A STUDY OF TIME EFFECTS ON PILE CAPACITY

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Abstract

The objective of this R&D project is to establish practical design procedures that account for effects of time on bearing capacity of piles. None of the present design methods or codes account for the potential gain in pile capacity after the normal set-up or reconsolidation period. Five test sites with different ground conditions are established for execution of pile load tests. Four of the test sites are located in Norway, and consist of ground conditions of low plastic normally consolidated clay, high plastic normally consolidated clay, loose fine sand and dense medium to fine sand. The last test site is located in Cowden in the UK, and has ground conditions of low plastic stiff over consolidated clay (glacial till). Six tubular steel piles are installed and testing of the piles is currently being undertaken at each test site. Results from the testing will only be released after the end of the testing program. Therefore no results will be given in this paper.

If the expected increase in bearing capacity with time can be utilized in design, it will open significant new possibilities in upgrading existing piled foundations. Especially for piled foundations that need to support higher loads than those they were originally designed for. Enabling the designer to account for the increase in pile capacity with time would also have a positive impact on the initial design of pile foundations. There are often several months between installation of piles and the completion of the overlying structure, hence piles may experience "time effects" before the actual design load is applied. For example, this is commonly the case for bridges.

Key words

Time effects, tubular steel piles, bearing capacity

1 INTRODUCTION

In 2006 NGI made the initiative to look into the potential gain in bearing capacity of piles with time. NGI and Multiconsult AS are carrying out a joint industry project on pile testing in full scale. Multiconsult AS is in charge of the project, while NGI is responsible for the management and execution. The client, The Research Council of Norway, is contributing with a significant part of the financial funding. Other industry partners with financial funding are the Danish-German Femern Belt and the oil companies Total, Aramco, and Statoil. Solutions, Ruukki, Entreprenørservice, FAS, Kynningsrud, Skanska, BRE and the Directorate of Public Roads (DPR) contributes with equipment, data and own experience.

The expected gain in pile capacity is not incorporated in existing design codes and design guidelines like the Norwegian "Peleveiledning", DNV's guidelines, the ISO code for foundation design or the American Petroleum Institute's (API) recommended practice. The API recommended practice, despite being prepared for offshore foundations, is the most commonly referred to standard for pile practice on land.

The project has the following sub-objectives:

- Establish state-of-the-art on time effects on pile bearing capacity
- Perform new pile load tests in the field, with specific focus on time effects
- Develop new design procedures
- Disseminate results to ensure that they get incorporated into national and international design guidelines and codes

2 DESIGN METHODS

If the expected increase in bearing capacity with time can be utilized in design, it will open significant new possibilities for the upgrading of existing piled foundations, especially for piled foundations that need to support higher loads than those they were originally designed for.

Design methods for piles in clay and sand have been a controversial matter within geotechnical engineering in many years due to their empirical nature. Therefore, the design of piles has remained a constant source of attention, especially with regard to the methodology for predicting the capacity. As a result numerous calculation procedures are proposed in the literature, see for example De Cock and Legrand (1997) [5], Jardine and Chow (1996) [6], API (1993) [1], Clausen and Aas (2000) [4], and references given In Lacasse and Nadim (1996) [10] and Augustesen et al. (2005a,b) [2,3].

2.1 NGI Approach

One of the calculation procedures is the NGI-05 approach. According to the NGI-05 [7] method the caracteristic undrained skin friction in clay is given by:

$$\tau_{su,k} = \alpha \cdot c_{u;k} \tag{1}$$

where α is an empirical side friction factor found in Figure 1, and $c_{u;k}$ is the caracteristic *in situ* undrained shear strength from DSS in a given depth.

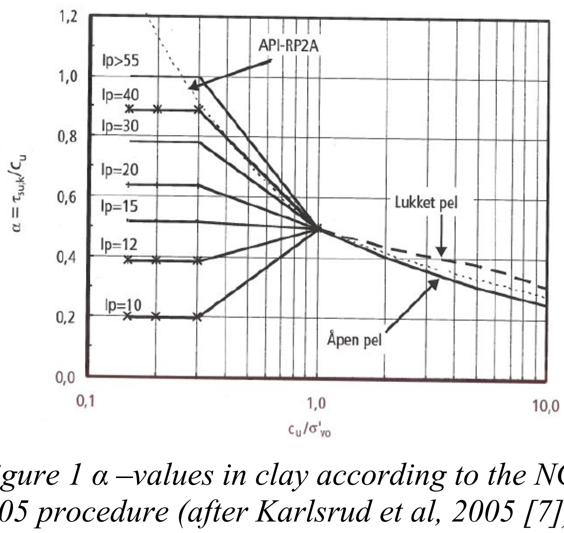

Figure 1 α –values in clay according to the NGI-05 procedure (after Karlsrud et al, 2005 [7])

3 TIME EFFECTS

When designing pile foundations, static design equations, pile driving formulae, static loading tests or stress wave analyses can be employed to estimate the axial capacity of single piles. Both laboratory and field tests show that soil exhibits time-dependent behavior. Important results show that soil gains additional strength and stiffness with time due to time-dependent processes such as ageing. Similarly, results show that the capacity of piles increases, to certain extent, with time after installation due to time-dependent processes in the soil.

