Optimization of Driveability Predictions for Large Diameter Monopiles in London Clay

Optimisation des prédictions de battage de monopieux de large diamètre dans l'argile de Londres

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ABSTRACT: This paper describes back calculations of pile driving records undertaken for large diameter monopiles in the London Clay formation. The piles were installed using a double acting hydrohammer with high operating efficiency. Back calculations were made prior to the project preparation based on records from 2 adjacent sites to calibrate driveability prediction methods. Comparison is made between the measured results and predictions made using the calibrated methods.

1 INTRODUCTION.

GeoSea is a specialist in offshore marine engineering projects. In recent years, Geosea has executed several driven monopile (MP) installation projects in London Clay. Back-analysis shows that predictions with CPT-based methods do not always fit well with measured records.

This paper presents back calculations from 3 projects in the London Clay formation, considering GeoSea's in-house driveability method and the Alm & Hamre (2001) method. MPs had a diameter between 4.7-7.5m, with some MPs having a conical section and others straight MPs.

1.2 Driveability modelling

The driveability prediction consists of 2 parts:

1. **Estimation of a static resistance to driving (SRD) profile:** The SRD consists of the resistance at a given embedment due to skin friction resistance (f_s) and pile toe resistance (f_{TIP}). GeoSea also uses in-house methods that are refined based on project experience.
2. **Modelling of hammer-sleeve-pile system:** The hammer, sleeve and pile are modelled as series of discrete masses connected with springs and dampers are used to model the effects of skin and toe damping. GeoSea model this using software GRLWEAP.

GeoSea's standard in-house SRD method calculates unit skin friction, f_s and unit tip resistance, q_{TIP} based on direct interpretation of the tip resistance and sleeve friction in the CPT profiles. If available, adaptations are made, whilst taking into consideration, the site specific N_{kt} factors, the soil sensitivity and the overconsolidation ratio. The N_{kt} factor is used to calculate undrained shear strength from CPT q_{net} and is normally calibrated from triaxial tests. Predictions are made for Best Estimate (BE) and Upper Bound (UB) soil conditions. The following boundary conditions are used in GeoSea's in house method for clay: toe and skin quake = 2.5mm, skin damping = 0.6s/m, toe damping = 0.5s/m.

1.3 *Back calculations*

Back calculations showed large variability in the fit of predictions to measured results. Figure 1 shows a location where GeoSea's standard BE prediction gave a good fit, whereas Figure 2 shows a location where GeoSea's BE under predicted the final blow count.

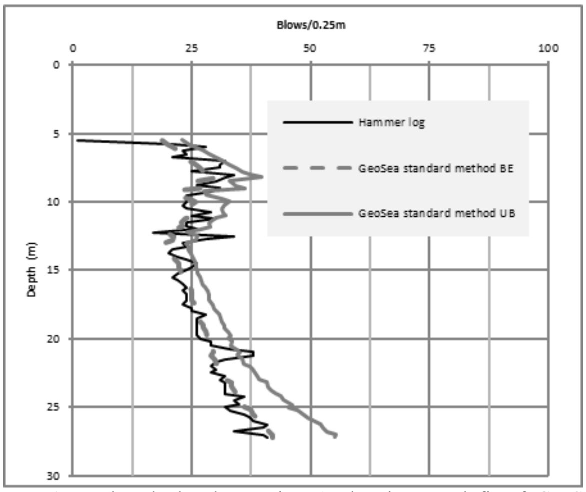

Figure 1. Back calculated Location A showing good fit of GeoSea standard SRD method

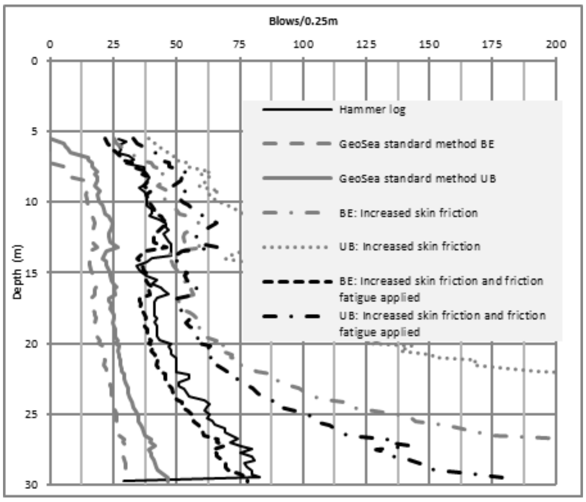

Figure 2. Back calculated Location B required adjustment to achieve good BE fit

GeoSea's standard method was calibrated by fitting the BE prediction to measured hammer logs for the harder driving locations. The majority of SRD for the open ended monopiles in clay is due to skin friction rather than end bearing, SRD was increased by applying a higher factor to the skin friction to achieve a better fit. The skin friction was increased until it was almost equal to the undrained shear strength. This resulted in a large over prediction of blow counts at end of driving, shown in Figure 2. Therefore, friction fatigue using the Heerema (1978) method was introduced in the GRLWEAP analysis with the following parameters: Limit length=70m, setup factor=5, f_o=0.001, f_L=0.01. This gives a reasonable fit of the prediction against the hammer log.

