PILE DRIVING IN SOFT GROUND: MEASURES TO MITIGATE IMPACT ON EXISITING INFRASTRUCTURE

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ABSTRACT

This paper presents a case study of pile driving in soft clay from a freeway project in Melbourne, Australia. The paper presents an overview of finite element modelling and full-scale field trials to inform design and construction. Given the presence of soft soils to significant depth, precast concrete driven piles were considered a cost effective and suitable foundation construction methodology for the proposed freeway bridges. Modelling showed that as large group of new piles were installed the soft soils would displace laterally, the magnitude of lateral displacement needed to be assessed. This mechanism was not well understood in the industry during the design phase leading to further assessment, field trials, model validation and monitoring during the construction phase. This study presents methods to predict ground movement, field trials and monitoring undertaken to validate modelling predictions and back analysis of monitoring data to inform selection of suitable mitigation measures for piling operations.

KEYWORDS

Precast Concrete Driven piles, soft ground, Ground movement, Full Scale Field trials, Finite Element Analysis

INTRODUCTION

Driven precast concrete piles are displacement piles (AS 2159, 2009), meaning that their installation causes soil displacement equivalent to the embedded volume of the pile. Where the soil profile is granular or comprises clay of reasonable strength (generally stiff or better) the soil displacement results in a zone of compacted material surrounding the pile and the geotechnical design can take advantage of this and adopt somewhat higher design parameters (compared with a drilled, non-displacement pile). However, when such piles are driven through soft clay, such as Coode Island Silt (CIS), the mechanism of soil displacement is different. The soil volume changes during pile installation through soft clay such as CIS is effectively nil, and consequently, the volume of displaced material will correlate directly to the volume of the driven pile. The magnitude of this displacement (heave and lateral movement) and subsequent ground movement is generally dependent on the type and size of piles, size of pile group and soil type.

The typical pile group considered in this paper, shown below, comprised groups of 12 to 30 No 400x400 square precast driven piles with estimated pile toe levels 30m below ground level terminating within dense to very dense sands.

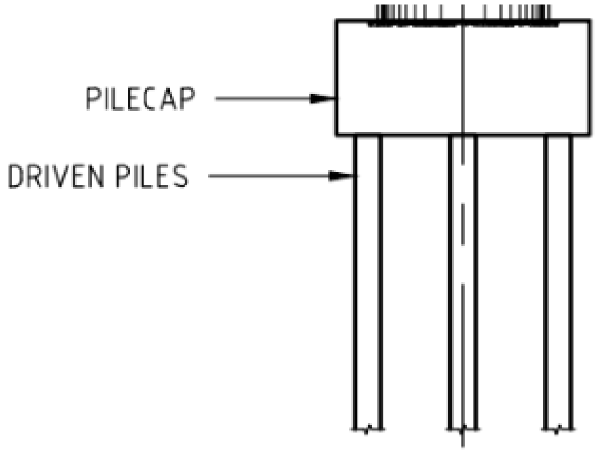


Figure 1 - Typical pile cap layout

GROUND CONDITIONS & GROUND BEHAVIOUR

The project is located to the west of Melbourne CBD and covers an extensive area within the Yarra Delta region. The Yarra Delta, situated at the head of Port Philip Bay, is an area of Quaternary sedimentation with an intercalated flow of basalt in its eastern part. The Quaternary geological units which together comprise the Yarra Delta rest on an undulating plane inclined to the south-west at a low angle, which is a terrain of both steeply dipping Silurian Melbourne Formation Siltstone and sandstone. Subsurface ground profile of the project area comprises typically 1m to 5m of historical uncontrolled fill, underlain by up to 20m thick of CIS which is in turn underlain by >2m thick layer of firm-stiff and very stiff layer of Fishermens Bend Silt (FBS) unit. Moray St Gravel which typically comprises dense sands is encountered below this depth where the precast driven piles are founded into. Of the geological units within the Yarra Delta, the Coode Island Silt (CIS) which is a locally well-known soft soil is of main interest of this paper. General subsurface ground profile of the project area is provided in Figure 2.

