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ANALYSIS OF FORCES AND DISPLACEMENT IN FLOATING PILE WITH DIFFERENT ANALYTICAL METHODS

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ABSTRACT

This report presents, load distribution in a long floating pile as function of pile head load and down drag effect. Also installation effects on instrumented pile investigated. Zhang's Load transfer- softening nonlinear model of skin resistance and bilinear base load-displacement model and neutral plane approach were also used in analysis. Two case studies of instrumented pile in Gothenburg region where examined, literature studies and interview with one of the involved person. The result of the load – settlement analysis, shows that at the pile head load of 3000kN on a pile length of 65m, nonlinear relationship exist between the skin resistance and displacement. Also, displacements and load distributions were linear, decreasing with depth. Pile head settlement of 0.052m, end displacement of 2x10-4 m with base load of 127.8kN observed. With neutral plane approach, the neutral plane was found to be at 32m depth. Total settlement below the neutral plane was 0.638m with average strain of 1.2% and pile capacity is 3582KN. With this approach, pile behaviour was good enough compared with all the theories cut across in the study. Investigation on the installation effects on pile instrumentation, shows that challenges starts with human error in calculation and improper placement of the instrumentation equipment. Hammer blows from installation process, incorrect prediction of strength of soil layers in relative to hammer impact from the installation and pore water penetration are the causes of failures observed.

KEYWORDS*: *Forces, Displacemen, Floating, Pile, Different, Analytical, Method

1. INTRODUCTION

Anisotropic and variable properties of soil in different area, pose challenge and complex situation for geotechnics engineers. To ascertain and have a common model for foundation-soil relative behaviour when on load and settlement nature become task. Use of deep foundation in transmission of load from super structure to firm strata in sub soil is a common practice in area of soft soils like Gothenburg region in Sweden. Nature of settlements and pattern of load transfer to the soil layer have be major concernin all large construction projects in soft soil. To achieve serviceability limit state in structure; sound analysis and proper understanding of pile-soil relative behavior is imperative.

1.1 Background

City developments and technology advancement places high demand on existing buildings and infrastructures. In Lilla-Bommen-Mariaholm section of E45 highway, Swedish Transport Administration Agency (Trafikverket), proposed a tunnel to expandinfrastructure and easy expected high-volume traffic in near future.

The foundation of tunnel, is founded on deep layered clay. Approximately 250 000 m long floating concrete piles will be installed in the foundation. The piles where designedwith FEM calculation with experiences of short piles. Due to method of design, heavy loads expected and settlement nature of soft clay found in the section. Instrumented piles where included to study behaviour of the piles and its capacity.

Due to uncertainties in the method of design of the foundation and assumptions made,four instrumented piles will be installed to measure forces, movements and pore pressure in the earth. Also, to study the piled foundation capacity and settlement natureof long floating piles in soft clay. Analysis of these made to ascertain the behaviour ofthe piles in short and long term for future references.

1.2 Aim and Objectives

The purpose of this project is to study the

The aim of this master thesis is to study forces and displacements in long floating pile in soft clay as a function of pile load and background settlement at Lilla-Bommen- Mariaholm tunnel project. Also, effects of installations process on instrumentation.
This aim will be accomplished through the following objectives;

- Use of Zhang's load transfer method to analysis forces and displacements in the pile segments.
- Application of Neutral plane approach to detect a frictionless zone, strains and settlement below the plane.
- Study of past pile instrumented reports and interview with person(s) involved in the project to understand the steps adopted and challenge(s) encountered.
- Desktop study of pile analysis methods, instrumentation & installation procedures.

1.3 Limitation/Scope

The work will focus on analysis of floating pile in soft clay, instrumentation and installation processes of floating piles. The study considers only one-dimensional displacements i.e. vertically; lateral displacements and deformation in pile element areneglected. The analysis of pile where limited to single.

2. FOUNDATION

Foundation is integral part a structure which holds and transmits superstructure and other loads to firm strata of soil at acceptable settlement. They are two basic types: **shallow foundation** - footings/raft or **deep foundation** - piles, piers or caissons foundation. According to Knappett &

Craig (2012), shallow foundations width are often greater than their depth, while deep are those which ratio of depth to breath is greater than or equal to one. The type to use depends on load to be transmitted, soil bearing capacity, slope of the soil, geotechnical conditions etc. However, to perform satisfactorily, its designed should meet two principal requirements; **ultimate limit states** and **serviceability limit states** (Knappett & Craig, 2012).

2.1 Pile Foundation

In certain situations, use of shallow foundation is uneconomical and unsafe. When design loads are large, near surface soils have low stiffness, soil layers are inclined, settlement sensitive structured are to be build, in marine environments where tidal, wave or flow actions are anticipated. In such situation(s) deep foundation becomes necessary to have stable and safe substructure (Knappett & Craig, 2012).

Pile is the most common type of deep foundation, which is a column of concrete, steelor timber installed in ground. It may be circular or square in section with outside diameter (D_O) or width (B_P) that is very much smaller than their length (L_P), i.e. $L_P >> D_O$ (Knappett & Craig, 2012). Common in parts of the world with glacial or alluvial sediments and area with quaternary geology. Its main function is to transfer loads from superstructure to deep layers of soil (Claes, 2012). It is commonly subjected tocompression loads (Yanne, 2016).

According to Alen C., 2009 and (Knappett & Craig, 2012), Piles are classified intodifferent types based on;

- material of pile elements - steel, pre-cast concrete, In-situ casted concrete or timber piles;
- installation method and effect of installation - driven/displacement and boredpiles;
- type of soil the piles are installed in – Friction/Cohesion/floating Pile and
- Way the piles are loaded -Axially loaded (compression or tension) and transversally loaded piles.

