Driveability aspects of tubular piles in chalk

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ABSTRACT

The Colne Valley Viaduct is a planned bridge, part of the High Speed line HS2 phase 1, designed to be 3.4 km long. VolkerStevin Ltd. has been commissioned by Align to install approximately 394 no. tubular piles over four different jetties (Jetty A to D) required for the construction of the HS2 Colne Valley Viaduct. Geobest B.V., as subcontractor to Volker Stevin, performed several driveability studies for this project. All steel tubular piles, of different dimensions and penetration lengths, will be installed in hard chalk layers. The main challenge has been to predict the expected pile resistance (SRD), as pile driving in chalk is subject to significant uncertainty. Literature also provides little and also varying guidance on how to estimate soil resistance to driving in chalk. In this document, the process leading to the prediction of the expected pile resistance is discussed. Driving records are then used to verify the performed prognosis and to back calculate the driving resistance in the chalk layers. In conclusion, insights are given on how to approach future chalk projects.

Keywords: Chalk, Driveability, Colne Valley viaduct, HS2

1 INTRODUCTION

The Colne Valley viaduct is a planned bridge, part of the High Speed line HS2 phase 1, designed to be 3.4 km long. The viaduct will carry the High Speed 2 railway through beautiful countryside to the west of London, over the Colne Valley Regional Park and the Grand Union Canal. It will have a curved structure and will cross the water with 80 metre spans with shorter spans above land.

Align is a joint venture between Bouygues Travaux Publics, Sir Robert McAlpine, and VolkerFitzpatrick, which has been contracted by HS2 to deliver the Central 1 section of HS2 phase 1, including the viaduct across the Colne Valley. VolkerStevin Ltd. has been commissioned by Align to install approximately 394 no. tubular piles over four different jetties required for the construction of the HS2 Colne Valley Viaduct. Geobest, as subcontractor to Volker Stevin, performed several driveability studies for this project.

Fig. 1. Animation of future Colne Valley Viaduct.

All steel tubular piles (864 mm diameter with a wall thickness of 12.5 mm, 16 mm and 18 mm) will be installed in hard chalk layers. The main challenge has been to predict the expected pile resistance (SRD), as pile driving in chalk is subject to significant uncertainty. Literature also provides little and also varying guidance on how to estimate soil resistance to driving in chalk.

In the first phase, the expected pile resistance (SRD) was mapped by means of soil research and information from existing literature, including the CIRIA guidelines (CIRIA 574, 2002). Driveability analyses were performed using the program GRLWEAP (Goble and Rausche, 1976).

In the second phase, an extensive soil investigation campaign was carried out and two pile load tests were performed at two separate compounds (tubular piles, diameter 864 mm, closed and open ended). Driving records were used to back-calculate the chalk SRD parameters in order to adjust the expected pile resistance. Based on the soil description at the boreholes, a distinction was made between structured, Grade A to B (CIRIA 574, 2002), and unstructured chalk, Grade Dm and Dc (CIRIA 574, 2002).

Driving records have been then used to verify the performed prognosis and for back calculation of driving resistance in the chalk layers.

2 SOIL CONDITIONS

The Soil Investigation programme consisted of Cone Penetration Tests, Boreholes with Standard Penetration Tests (SPT) and laboratory testing. The soil stratification at the site consisted of River Terrace Deposits (sand and gravel), and alluvial layers overlying chalk strata interspersed, locally, with heavy flint bands. The properties of the chalk material, as described at the boreholes, varied from Grade D to A (CIRIA 574, 2002) throughout the site and in depth. Based on the soil description at the boreholes, a distinction was made between structured (Grade A1 to B4) and unstructured chalk (Grade Dm and Dc).

The maximum thickness of unstructured chalk is 10.0 m. Beneath this, structured chalk has been found to the maximum penetration depth. The structured chalk is described as weak to very weak, of medium to high density with closely to medium spaced fractures.

At different boreholes, rock strength has been investigated by means of unconfined compression and point load index testing. The unconfined compressive strength (UCS) for chalk varies between approximately 0 and 8 MPa, while between 80 and 100 MPa for flint.

All CPTs were performed to insufficient depth. No cone resistance information was available in grade A and B chalk due to early CPT refusal. A typical CPT profile and a typical soil profile are shown in Figures 2 and 3.

