A CASE FOR THE OPTIMISATION OF CFA-BORED PILE DESIGN IN UK & IRELAND CLAYEY SOILS

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ABSTRACT

The main competencies of a chartered/professional engineer include demonstrated abilities to implement knowledge, skills and attitudes towards the restriction of the amount of natural resources consumed on projects, limitation of the quantities of wastes produced during construction, whilst ultimately minimising the overall carbon footprint associated with every scheme. These are important obligations to the environment and society that must be dutifully fulfilled by every practising engineer, by continually striving to maintain reasonably good balance between safety and economy on every project.

In support of the above professional obligations, this paper details independent literature review of shaft adhesion factors that are appropriate for the economical designs of CFA-bored piles in clay in the UK and Ireland. The geotechnical appraisals had originally been carried out by Deep Foundations Specialists (DFS) as independent 3rd party-checks to resolve disputes between a number of piling contractors and structural warranty companies in respect of the design aspects of the piling works for large scale residential developments in Hampshire and Cambridgeshire, England. The geotechnical appraisals are supported with case histories of 15 No. historical piling projects completed, static load-tested and back-analysed in different geographical regions of the United Kingdom & Ireland.

Essentially, the literature review confirms the shaft adhesion factor, $\alpha = 0.6$ adopted by the piling contractors in designs for the initially disputed schemes to be appropriate, safe and economical, albeit higher than the generic value, $\alpha = 0.5$ recommended by guide documents including the BS8004 (2015) and the London District Surveyors Association's Guidance Note No. 1 for the Design of Straight Shafted Bored Piles in London Clay (2018). The conclusions of the literature review ultimately resulted in the acceptance of the piling contractors' designs by the structural warranty providers.

The paper recommends that whenever it is possible, design engineers should place greater reliance on site-specific pile test data or pile test data from other sites with similar ground conditions, pile geometries and pile installation methods, in order to produce the most economical and sufficiently optimised pile design for every site.

Keywords: sustainability, carbon footprint, safety, economy, CFA, bored piles, foundations, design, shaft adhesion factors, piling, static load testing, factors of safety, case histories, standards.

INTRODUCTION

Sustainability is increasingly becoming one of the most important aspects of civil & structural engineering practice. The significance of sustainable practice in the delivery of underground structures had already been highlighted by a number of authors e.g. Adekunte (2015), Jefferson et al. (2006 & 2017) and Brundtland (1987). Brundtland (1987) categorically defines sustainable development as an approach that fulfils the requirements of the present day, with no negative impact on the potential of future generations to satisfy

their own requirements. In essence, Brundtland's (1987) definition clearly conveys the significance of sustainable practice to both the present society and the future.

Therefore, in the area of ground engineering practice, in addition to standard safety requirements, there are a few other vital requirements that must be satisfied by the present-day geotechnical engineer/geostructural engineer. These include the delivery of sustainable and cost-effective solutions, with reduced environmental and societal impacts. Essentially, many ethical codes now compel ground engineering specialists to limit the consumption of natural resources and energy on development schemes. They are also required to minimise the quantities of wastes produced, as well as the levels of environmental pollution, noise and disruption to traffic and normal societal life around every construction site.

In line with the requirements outlined above, it is vital for geotechnical design engineers to explore ways through which existing design practices may be optimised in order to produce more efficient foundations, with reduced degrees of redundancy in service. One of such recent modifications to existing geotechnical design practice is the use of shaft adhesion factors α that are slightly higher than $\alpha = 0.5$, which is generically recommended by industry standards and guide documents for the design of CFA-bored piles in clay soils in the United Kingdom and Ireland. However, a number of design engineers do have reservations over the adoption of higher adhesion factors ($\alpha > 0.5$) in the design of CFA-bored piles in clay, as they do consider $\alpha > 0.5$ to be quite optimistic, unsafe and inappropriate.

In order to shed more light on appropriate α values for the design of CFA-bored piles in UK & Ireland clayey soils, whilst also justifying the suitability/adequacy of α values as high as 0.6, Deep Foundations Specialists (DFS) have embarked on an appraisal of propositions and recommendations available in the literature in respect of α values for CFA-bored piles in ground conditions similar to those that commonly underlie project sites in the UK & Ireland. The literature review is also supported with case histories of 15 No. historical piling projects completed by others in different geographical regions of the UK & Ireland, on which CFA-bored piles had been designed with α value of 0.6 and static load-tested to verify the adequacy of the higher adhesion factor. The back-analysed results of some of the static load tests are also compared with the original theoretical shaft capacity estimates.

This technical paper presents the geotechnical appraisal outlined above, while conclusions are also drawn on the suitability of shaft adhesion factor $\alpha = 0.6$ for the design of CFA-bored piles in clay soils across the UK & Ireland.