Available data suggest that the increase in pile capacity with time depends on soil type, but there is at present not sufficient data to establish a clear and unique link to key soil parameters. One reason for this is that many published pile load tests have not included a sufficiently extensive study of all relevant soil characteristics.

The gain in capacity (after the end of the installation and consolidation phases), can be the result of a combination of factors such as:

- An increase in the earth pressures against the pile surface on the long term, due to creep of the soil structure
- A long-term build up of new diagenic bonds between soil particles, after the complete destruction of the soil structure due to the severe displacements and disturbance resulting from the driving of the pile into the ground
- Chemical bonding due to the interaction between the steel pile surface and the soil minerals (cation exchange)
- The effects of sustained loads on the piles, gradually causing a more stable soil structure and increased strength
- The effects of previous loading and unloading cycles of the piles, which can have similar effects as sustained loading

3.1 Effect of Time between Pile driving and Testing

The reference pile capacity used by the NGI-05 method is the capacity measured 100 days after pile driving. NGI-05 assumes that the strength increase after dissipation of excess porewater pressures can be expressed as [7]:

$$Q(t) = Q(100) \cdot [1 + \Delta_{10} \cdot \log_{10} (t/100)] \qquad (2)$$

Where t is the time between driving and the loading, Q(t) is the capacity after t days and Q(100) the reference capacity after 100 days. This approach assumes that at both time t and time 100 days, full dissipation has taken place. The Δ_{10} value is dimensionless capacity increase for a ten-fold time increase:

$$\Delta_{10} = 0.1 + 0.4 \cdot (1-I_p / 50) \cdot OCR^{-0.8} \qquad (3)$$

$$0.1 < \Delta_{10} < 0.5 \qquad (4)$$

Where I_p and OCR are average values along the pile shaft.

4 PREVIOUS WORK ON TIME EFECTS ON PILE CAPACITY

Some of the previous work on time effects on pile capacity is the "*Axial Static Capacity of Steel Model Piles in Overconsolidated Clay* at Haga test site in Norway [8], and the „*Evidence of Long Term Ageing Effects on Pile Capacity of Piles in Soft Clay*" in Oromieh salt lake in Iran [9].

4.1 Haga-Piles

Among the executed tests in this work one pile was tested static several times, but with different times of reconsolidation in between tests. Such tests clearly expressed the effect of previous loading on present capacity (pre-shearing effects). In Figure 2 the static capacities from these tests are plotted as a function of time after pile installation and clearly show the effect of pre-shearing.

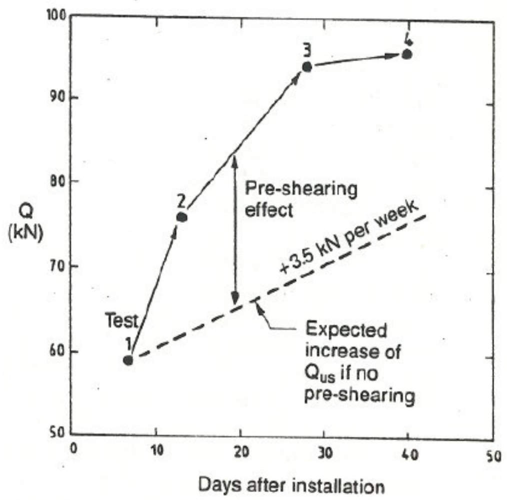

Figure 2 Influence of static pre-shearing on static pile capacity [8]

4.2 The Oromieh case

In this work pile load testing was carried out on two piles installed in a soft normally consolidated clay deposit in Oromieh salt water lake in Iran. One of the test piles was a new pile installed for the purpose, and the other pile was an old pipe pile that had been installed in the lake 15 years earlier. The piles have different lengths and diameters.

Bothe test piles were loaded incrementally and subjected to an unloading and reloading sequence after failure was first approach. Figure 3 present the load displacement curve for both piles, the new pile tested 5 months after installation and the old pile 15 years after installation.

