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3D Finite Element Modelling for Group Pile Displacement Based on Full Scale Test

Michael Sutoyo, Paulus Pramono Rahardjo

Abstract—As construction trends get to be more complex from time to time, the loads carried by foundation system tend to be more complicated and bigger. In terms of lateral loading, the lateral capacity is determined by allowable deformation or by applying a reduction factor when calculating the capacity known as p-multiplier. When designing group pile subjected to lateral loading, the allowable displacement can be obtained from instrumented lateral loading test readings or based on the values determined in design standards. The allowable deformation from design standards will then be used as control variable in modelling as a substitution for the lateral load itself. For modelling the interaction of group pile, it is most suitable to model it in 3D finite element program as the lateral behavior of each single pile can be observed. It is essential to acknowledge the correlation between displacement resulted from 3D finite element modelling and obtained from instrumentation reading. The lateral behavior of pile such as the depth of fixity point, the deformation value and pattern, and the deformation curve will be correlated between modelling results and instrumentation readings in order to identify the model's ability in simulating real behavior on the field based on a full scale group pile subjected to lateral loading test.

Index Terms— Allowable Deformation, Finite Element Model, Fixity Point, Full Scale, Lateral Behavior, Lateral Loading Test, Displacement Curve.

1 Introduction

LATERAL capacity of piles becomes a critical and expensive issue when dealing with massive lateral load. Pile foundation system is generally designed as a group pile connected under a pile cap. In the design process of group piles, it is mandatory to fulfill the allowable displacement prerequisity or to apply a reduction factor in calculating the capacity, which commonly stated as efficiency.

In designing group pile subjected to lateral loading, the lateral capacity of group pile is determined by allowable deformation according to universal design standards. Generally, when modelling a group pile, a design lateral load is applied to the group pile. As the load is transferred, the piles begin to deform in which will result in the displacement vs depth curve. The displacement along pile can be obtained when it is modelled in a 3D finite element method program. When the resulted deformation is still below the allowable deformation, thus the lateral resistance of group pile is sufficient in carrying design lateral load applied to it. As well as if the deformation from modelling result surpasses the allowable value, then the group pile fails to accommodate future loading.

It is essential to identify the deformation pattern resulted from modelling with that from instrumentation reading. By knowing how close this results correlate will give deeper comprehension in simulating group pile deformation behavior in 3D finite element program. Thus, this paper intended to model a full-scale group pile subjected to lateral load and validate the modelling results with readings from inclinometer instrumentation attached to the piles**.**

- *Michael Sutoyo is currently pursuing master's degree program majoring in geotechnical engineering in Universitas Katolik Parahyangan, Indonesia.*
- *Paulus Pramono Rahardjo is a Professor and Lecturer in Geotechnical Engineering Department, Faculty of Engineering, Universitas Katolik Parahyangan, Indonesia.*

2 Full-scale Test Overview

A full-scale lateral loading test is conducted in Banten Province, Indonesia. A group pile consists of 6 single piles in 2x3 pile configuration is loaded with concrete blocks with loading cycle of 1 ton, 2 ton, 3 ton, and 4 ton. The pile diameter is 30 cm with spacing between piles is 2D, 60 cm. Type of piles used in this test is bored pile with each pile has an inclinometer pipe embedded to it. The pile length is 5.5 m and the inclinometer reading is in 0.5 m intervals.

The loading from concrete blocks is distributed by a steel plate welded to pile's casing, so the pile head is conditioned as free head. After each load cycle, the angular displacement (in degree) of each pile is measured from inclinometer and then computized to obtain the displacement data in length (mm).

This study will focus on the displacement behavior obtained from inclinometer readings. The modelling result will be then verified with instrumentation results.

3 Numerical Model

The modelling of group pile subjected to lateral load will be using a 3D finite element program Plaxis 3D 2017. Soil stratification is determined by a combination of a standard penetration test conducted near the group pile and laboratory tests at certain depths which consist of index properties, grain size analysis, Atterberg Limit, specific gravity, triaxial unconsolidated undrained, unconfined compressive test, and consolidation test. By combining soil parameters correlation from insitu testing and laboratory tests result, a set of soil parameter is determined to be used in modelling as shown in the following figure and table.

TABLE 1
SOIL PROPERTIES FOR MODELLING

Layer	Depth (m)	N_{SPT}	γ (kN/m³)	γ_{sat} (kN/m³)	S_u (kN/m²)	c' (kN/m²)	ϕ' (deg)	E_{ur} (kN/m²)
1	0-2	9	15	16	40	0.4	30	18000
2	2-5	11	16	17	60	0.6	33	24000
3	5-8	18	17	18	90	0.9	37	40500

Soil condition on the field is modelled in Plaxis 3D 2017 using hardening soil model with drainage type undrained A. Hardening soil model is determined due to its reliability and accuracy in simulating the stress-strain behavior of soils. The stress-strain curve is in the shape of hyperbola, different from that of perfectly-plastic model from Mohr-Coulomb. Drainage type undrained A is short-term material behavior in which stiffness and strength are defined in effective properties. Pore water pressure and excess pore water pressure are calculated, even above the phreatic surface.

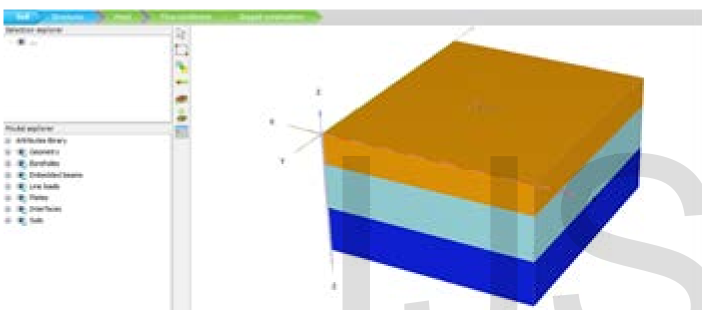

Fig. 1. Soil Geometry in Plaxis 3D 2017

In Plaxis 3D 2017 modelling, the structural components are modelled as embedded beams for bored piles and plate for the steel plate. The load is modelled a fully-distributed line load at the right side of group pile configuration.