Commonly classified based on pattern of installation as displacement and non- displacement/replacement piles. In summary, it is classified as illustrated in Figure 2.1

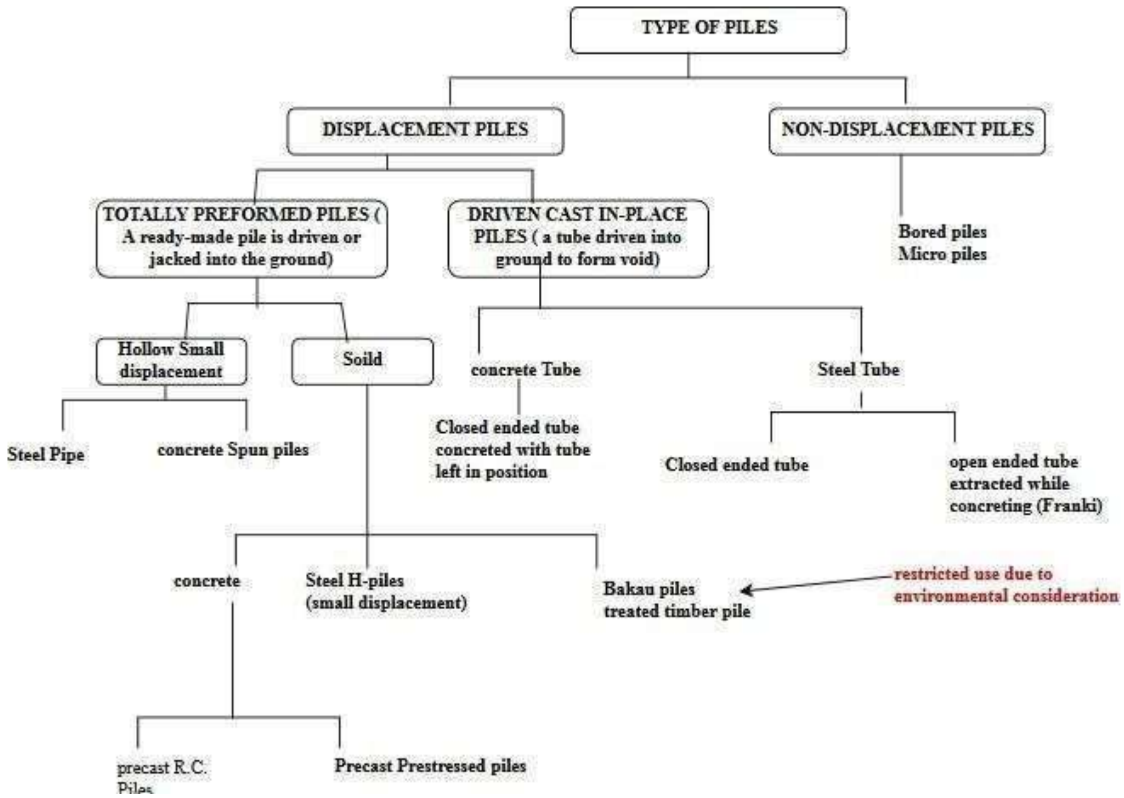

Figure 2.1: Classification of piled foundation (Sew & Meng, 2017)

From the geotechnical aspects, piled foundations are further classified based on load bearing capacity as **shaft bearing piles, end bearing piles and/or combination of both types.**

Friction piles are piles installed in frictional material, it drives most of its bearing capacity from toe and normally analysed based on effective stress analysis. While cohesion often called, floating piles are piles in clay, its bearing capacity are mainly from its shaft and can be analyse with the total stress concept. Figure 2.3, illustrate pile foundation classification based on load bearing ability.

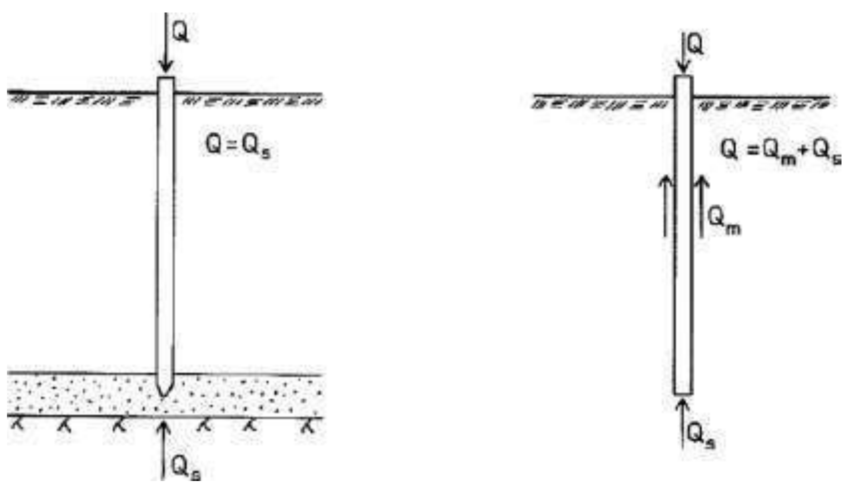

Figure 2.2: Bearing piles (a) End-bearing pile (b) Shaft bearing pile (Claes, 2012)

2.3 Displacement/Replacement piles

According Yannie J, 2016, method of pile installation has effect on the pile cycle. In displacement method, pile is driven into the ground with aid of jack or hammer while in replacement method hole is bored and soil remove before pile is driven into bored hole. There is no displacement of soil. In the displacement method soil at the toe is distorted, pushed downward and displaced laterally at the process of installation, causing remoulding of the soil structure and increase in total stresses in the soil. The tension loads are generated at process from the stress wave in the pile, this wave can lead to crack in concrete, hence reducing the cross-section stiffness and exposing steelreinforcement to corrosion (Yanne, 2016).

2.4 Pile Selection

The choice of pile to use are influenced by the following factors:

- Installation method
- Type of piles available in market
- Contractual requirements
- Ground conditions (e.g. Limestone, etc.)
- Site conditions and constraints (e.g. Accessibility)
- Type and magnitude of loading
- Development program (Sew & Meng, 2017) and cost (Sew & Meng, 2017).

The flow chart in Figure 2.3 illustrate pattern of pile selection putting into consideration all the factors mentioned above.