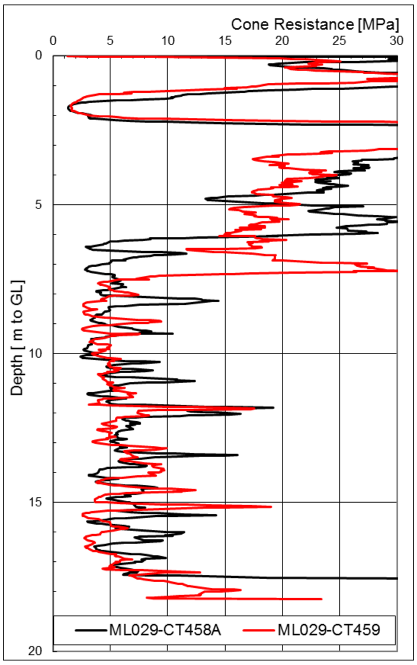

Fig. 2. Typical CPT profile.

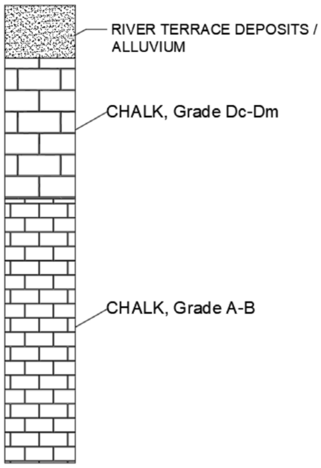

Fig. 3. Typical soil profile.

3 TEST PILES

3.1 General

In November 2019 pile tests (tubular piles, diameter 864 mm) were carried out for open ended piles (pile toe at OD +26.0 m and OD +11.0 m). The piles were installed by vibro driving (TM22 leader rig) followed by impact driving (BSP CG-180) into structured chalk. An additional pile test for closed ended piles was carried out in June 2020. The pile was installed by impact driving using an BSP CG-240 impact hammer.

3.2 Back calculation

Driving records were used to back calculate SRD for open ended and closed ended piles.

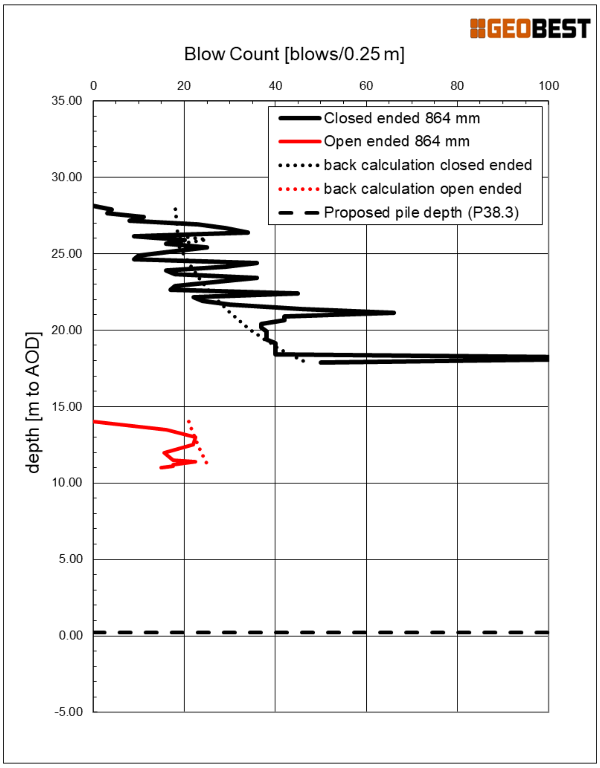

Fig. 4. Back calculation of test piles.

The back calculated blow count vs depth in OD for a closed ended pile is shown in black in Figure 4, while the back calculated blow count vs depth for an open ended pile is shown in red. The proposed pile depth between the different jetties varies between approximately OD +13.0 m and OD, so there is a lack of information from the pile tests at greater depths.

