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NUMERICAL ANALYSIS OF THE BEHAVIOUR OF THERMO-ACTIVE PILES IN LONDON CLAY

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ABSTRACT

The increasing demand for low carbon heating and cooling in the UK in recent years has been the main driving factor to investigate the geotechnical performance of thermo-active piles. A number of numerical models have recently been developed to improve the understanding and ultimately establish a guideline to design thermo-active piles. This research uses Imperial College Finite Element Program (ICFEP) by Potts & Zdravkovic (1999) to carry out a simulation of the Lambeth College pile test that was carried out in in 2007 in London (Bourne-Webb et al., 2009). Further investigation on the behaviour of thermo-active piles is included through a parametric study performed on a single pile in London Clay where the effect of mechanical and the thermal properties of soil on the geotechnical performance of a thermo-active pile are investigated.

FINITE ELEMENT MODELLING

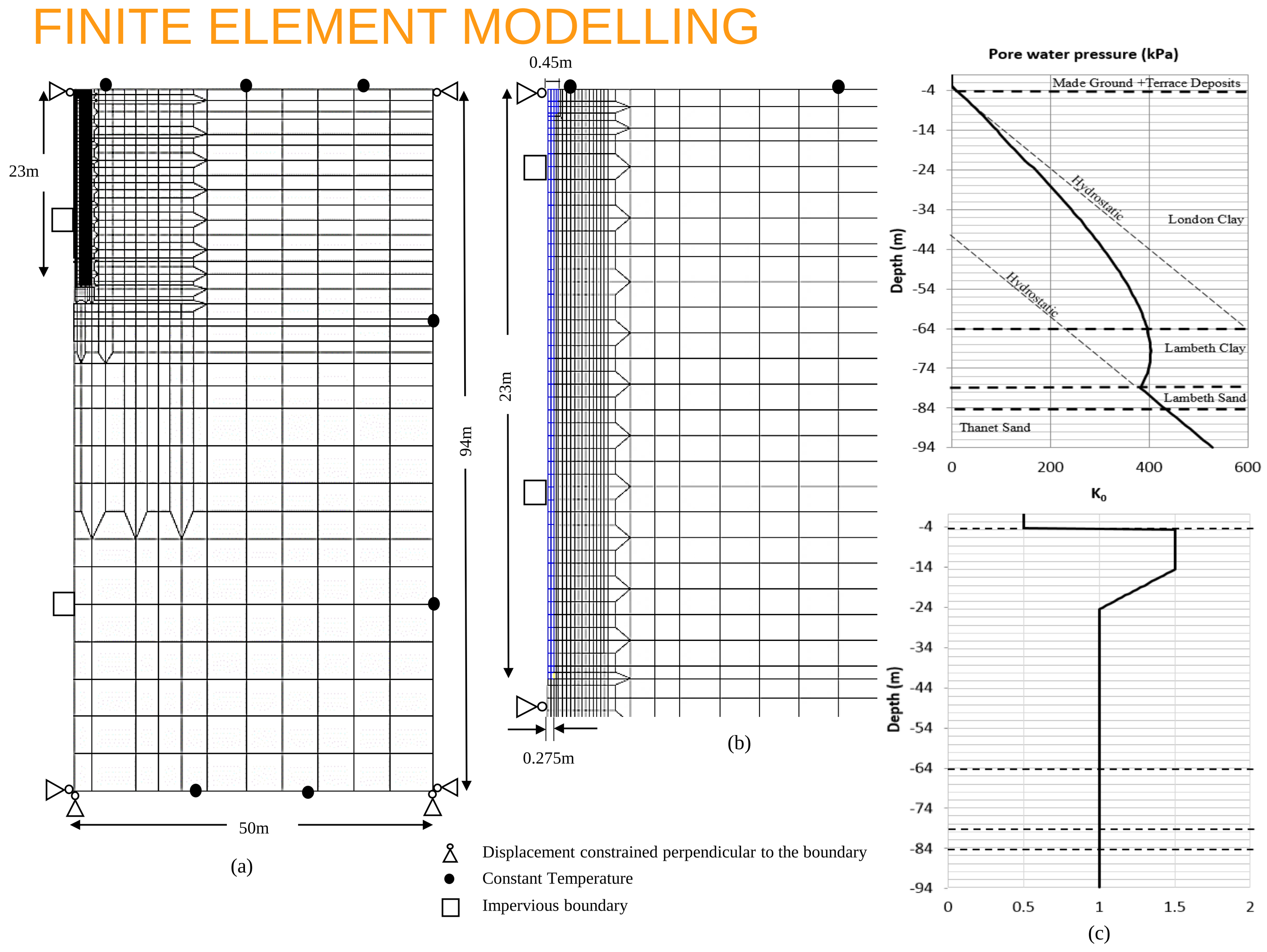

Figure 1: Finite element mesh and boundary conditions (a) General view (b) Detail of pile (c) Initial conditions