OUTLINE OF GEOTECHNICAL APPRAISAL

With reference to clause 6.4.1.2.3.3 of the BS8004:2015+A1:2020, the ultimate unit shaft resistance of piles in cohesive soils can be estimated with total stress parameters by using the empirical correlation shown below:

$$Q_s = \alpha * C_u \qquad [1]$$

In equation 1;

α = empirical coefficient for a cohesive layer that depends on the strength of the soil, effective overburden pressure, pile type and method of construction. This coefficient may also be referred to as the pile's shaft adhesion factor.

C_u = undrained shear strength of the soil layer

Clause 6.4.1.2.3.5 of the same design standard (BS8004:2015+A1:2020) recommends that the value of α in equation [1] should be obtained from previous evidence of acceptable performance in static load tests on the same type of pile of similar length and cross-section, in similar ground conditions.

While clause 6.4.1.2.3.9 of the document generically recommends the adoption of an α value of 0.5 for the design of piles in stiff clays such as London clay, Gault clay, Lias clay, Oxford clay and Weald clay in the absence of reliable test data/previous evidence, clause 6.4.1.2.3.10 of same guide document confirms that the use of alternative α values are allowed, provided that there are previously documented evidence of the successful performance of the same type of pile in similar ground conditions where the alternative α value had been used in design.

Therefore, on the basis of clauses 6.4.1.2.3.5 and 6.4.1.2.3.10 of the BS8004:2015+A1:2020 outlined above, this paper presents a detailed review of a number of technical publications and project case histories that involved the design and load-testing of CFA-bored piles on the basis of an α value of 0.6 (which is essentially higher than the generic value of $\alpha = 0.5$ recommended in clause 6.4.1.2.3.9 of the BS8004:2015+A1:2020 in cohesive soil layers that are similar in strength, stiffness, plasticity, consistency and composition to clay strata that commonly underlie UK & Ireland construction sites.

The literature review and case histories are presented in the following sections of the paper and they are essentially aimed at justifying the use of α value of 0.6 for the design of CFA-bored piles in UK & Ireland. The project case histories have been carefully chosen from different geographical regions of the UK & Ireland. Pile sizes vary between ∅300mm - ∅750mm, working loads in compression vary between 195 KN/pile – 1800 KN/pile, while service tension loads are as high as -350 KN/pile.

The designs for the piles had generally been based on the traditional bearing capacity approaches, whilst adopting equation [1] for the estimation of ultimate unit shaft resistance. Designs had also accounted for minimum partial factor of safety of 1.2 on shaft friction resistance only, in order to limit the potential of shaft friction resistance being fully mobilised under working loads and thus restricting pile movements under service loading within tolerable limits.

LITERATURE REVIEW

UK design guide documents for bored piles in cohesive ground e.g. BS8004:2015+A1:2020 and the London District Surveyors Association's (LDSA) Guidance Note No. 1 for the Design of Straight Shafted Bored Piles in London Clay (2017) generically recommend an adhesion factor $\alpha = 0.5$ for the estimation of shaft friction resistance of piles in clay layers. This α value of 0.5 is recommended by the guide documents to cover all design scenarios for bored piles, irrespective of site location, pile installation methodology and pile geometry, in the absence of site-specific or historical load test data in similar ground conditions, provided that the drillholes for the piles are left open for less than a period of 12 hours prior to concreting.

Martin et al. (2016) do consider the above 'one size fits all' approach to bored pile design to be quite conservative. Martin et al.'s (2016) paper chiefly focuses on the philosophy behind the pile design, pile load testing and back-analysis of maintained load testing (MLT) results for preliminary test piles installed as part of a large-scale development in Whitechapel London that comprised of multiple high-rise structures. The sacrificial test pile was chiefly embedded in London clay, which was described as firm to stiff to very stiff silty clay with partings of silt and fine sand and occasional selenite crystals.

Through the back-analysis of the static load test results for the site, Martin et al. (2016) established the appropriate adhesion factor for the site and essentially justified the use of a higher adhesion factor $\alpha = 0.6$ for the design of the working piles on the site, with significant savings in construction cost and programme.

Prior to the works of Martin et al. (2016), Gavin et al. (2008) in their review of the works completed by Farrell & Lawlor (2008) in relation to the results of static compressive load test on a CFA-bored pile in stiff to very stiff Dublin boulder clay, which show the test pile to have mobilised α value of 0.65 during the load test, suggested that traditional design practice of the sort described at the beginning of this section, which is used to routinely estimate shaft resistance around CFA-bored piles in clay is somewhat conservative.