4 DRIVEABILITY STUDIES

4.1 Assumptions

Driveability analyses were performed using the program GRLWEAP (Goble and Rausche, 1976). GRLWEAP is a one-dimensional Wave Equation program that simulates the pile response to pile driving equipment. The program requires the input from the following elements: soil resistance during driving, damping and quake parameters, hammer and cushion properties and pile properties.

A shaft damping value of 0.16 s/m was chosen for non-cohesive strata and 0.54 s/m for cohesive strata while 0.5 s/m was chosen for the toe damping. Quake (shaft and toe) values were assumed to be 2.5 mm. The impact hammer type used in the calculations are: BSP CG-240, BSP CG-180 and IHC S-105.

4.2 SRD methods for chalk

Governing factor for this project was the determination of SRD in chalk strata. Literature provides little and also varying guidance on how to estimate soil resistance to driving in chalk. Newly available methods, as the 'Chalk ICP-18' effective stress method (Jardine et al., 2018) require the use of CPT cone resistance to predict chalk resistance to driving. For this project it was therefore not possible to apply the above methods, due to the lack of cone resistance information in structured chalk.

4.3 Open vs closed ended piles

During the project, the feasibility of using closed ended piles with a considerable reduction in pile length was analysed. Shorter piles will react stiffer and driving becomes easier.

Initially, a driveability study was performed for location P19 (gravel thickness of 5 m). As gravel thickness varies throughout the site (maximum thickness 8.8 meter), a sensitive analysis was carried out. The N_{60} values vs depth in OD in gravel are shown in Figure 5.

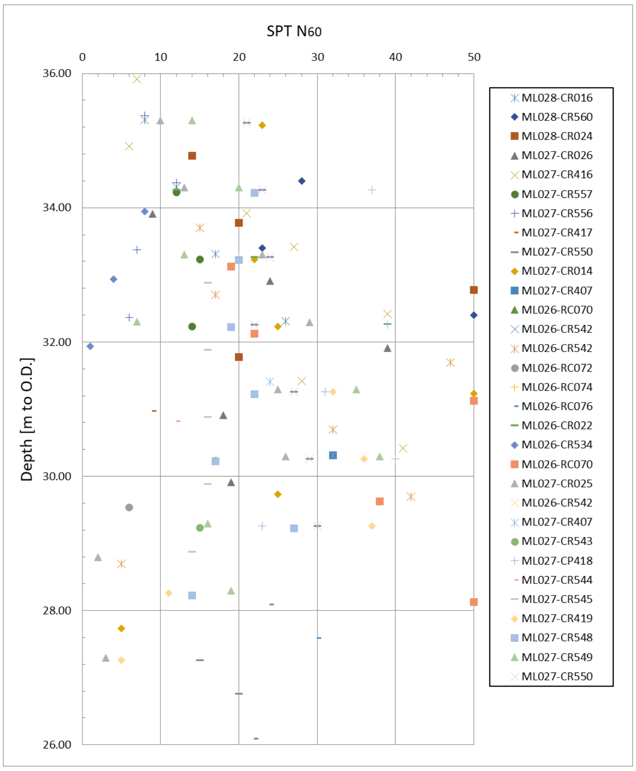

Fig. 5. N_{60} vs depth in gravel.

Conclusion was that above 6 m of gravel, the chances of refusal in gravel are very high. Driving resistance will increase significantly when compared to open ended piles. Due to these results, the application of closed ended piles was abandoned.

5 PILE DRIVING PREDICTIONS

Due to the large variation in strength found in structured chalk, the assessment was originally performed assuming a higher (HB) and lower bound (LB) of soil parameters. The LB approach was chosen in addition to the HB approach to get insight in the variation in blow counts. The HB approach was used to assess the feasibility of driving through the gravel (for the closed ended piles) or the structured chalk (open ended piles) and to derive design steel stresses. In a later phase of the project, it was decided to assess a best estimate (BE) value in order to calculate realistic driving times. The study of literature and back calculation from pile tests led to the selection of the SRD parameters as shown in Table 1.

Table 1. back-calculated SRD Chalk strata.

Layer	Shaft friction (kPa)	End bearing (kPa)
Chalk Grade Dm	20	2,000
Chalk Grade Dc	30-50	10,000
Chalk Grade A-B (LB)*	40-80	20,000
Chalk Grade A-B (BE)*	70-130	20,000
Chalk Grade A-B (HB)*	100-170	20,000

To model the heavy flint bands found at the boreholes, hard layers of 0.5 m (Best Estimate) or 1.0 m (Higher Bound) thickness were included locally.