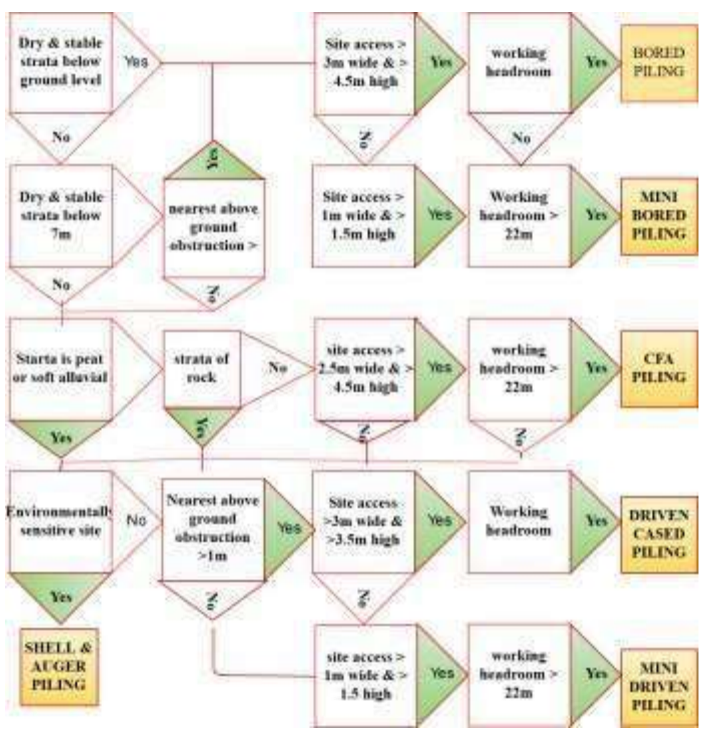

Figure 2.3: Flow chat for pile selection (Rao, 2009)

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2.5 Geotechnical Bearing capacity of piled foundations

The allowable pile capacity is the minimum of allowable structural capacity or allowable geotechnical capacity. Piled foundations drive its bearing capacity/resistance from its shaft and end toe. For shaft bearing pile, it is governed by the shaft area. Shearforces mobilized between the piles and soil while end-bearing pile are governed by mobilized end toe shear forces (Eriksson, et al., 2004). According to Swedish practicethe geotechnical bearing capacity of shaft bearing pile (e.g. cohesion piles) is calculatedbased on the undrained shear strength of the soil and can be expressed as the summation of the shaft resistance and end resistance. Swedish Commission on pile Research, recommends calculation of bearing capacity of a shaft bearing pile according to Equation (2.1). In long pile, the end bearing capacity is small compare to the shaft bearing capacity and often ignored in the calculation.

$$R_d = \frac{1}{\gamma_n} \int_{L_p} \frac{\alpha}{\gamma_{m\alpha}} \cdot \frac{\theta}{\gamma_{m\theta}} \cdot \frac{c_{uk}}{\gamma_{mcm}} \, dz + \frac{N_{cp}}{\gamma_{mNcp}} \cdot \frac{A_s}{\gamma_{mAs}} \cdot \frac{c_{uk}}{\gamma_{mcs}} \quad (2.1)$$

Where: R_d = the bearing capacity of pile (designed value) [KN] L_p = the length of the pile [m]

α= adhesion factor [-]

θ = circumference of the pile [m]

c_{uk} = undrained shear strength of the soil (unreduced) [KPa] N_{cp} = bearing capacity factor for pile toe [-]

A_s = area of the pile section at the toe [m^2] γ [-] = partial factors [-]

According Varanasi Rama Rao, 2009, factors influencing pile capacities are as follows,

- The surrounding soil
- Installation technique like driven or bored
- Method of construction (pre-cast or cast in situ)
- Spacing of piles in a group
- Symmetry of the group
- Location of pile cap i.e. above or below soil
- Shape of the pile cap, etc.
- Location of pile in the group and
- Drainage conditions in soil

2.6 Instrumented pile

Complex nature of soil and its variation in places, make it difficult to theoretically determine actual bearing capacity of pile and its behaviour with surrounding soil. Determination of the actual bearing capacity and behaviour of pile-soil interfacedemand field test. In deep foundation involving piles, instrumented piles are introduced to determine geotechnical bearing capacity, settlements, pore pressure, inclination andpile-soil interface behaviour. Figure 2.4 shows possible measurements during static testing. Instrumentation equipment are used to measure different parameters base on the aim of test study. Optical fibre sensing, extensometer, strain gauge and vibrating wire are used in measurement of strains.

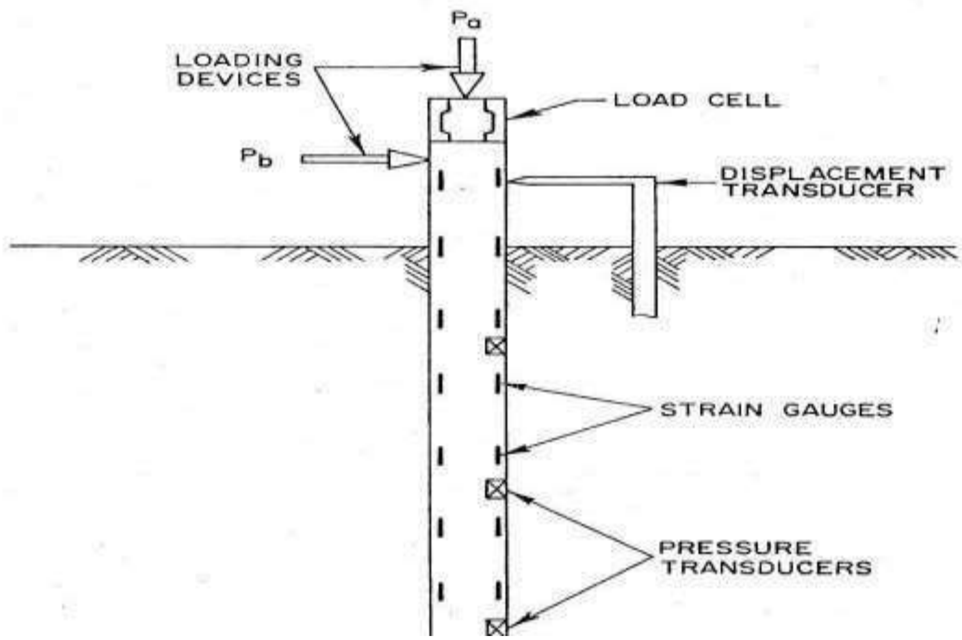


Figure 2.4: Possible measurements during static testing (Hirsch, Coyle, Lee L. Lowery, & Charles H. Samson, 1970)

3. OPTICAL FIBRE

Optical fibre sensing that allows continuous strain measurement along the full length (up to 10km) when properly installed with Brillouin Optical Time-Domain Reflectometry (BOTDR). Optical fibres can measure both axial and lateral deformationby measuring strains from a single optical fibre placed along two sides of structure’s plane. It is fragile and care must be taken when installing it and pile if driven method is to be use. Local features like cracking are often detected in pile (Mohamad, Soga, &Bennett, 2009). The optical fibre sensing has been successfully used in two different techniques; fixed-point-method for load bearing pile and end-clamped technique for secant-piled wall. Figure 2.4 show a configuration of optic fibre with BOTDR.