Poulos (1989) in his review of the main characteristics of single pile & pile group behaviour under static & cyclic loading, presented a set of empirical correlations and design charts for the prediction of axial capacities of bored and driven piles in cohesive and cohesionless soils. These empirical correlations were based on earlier works/test results completed and published by multiple workers on various pile types, with different geometrical properties, in different ground conditions. Empirical correlations presented in Poulos' (1989) paper, which essentially relate pile shaft resistance f_s to standard penetration test N_{spt} values, were subsequently published in the CIRIA Report No. 143 (1995).

In essence, with references to Poulos (1989) and CIRIA Report No. 143 (1995), which are both underlain by the earlier works of Shioi & Fukui (1982), ultimate shaft friction resistance between a pile and surrounding soil layers may be estimated with the following expression;

$$f_s = a + \beta * N_{spt} \quad [2]$$

where f_s = ultimate unit shaft resistance, N_{spt} = standard penetration test N value, while a and β are constants that are dependent on soil and pile type.

For bored piles in cohesive materials, Poulos (1989) and Shioi & Fukui (1982) recommend a and β to be taken as a = 0.0 and β = 5.0. However, in UK & Ireland piling practice, most designers routinely adopt a lower β value of 3.0 while using equation [2]. If the constants a and β are substituted with values of 0.0 and 3.0 respectively in equation [2], equation [2] becomes;

$$f_s = 3N_{spt} \quad [3]$$

In UK & Ireland piling practice, the relationship between N_{spt} and undrained shear strength C_u of clay is typically expressed as;

$$C_u = 5N_{spt} \text{ (after Stroud, 1989)} \quad [4]$$

$$\therefore N_{spt} = C_u/5 \quad [5]$$

Replacing N_{spt} in equation [3] with the newly derived equation [5], equation [3] becomes;

$$f_s = 3 * [C_u/5] = 0.6C_u$$

$$\therefore f_s = 0.6\ C_u \quad [6]$$

Equation [6], which has been logically deduced from the empirical correlation originally proposed by Shioi & Fukui (1982), Poulos (1989) and subsequently recommended in the CIRIA Report No. 143 (1995), essentially point to the suitability of adhesion factors α of 0.6 or higher, for the design of bored piles in cohesive soils in the UK & Ireland.

A number of CFA-bored piles in the UK & Ireland have been designed on the basis of equations [2] – [6] above, which essentially translate to the adoption of adhesion factor $\alpha = 0.6$ on each of these projects. More importantly, many of the piles have been tested by maintained load testing (MLT) techniques, in order to verify the adequacy of the theoretically assumed α value of 0.6. Some of these projects are outlined in the following section of this paper.

CASE HISTORIES OF UK & IRELAND PILING PROJECTS DESIGNED & LOAD-TESTED WITH SHAFT ADHESION FACTOR OF $\alpha = 0.6$

A number of CFA-bored piling projects in the UK & Ireland have been designed based on equations [2] – [6], which are essentially equivalent to the adoption of adhesion factor $\alpha = 0.6$ in equation [1]. These piles have also been tested by maintained load testing (MLT) techniques in accordance with the recommendations of the Institution of Civil Engineers' Specification for Piling & Embedded Retaining Walls (ICESPERW, 2007 & 2017), in order to justify the use of $\alpha = 0.6$ in the original theoretical design estimates. Details of these projects are presented in Table 1.

This paper also back-analyses the results of the test piles that were loaded up to a minimum of 2.0 times the design verification load in order to ascertain the measured shaft capacities of the piles, whilst comparing same with the theoretically estimated shaft capacities (based on $\alpha = 0.6$). The back-analysis have been carried out with industry-established/approved hyperbolic methods for the analysis of pile load-settlement behaviour and capacities and they are presented in the later parts of this section.

The Federation of Piling Specialists UK (FPS, 2006) recommends the following pile test back-analysis methods;

- Davisson's method;
- Butler & Hoy's method;
- De Beer's method;
- Fuller & Hoy's method;
- Vander Veen's method;
- Brinsch Hansen's method;
- Mazurkiewicz's method;
- Chin's (1970 & 1971) method;
- Fleming's (1992) method.

In addition, the ICESPERW (2007 & 2017) recommends the use of either of Chin's (1970 & 1971) approach or Fleming's (1992) method for the back-analysis and interpretation of pile load test results. Therefore, in line with the above recommendations of the FPS (2006) and ICESPERW (2007 & 2017), the verification of the ultimate shaft capacities of the selected test piles from test data, as presented in this paper, are generally based on the hyperbolic method of Chin (1970 & 1971). These are detailed in the later parts of this section.

Table 1 – Case histories of CFA-bored piling projects in UK & Ireland on which piles had been designed with adhesion factor $\alpha = 0.6$ and capacity-verified with static load tests.