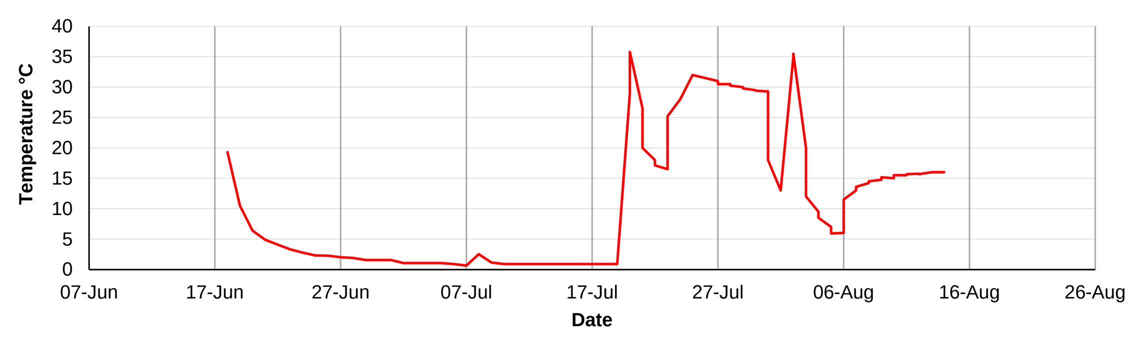

Figure 2: Induced temperature of pile from the start of cooling to the end of test applied during simulations

RESULTS: BASE ANALYSIS

The results from the base analysis (Run 1.0) shows that the numerical model is successful in simulating only the first loading phase where the obtained pile head displacement and axial strain profile in the pile show very good agreement to the field data as shown in Figure 3 and 4, respectively. Residual strain profile and permanent pile displacement are not accurately reproduced in the model during unloading and reloading indicating that the soil behaves predominantly elastically within the applied stress levels. The thermo-mechanical behaviour of pile during cooling and heating is poorly predicted where overestimation of the pile head displacement is recorded. A parametric study is carried out to further investigate the behaviour of the pile.

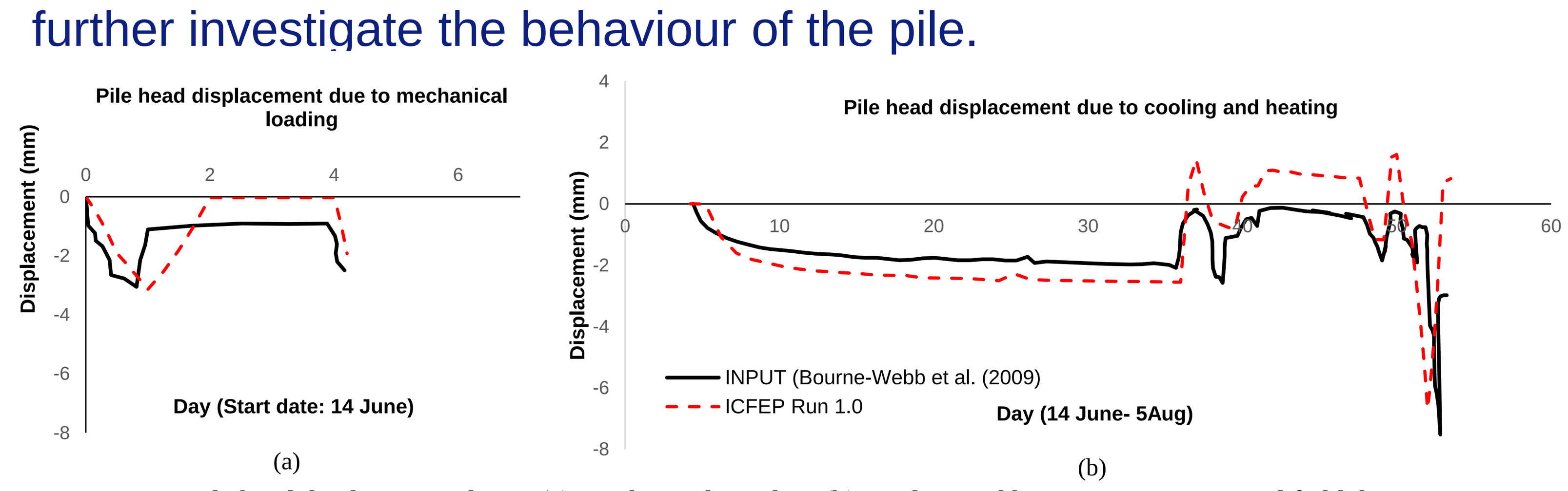

Figure 3: Pile head displacement due to (a) Mechanical Loading (b) Cooling and heating for Run 1.0 and field data