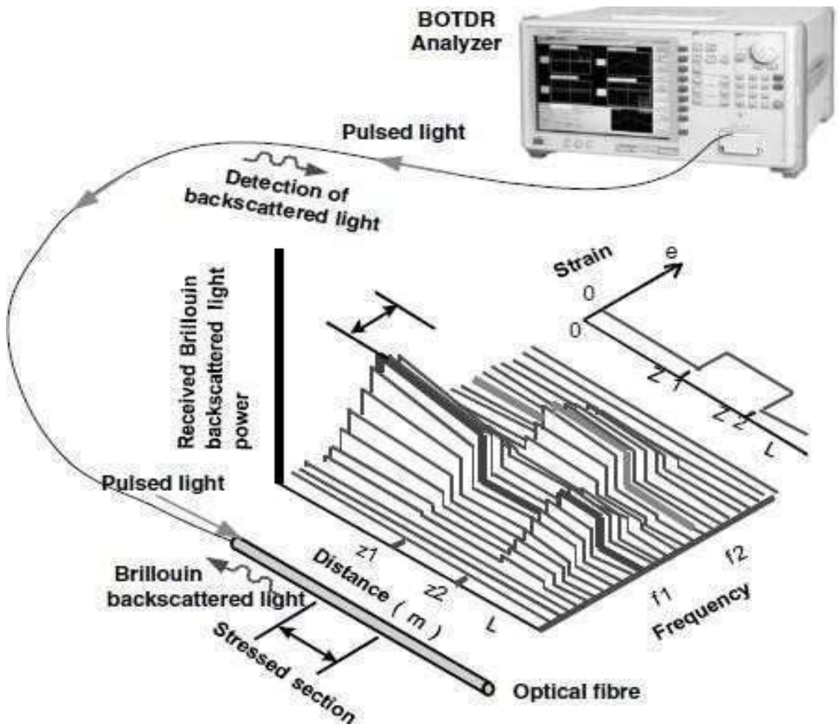


Figure 2.5: Optical fibre with BOTDR (Mohamad, Soga, & Bennett, 2009)

4. VIBRATING WIRE

Vibrating Wire Rebar Strain Gauges are used in monitoring the stresses in reinforcingsteel in concrete structures, such as bridges, concrete piles and diaphragm walls. Figure **2.7** shows the components of vibrating wire. The strain meter comprised of a length of high strength steel, bore along its central axis to accommodate a miniature vibrating wire strain gauge. The measurement of load or stress is made with a data logging system. Strain meters are robust, reliable and easy to install. It is not easily effected by moisture and cable length. However, unlike the optic fibre, takes measures strain within a point. Hence, when installed location and serial numbers of all instruments are noted.

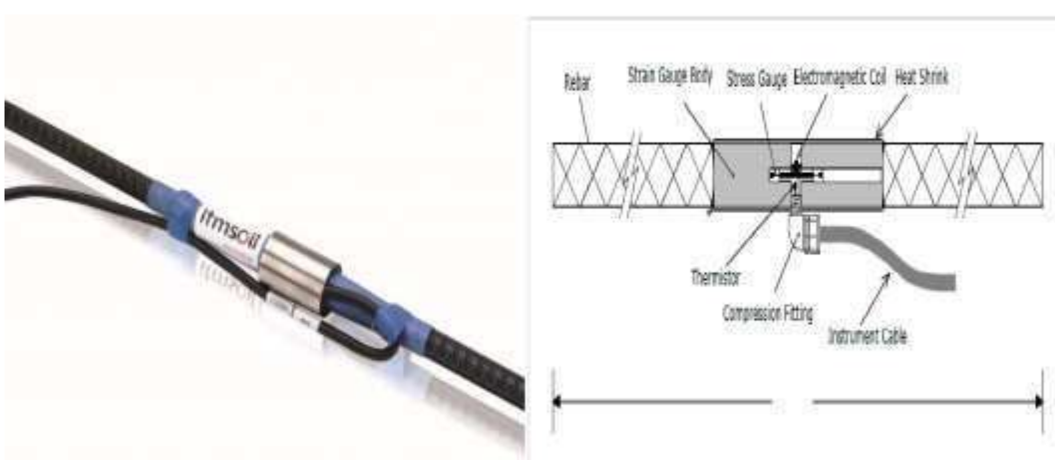


Figure 2.6: Vibrating wire rebar strain gauge and its components (Kim Malcolm, 2014)

5. RESULTS AND DISCUSSION

The results from the two methods and findings on effects of pile installation process on instrumentation are presented in this chapter.

5.1 Neutral plane Approach

In this Section, the results of analysis made with the neutral plane approach are presented. For the input data used and detailed calculation, see Appendix B1. From this analysis, the characteristic bearing capacity, R_k, of the 65m pile is 3582 KN. In the calculation of action effect and resistance, 4m depth of fill was neglected, since in realsituation, there may not be friction at that length because of holes likely to exist in the depth and will not contribute to skin friction experience by the pile.

Figure 5.1 and 5.2 shows the neutral plane estimate from action effect and resistance computation and strain distribution below neutral plane respectively. From the analysis,as shown in Figure 5.1, the neutral plane is at 32m (i.e. 28+4m fill above) corresponding with a load of 2350KN. From this plane, the pile-soil relative displacements become uniform and settlements are governing by the soil. Prior to it occurrence is govern by the compression in the pile element. For analysis of the strain distribution below the plane, 3000KN, assumed total depth of 85m clay, equivalent footing at neutral plane and load surface of 20x30 immediately after the fill was used.

From Figure 5.2, the average strain below the neutral plane is 1.2% and hence total settlement of 0.638m estimated below the plane.