A total of 394 piles will be installed. A selection of piles was made to get a better insight in the spreads of blow counts, pile stresses and driving times. Table 2 gives the piles taken as belonging to Jetty C and Jetty D.

Table 2. pile properties.

Jetty	Pile no.	Outer diameter (mm)	Wall thickness (mm)	Cut-off level (m OD)	Installation depth (m to OD)
C	P30.2	864	12.5	36.7	13.2
C	P33.4	864	16.0	36.7	3.2
C	P31.1	864	12.5	36.7	8.7
D	P38.3	864	18.0	37.7	0.2
D	P38.1	864	16.0	37.7	7.7
D	P37.3	864	18.0	37.7	6.2

The results of the driveability analyses are summarised in Table 3. From the assessment follow that the required depth can be reached with either the BSP CG-180 impact hammer or the IHC S-150 impact hammer. For shorter piles, the differences between these two hammers are small. With longer piles, the IHC hammer shows the benefit of higher efficiency and higher blow rate. The results are based upon full energy setting of hammers. Hereafter, the results assuming the use of a BSP CG-180 impact hammer will be used.

Table 3. result driving analyses impact driving Jetty C and D – BSP CG-180 hammer.

		Best Estimate		Higher bound	
Jetty	Pile no.	Max. blow count (blows/25 cm)	Driving time (min)	Max. blow count (blows/25 cm)	Driving time (min)
C	P30.2	15	15	20	20
C	P33.4	45	45	90	85
C	P31.1	26	30	55	40
D	P38.3	70	70	125	115
D	P38.1	31	35	47	45
D	P37.3	35	35	50	55

6 PILE DRIVING ACTIVITIES

6.1 General

The execution of works started in May 2021. The piling works will take approximately one year. Driving records are used to verify the performed prognosis and for back calculation of driving resistance in the chalk layers.

6.2 Pile driving records

Figure 6 and Figure 7 show the driving records (blow counts vs depth in OD) regarding the installation of 10 piles belonging to Jetty C and D, respectively. The blow count was standardised in relation to an energy level of 170 kJ, which corresponds to the maximum energy of a BSP CG-180 impact hammer.

Figure 8 gives the last recorded blow count for piles less than 35.0 metres long at Jetty D. The estimated maximum blow count (higher bound and best estimate) is shown in red.

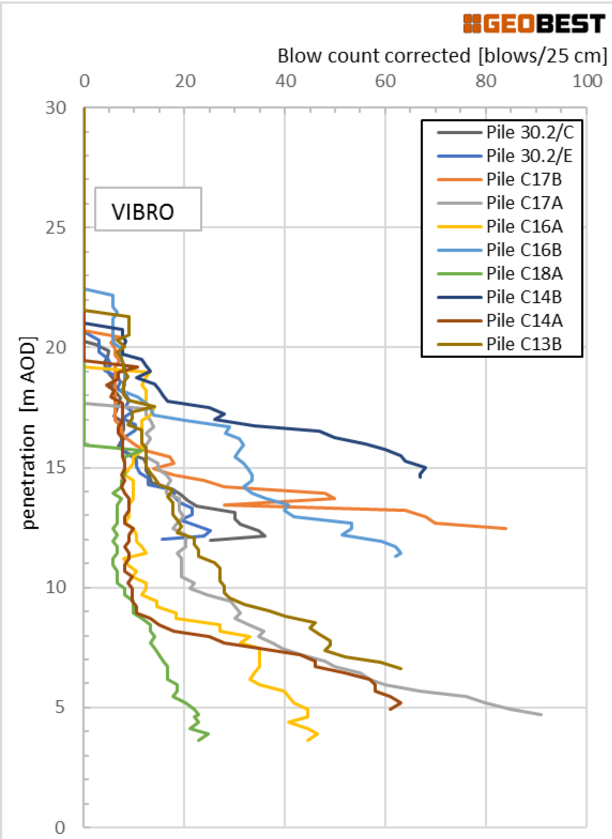

Fig. 6. Blow count corrected vs depth in OD - Jetty C.

