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A new and openly accessible database of tests on piles driven in sands

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This paper reviews the critical need to develop better load test databases for piles driven in sand before reporting on the significantly augmented, openly accessible, Zhejiang University/Imperial College London (ZJU-ICL) database. Key quality parameters, the population of current entries and the reporting format are described before offering preliminary results obtained from comparisons between axial capacities calculated by various predictive approaches and site measurements. The results confirm that the offshore industry-standard 'Main Text' American Petroleum Institute RP2GEO procedures are less reliable and have larger coefficients of variation than alternative cone penetration test (CPT) methods, among which the ICP (Imperial College piles) and UWA (University of Western Australia) procedures appear to give the least bias and scatter. It is also shown that the 'simplified' ICP variant proposed by some practitioners is over-conservative and that its use could be discontinued. The new pile capacity and stiffness database offers broad scope for evaluating potential prediction biases relating to a wide range of soil and pile parameters. The submission of further high-quality tests for inclusion in regularly updated versions of the ZJU-ICL database is encouraged.

KEYWORDS: design; full-scale tests; piles; sands

INTRODUCTION

Predicting the behaviour of piles driven in sand is an important industrial issue, particularly in offshore engineering where it can affect the practicality and economics of major oil, gas and wind energy projects. Axial capacity predictions are crucial to many applications, especially those involving offshore tension leg, tripod or jacket structures (e.g. Overy, 2007; Merritt *et al.*, 2012; Jardine, 2013). Foundation stiffness can also be important to both structural fatigue life and wind turbine operations. Database studies in which field measurements are compared with results from routine predictive calculations show that the latter's accuracy and reliability are often far lower than practitioners appreciate. For example, Briaud & Tucker (1988) demonstrated that conventional axial capacity calculations (Q_c) show considerable bias and scatter when predictions are compared to the capacities measured in careful field tests (Q_m).

Fundamental research with field Imperial College piles (ICPs) equipped with high-quality surface stress transducers carried out by Lehane *et al.* (1993) and Chow (1997) revealed that the routine methods fail to capture key aspects of the stress regime that develops around pile tips and shafts during penetration in sand. The tip stresses were found to correlate directly with local cone penetration test (CPT) resistances (q_c), as did the radial stresses (σ'_{rc}) set up on the pile shafts. The latter also reduced systematically, at any given depth (z) below ground level, as the pile tip advanced and the relative height above the tip ($h=z-z_{tip}$) increased. A weak dependence on the free-field vertical effective stress (σ'_{v0}) was also identified. Jardine *et al.* (2005) proposed functions that related σ'_{rc} to q_c, σ'_{v0} and h/R for closed-ended piles that only required slight modification (substituting an equivalent radius R^*) to be used for open-ended piles. The ICP experiments also showed that shaft loading generated local radial stress changes that varied with pile diameter and loading sense, while local shaft failure developed once a critical state interface shear angle was developed that could be predicted from laboratory tests and correlated with grain size and pile shaft roughness. Simple expressions were developed that captured the above shaft capacity phenomena and also pile end bearing capacity. Subsequent research has considered additional factors, including

- the influence of load cycles imposed during installation (White & Lehane, 2004; Jardine *et al.*, 2013a)
- time effects (Jardine *et al.*, 2006; Gavin *et al.*, 2013; Karlsrud *et al.*, 2014)
- how particle breakage under the tip and surface abrasion affect the stresses and the development of a well-defined interface shear zone (Yang *et al.*, 2010)
- the stress regime developed in the surrounding soil mass (Jardine *et al.*, 2009, 2013b)
- the influence of cyclic loading (Tsuha *et al.*, 2012).

Yang *et al.* (2014) and Zhang *et al.* (2014) have gone on to relate stress measurements from experimental investigations and numerical analyses by other workers.

New practical design tools were proposed from the work of Lehane *et al.* (1993) and Chow (1997), which evolved into the updated Imperial College (ICP-05) method detailed by Jardine *et al.* (2005). Other groups developed alternative approaches that recognised similar features of physical behaviour through alternative formulations. These include Fugro-05 (Kolk *et al.*, 2005), Norwegian

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Geotechnical Institute NGI-05 (Clausen *et al.*, 2005) and University of Western Australia UWA-05 (Lehane *et al.*, 2005). Rigorous database studies have become key tools to assess the potential efficacy of these new design procedures. Lehane & Jardine (1994), Chow (1997), Clausen *et al.* (2005), Jardine *et al.* (2005), Kolk *et al.* (2005) and Schneider *et al.* (2008) all assembled databases to test their new CPT-based design procedures in comparison with the offshore industry-standard 'Main Text' American Petroleum Institute RP2GEO (API, 2014) approach and its forebears. They found that the Main Text approach was subject to surprisingly high overall coefficients of variance (CoVs) in Q_c/Q_m (up to 0·88) when predicting compression capacity in sand and that the new procedures led to lower CoVs and less bias with respect to pile geometry (diameter (D) and L/D ratio (L = embedded length)), loading sense (tension or compression) and sand relative density (D_r). Williams *et al.* (1997), Jardine *et al.* (2005) and Overy (2007) reported case histories where the Main Text approach gave Q_c/Q_m values ranging from 0·4 to 2·9.

