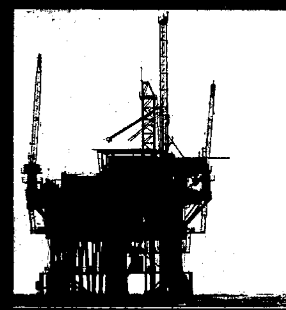

New Design Methods for Offshore Piles

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1 SUMMARY

An extended programme of research by a group from Imperial College, London has led to new methods for assessing the axial capacity of offshore piles. Following the introductory comments offered below, this document summarises the new procedures and provides:

- A description of the new methods sufficient to allow practising engineers to apply them
- A demonstration that they offer considerable theoretical and practical advantages over existing methods
- Full validation of the methods for offshore conditions, showing that they are far more reliable and accurate than existing methods
- Comments on how pile age, group action and other factors could influence field performance.

The report summarises and puts in context the research findings that led to the new methods. For detailed descriptions of the experimental work, background theory and validation of results the reader is referred to Appendix I which lists the key PhD theses, OTH reports and papers relating to the research. Appendices II and III contain the full references for cited publications by others, while Appendix IV defines the notation and symbols used in the document.

2 INTRODUCTION

2.1 Rationale for Developing New Design Approaches

Predictions from current empirical methods for assessing the axial capacities, Q, of displacement piles are relatively unreliable. As detailed later, the Coefficient of Variance (COV)[1] in $Q_{calculated}/Q_{measured}$ (Q_c/Q_m) for test piles analysed according to the API RP2A 20th edition (1993) offshore recommendations falls between 0.5 – 0.7.

These high COV values are not compatible with the relatively low safety margins (typically 1.5) adopted for most offshore pile designs.

At the same time, many practitioners consider the existing methods to be over-conservative in certain circumstances. For example, it is recognised that in sand the API RP2A approach leads to strong and systematic skewing of Q_c/Q_m with respect to pile slenderness and sand relative density, leading to under-predicted capacities for short piles in dense strata.

Foundation problems are relatively rare among the existing population of piled offshore structures. However, a clear need exists to improve predictive methods to obtain economies in some cases and enhance performance, and safety, in others. The implementation of new methods needs to be co-ordinated with any parallel developments in the characterisation of environmental loading, with account being taken of any trends towards structural designs which impose different patterns of loading on their foundations.

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[1]The Coefficient of Variation (COV) is defined as the standard deviation, s, divided by the mean value, μ.

2.2 Imperial College Research Programmes

2.2.1 Research Aims

The Imperial College research has been aimed towards achieving: (i) a more fundamental and thorough understanding of pile behaviour, and (ii) practical simple design methods that capture the basic mechanics of driven piles. The main tasks were to identify:

- How piles behave in different soils and layering sequences
- The scaling laws that relate the behaviour of models to that of full-scale piles
- The effects on capacity of pile properties (dimensions, wall thickness, end conditions, surface roughness, material hardness, etc.) and installation methods
- Any changes in capacity and stiffness associated with time after pile installation
- The response to different loading types, including group effects and cyclic loading
- The controlling soil parameters that should be measured in site investigations.

2.2.2 Field Tests with Instrumented Piles

Until recently, the stress conditions surrounding driven piles have been open to conjecture. A central feature of the Imperial College research has been the development of accurate and reliable on-pile instrumentation to study the pore pressures, radial total stresses, local shear stresses and temperatures developed on pile shafts. The gauges were mounted on 6 – 20 m long, 102 mm diameter, closed-ended[2] steel pipe piles (termed ICPs) and used in intensive test programmes involving a wide range of geomaterials between 1986 – 1994 at the six sites identified in Table 1 and Figure 1.

The ICPs were installed by fast jacking, allowing comprehensive measurements of the effective stress conditions developed close to the shafts to be made at multiple levels during installation, long-term equalisation and load testing to failure.

Detailed site investigations were also performed, involving in-situ tests and advanced laboratory experiments. "Strain Path Method" numerical simulations of the ICP tests performed at Canons Park and Bothkennar were also carried out in conjunction with Professor A. Whittle from MIT as described by Bond (1988) and Lehane (1992).