Project Title	Piling Technique	Pile Diameter (mm)	Description of Clay Layers	Maximum Service Load (KN)	Maximum Pile Length (m)	Remarks on Pile Load Tests
Harmondsworth Immigration Removal Centre, Middlesex.	CFA	400.0	Stiff Silty Clay	830.0	21.5	Results of test on 1 No. sacrificial test pile loaded up to 2.5 x DVL were satisfactory. Test results were back-analysed to confirm that actual shaft capacities were higher or in good agreement with theoretical predictions that had been based on an α value of 0.6. Measured load-settlement responses of test pile under applied loading of up to 1.5 x DVL were remarkably much better than the performance limits stipulated by the Federation of Piling Specialists UK (FPS, 2006) and the Institution of Civil Engineers (ICESPERW, 2007 & 2017). Back-analysis confirms that under applied test loads of up to 1.5 x DVL, loads were mainly supported in shaft friction only, with negligible or no-load transfer to the pile toe.

Project Title	Piling Technique	Pile Diameter (mm)	Description of Clay Layers	Maximum Service Load (KN)	Maximum Pile Length (m)	Remarks on Pile Load Tests
Kings Down, Bridgwater, Somerset.	CFA	300.0	Firm Silty Clay/Clayey Sandy Silt	195.0	12.0	Results of tests on 3 No. sacrificial test piles loaded up to 2.0 x DVL were satisfactory. Test results were back-analysed to confirm that actual shaft capacities were higher or in good agreement with theoretical predictions that had been based on an α value of 0.6. Measured load-settlement responses of test pile under applied loading of up to 1.5 x DVL were remarkably much better than the performance limits stipulated by the Federation of Piling Specialists UK (FPS, 2006) and the Institution of Civil Engineers (ICESPERW, 2007 & 2017). Back-analysis confirms that under applied test loads of up to 1.5 x DVL, loads were mainly supported in shaft friction only, with negligible or no-load transfer to the pile toe.

Project Title	Piling Technique	Pile Diameter (mm)	Description of Clay Layers	Maximum Service Load (KN)	Maximum Pile Length (m)	Remarks on Pile Load Tests
Great Suffolk Street, London SE1.	CFA	600.0	Stiff Silty/Sandy Clay	1775.0	26.0	Results of tests on sacrificial/preliminary test piles loaded up to 2.5 x SWL were satisfactory, with < 9.0mm pile head settlement recorded @ 2.0 x SWL. Test results were back-analysed to confirm that actual shaft capacities were higher or in good agreement with theoretical predictions that had been based on an α value of 0.6. Measured load-settlement responses of test pile under applied loading of up to 2.0 x SWL were remarkably much better than the performance limits stipulated by the Federation of Piling Specialists UK (FPS, 2006) and the Institution of Civil Engineers (ICESPERW, 2007 & 2017). Back-analysis confirms that under applied test loads of up to 1.5 x DVL, loads were mainly supported in shaft friction only, with negligible or no-load transfer to the pile toe.

Project Title	Piling Technique	Pile Diameter (mm)	Description of Clay Layers	Maximum Service Load (KN)	Maximum Pile Length (m)	Remarks on Pile Load Tests
Ochre Yard, Gateshead, Newcastle-upon-Tyne.	CFA	300.0	Soft to Firm to Stiff to Very Stiff Sandy/Gravelly Clay	150.0	10.0	Results of tests on sacrificial/preliminary test pile were satisfactory, with < 7.0mm pile head settlement recorded @ 1.5 x SWL. Test results were back-analysed to confirm that actual shaft capacities were higher or in good agreement with theoretical predictions that had been based on an α value of 0.6. Measured load-settlement responses of test pile under applied loading of up to 2.0 x SWL were remarkably much better than the performance limits stipulated by the Federation of Piling Specialists UK (FPS, 2006) and the Institution of Civil Engineers (ICESPERW, 2007 & 2017). Back-analysis confirms that under applied test loads of up to 1.5 x DVL, loads were mainly supported in shaft friction only, with negligible or no-load transfer to the pile toe.

Project Title	Piling Technique	Pile Diameter (mm)	Description of Clay Layers	Maximum Service Load (KN)	Maximum Pile Length (m)	Remarks on Pile Load Tests
Chiswick Lodge, London	CFA	350.0	Stiff to Very Stiff Silty Clay	875.0	19.5	Results of tests on sacrificial/preliminary test piles were satisfactory, with < 9mm pile head settlements recorded @ 2.5 x SWL.
Dublin Port's New Ro-Ro Ramp 2, Dublin Docklands.	CFA	750.0	Stiff Sandy Clay/Very Stiff to Hard Gravelly Clay	1415.0	20.0	Results of tests on piles satisfactory, with < 3.1mm pile head settlement @ 1.5 x SWL.
Addison Road, Holland Park London.	CFA	350.0	Firm to Stiff Sandy Clay & Stiff to Very Stiff Silty Clay	650.0	17.5	Results of test on sacrificial/preliminary test pile were satisfactory and remarkably much better than the performance limits stipulated by the Federation of Piling Specialists UK (FPS, 2006) and the Institution of Civil Engineers (ICESPERW, 2007 & 2017).
Brockley Primary School, Lewisham London.	CFA	450.0	Firm to Stiff to Very Stiff Sandy/Silty Clay	1440.0	21.0	Pile load test results were satisfactory and remarkably much better than the performance limits stipulated by the Federation of Piling Specialists UK (FPS, 2006) and the Institution of Civil Engineers (ICESPERW, 2007 & 2017).