The driving behavior does not always appear to correlate directly to the CPT. Figure 3 shows 2 locations, with D having significantly stronger clay beneath 25m depth. However, the blow count (normalized to the same energy) appears very similar for these two locations, indicating that SRD was similar. The reasons for why the driving behavior does not directly follow the CPT is not clear and the friction ratio of the D and C appeared very similar.

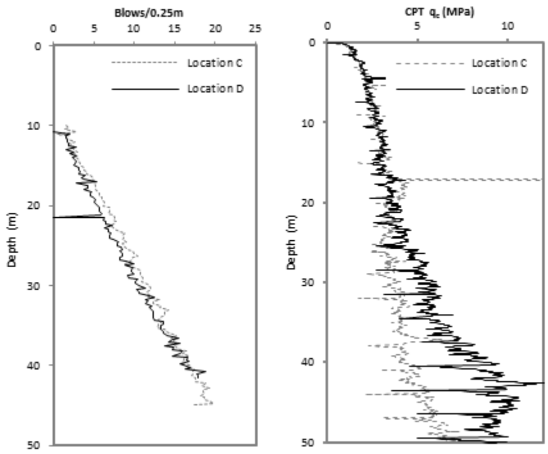

Figure 3. Similar driving behavior for dissimilar CPTs

1.4 *Comparison of predictions vs measured results with updated method*

Figure 4 shows that the updated driveability prediction achieved a good fit, with the hammer log following the BE prediction. The GeoSea standard method would have under predicted the end of driving blow count.

It should be noted that at some locations the calibrated SRD method tended to over predict the measured blow counts. The range of N_{kt} values from lab tests was relatively large, typically N_{kt} =20-35 depending on how lab tests were weighted. This large range of N_{kt} values may indicate significant strength variation even comparing similar CPT profiles, which could explain the variation in driving for apparently similar CPT profiles. Other factors apart from the in-situ strength measured from CPT that may influence drivability are soil index properties, over consolidation ratio, radial damping or soil sensitivity to remoulding. Soil with a sensitivity factor less than unity may experience and increase in skin friction due to remoulding that occurs during driving.

A comparative analysis has been made for the same location using the Alm & Hamre (2001) method (Figure 5) to consider how this compared to the calibrated method used by GeoSea. This shows that the Alm & Hamre BE method under predicts the measured blow counts and that the measured blow counts are in line with the Alm & Hamre UB prediction. A reasonable fit was achieved by increasing the Alm & Hamre (2001) expected SRD by 25%. This raises the possibility that the Alm & Hamre (2001) method either underestimates the initial skin friction or overestimates the friction fatigue in the London Clay.

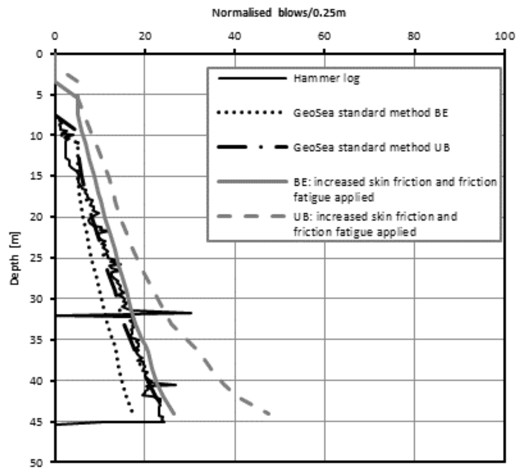

Figure 4. Comparison of predictions vs measured a location from the project site

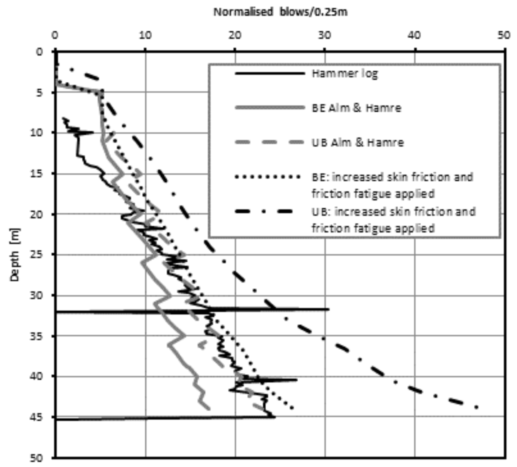

Figure 5. Comparative analysis using Alm & Hamre method

2 CONCLUSION

Driveability back calculations were made based on records from 3 sites in London Clay. Driveability records showed considerable variability for similar CPTs so the approach was taken to calibrate the GeoSea's BE prediction to the measured logs for the harder driving locations. The calibration was made by increasing the skin friction and introducing friction fatigue.

The calibrated GeoSea method gave a prediction of the measured driving logs for a number of locations. However, it was noted to over predict the driving resistance at some locations. Results show that the driving behavior does not always appear directly linked to the in-situ strength measured from CPT. Some locations with large differences of in-situ strength experience very similar driving behavior. This suggests that the driving resistance is influenced by factors not directly measured using CPT, which could include index properties, overconsolidation and sensitivity to remoulding.

3 REFERENCES

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