The Pentre piles (Figure 1) were installed close to the large-scale driven piles (LDP) described by Clarke (1993); tests on less intensively instrumented open-ended driven piles were conducted at Canons Park, Cowden and Dunkirk.

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[2]The use of closed-ended piles allowed more accurate and robust instrumentation to be deployed.

TABLE 1. SUMMARY OF RECENT IMPERIAL COLLEGE PILE RESEARCH SITES

Site		Soil conditions
1.	Canons Park	London clay: stiff to very stiff, high plasticity, Eocene marine clay; high YSR
2.	Cowden	Cowden till: stiff to very stiff, lean, glacial lodgement till; high YSR
3.	Bothkennar	Carse clay: soft, high plasticity, moderately organic, Holocene marine-estuarine clay-silt, lightly cemented; moderate YSR
4.	Labenne	Dune sand: loose to medium dense, medium-sized, Holocene; low YSR
5.	Pentre	Glacio-lacustrine clay-silt and laminated clays: very soft to firm, low plasticity; low YSR
6.	Dunkirk	Marine sand: dense to very dense, shelly medium-sized sand, Flandrian; low YSR

Note: Yield Stress Ratio (YSR) is the apparent OCR as defined in Appendix IV

2.2.3 Results from Phases 1, 2 and 3

The research has taken place in three phases. The first involved developing the ICP instruments and experimental procedures, and performing multiple ICP tests and other experiments at the Building Research Establishment's (BRE) Canons Park test site. The research was summarised by Bond (1988) and Bond and Jardine (1990).

The scope was broadened in Phase 2 to cover tests in sand at the French Ponts et Chausseés test site at Labenne, the BRE's stiff till site at Cowden, and the Engineering and Physical Sciences Research Council's (EPSRC) national soft clay test site at Bothkennar. At each location an advanced site investigation was performed, a field pile testing facility established, and a programme of multiple (closed-ended) ICP tests carried out. Clear and striking results emerged from the experiments which allowed new design approaches to be proposed for closed-ended piles. The Phase 2 work was reported by Lehane (1992) and Jardine and Lehane (1994).

The third phase, which has recently been completed, involved:

1. Establishing test facilities and performing advanced site investigations and multiple ICP tests at the Pentre (clay-silts/laminated clays) LDP research site and at the Dunkirk "CLAROM" dense sand research site.

2. Interpreting and performing tests on full-scale driven open-ended piles (with diameters up to 760 mm) at the ICP sites to assess the effects of scale, installation methods and pile-end conditions.

3. Experiments to assess pile group and ageing effects in dense sand.

4. Using the above to refine the new approaches for closed-ended piles and extend the design methods to cover open-ended driven piles.

5. Collating an up-to-date and critically approved database of full-scale pile tests that met rigorous quality criteria.

6. Using the above to calibrate and validate the new methods for a wide range of practical applications.

The work is reported by Chow (1996) and Chow and Jardine (1996).

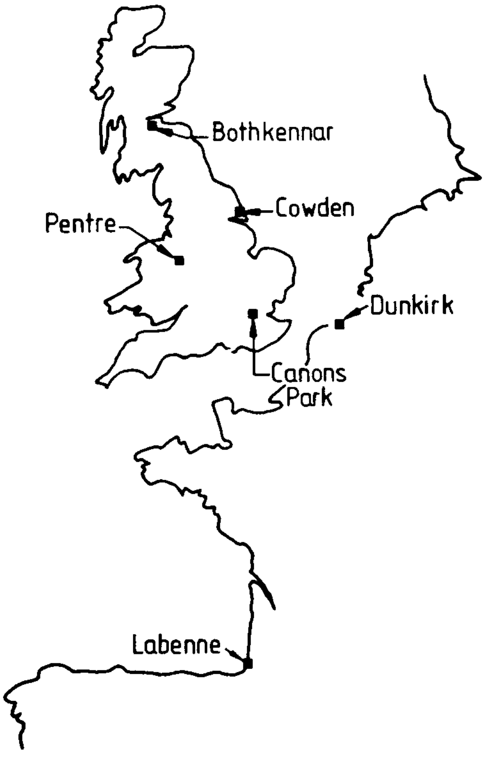

Figure 1. Locations of ICP test sites.