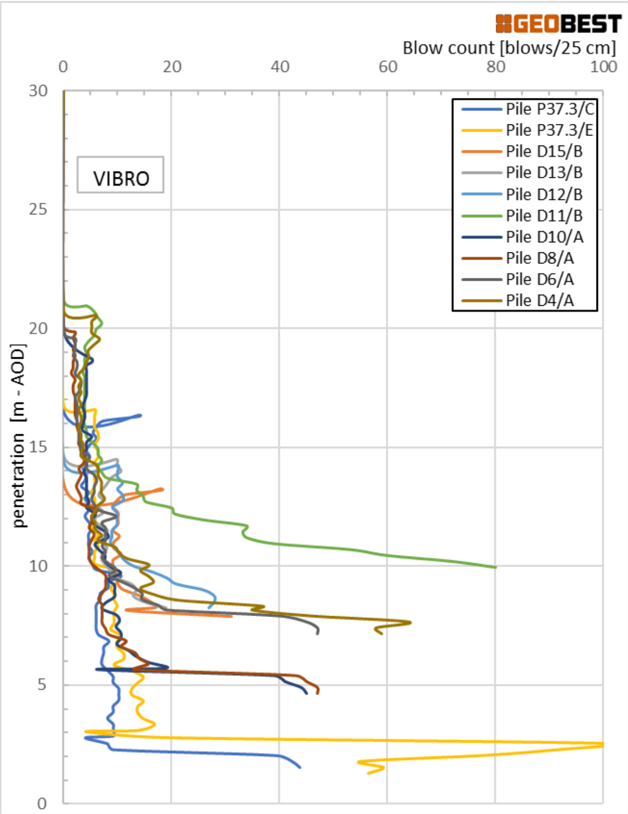

Fig. 7. Blow count vs depth in OD - Jetty D.

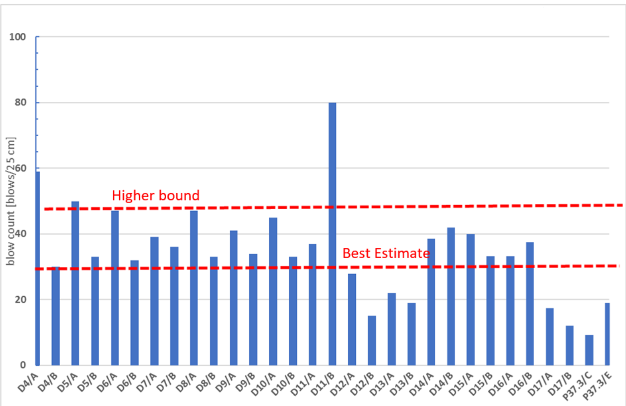

Fig. 8. Last blow count Jetty D, pile length less than 35 metres

Figure 9 and Figure 10 show the last recorded blow count for a number of piles, belonging to Jetty C, with a length greater and less than 29 metres respectively. Predicted values are shown in red.

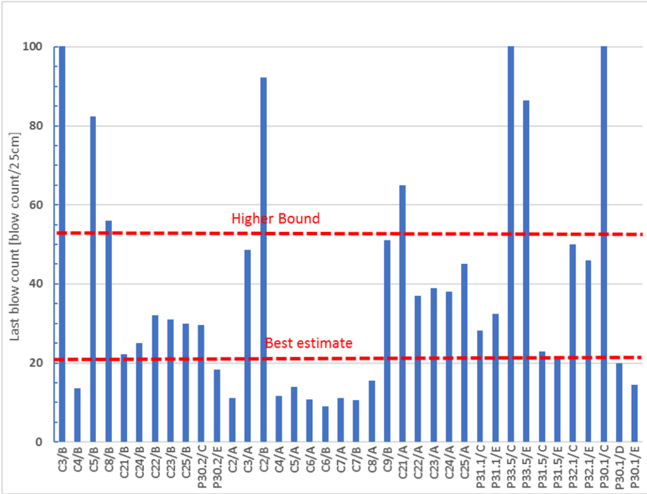

Fig. 9. Last blow count Jetty C, pile length less than 29 metres.