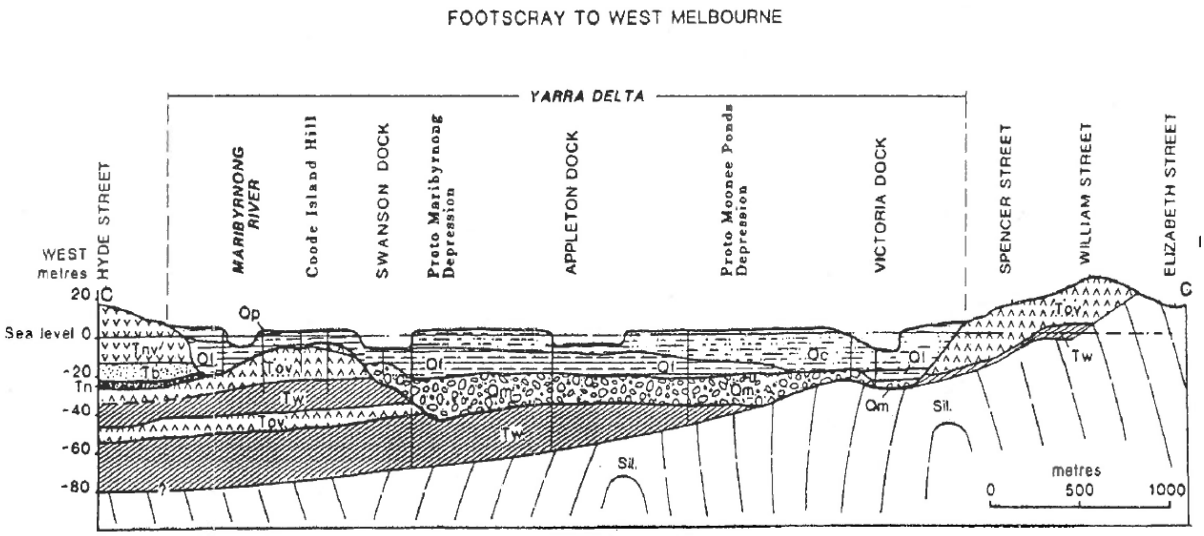


Figure 2 - Geotechnical Section Yarra Delta (J.L. Neilson, 1992)

GROUND MOVEMENT DUE TO PILE DRIVING

Where ground conditions comprise granular soils or cohesive soils of firm or better consistency, pile driving process will create a zone of highly compacted material immediately surrounding the pile. In these conditions soil displacements are generally limited to the immediate surrounding of the pile being driven. i.e. in these conditions, extent of ground movement is more localised because of compaction and densification of the soil. However, when driven displacement piles are installed into soft soils such as Coode Island Silt (CIS), a different soil displacement mechanism is likely to occur. Depending on the strength and nature of the soft soil, the volume of installed piles is likely to cause displacement of the in-situ ground, which may be equivalent to the volume of driven piles. The displacement caused as a result of pile driving likely to take place in the form of heave and/or lateral displacement of surroundings soils and can extend to considerable distances from the location of piles being driven. Where there are existing foundations or structures in the vicinity of the piles being driven, this may have an adverse impact on nearby installations, structures and assets. In such cases, where existing installations and structures exist in the vicinity of piles being installed, it is essential that a ground movement and impact assessment is undertaken.

The next section discusses the approach taken as part of this project to predict magnitude and extent of soil displacement.

PRE-PRODCUTION SITE TRIAL AND FIELD MEASUREMENT

Given the lack of available data and experience with assessment of ground movement related to pile driving locally, a pre-production trial was undertaken. As part of the trial, three out of a proposed 22 pile group of 400x400 precast piles were driven. Inclinometers were installed at varying distances from the pile group to record the ground movement during pile driving. Inclinometers were installed at 2.1m distance from location of piles installed.

Trial piles were installed to the nominated pile founding depths i.e. pitched piles of 33-34m in length with driven lengths of 30.0m. Inclinometers were installed to the siltstone rock below ~RL-40m i.e. to a total depth of 43m below platform level. During the trial piling, a pre-bore depth of 9m (min) was recommended, due to available equipment limitation on site, pre-bore depth was limited to 3m. Manual inclinometer readings were undertaken at both inclinometer locations at the end of each pile being driven to their nominated depths as per sequence shown above.