The current RP2GEO (API, 2014) acknowledges the limitations of its Main Text approach and the potential advantages of the new CPT methods. But it also notes industry's lack of experience with the new methods. Practitioners are uncertain as to which, if any, of the four methods they should adopt for routine application, and their assessments are made difficult by the general limitations of pile test databases and in particular a lack of high-quality tests on large piles in silica sands at sites that have been characterised to a high standard.

The most comprehensive sets appear to be those assembled by Chow (1997) and later updated by Jardine *et al.* (2005), termed here the ICP database, and that published by Schneider *et al.* (2008), which is here referred to as the UWA database. Taken together, these include over 100 different piles driven in silica sand and tested to failure. However, only 11 piles (from just three sites) were open-ended, had $D \geqslant 600$ mm and full CPT profiles. Further tests are required to augment this sparse dataset, obtain information from a wider range of international sites and gain further insight into uncertain factors such as the effects of layering on base resistance (Xu, 2006) and the effects of pile age on capacity (Jardine *et al.*, 2006; Gavin *et al.*, 2013; Karlsrud *et al.*, 2014).

The Zhejiang University/Imperial College London (ZJU-ICL) database project was initiated in 2011 to augment the internationally available open database of high-quality pile load tests and so allow design pile capacity and stiffness design methods to be tested and improved. This paper outlines how the database may be accessed, used and added to by other workers. It also describes the methodology adopted, the population of current entries and the digital reporting format, before describing some preliminary results obtained in comparisons of axial capacities calculated by various approaches and site measurements.

DATABASES FOR PILES DRIVEN IN SANDS

The starting point for the new ZJU-ICL was the ICP and UWA databases. The ICP set reported by Jardine *et al.* (2005) added a significant number of new case histories to those assembled by Lehane & Jardine (1994) and Chow (1997), and offered a total of 83 tests in sand. Schneider *et al.* (2008) augmented the ICP tests, adding 26 previously unrecognised entries. The UWA team also applied further quality filters, such as excluding any tests without full CPT profiles.

The ZJU-ICL database applies similar, but marginally more stringent, criteria as follows.

- All entries must be accompanied by an adequate site investigation, including a complete CPT profile from a close location, soil descriptions, information on groundwater levels and sand grain size distribution. Ideally, good measurements of in situ density and interface shearing angles should also be available. Only silica sand sites may be included.
- Complete information on driving method, pile embedment, diameter, tip end conditions, wall thickness and material must be provided. Ideally, the pile driving records and pile age after driving should also be available. The database is then divided into a main set with pile ages of 10–100 d, and a sub-set of tests conducted at both earlier and later ages. Tests for which

Table 1. General characteristics of the ICP, UWA and ZJU-ICL databases (pile age = 10–100 d)

	ICP database (2005)	UWA database	Total ZJU-ICL database
Total number of tests	64 + 19 = 83	77	115
New tests	83	26	47
Accepted new tests	37	41 (36 from ICP, plus 5 from UWA)	80 (37 from ICP, 5 UWA and 38 ZJU-ICL)
Pile types	Mainly driven, but with one vibro-driven and eight jacked	Only driven piles	Only driven piles
Pile shape	Circular, square and octagonal	Circular, square and octagonal	Circular, square and octagonal
Pile diameter: mm	200–2000	200–2000	200–2000
Pile length: m	5·3–46·7	5·3–79·1	5·3–79·1
Soil description	Mainly siliceous sands, carbonate contents less than 15%, shaft length in clay <40%	Pile tips bearing siliceous sand and siliceous sand contributes >50% of shaft capacity	Pile tips bearing a siliceous sand and siliceous sand contributes > 65% of shaft capacity
Load test	Static; base and shaft capacity separated individually	Static	Static
Failure criterion	If no clear peak indicated in compression, pile head displacement of 0·1*D* (outer diameter); failure in tension usually well defined	If no clear peak indicated in compression, pile head displacement of 0·1*D* (outer diameter); tension defined as maximum uplift load minus pile weight	If no clear peak indicated in compression, pile head displacement of 0·1*D* (outer diameter); tension defined as maximum uplift load minus pile weight
Age on testing	Pile tests conducted 0·5 to 200 d after driving. Average age after driving was 34 d. Time details reported in 74% of case records	Time between driving and load testing typically 0·5 to 200 d (average 24 d). Time details reported in 77% of the case records	Pile tests conducted 11 to 89 d, with an average of 35 d after driving. Time details reported in 50% of the case records

