2GEO (2011) at the same depth. It was observed that the degradation factor decreases with pile penetration (0.45 to 0.6 at shallow depths up to 60 m then decreasing linearly to 0.1 to 0.25 at around 140 m). The set-up effect, defined as ratio of shaft resistances at restart of driving over the shaft resistance at end of initial drive, was found to develop from 2.5 after 24 hours interruption to approximately 4.0 after 5 days interruption. The shaft Smith damping was observed to be around 0.7 s/m at the end of continuous driving and 0.4 s/m at restart after driving interruption. One of the main concerns of hammer selection and defining pile installation sequences is the evaluation of hammer capability to restart driving after a significant driving interruption. This evaluation is therefore directly related to the understating of the set-up effect (SRD evolution with time) and the soil dynamic parameters after driving interruption.

Finally, the site-specific parameters proposed in this paper where integrated into the driveability prediction for a recent platform X in the region and allowed to successfully reduce the uncertainty related to soil behavior and hence resulted in optimization of hammer selection and pile installation sequences during execution.

The guidelines described in this paper are applicable to calcareous clays. If no other guidelines are available, they can be extended to carbonate clays to some extent by the geotechnical consultant.

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