Inclinometer readings obtained from two inclinometers installed at varying distance from the location of trial piles are shown below. Each plot shows three readings; each obtained as the first 3 trial piles were driven. Axis A readings show movement perpendicular to the pile being driven, while axis B shows the readings parallel to the pile.

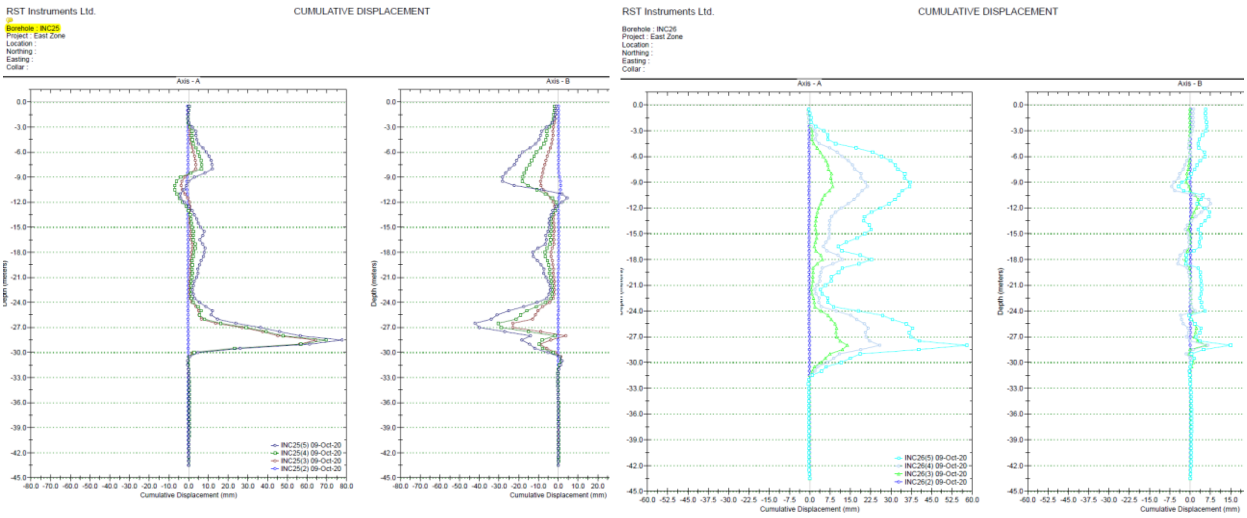


Figure 3 – Inclinometer readings for trial piling

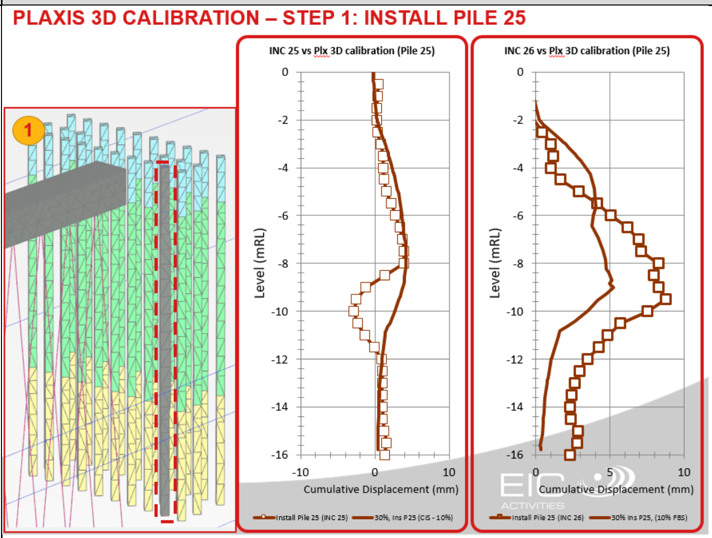
MODEL DEVELOPMENT AND CALIBRATION

A PLAXIS 3D analysis was undertaken prior to the pre-production trials. The preliminary PLAXIS analysis was based on assumptions and review of literature elsewhere. Results of the site-specific trial piling and inclinometer readings were used to calibrate ground movement in PLAXIS 3D. The following stages were modelled in PLAXIS 3D to replicate the site trials.

