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# Comparison of rapid load pile testing of driven and CFA piles installed in high OCR clay

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**Abstract**

The current analysis of rapid load tests (RLT) such as Statnamic is normally based upon empirical correlations with static pile tests in similar soils. In certain soil types, such as clays, the number of case studies used to develop analysis and allow selection of appropriate rate effect correction are limited. Due to these limitations, no distinction is made in the selection of correction factors between pile type and pile installation techniques. In clay soils it is well known that driven piles may have a significantly enhanced capacity over cast in situ piles of similar cross-section. To test the effect of pile installation techniques on RLT analysis, RLT testing and static testing were undertaken on precast driven concrete piles and cast in situ CFA piles installed in high plasticity London Clay. The results show that the installation technique does not appear to affect the magnitude of the rate effects, provided modifications are made to the analysis to account for the previously reported differences in static capacity between different installation techniques. Based upon the findings, it is suggested that a distinction should be made in RLT analysis between pile type and installation techniques, and for existing analysis techniques, further case studies based on rate correction parameters are required, especially in clay soils.


*Keywords:* Rapid load testing; Driven piles; CFA piles; Rate effects; Clay (IGC: A01, E04, K07)

## 1. Introduction

The analysis of rapid load pile testing (RLT) such as Statnamic (Middendorp, 2000) is currently heavily dependent on the use of empirically derived damping or rate effect parameters to correct for the viscous effects in soil at elevated strain rates. Recent developments to RLT analysis include the selection of damping and correction parameters based upon soil type (Paikowsky, 2004; Middendorp et al., 2008) and measureable properties such as Atterberg limits in clays (Powell and Brown, 2006).

Currently the rate effect parameters are derived from a direct comparison of the RLT load-settlement behaviour with that of a static pile test on the same pile or an identical pile installed in close proximity. Alternatively, the parameters may have their origin in high strain rate laboratory element testing (for example Schmuker, 2005). Unfortunately, in the former case there is a lack of high quality case study data upon which to confidently specify rate effect parameters especially in fine grained soils such as clays or silts. This has led to reluctance by some authors

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**Nomenclature**

| | |
|---|---|
| $A$ | pile shaft or base surface area |
| $a$ | pile acceleration |
| $F_{base}$ | pile base resistance |
| $F_{shaft}$ | shaft friction resistance |
| $F_{STN}$ | measured rapid load test resistance |
| $F_u$ | derived static equivalent capacity |
| $F_{u,design}$ | design static capacity |
| $I_v$ | viscosity index |
| LI | liquidity index |
| LL | liquid limit |
| $M$ | pile mass |
| $m$ and $n$ | Soil dependant rate parameters |
| $N_q$ | bearing capacity factor |
| PI | plasticity index |
| $s_u$ | undrained shear strength |
| $\Delta v$ | relative velocity or penetration rate of pile and soil |
| $v_0$ | reference velocity |
| $v_{\min}$ | lowest velocity used in derivation of rate parameters |
| $\alpha$ | adhesion factor |
| $\gamma$ | bulk density |
| $\delta_h$ | pile-head settlement |
| $\mu$ | UPM correction or reduction factor |
| $\tau_{lim}$ | limiting elevated rate shaft friction |
| $\tau_s$ | static shaft friction |

to specify correction parameters in clays (McVay et al., 2003). This may result in a lack of end-user confidence in test results determined in fine grained soils and ultimately limit further development. Determining rate effect parameters from laboratory element testing is appealing from the point of view of material consistency and control of testing conditions, but, historically, testing has been undertaken at strain rates much lower than those experienced in full scale RLT (Leinenkugel, 1976; Sheahan et al., 1996; Katti et al., 2003). Rate effect analysis techniques developed on this basis (Krieg and Goldscheider, 1998; Schmuker, 2005) may then not be appropriate when applied to RLT tests.

Although the effect of soil type on RLT analysis appears to have been recognised (Paikowsky, 2004; Powell and Brown, 2006; Middendorp et al., 2008), the effects of pile type and installation techniques has had limited investigation. For instance, in clay soils a driven pile (displacement) is likely to have relatively higher static ultimate capacity than a pile of similar cross section and length installed by boring techniques and cast in situ (non-displacement). The effect on pile shaft capacity of the method of installation is well documented with bored piles displaying approximately 70% of a driven pile's shaft capacity (Fleming et al., 2009). This is also reflected in the higher adhesions factors used in total stress design for driven piles (Weltman and Healy, 1978). It is not currently clear if an associated increase in pile resistance would be measured during an RLT test, which would therefore allow the use of the same correction parameters for both displacement and non-displacement piles.

Due to the tendency for increased static capacity of displacement piles over non-displacement piles in clay, it is necessary to investigate this effect on both RLT analysis and parameter selection. For instance, the technique proposed by Schmuker (Krieg and Goldscheider, 1998; Schmuker, 2005; Middendorp et al., 2008) has its origins in low strain rate laboratory element testing, which cannot easily replicate pile-soil interface behaviour, complicated variations in situ effective stress or the effects of the high soil strain levels encountered during pile driving. The analysis method proposed by Powell and Brown (2006) and Brown and Hyde (2008) derives the majority of its soil dependant rate parameters from both back analysis of RLT field studies on non-displacement cast in situ piles and high strain rate (push-in) probing tests (Brown, 2008). Although the probe tests are a "displacement" type event, they do not reflect the "restrike" approach of RLT testing, where the pile is tested some time after installation.

In order to investigate the effect of pile installation technique and increase the available case study information for RLT in fine grained soils, a series of driven precast piles were installed at a research site underlain by Quaternary London Clay. The results of RLT and static testing of these piles was compared with the results from testing cast in situ continuous flight auger (CFA) piles installed at the same site. The pile testing described in this paper was undertaken as part of an industry led research project (RaPPER, Rapid Pile Performance Evaluation Resource) which was designed to give guidance on testing piles for re-use (Butcher et al., 2006) and the applicability of different pile testing methods in different soil types.

## 2. Field study site

The study site is located at Lodge Hill Camp, Chattenden, Kent in the UK and is underlain by London Clay to a depth in excess of 35 m. The upper 4 m is typically weathered/desiccated brown London clay (OCR 50–24) which overlays unweathered blue clay of very high plasticity. The undrained shear strength in the upper 10 m gradually increases with an average shear strength of 100 kPa (average OCR 18). The plasticity index, $PI=60\%$ in upper 10 m, rises to 63% for 10–15 m. The average moisture content in the upper 15 m was 29% and the bulk density, $\gamma$, was 19.4 kN/m$^3$. The water table was at approximately 1 m depth. The soil strength and characterisation data are shown summarised in Fig. 1. The site has been used extensively in recent times for pile behaviour testing (Skinner et al., 2003, Powell and Skinner, 2006) and more specifically to investigate RLT testing in clays (Powell and Brown, 2006, Brown and Powell, in press).