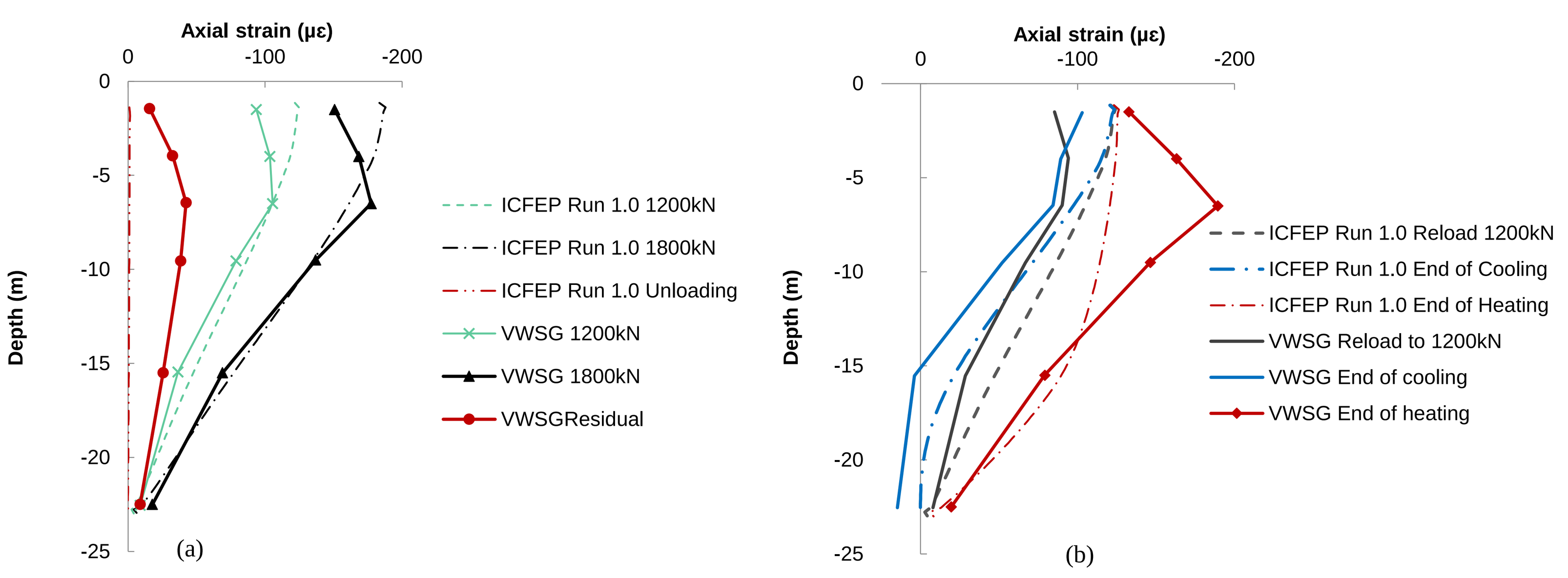

Figure 4: Axial strain profile for Run 1.0 and field data at the end of (a) Loading and unloading (b) Cooling and heating

PARAMETRIC STUDY: SOIL STIFFNESS

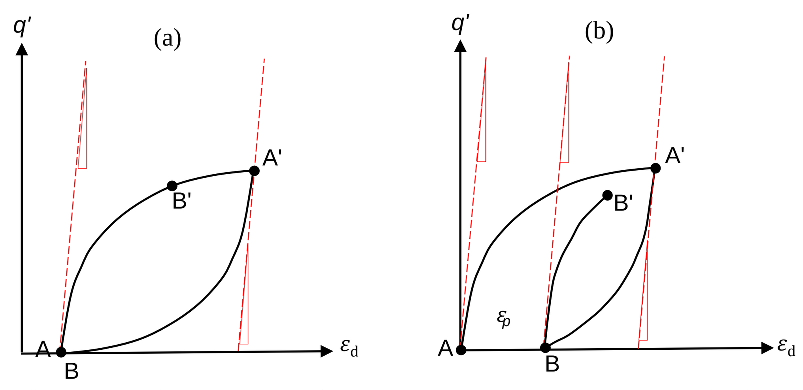

Figure 5: Illustration of typical stress strain path during loading, unloading and reloading for cyclic stiffness approach (a) Without Masing rules (b) With application of Masing rule