- Generate initial stress
- Install existing structure foundations
- Step 1: Install 1st Pile – Review ground movements and compare against inclinometer data
- Step 2: Install 2nd Pile – Review ground movement and compare against inclinometer data
- Step 3: Install 3rd pile – Review ground movement and compare against inclinometer data

Results of the calibration modelling from PLAXIS 3D are summarised in Table 1 below.

Table 1 – PLAXIS 3D Calibration against Inclinometer Data

<table>
<tr><th>Stage</th><th>PLAXIS 3D Prediction</th></tr>
<tr><td>Step 1 – Install 1st Trial Pile</td><td>
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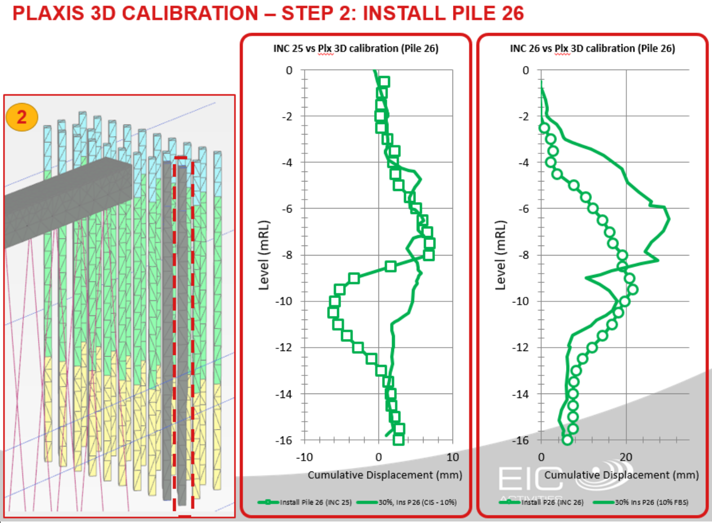
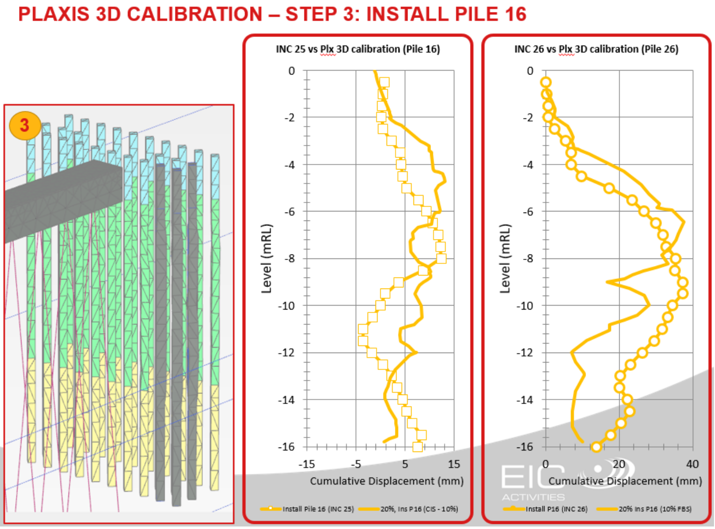
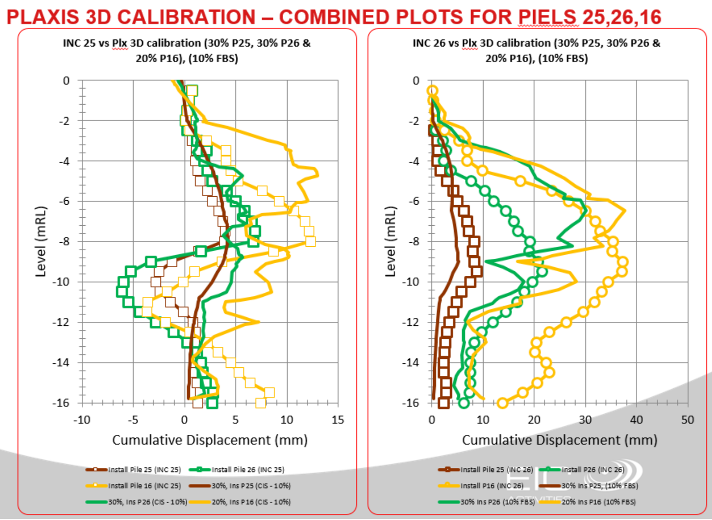
Step 2 – Install 2nd Trial Pile	
Step 3 – Install 3rd Trial Pile	
Combined inclinometer vs PLAXIS 3D plots for all three piles	