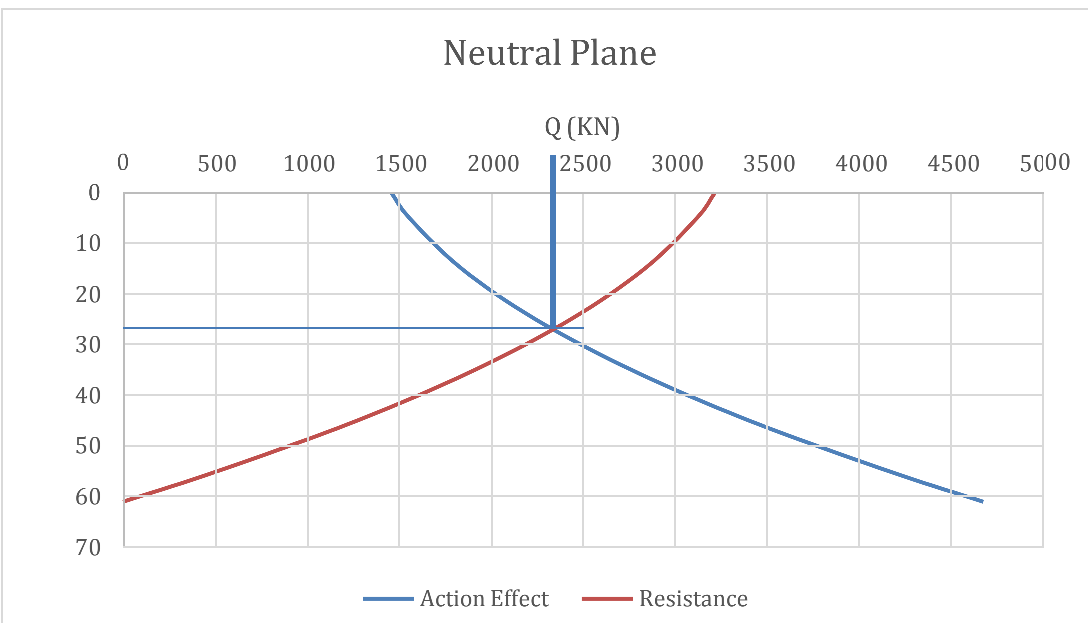


Figure 5.1: Neutral Plane

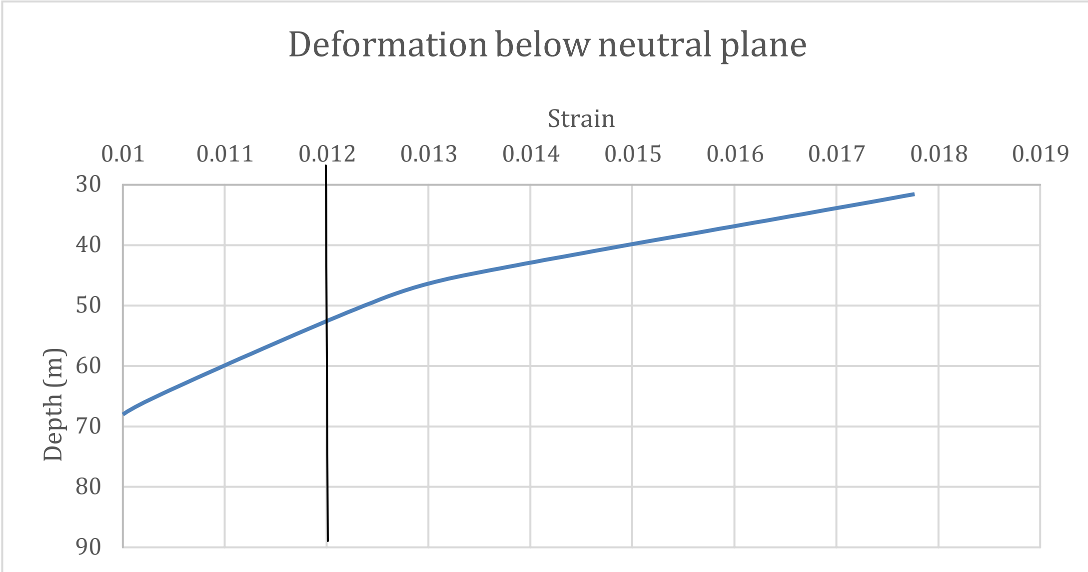


Figure 5.2: Strain in the pile below the neutral plane.

5.2 Load transfer method

The result of load transfer approach with three scenarios considered are presented and discussed in the following Sections below. For the input data and calculation sheet seeappendix B2.

5.2.1 Scenario 1: Behavior of pile as function varying pile head load

The result of load distribution and pile head displacement with varying constant pile head loads are as shown in Figure 5.3 and 5.4 respectively. As discussed previously, loads of 2000KN, 3000KN and 3500KN were used in the analysis, to study distribution behaviour along the pile shaft and it capacity. At application of 2000KN load in the analysis, at about 53m depth, mobilised base load Pb, become comes zero. Thereafter, Pb, average axial load P, and compression in pile element turned to negative values, with settlement in the pile head of 0.0268m, Figure 5.4. Indicating positive skin frictionexist below depth of 53m, and toe resistance is high. This implies that about 13m lengthof the pile where not fully in use.

With 3000KN load, mobilised base load, compression and pile head settlement are 127.80KN, $4.4x10^4$ m and 0.052m respectively. In theory, larger part of load imposed on a floating piles are distributed along the shaft. Indicating 65m length of pile is slightly low to distribute the load of 3000KN. Which results to high compression in pile element and settlement at pile head with probability of further settlement in soft clay. The behaviour of the pile with 3500KN load is similar to the 3000KN with slight increase in mobilised base load, compression and settlement at pile head as follows 411.19KN, $2.1x10^3$m and 0.068m respectively. The load distribution and load- displacement curves behaviour of pile follows the theory.