Following the base analysis results, a simulation which incorporated the Masing Rules was carried out in Run 2.2, to simulate hysteretic soil behaviour. This reduces the rate of degradation to half the initial value upon the first reversal of straining direction, producing irreversible strains during unloading as illustrated in Figure 5.

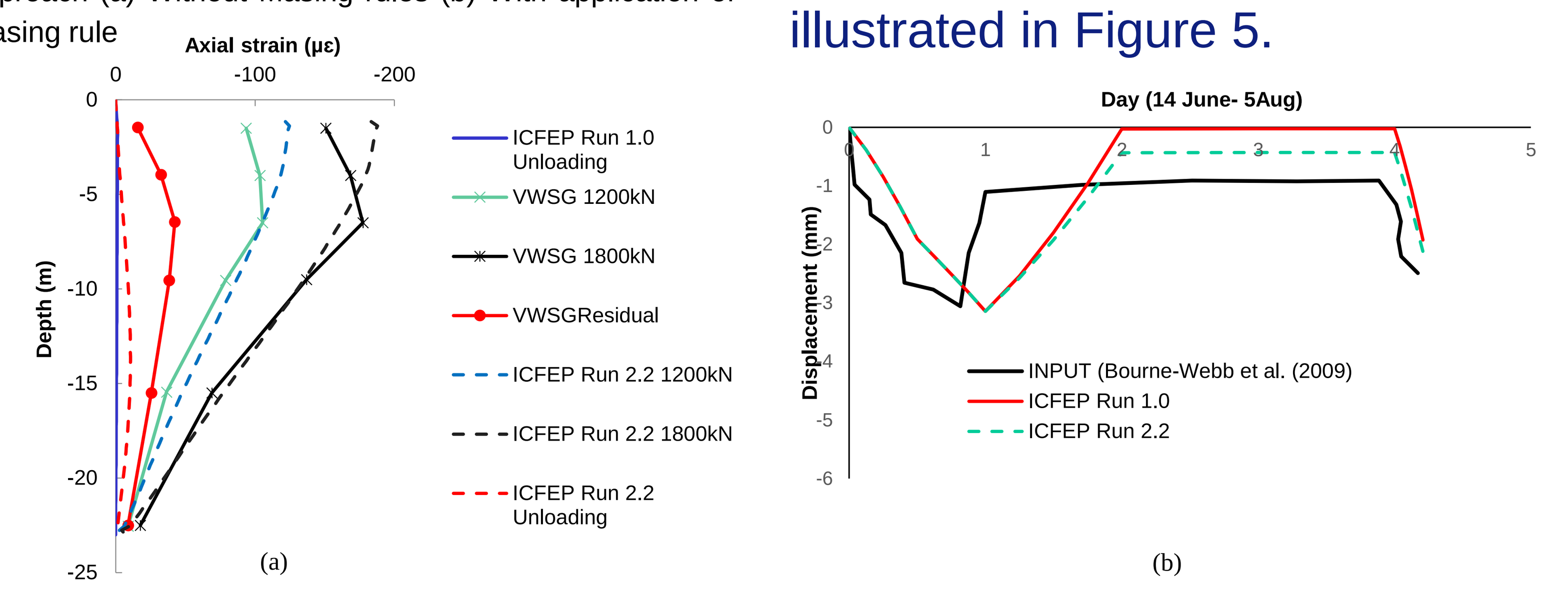

Figure 6: (a) Axial strain profile (b) Pile head displacement during mechanical loading for Run 2.2, Run 1.0 and field data

The results from Run 2.2 show higher residual strains and better pile head displacement prediction at the end of unloading as illustrated in Figure 6.