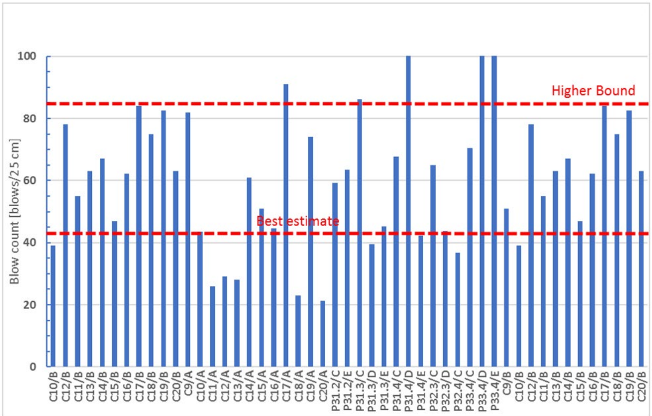

Fig. 10. Last blow count Jetty C, pile length over 29 metres.

Figures 11 to 14 show the blow count (standardized with respect to energy) versus depth for piles P30.2, P33.4 and P31.1 belonging to Jetty C and for pile P37.3, belonging to Jetty D. Driving record are shown with a solid line and pile driving predictions (best estimate and higher bound) with a dotted line.

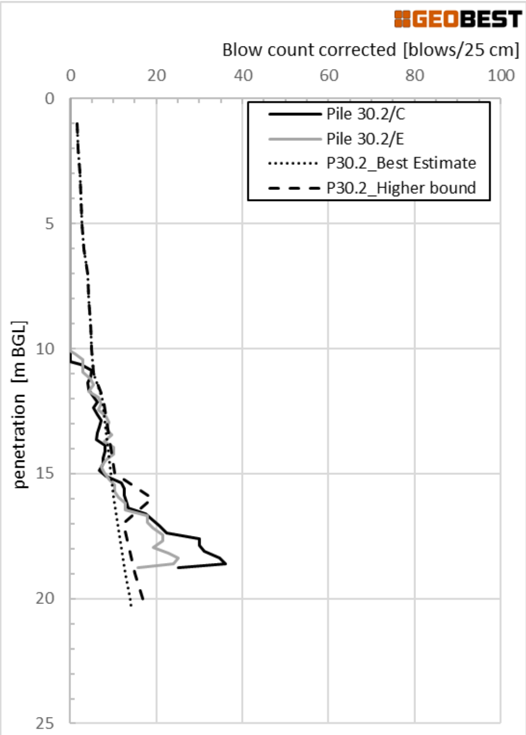

Fig. 11. Blow count corrected vs depth, pile 30.2 (Jetty C)

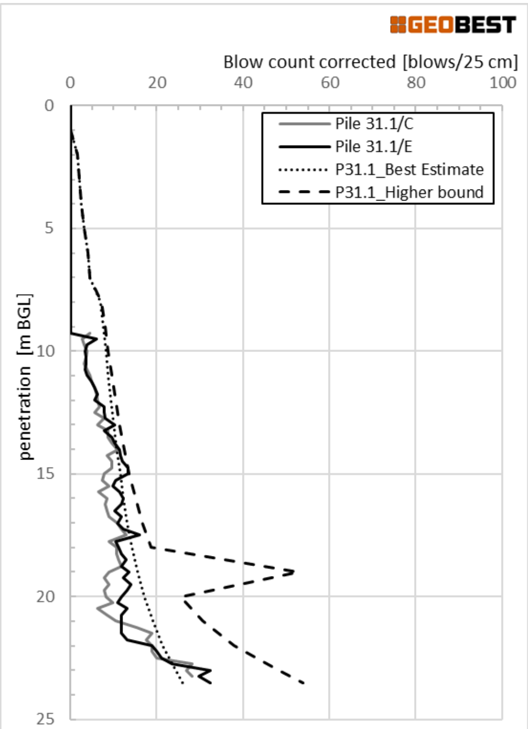

Fig. 12. Blow count corrected vs depth, pile 31.1 (Jetty C)