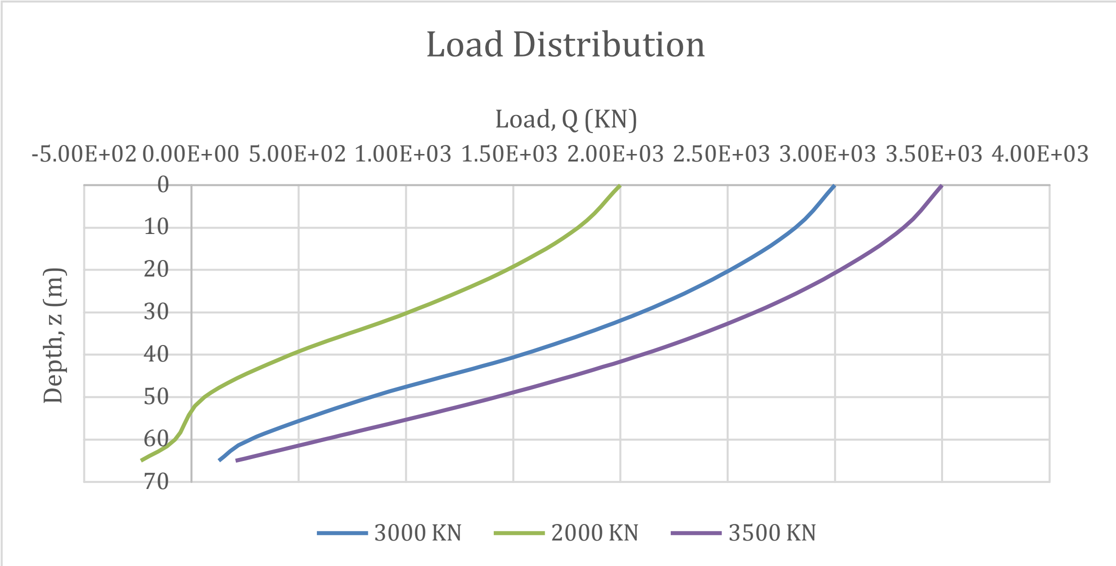


Figure 5.3: Load distribution with varying pile head load

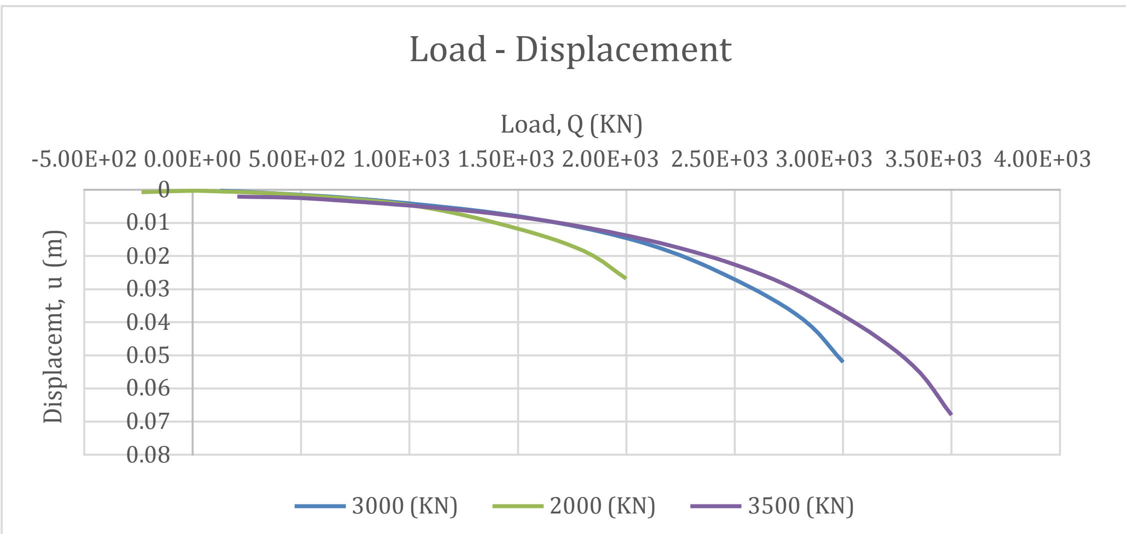


Figure 5.4: Load-displacement with varying pile head load

5.3 Scenario 2: Pile stiffness (modulus of elasticity) effect

In this scenario modulus of elasticity of 30GPa E, and 45GPa, E', where compared to study behaviour of pile due to changes in its stiffness with time cause by temperature changes (heating and cooling), swelling of concrete, and reconsolidation by the soil (Fellenius B. , 2012) . With each of the modulus, the strains along the pile element where deduce with 3000KN load and plotted against depth Figure 5.7, to show likely pile deformation on site.

From Figure 5.5, at beginning part of pile element, there were no different in load boredby the pile shaft up to depth of about 43m. Between the 43 to 60m depth, the pile at elastic modulus of 45GPa shows an increase in strength and shaft absorbed more load compare to 30GPa elastic modulus. With elastic modulus of 45Gpa, the load distribution shows that the pile has more strength to withstand load.

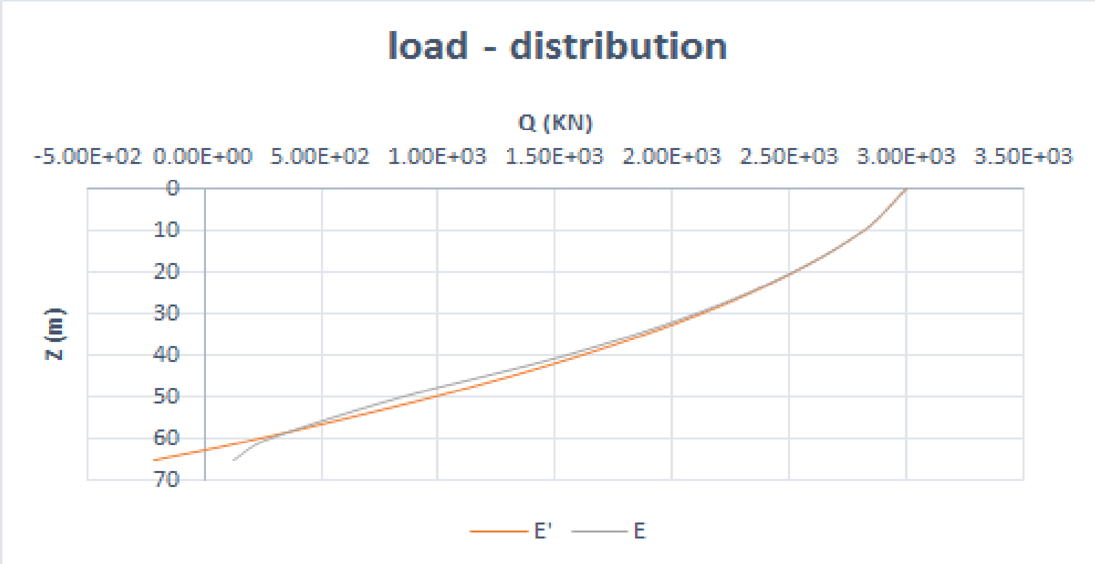


Figure 5.5: Load-distribution with different elastic modulus

Figure 5.6, shows difference in pile end displacement. At 30GPa E, mobilised base load Pb, and compression in pile SC 'at last segment are 127.79 KN and 0.00044m respectively while with 45GPa E', Pb and Sc' are -212.658KN and $4.90x10^{-6}$m respectively. This result indicate at elastic modulus of 45GPa i.e. higher concrete strength, with load of 3000KN, the pile shaft still has capacity to absorb more loads with excessive deformation in pile length.