Project Title	Piling Technique	Pile Diameter (mm)	Description of Clay Layers	Maximum Service Load (KN)	Maximum Pile Length (m)	Remarks on Pile Load Tests
Dublin Airport Water Reservoir & Pump Station, Dublin.	CFA	500.0	Soft to Firm to Stiff to Very Stiff Gravelly Clay	-350.0 (Tension)	5.0	Results of tension loading tests on 2 No. piles were satisfactory. Pile upward movements under 1.5 x service tension loads were generally < 4.0mm.
Lyme Grove, Hackney London.	CFA	350.0	Stiff to Very Stiff Sandy/Silty Clay	750.0	18.0	Pile load test results were satisfactory and remarkably much better than the performance limits stipulated by the Federation of Piling Specialists UK (FPS, 2006) and the Institution of Civil Engineers (ICESPERW, 2007 & 2017).
Extra Care Scheme, Richmond-upon-Thames.	CFA	450.0	Stiff to Very Stiff Sandy/Silty Clay	900.0	12.8	Pile load test results were satisfactory and remarkably much better than the performance limits stipulated by the Federation of Piling Specialists UK (FPS, 2006) and the Institution of Civil Engineers (ICESPERW, 2007 & 2017).

Project Title	Piling Technique	Pile Diameter (mm)	Description of Clay Layers	Maximum Service Load (KN)	Maximum Pile Length (m)	Remarks on Pile Load Tests
Sleeperz, Westgate Road Newcastle-upon-Tyne.	CFA	450.0	Firm Sandy Silty Clay/Firm to Stiff to Very Stiff Gravelly Clay	1150.0	19.0	Pile load test results were satisfactory and remarkably much better than the performance limits stipulated by the Federation of Piling Specialists UK (FPS, 2006) and the Institution of Civil Engineers (ICESPERW, 2007 & 2017).
St. Augustine's School, Kilburn London.	CFA	600.0	Firm to Stiff to Very Stiff Silty Clay	1090.0	19.5	Pile load test results were satisfactory and remarkably much better than the performance limits stipulated by the Federation of Piling Specialists UK (FPS, 2006) and the Institution of Civil Engineers (ICESPERW, 2007 & 2017).
Thornton Road, Bradford.	CFA	500.0	Firm to Stiff Gravelly Clay	1800.0	13.5	Pile load test results were satisfactory and remarkably much better than the performance limits stipulated by the Federation of Piling Specialists UK (FPS, 2006) and the Institution of Civil Engineers (ICESPERW, 2007 & 2017).

Project Title	Piling Technique	Pile Diameter (mm)	Description of Clay Layers	Maximum Service Load (KN)	Maximum Pile Length (m)	Remarks on Pile Load Tests
Northern Woods, Waterbeach, Cambridge.	CFA	300.0/450.0/600.0	Firm to Stiff to Very Stiff Gault Clay	800.0	22.0	Pile load test results were satisfactory and remarkably much better than the performance limits stipulated by the Federation of Piling Specialists UK (FPS, 2006) and the Institution of Civil Engineers (ICESPERW, 2007 & 2017).

The project case histories outlined in Table 1 above have involved piles installed by continuous flight auger (CFA) drilling technique through cohesive layers of various characteristics and engineering properties down to various depths in different geographical regions of the United Kingdom and Ireland and therefore, they may be considered to be sufficiently representative of clayey ground conditions that are typically encountered during CFA-bored piling works in the UK & Ireland. Essentially, the main constants across all the 15 No. case histories are the installation technique (CFA-bored piling) and the adhesion factor adopted in the pile designs ($\alpha = 0.6$).

Results of a number of test piles on the historical sites that were loaded close to ultimate conditions (> 2.0 x DVL) have been back-analysed by the hyperbolic method of Chin (1970 & 1971) in order to separate the ultimate shaft capacities from the end-bearing capacities and thus establish the basis to compare the measured shaft capacities with theoretically estimated shaft capacities obtained with $\alpha = 0.6$. The back-analysis curves for the sacrificial test piles at Great Suffolk Street London, Kings Down Bridge Water Somerset and Ochre Yard Gateshead Newcastle-upon-Tyne are presented and compared with theoretical predictions based on adhesion factor $\alpha = 0.6$ in Figs. 1-3.

