Recovery of Skin Friction of Cambridge Gault Clay with Time Effect

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ABSTRACT

The link between pile wall adhesion factor (soil shear strength modification factor) α and undrained shear strength Cu was widely analyzed by a number of researchers. The adhesion factor is used to calculate the ultimate skin friction of piles. However, how much the skin friction increases from installation stage i.e. mobile skin friction, to the maximum value i.e. static skin friction is not widely researched. Due to the uncertainty, the static skin friction is often underestimated, especially, when the skin friction during pile installation is low. This paper features the tendency of the recovery of the skin friction and time effect on the recovery. As a research model, over consolidated clay, called Cambridge Gault Clay was studied.

Key words: *Press-in Method, Skin Friction, Clay*

1. Outline of the project

1.1. Place

Grand Arcade is located in the heart of Cambridge city centre. Cambridge is a university city and the county town of Cambridgeshire, England, on the River Cam approximately 80 km north of London. Cambridge is home to the world-renowned University of Cambridge, which was founded in 1209. The university includes King's College Chapel, Cavendish Laboratory, and the Cambridge University Library, one of the largest legal deposit libraries in the world.

1.2. Background and objectives of the project

The Grand Arcade development site extends to 2.8ha of land in the historic core of Cambridge. It contained a range of listed and unlisted buildings in varying ages. The development composed of four main areas.

- New Robert Style Department Store
- 50 retail units set in two arcades linked by Central Atrium
- New Magistrate Court
- Replacement 600 space car park

2. Structural type and piling method

2.1. Site condition

The development involved constructing a basement and the sheet pile perimeter wall was installed adjacent to existing buildings. The scope description specified "design and installation of temporary and permanent works steel piling and perimeter protection all sheet piling to be virtually silent and virtually vibration free as Giken system or similar". Various types of sheet piles were utilized depending on locations, which were from 6.6m to 15.5m long and 600mm wide U sheet piles, 6.0m to 14.0m long and 580mm wide Z sheet piles, and 8.1m to 11.0m long Zero sheet piles.

2.2. Ground condition

In the Cambridge area, over-consolidated clay known as "The Gault Clay" is underlying made ground and alluvial sand & gravel layers.

The Gault Clay in the Cambridge area, is a high plasticity (LL > 70%, PI > 40%), over-consolidated stiff to very stiff, slightly silty, very closely fissured CLAY with bands of very stiff to hard clay marl. The stratum is also known to have a high calcium carbonate content and it is understood that the carbonate is present as silt sized particles within the clay matrix, and only provides a limited cementing effect.

The Gault Clay formation was laid down under marine conditions and was overlain by about 150 m to 400 m of Chalk that has subsequently been eroded. Following the glacial period, which would have reloaded the strata but probably not in excess of its previous loading, further erosion has occurred followed by deposition of the existing Terrace Deposits. It is very uncertain what the actual thickness of Chalk/Gault that has been eroded might be. However, pre-consolidation pressures in range of 3400 kPa and 7000 kPa indicates OCR (over consolidated ratio) of 10, which supports a postulated depth of burial/exhumation in the range of 170 m to 700 m.

Sandwiched between the Lower Greensand and the Chalk (previously), the Gault Clay will have experienced a similar geological history to these strata which not only includes vertical changes in stress but changes in horizontal stress due to tectonic processes such as the Alpine Orogeny. Therefore, conventional methods for estimating in situ stresses based on vertical stress changes only, will not necessarily be appropriate for this material.

Typically, the water level lies between 0.5 m below and 1.0 m above the surface of the clay. The typical SPT N values and undrained shear strength of the Gault Clay are plotted as shown in **Fig. 1** and **Fig. 2** respectively.