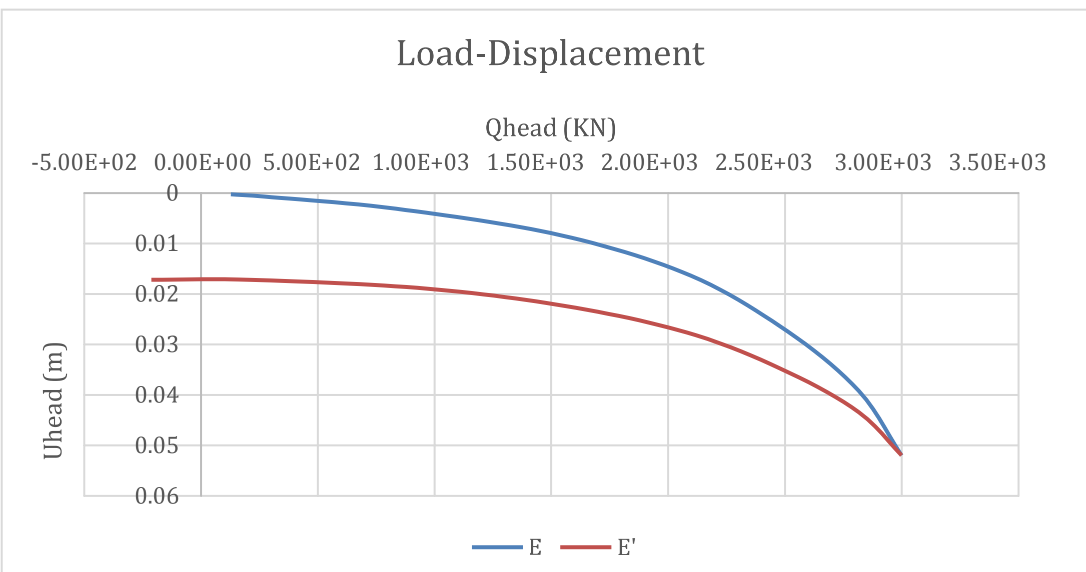


Figure 5.6: Load-displacement with different elastic modulus

Figure 5.7, illustrates Strain distributions in pile as deduced with different elastic modulus of 30GPa, E and 45GPa, E' and load of 3000KN. The Figure 5.7, shows that in both cases the strain in pile decreases with depth. With 30GPa at pile head, the strainis $1.0x10^{-4}$, and $4.25x10^{-6}$ at 65m depth. While on 45GPa at pile head, is $6.67x10^{-5}$ and

$-4.73x10^{-6}$ at 65m depth. The strain distribution in the case of 45GPA, varies slightly along the pile length than in 30GPa. These indicates that the pile at elastic modulus of 45GPa has the capacity of absorbing more load and agrees with the theory, the more strength the less the deformation

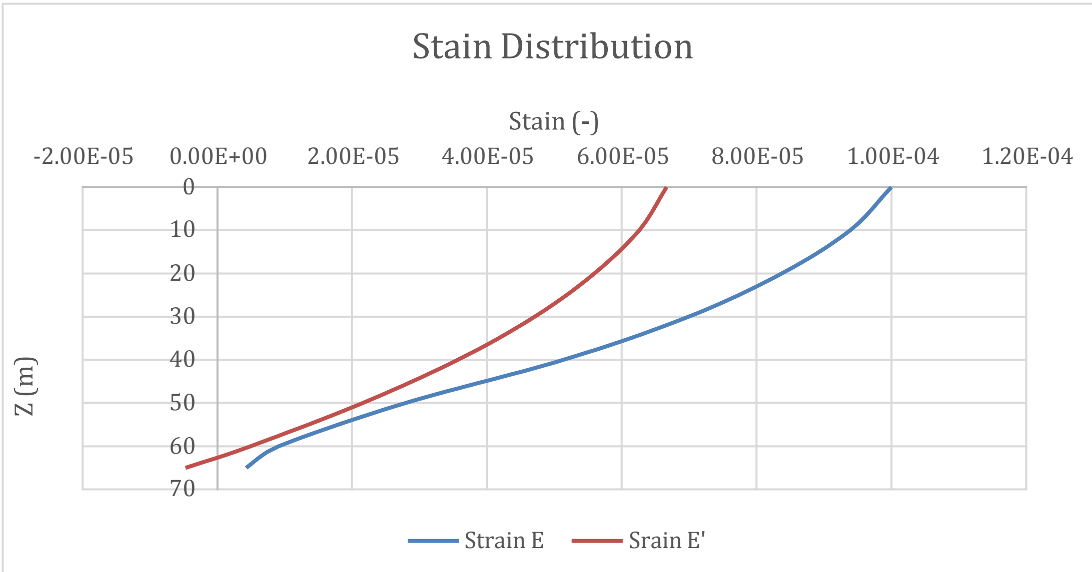
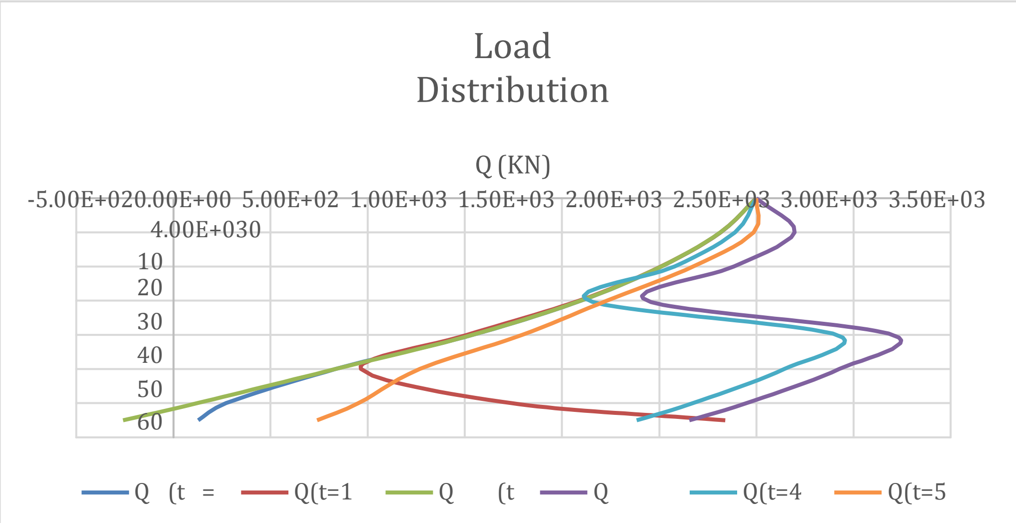