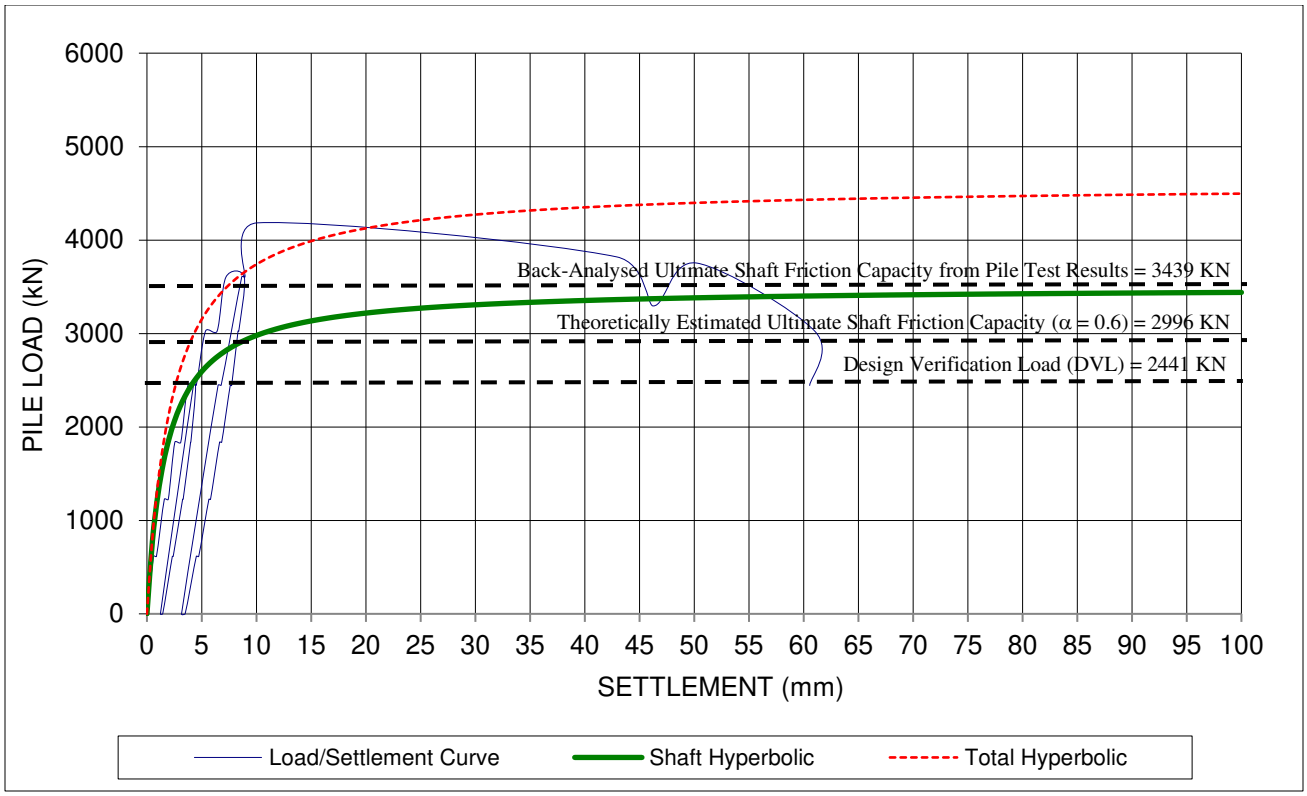


Fig.1. Comparison of theoretically estimated ultimate shaft capacity (α = 0.6) with back-analysed ultimate shaft capacity of sacrificial test pile at Great Suffolk Street, London.