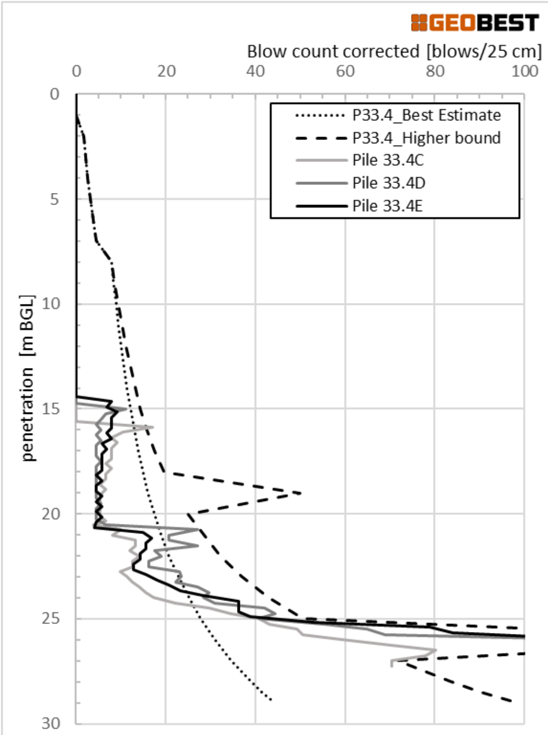

Fig. 13. Blow count corrected vs depth, pile 33.4 (Jetty C)

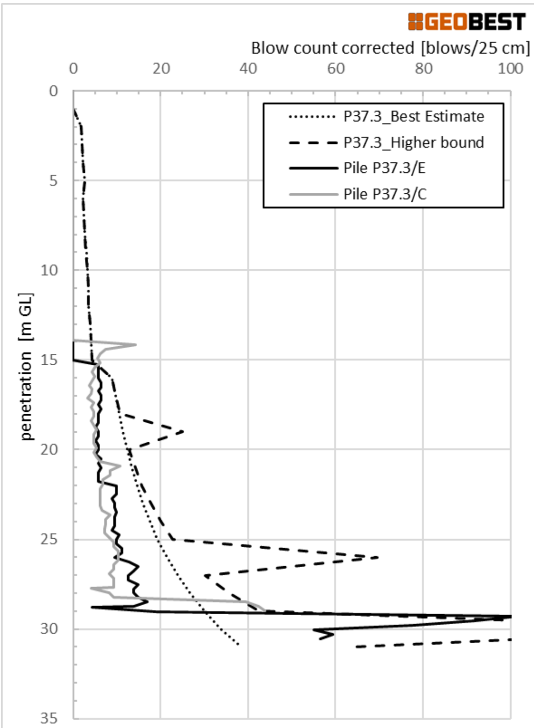

Fig. 14. Blow count corrected vs depth, pile 37.3 (Jetty D)

6.1 Discussion of results

The driving records shown a great variability of chalk parameters with depth.

Based on the driving data received at this stage, the last blow count corrected at Jetty D varies from around 10 blows/25 cm to 50 blows/25 cm, with the exception of pile D11B where the last blow count is 80 blows/25 cm. The data show that the expected higher bound was exceeded during the installation of 2 piles, while during the installation of 7 piles, a last blow count lower than the best estimate was recorded. In approximately 70% of the recorded data in our possession at the Jetty D the last blow count is within the range between the best estimate and the higher bound. At Jetty C this percentage is reduced to 55 % for piles less than 29 metres long (Figure 8) and becomes 80% for piles over 29 metres long.

Figures 12 to 14 show that the predicted values deviate the most from the values recorded on site for piles P33.4 and P37.3, where the depths reached are greater. This could be due to the lack of information available at greater depths from pile tests, since these were not conducted to a sufficient depth.

9 CONCLUSIONS

The results at this project again show that pile driveability assessment is extremely difficult due to the large variation in structure, density, and hardness of the chalk.

Literature provides limited and variable guidance on how to estimate the expected pile resistance (SRD) in chalk, thus leading to significant uncertainty in pile driving. Most of the available methods involve the use of CPTs however, as these are not always conducted to a sufficient depth due to refusal in the structured chalk, it emerges a need for future chalk projects of SPT-based methods for estimating SRD rather than CPT-based methods.

The results from this project also prove the relevance of carrying out test piles to sufficient depth to achieve more reliable predictions.

AKNOWLEDGEMENTS

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