Figure 5.7: Strain distribution along the pile at different elastic modulus.

5.4 Scenario 3: Down drag effect

Figure 5.8 shows load distribution behaviour of pile due to superimposed settlements of soils (down drag) around the pile shaft. The Figure illustrate down drag effect at different time period, starting from the installation (no settlement) time t, = 0 to 5year (time t, = 0 – 5year) with assumed pile head load of 3000KN. The behaviour of the pileat different time agrees with Fellenius, B.H., 1984 founding, that "*a static load to the pile head caused the dragload in the pile to be reduce by the magnitude of the load applied, if the applied load becomes permanent, the negative skin friction built up again and the end effect, the applied load and dragload combines in the pile.*"

From Figure 5.8, curve t =1, returns at certain point in load distribution to equalised thepile head load. And at t = 2 the negative skin friction built up again and combine with the applied pile head load to increase the magnitude of load on the pile. However, the curve t = 2, gives a negative mobilised base load, indicating that magnitude of negativeskin friction built up is greater than the combine loads. The time, t = 3 and 4 also tends to equalise the load and time, t =5 combines the pile head load and download to be theload acting on the pile as distributed.



6. CONCLUSION

The aim thesis was to study forces and displacements in long floating pile and effect of installations process on instrumentation with E45 tunnel foundation and report of previous pile instrumentation within Gothenburg as case studies. The pile analysis wasperformed with a single pile of 65m pile length with assumption that it will be similar with other piles.

Two different analytical methods were used, neutral plane approach and Zhang's loadtransfer method. The load transfer method were made in three different scenarios; function of pile head load, stiffness of pile element and down drag effects on the pile. In both methods used including scenarios employed, the results of the analysis agreeswith theories of pile behaviours in soft clay. With neutral plane approach, the neutralplane was found to be at 32m depth which agrees with (Fellenius B. H., Negative skinfriction and settlement of piles, 1984) that states that neutral plane is likely to occur atmid of the pile length. Total settlement below the neutral plane was 0.638m with average strain of 1.2% and capacity of pile 3582KN. With this approach, pile behaviourwas good enough compared with all the theories cut across in the study.

In study of displacements and load distribution along pile shaft, with 3000KN pile headload, result of load transfer method shows that 65m length successfully distributed proposed load in agreement with known theories of floating piles. Nonlinear relationship exists between the skin resistance and displacement. Also, displacements and load distributions were linear, decreasing with depth. Pile head settlement of 0.052m, end displacement of $2x10^{-4}$ m with base load of 127.8kN observed.

The study of installation effects on instrumentation works, reviews that often failures occurs due to effects of vibration wave from hammer blows on the instrumented pile, calculation errors and pore water penetration into the sensitive equipment in contact with soil.

REFERENCES

1. Albuquerque, P. J., Neto, O. d., & Garcia, J. R. (n.d.). Behavior Of Instrumented Omega Pile In Porous Soil. *Advanced Materials Research*.

1. Bond, A. J., & J., J. R. (2014). Effects of installing displacement piles in a high OCR clay. *Geotechnique 41*, No.3, 341 - 363.
2. Claes, A. (2012). Pile Foundation - Short handbook (Educational material in Geotechnics). *version 1.1 2012*. Gothenburg: Chalmers University ofTechnology.
3. Dembicki, G., & Horodecki, E. (2016). *Impact of deep excavation on nearby urban area.* Gdansk: Department of Geotechnics and Applied Geology, Gdansk University of technology, Poland. DGSI. (2017, June 20). *Slope indicator*. Retrieved from http://www.slopeindicator.com/instruments/ext-intro.php.
4. Eslami, M., & Abolfazl, Z. (2016). Behavior of Piles under Different Installtion Effects by Physical Modeling. *International Journal of Geomechanics, ASCE*, 04016014-1 - 04016014-12.
5. Frank, R. (2008). Design of pile foundations following Eurocode 7-Section 7. Gary, A. (2000). *LONG-TERM SET-UP OF DRIVEN PILES IN SAND.* Stockholm.
6. Gebreselassie, H.-G., & Berhane, K. (2006). *Excavation and Foundations in SoftSoils.*
7. Hajduk, S. G., & Paikowsky, E. L. (2004). Design and Construction of Thre Instrumented Test Piles to Examine Time Dependent Pile capacity Gain. *Geotechnical Testing Journal*, 19428-2959.
8. Hirsch, T. J., Coyle, H. M., Lee L. Lowery, & Charles H. Samson. (1970). Field Instrumentation for piles. *Conference on Design and Installation of pile foundations and cellular structures.* Pennsylvanial.
9. Knappett, & Craig, J. (2012). *Craig;s Soil Mechanics, Eighth Edition.* Dundee, Uk:CRC Press.
10. Kovacs, R. D., & Holtz, W. D. (1981). *Introduction to Geotechnical Engineeering.*
11. Lönnroth, L. (2000). *Option på framtiden: den värderingsstyrda ekonomin.* Stockholm.
12. Medin, F., & Johanna, B. (2015). *Analysis and modelling of settlements of.* Gothenburg.