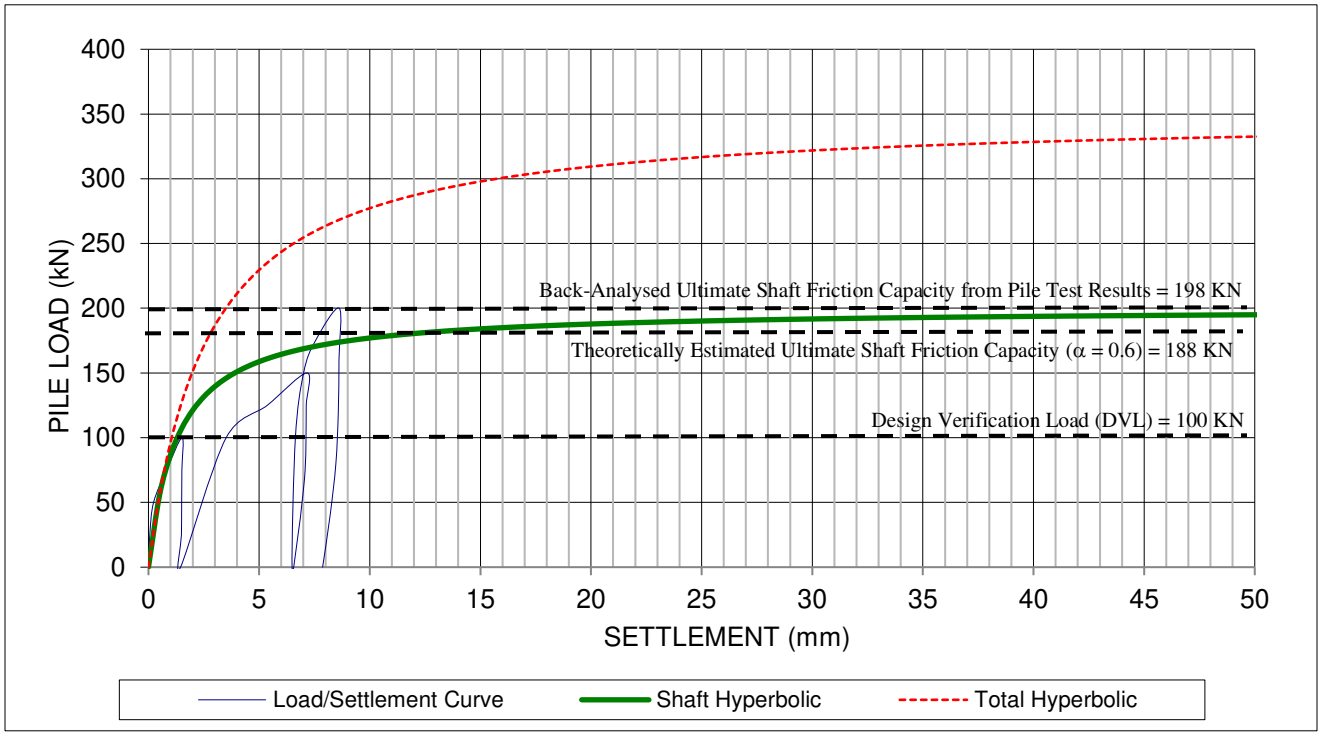


Fig.2. Comparison of theoretically estimated ultimate shaft capacity (α = 0.6) with back-analysed ultimate shaft capacity of sacrificial test pile at Kings Down, Bridgwater, Somerset.