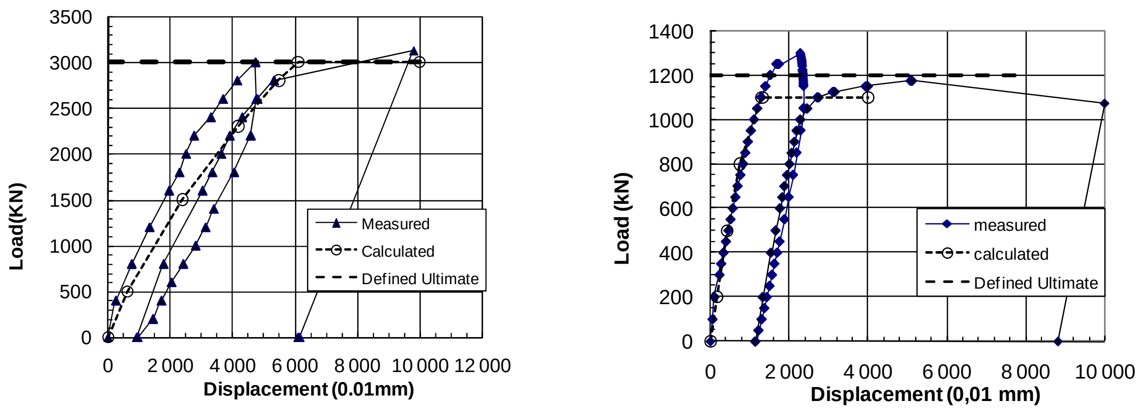

Figure 3 Results of tests on new pile (left) 5 months after installation and old pile (right) 15 years after installation [9]

Table 1 presents the ultimate (nominal) static capacity of the two piles, the avarage ultimate skin friction, t_{us}, and values normalized with respect to the avarage vertical efective stress along the piles. With $c_{uD} = 0{,}27\sigma'_{v0}$ the apparent back-calculated α-value (from NGI-05) is 0.74 for the new pile and 1.69 for the old pile. Thus, the old pile shows 2.28 times larger capacity as the new pile.

Tab 1 Summary of pile test results

Pile test	Defined ultimate capacity Q_{us} (kN)	Average ultimate skin friction, t_{us}, (kPa)	Average vertical effective stress, σ_{v0}' (kPa)	Average ultimate normalized skin friction, t_{us}/σ_{v0}'	Apparent $\alpha = t_{us}/s_{ud}$
Old pile	1200	48.7	106	0.46	1.69
New pile	3000	47.2	236	0.20	0.74

5 TEST SITES - IN PROGRESS

Five test sites with different ground conditions are established for execution of pile load tests. Four of the test sites are located in Norway, and consist of ground conditions of low plastic normally consolidated clay, high plastic normally consolidated clay, loose fine sand and dense medium to fine sand. The last test site is located in Cowden in the UK, and has ground conditions of low plastic stiff over consolidated clay (glacial till).

Tab 2 Test Sites and type of soils

Site	Type of soil
Stjørdal	Low Ip-NC clay
Onsøy	High Ip-NC clay
Larvik	Loose fine sand
Ryggkollen	Dense medium to fine sand
Cowden, UK	Low Ip OC clay (Glacial till)

6 PILE INSTALLATION

The piles are driven into the ground. At both sand sites, PDA measurements were made on 6 piles altogether (4 in Larvik and 2 at Ryggkollen). The depth to the top of the soil plug was also measured at different stages of driving.

Pile No 6 at each site was equipped with two earth pressures cells located at a depth of about 10- 11 m below ground level.

7 TESTING ARRANGEMENTS

7.1 Loading Frame

The piles are tested at tension with loading frames, produced for this purpose, designed for a maximum axial load of 2000 kN. One exception is the frame at Ryggkollen, where it is used an upgraded old loading frame with a maximum axial load of about 4000 kN.

Figure 4 and 5 shows a photo and drawings of the loading frame produced and used at three of the test sites in Norway.

Figure 4 Phote of loading frame

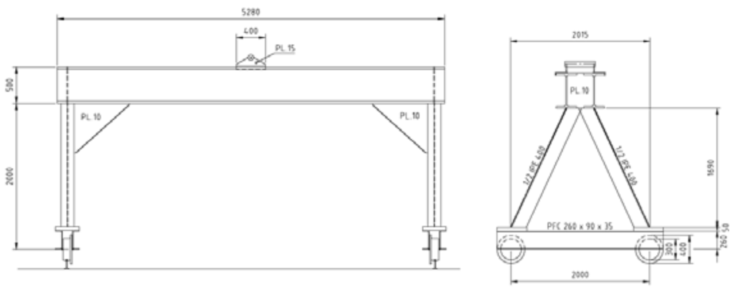

Figure 5 Drawing og loading frame with dimensions

The loading frames are equipped with wheels supported on reinforced concrete foundations so that it is easy to move from one pile to the next.

The axial tension load is applied through a hydraulic cylinder, using a special actuator that can also maintain the load constant over a time period of 1 year, as is planned for test pile 6 at each site.

The load is measured by means of specially delivered load cells mounted in between the top of the pile and the hydraulic cylinders.