PARAMETRIC STUDY: THERMAL BOUNDARY CONDITIONS

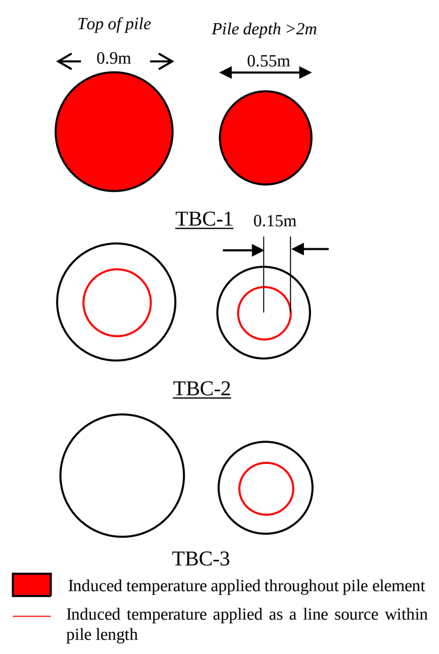

Figure 7: Illustration of different thermal boundary conditions

Several analyses have been carried out to investigate the thermo-mechanical behaviour of the pile by changing the coefficient of thermal expansion, conductivity of the soil and the thermal boundary condition (TBC) of the pile. It is found that the latter had the most significant impact on the pile head displacement prediction. Figure 7 illustrates 3 different thermal boundary conditions employed in the numerical analysis. TBC-1 specifies a uniform temperature value across the entire cross section of the pile, whereas in TBC-2 and TBC-3 the temperature is prescribed along a line within the pile, except at the top 2 m of the pile in TBC-3 where the temperature is allowed to vary according to heat transfer to simulate the effect of atmospheric temperature in this region.

From Figure 8, it can be observed that Run 6.2 which employed TBC-3 gives the closest prediction of pile head displacement during cooling. It is also observed that the pile displacement prediction is much better during cooling than it is during heating phase.

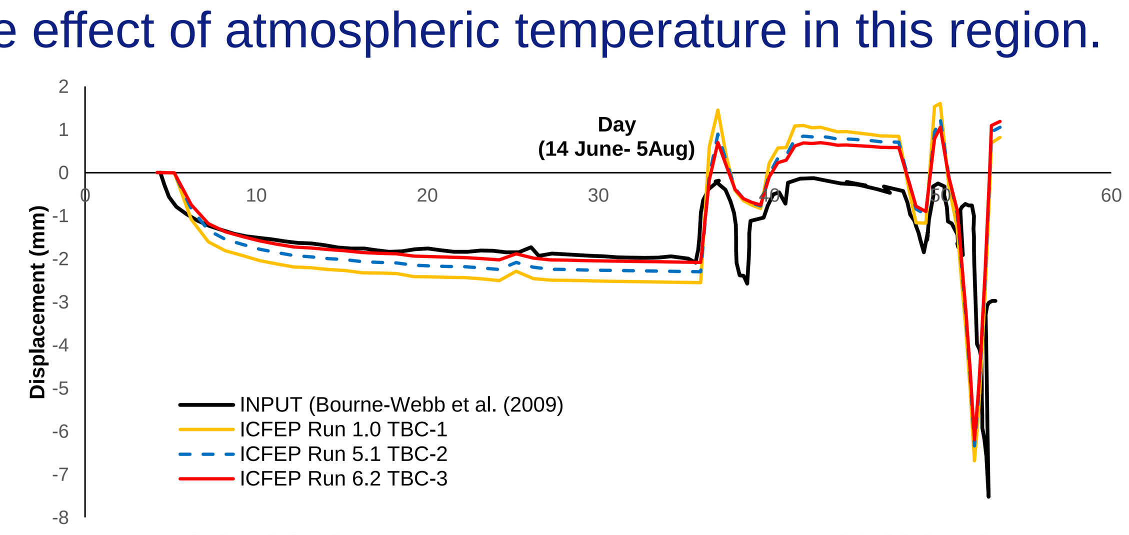

Figure 8: Pile head displacement for Run 6.1, Run 5.1, Run 1.0 and field data due to cooling and heating

CONCLUSIONS

It is concluded that a numerical model of Lambeth College pile test has been successfully developed to simulate the behaviour of the thermo-active pile observed in the test. Material properties from Schroeder, Potts & Addenbrooke (2004) have been shown to reproduce well the response of the soil. The thermal parameters adopted in this study with thermal boundary condition (TBC-3) successfully reproduced the response of the pile during cooling. The behaviour of the thermo-active pile during heating is reproduced with more limited accuracy. The prediction of the permanent pile displacement and the residual axial strain profile can be improved with the use of elasto-plastic models with limited elastic region (e.g. Modified Cam Clay and Bubble model).

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REFERENCES

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