TRIAL MITIGATION OPTIONS AND PREDICTED GROUND MOVEMENT

Building on the calibrated model, the entire pile cap was then simulated in PLAXIS 3D. A similar approach as the calibration model was adopted. Previous studies and published literature indicate that there is some benefit due to “shielding effect” from the installed piles, which was adopted in the modelling.

Two cases were analyzed in PLAXIS 3D to provide an understanding of the benefits, preboring the soil before pile driving and installation of a steel casing before pile driving. Case 1, all piles pre-bored to 9m and Case 2, all piles pre-bored to 9m and also 6 nearest piles provided with casing over the first 9m. 9m casing length was considered a maximum practical depth to which casing could be installed safely. This would also ensure driven piles through existing 'uncontrolled' fill would not generate excessive ground movement. Results and analysis approach for these two cases are presented in the next section.

Case 1: All Piles Pre-Bored to 9m

Peak ground movements are generated within the top 10m due to presence of the soft soil layer which undergoes largest movements. Effectiveness of pre-boring depends on type of soil (how long the hole can remain open for) and depth of pre-bore amongst other factors. Based on past experience and the influence of groundwater on hole stability, the following pre-bore effectiveness has been considered in the PLAXIS analysis;

0 – 3.0m: 100% effective

3 – 9.0m: 70% effective

9 – 10.8m: 50% effective

Predicted deflections calculated in PLAXIS 3D based on the above is presented below.