Displacements at the pile top are measured with LVDT displacement transducers mounted to a reference beam. The reference beam is supported on two footings placed at a distance of 3 m from the piles to be tested. Figure 6 shows a photo of the reference beam set up.

Figure 6 Referense beam set up

7.2 Pile dimensions

There are installed 6 tubular steel piles at each site. Table 3 presents the dimension and depth of the test piles installed at each site.

Tab 3 Pile dimensions

Site	Pile diameter (mm)	Wall thickness (mm)	Depth of casing (m)	Depth to pile tip (m)
Stjørdal	508	6.3	1	23.6
Onsøy	508	6.3	1.4	19.1
Larvik	508	6.3	1.4	21.5
Ryggkollen	406.4	12.5	5	20.0
Cowden	457	12.5	Not yet	installed

Because the ground water table is located at a depth of about 10 m below ground level at Ryggkollen, there are installed casings to a depth of 5 m to reduce the friction during installation of the piles.

7.3 Execution of Pile Load Test

To identify to what extent the increase in capacity is only due to time effects, or also caused by sustained loads or previous load testing, the following test program will be followed:

- Pile 1: Load testing after 1 month, 3 months and 6 months, 1 year and 2 years
- Pile 2: Load testing after 3 months, 6 months, 1 year and 2 years
- Pile 3: Load testing after 6 months, 1 year, and 2 years
- Pile 4: Load testing after 1 year and 2 years
- Pile 5: Load testing after 2 years
- Pile 6: Load testing after 3 months, then the load will be sustained at a level of 60 % of the first failure load and the pile load tested again after 1 year.

The time is given after finished installation.

8 FURTHER WORK

So far, there have been only few and very limited studies undertaken to look specifically into time effects on the long term axial capacity of piles, apart from the direct effect of consolidation time following pile installations in clay deposits, which is reasonably well understood. Existing data suggest that the axial capacity of piles in clay may increase by as much as 10 to 50 % within 1 to 2 years after pile installation and by 50-100% after 10 years. There is also some evidence that the pile capacity may increase significantly with time even for piles in sand.

8.1 Interpretation and development of design procedures

The new pile load tests will be interpreted in detail, and then compared to data in the present and up-dated data base. Given that the new results show clear trends and correlations, procedures will be proposed for how to account for the time effects in design. This will most likely differentiate between pure time effects and effects related to past loading history.

References

[1] API (1993) Recommended practice for planning, designing and constructing fixed offshore platforms – working stress design
API RP 2A-WSD, American Petroleum Institute. 20th edition, July 1, 1993

[2] Augustesen, A., Andersen, L., and Sørensen, C.S. (2005a)
Capacity of piles in Clay. Available from the Department of Civil Engineering, Aalborg University, Denmark, Internal report, ISSN: 1398-6465 R0502

[3] Augustesen, A., Andersen, L., and Sørensen, C.S. (2005b)
Capacity of piles in Sand. Available from the Department of Civil Engineering, Aalborg University, Denmark, Internal report, ISSN: 1398-6465 R0519

[4] Clausen and Aas (2000)
Bearing capacity of driven piles – Piles in Clay. NGI report 525211-1, Norwegian Geotechnical Institute

[5] De Cock and Legrand (1997). Design of Axially Loaded Piles – European Practice. Proceedings of the ERTC3 (The ISSMFE European Regional Technical Committee 3 “Piles”), Design of Axially Loaded Piles – European practice
(eds. De Cock and Legrand), Balkema, Rotterdam, ISBN: 90 5410 873 8

[6] Jardine and Chow (1996). New design methods for offshore piles. Marine technology directorate Ltd., publication MTD 96/103, London, ISBN 1 870553 31 4

[7] Karlsrud, K., Clausen, C.J.F. and Aas, P.M. (2005)
Bearing Capacity of Driven Piles in Clay, the NGI Approach
Proc. Of the ISFOG Conference, Pert, WA, September 2005

[8] Karlsrud, K., Haugen, T. (1985)
Axial Static Capacity of Steel Models Piles in Overconsolidated Clay
Int. Conf. on Soil Mech. And Found. Eng. 11, Proc. San Francisco

[9] Karlsrud, K., Mahan, A.
Evidence of Long Term Ageing Effects on Axial Capacity of Piles in Soft Clay

[10] Lacasse and Nadim (1996). Model uncertainty in pile axial capacity predictions
Offshore Technology Conference, Houston, May 1996, Paper OTC 7996

[11] NGI-report 20061251-00-247-R “Time Effects on Pile Capacity”
Dated 2009.10.28

[12] NGI. R&D Proposal to the Research Council of Norway. Project for the Industry Initiated Innovation Arena Programme (BIA). “Time Effects Piles – Upgrading bearing capacity of piled foundations to account for time effects”