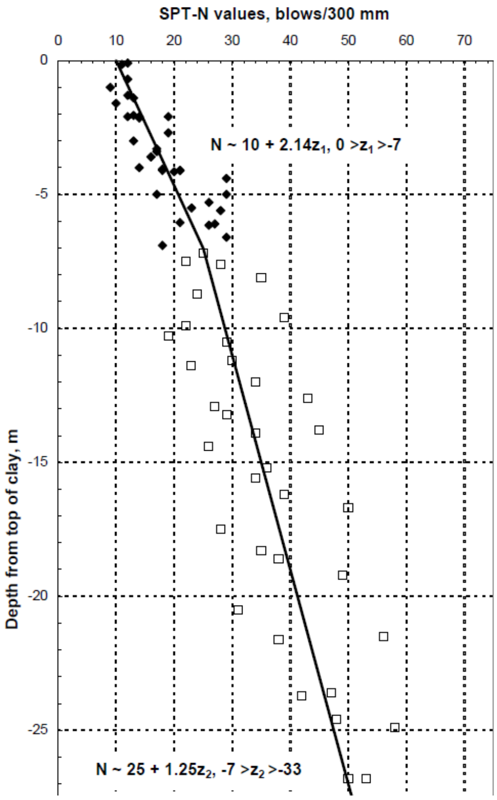

Fig. 1 SPT N Value vs Depth: The Gault Clay

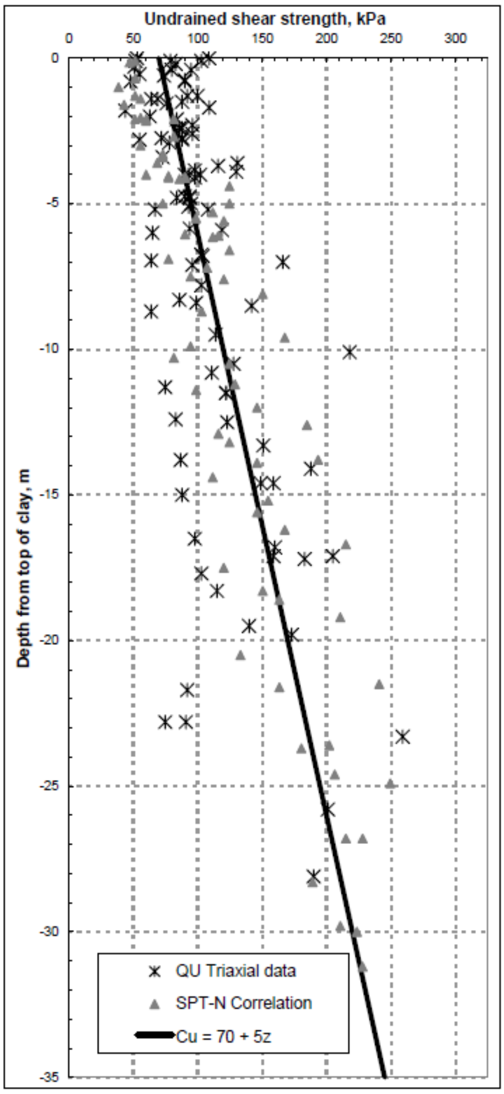

Fig. 2 Undrained Shear Strength vs Depth: The Gault Clay

2.3. Structural type

Due to the presence of the stiff Gault Clay, a raft type foundation was designed for the project and the majority of the building load is carried by the raft slab. To construct a basement, 421.2m of perimeter wall was installed utilizing steel sheet piles. The retained height of the sheet pile wall in the temporary condition ranged from 3.35m to 7.7m and 85% of the perimeter wall was propped with 1 to 3 levels of raking strut system. In the permanent condition, the sheet pile walls were cladded with 900mm thick reinforced concrete to provide vertical load transfer and a grade 3 basement environment.

2.4. Piling method

In order to install sheet piles into the stiff Gault Clay, water jetting was employed for the Press-in Method as a driving assistance. The water jet temporarily and locally softens soil at the pile toe, and lubricates the pile surface. Thus, the installation resistance is reduced, resulting in improvement of drivability and reduction of pile damage. Once the sheet piles were installed, they were left in place as the permanent basement walls.

3. Press-in piling

3.1. Layout

The plan layout of the retaining walls are shown in bold lines in **Fig. 3**.

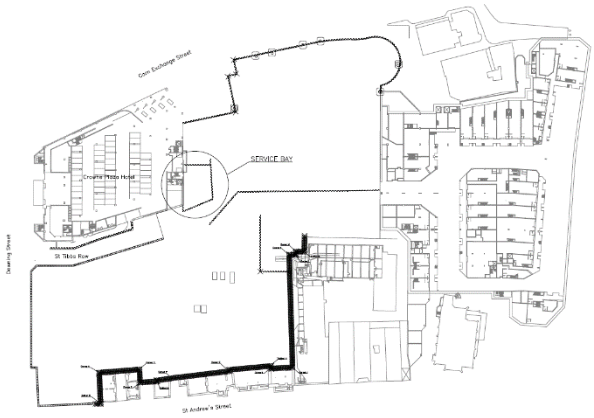

Fig. 3 Project Layout Plan

3.2. Productivity

The piling work was carried out from February to September in 2005 by utilizing 3 different types of Silent Pilers. Due to the complexity of the job site, the piling work was carried out intermittently. The typical production rate was between 200m and 300m a day of total driving pile length excluding downtime.