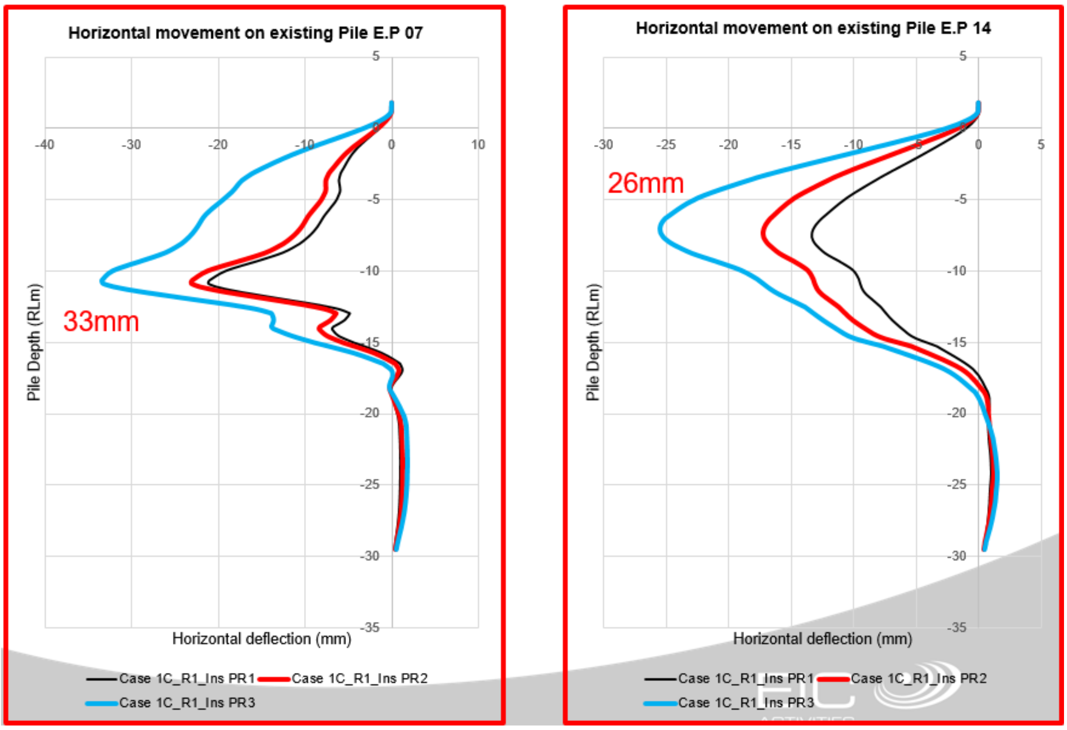


Figure 3 – Predicted pile deflection (pre-bore only)

It is noted that ground movement is likely to be much smoother than those predicted in PLAXIS 3D. The sudden changes in calculated movements are more due to modelling limitations i.e. changed soil stiffness, stepped increase in applied movements in the Finite Element model.

Case 2: All Piles Pre-Bored to 9m + Six nearest piles Cased

To understand the effectiveness of casing the piles, a second case was analyzed with the six nearest piles to the location of monitoring provided with steel casing to 10m depth.

The following construction sequence was adopted on site:

1. Drive 12mm thick, 680mm inner diameter, 10.5m long steel casing to 10m below existing ground surface for the six nearest piles as shown above.
2. Excavate/ bore out inside the casing to 10m depth bgl.
3. Fill up the casing with water to balance hydrostatic pressure outside the casing as drilling and boring out progresses.
4. Pre-bore further 2m locally in the middle of the casing.
5. Backfill the casing with peak sized gravels to existing surface and compact locally.

For this case, the following pre-bore effectiveness was considered in the PLAXIS analysis.

0 – 3.0m: 100% effective

3 – 9.0m: 70% effective (all piles)

9 – 10.8m: 50% effective (all piles)

9 – 12m: 100% effective (6 cased piles)