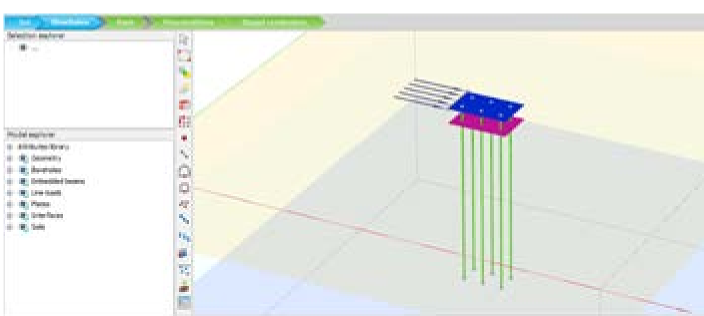

Fig. 2. Structural Geometry in Plaxis 3D 2017

After the completion of soil and structural modelling, meshing will be generated. Meshing in the uppermost layer is set to coarse (more dense than the layers beneath it) as the first soil layer is where the maximum deformation occurs. The more dense meshing gerenated, the more accurate the calculation will be

Final step before running the analysis is determining the construction stages. Stages consist of each loading cycle from 1 ton to 4 ton modelled as static loadings. Finally, the analysis can be then performed. Results expected from this numerical model is the deformation value and patter along the pile.

4 INCLINOMETER INSTRUMENTATION

Each bored pile tested is equipped with inclinometer pipe embedded to it. This pipe, measured by inclinometer rod, will measure angular displacement (inclination) along the pile due to lateral loading. This angular displacement will be measured to vertical axis. The reading has two directions, A+ A- and B+ B-.

Angular displacement readings can be then calculated to obtain the value of lateral displacement in length (mm). This displacement is the closest representation of pile movement on the field regarding the load cycle. As the reading is computed at 0.5 m intervals, hence the displacement along pile from pile head to bottom can be calculated.

5 RESULT

Based on the numerical modelling and inclinometer readings interpretation, displacement pattern between numerical model and instrumentation readings show similar characteristics. Fixity point of pile from numerical model obtained in depth 3.5 m whereas from instrumentation obtained in approximate depth of 3 m. Displacement versus depth relationships in average will be shown in the following figure.

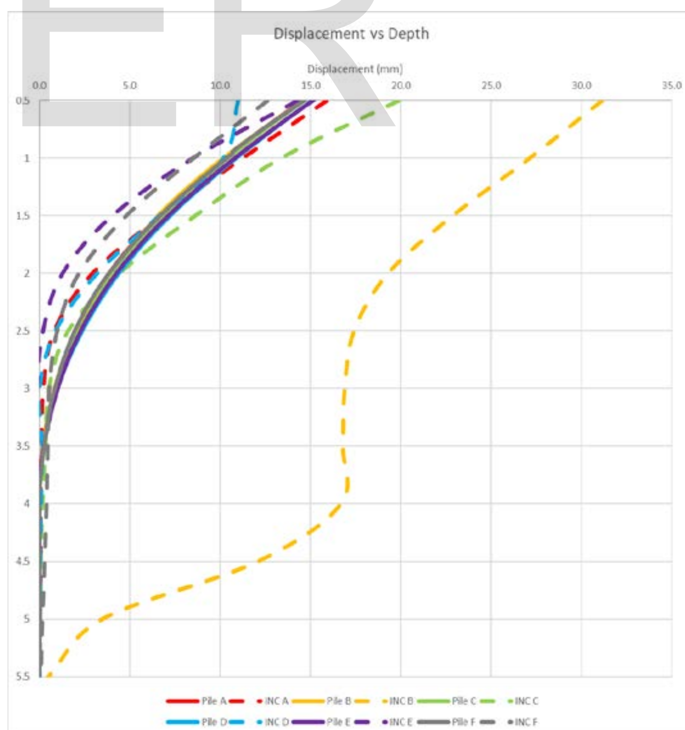

Fig. 3. Displacement versus Depth Graph from Plaxis 3D 2017 and Inclinometer Readings

Plaxis 3D 2017 modelling results are represented as full solid lines, and for inclinometer readings are in dotted lines. The graph starts at depth 0.5 m as the displacement in pile head is not measured from inclinometer. Furthermore, pile A and B is located in leading row (the farthest row as from the direction loading, pile C and D is in the middle row, and for the last trailing row is pile E and D. As for the displacement values, both results show similar values with difference ranging from 5% to 25%. There is a consistent result from numerical model which the displacement values between piles are relatively very small in difference. There are only 1% to 3% difference in displacement values analyzed from one pile to another.

As can be seen, there is an anomaly recorded from inclinometer readings in Pile B. This data is excluded due to its unusual pattern of deformation and is so distinctive from other readings. This can possibly happen due to some disturbances while recording the data such as human error and the inclinometer pipe is hit. There is a possibility that the inclinometer pipe defects while loading occurs.

6 Conclusion

Both numerical modelling and inclinometer readings show similar pattern and characteristic in pile displacement. The pattern of pile movement can be identified as similar as the fixity point from numerical model and inclinometer reading is relatively close. It can be concluded that the numerical model using material model of hardening soil and drainage type undrained A can provide a close relationship verified with instrumentation reading. A safety factor may be applied in order to accommodate the difference between displacement values from numerial modelling and inclinometer reading.

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