3.3. Piling data

Sometimes, the issue of ground disturbance is raised when considering water jetting to install piles. Giken Ltd. empirically knows that impact of water jetting is temporary and local with proper water pressure and volume control. However, there had not been research data on the use of water jetting in over consolidated stiff cohesive soil. Therefore, Giken Ltd. carried out experimental piling to figure out the impact of water jetting on Cambridge Gault Clay as described in Fig.4. Skin friction was monitored during and after the pile installation to quantify the recovery of skin friction. To measure the skin friction, an unclutched 14m long AZ48 sheet pile was installed. 200kN skin friction was recorded at the final depth. The surface area of AZ48 sheet pile is 1.90m^2/m and the embedded depth of the pile was 13.5m, which represents a unit mobile skin friction of 7.8kN/m^2.

Then after 24 hours, the pile was extracted and the skin friction was measured at 950kN, which represents a unit skin friction of 37kN/m^2. This indicates that the mobile skin friction became static friction, increased by 475% with time effect.

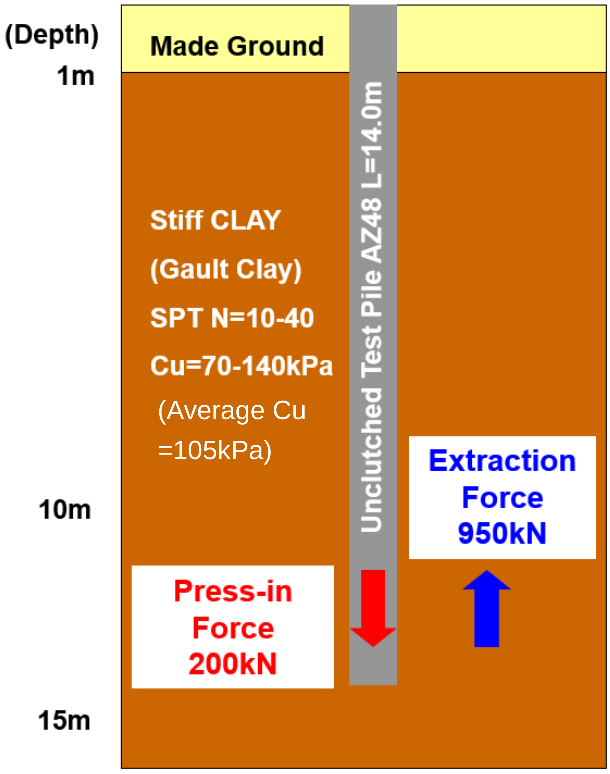

Fig. 4 Sideview of Experimental Piling

4. Back analysis

To determine the Gault Clay static friction, we carried out reverse calculation of the obtained geotechnical information.

The average undrained compressive strength Cu of the Gault Clay was 105kPa over the embedded pile length. The theoretical static skin friction Rft is worked out by the following formula.

$$Rft = \alpha CuAs \text{ (kN)} \quad (1)$$

α; Pile Wall Adhesion Factor (Soil Shear Strength modification factor) for Each Soil Layer (see **Fig. 5**)

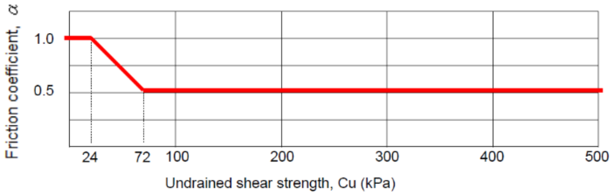

Fig. 5 α Factor versus Cu for Clay according to Tomlinson

Cu; Average Undrained Shear Strength of Each Layer (kPa)
As; Embedded Area of the Shaft of the Pile in contact with the soil (m^2)

Here, $As = LgD = 1.90 \times 13.5 = 25.7\text{m}^2$
Lg; Girth Length of Single Pile (m)
D: Embedded Pile Depth (m)

$$Rft = \alpha CuAs \text{ (kN)}$$
$$= 0.5 \times 105 \times 25.7$$
$$= 1{,}349 \text{ kN}$$

The actual skin friction Rf measured on the job site was as follows: -
200kN: during pile installation (15% of Rft)
950kN: 24 hours after installation (70.4% of Rft)
This sharp increase in the skin friction within a short period indicates that the water jetting did not soften the Gault Clay as initially thought. Moreover, the skin friction will even gradually recover further after the initial 24 hours.

5. Concluding remarks

This study reveals that the recovery of skin friction was faster than initially thought. However, although skin friction rapidly increased in the first 24 hours after the pile installation, it is concurred that a further increase occurs days or months after installation. Therefore, further research is required to determine a more precise adhesion factor of Gault Clay after water jetting.