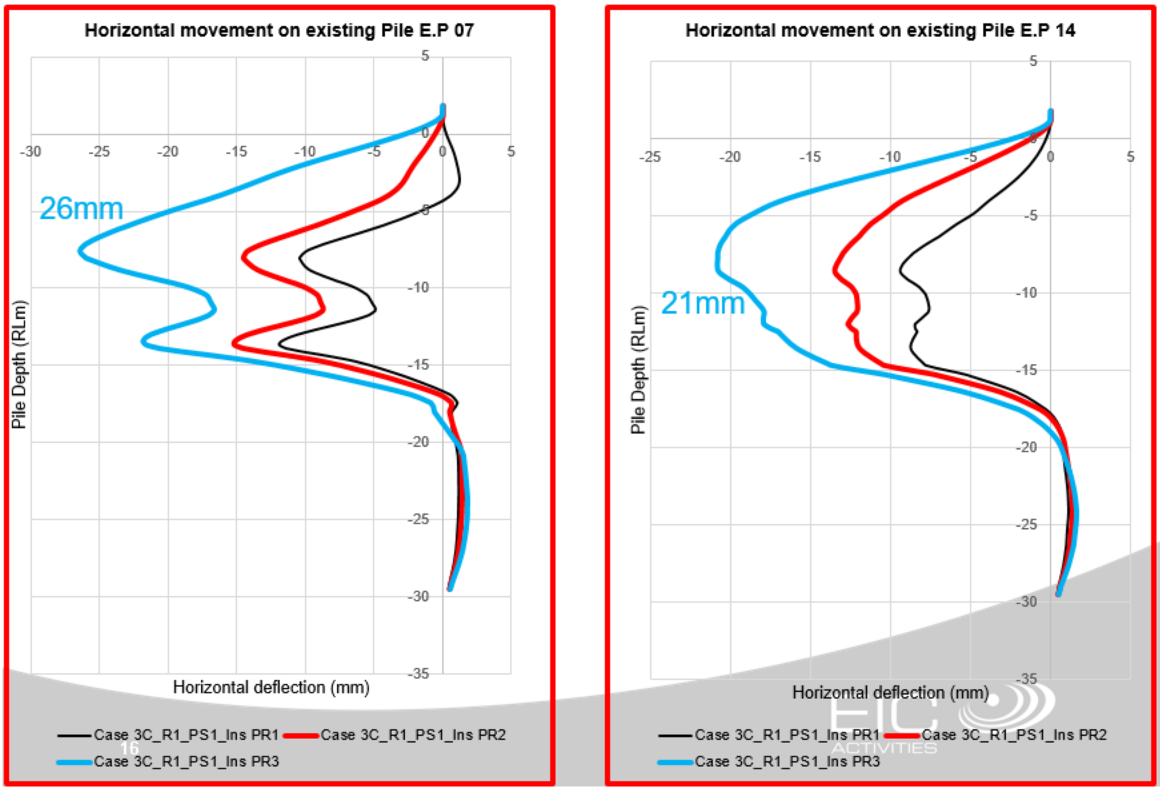


Figure 4 – Predicted pile deflection (pre-bore only+6 Piles with casing)

Based on the field trial and monitoring, the addition of a casing and pre-boring reduced the peak horizontal displacement by approximately 20%.

Case 3: Replacement of Precast Concrete Driven Pile with Steel H Piles

Further to trials using preboring and steel casing, additional trials were undertaken considering the replacement of precast driven piles on a one-for-one basis with low displacement steel H-piles. The chosen low displacement options were a combination of welded column sections (i.e. 350WC197 and 400WC212). Theoretically the soil displacement due to pile installation is directly proportional to the cross- sectional area of the installed pile. A 400WC212 and 350WC197 have a reduced cross-sectional area compared to the 400mm square precast driven pile, 12.9% and 15.6% of the cross-sectional area, therefore the lateral displacement caused by installation of these piles section should be reduced by a similar magnitude.

Analysis of the steel H-pile option was undertaken using in Plaxis 3D like the other trials discussed above. There was a concern that the H-Piles may plug as they are driven through the superficial fill, which would result in increased lateral displacement. The H-pile with a plug of soil wedged between the flanges has a gross section area approaching that of a 400 mm square PDP, and the resulting lateral displacement would likely exceed acceptable limits. The lateral soil displacement was measured using a Vertical Shape Accelerometer Array installed in an inclinometer casing to a depth of 32 m.

The installation methodology is summarised below:

1. Install inclinometer with detailed logging and sampling and obtain stable baseline readings.
   Install Test Pile 1 - 350WC197 with 810 mm casing through fill only. To prevent plugging of H-Pile, remove fill material and possible solid obstructions in temporary casing.
2. Install Test Pile 2 – 350WC197 with 760mm OD casing to 12m through Coode Island Silt. Muck out material inside casing to a minimum depth of 2m below fill or 6m depth;

The lateral displacement at an offset of 1.7m was measured using inclinometer. Monitoring results indicate that the lateral displacements resulting from the installation of Test Pile – TP1 are less than 2.5 mm.
Results of Case 3 trials indicated a significant reduction in magnitude of ground movement in these conditions.

SUMMARY AND CONCLUSIONS

Case studies from pile driving trials within soft clay in Melbourne Australia have been presented in this paper. Ground movement predictions based on pre-production trial site data shows that large lateral ground movements can occur, especially where driving groups of piles are undertaken. Field measurements have been used to calibrate finite element modelling and develop mitigation measures to limit the impacts due to driven piles in soft clay. Adoption of mitigation measures (in this case, preboring, casing and replacement of concrete precast piles with H-Piles) was informed by pre-production trials and calibrated finite element models. Based on the field trial and monitoring, the addition of a casing and pre-boring reduced the peak horizontal displacement by approximately 20%. Monitoring was undertaken during installation to verify the effectiveness of the mitigation measures and validate modelling assumptions. Results of the trials and modelling approach developed as part of the trials were adopted across the project with further site-specific trials, monitoring, refinement to model assumptions and adjustment to model parameters to suit local conditions.

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