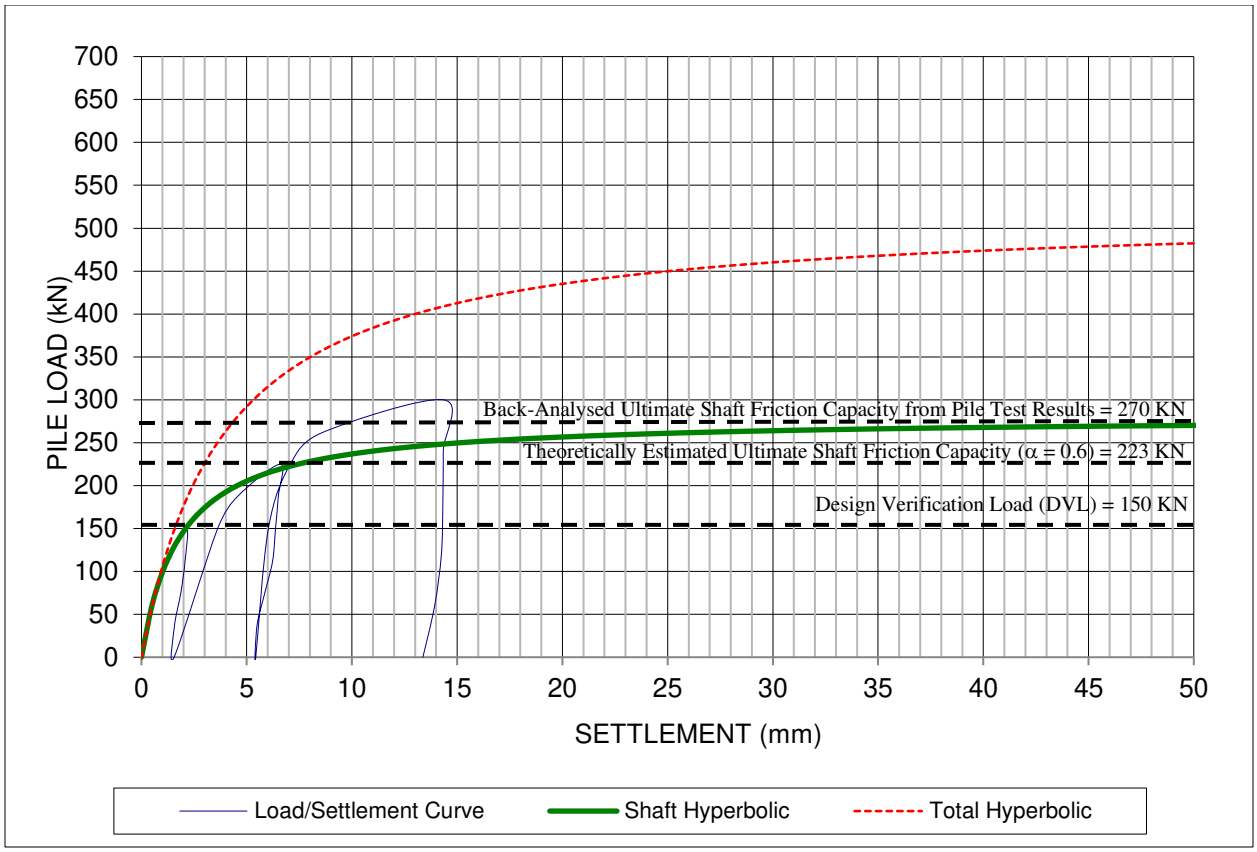


Fig.3. Comparison of theoretically estimated ultimate shaft capacity (α = 0.6) with back-analysed ultimate shaft capacity of sacrificial test pile at Ochre Yard, Gateshead, Newcastle-upon-Tyne.

Figures 1-3 generally show the theoretically estimated ultimate shaft friction capacities (α = 0.6) to be lower than the values back-analysed from the sacrificial pile test results. In addition, under applied loadings of up to 1.5 times the DVLs, measured pile settlements are shown to be generally < 7.0mm. The curves show applied loads of up to 1.5 x DVL to have been chiefly supported in shaft friction (only), with minimal or no-load transfer to pile toes.

The Institution of Civil Engineers' Specifications for Piling & Embedded Retaining Walls (2007 & 2017) recommends that pile head settlements of < 20mm under 1.5 x DVL should be considered to be acceptable. Therefore, measured settlements of < 7.0mm under 1.5 x DVLs may be considered as satisfactory serviceability performances by the 3 No. sacrificial test piles. The above observations do confirm that an adhesion factor α = 0.6 is reasonably safe and sufficiently conservative for the design of CFA-bored piles on the three sites. They also confirm that the permanent working piles installed on the sites would safely support the specified service loads under working conditions, with tolerable vertical deflections.

Furthermore, with reference to the multiple case histories outlined in Table 1, the pile load test results from all the sites have been satisfactory, while they also ultimately justify the adoption of shaft adhesion factor α = 0.6 in the theoretical designs for the piles. Therefore, on the basis of clauses 6.4.1.2.3.5 and 6.4.1.2.3.10 of the BS8004:2015+A1:2020, whilst also considering the fact that the test piles on the historical sites were chiefly of relatively similar geometries to those typically adopted in UK & Ireland piling practice and embedded in cohesive soils of strength, stiffness, plasticity, consistency and composition that are widely representative of site conditions typically encountered

on CFA-bored piling projects in the United Kingdom and Ireland, it would be safe to consider shaft adhesion factor $\alpha = 0.6$ as being largely appropriate for the prediction of shaft capacities of CFA-bored piles in UK & Ireland clayey soils.

CONCLUSIONS & RECOMMENDATIONS

This paper details independent literature review and geotechnical appraisal of shaft adhesion factors that are appropriate for the economical designs of CFA-bored piles in clay in the UK and Ireland. The geotechnical appraisal is supported by case histories of test piles on 15 No. historical piling projects completed, static load-tested and back-analysed in different geographical regions of the United Kingdom & Ireland.

Essentially, the literature review and geotechnical appraisal confirm shaft adhesion factor, $\alpha = 0.6$ to be appropriate, safe and economical for the theoretical design of CFA-bored piles on all the historical sites assessed. Therefore, on the basis of clauses 6.4.1.2.3.5 and 6.4.1.2.3.10 of the BS8004:2015+A1:2020, whilst also considering the fact that the test piles on the historical sites were chiefly of relatively similar geometries to those typically adopted in UK & Ireland piling practice and embedded in cohesive soils of strength, stiffness, plasticity, consistency and composition that are widely representative of site conditions typically encountered on CFA-bored piling projects in the United Kingdom and Ireland, shaft adhesion factor $\alpha = 0.6$ is recommended as being widely appropriate for the prediction of shaft capacities of CFA-bored piles in UK & Ireland clayey soils.

In addition, on a general note, whenever possible, geotechnical design engineers should place greater reliance on site-specific pile test data or pile test data from other sites with similar ground conditions, pile geometries and pile installation methods, in order to produce the most economical and sufficiently optimised pile design for every site.

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