Table 2. New data entries in ZJU-ICL database (pile age = 10–100 d)

Test ID [a]	Site [b]	Pile no. [c]	Pile material [d]	Pile shape [e]	*B* or *D*: mm [f]	*t*: mm [g]	z_{tip}: m [h]	Water table depth: m [i]	Test type [j]	Age: d [k]	Max Q_{m}: MN [l]	*w*: mm [m]	0·1*D* Q_{m}: MN [n]	Clay contribution Q_{sc}: MN [o]	Average IFR (if available) [p]	Interface friction angle δ_{f} [q]	Source [r]
001	Rio de Janeiro	PI-1	C	C	500	—	37·2	2·7	C	64	3·59	51	3·59	0·05	—	Default value	Tsuha [s]
002	Rio de Janeiro	PI-2a	C	C	500	—	21·4	2·7	C	72	1·95	32	1·95	0·05	—	Default value	Tsuha [s]
003	Rio de Janeiro	PI-3	C	C	700	—	35·6	2·53	C	89	6·01	21	—[u]	0·05	—	Default value	Tsuha [s]
004	Rio de Janeiro	PI-4	C	C	500	—	26·5	2·42	C	86	4·55	82	4·53	0·04	—	Default value	Tsuha [s]
005	Hampton River	P1	C	S	610	—	16·8	0	C	12	3·1	20	3·10	—	—	Default value	Pando *et al.* (2003)
006	Apalachicola	BR 1	C	S	610	—	29·9	0	C	—	4·31	32	4·31	—	—	Default value	Mayne [t]
007	Los Angeles	CA	C	S	610	—	29	0	C	—	5·69	70	5·60	—	—	Default value	Mayne [t]
008	MS Smith	1045	C	S	410	—	10·2	0	C	—	1·96	10	1·96	—	—	Default value	Mayne [t]
009	MS Desota	2108	C	S	460	—	7·6	0	C	—	1·60	48	1·60	—	—	Default value	Mayne [t]
010	MS Harrison	3028	C	S	460	—	16·2	0	C	—	1·42	28	1·43	—	—	Default value	Mayne [t]
011	Washington	3118A	C	S	410	—	7·6	0	C	—	0·75	27	0·75	—	—	Default value	Mayne [t]
012	Washington	3123B	C	S	360	—	16·6	0	C	—	1·10	28	1·10	—	—	Default value	Mayne [t]
013	Washington	3142A	C	S	360	—	6·2	0	C	—	0·92	53	0·92	—	—	Default value	Mayne [t]
014	Waddinxveen	P1&P2	C	S	350	—	10	10	C	33	1·15	61	1·15	0·01	—	Default value	Hölscher (2009)
015	Rotterdam	P6	C	S	380	—	30·6	0	C	—	4·32	41	4·32	—	—	Default value	de Gijt *et al.* (1995)
016	Rotterdam	P8	C	S	380	—	30·3	0	C	—	4·65	50	4·65	—	—	Default value	de Gijt *et al.* (1995)

Table 2. Continued

Test ID [a]	Site [b]	Pile no. [c]	Pile material [d]	Pile shape [e]	B or D: mm [f]	t: mm [g]	z_{tip}: m [h]	Water table depth: m [i]	Test type [j]	Age: d [k]	Max Q_m: MN [l]	w: mm [m]	$0{\cdot}1D$ Q_m: MN [n]	Clay contribution Q_{sc}: MN [o]	Average IFR (if available) [p]	Interface friction angle δ_f [q]	Source [r]
017	Rotterdam	P10	C	S	380	—	30·7	0	C	—	4·33	39	4·33	—	—	Default value	de Gijt *et al.* (1995)
018	Columbia	P1	S	C	610	—	45	0	C	15	4·00	134	3·75	0·06	—	Default value	Naesgaard *et al.* (2012)
019	Wuhu	K24	C	C	600	130	39·8	0·72	C	14	4·80	86	4·40	0·23	0·74	Estimated by GSD	Yang *et al.* (2015)
020	Wuhu	K24	C	S	500	127	39·8	0·72	C	13	4·80	84·9	4·55	0·23	0·73	Estimated by GSD	Yang *et al.* (2015)
021	Wuhu	K34	C	C	600	130	29·3	1·1	C	15	5·40	85	4·90	0·07	0·82	Estimated by GSD	Yang *et al.* (2015)
022	Wuhu	K27	C	C	800	130	29·2	0·3	C	13	5·40	87	5·27	0·04	0·74	Estimated by GSD	Yang *et al.* (2015)
023	ABEF Foundation	7	C	C	500	90	9·0	42·6	C	—	3·2	66	3·14	—	0·73	Default value	Mayne [t]
024	ABEF Foundation	8	C	C	500	90	7·5	14·7	C	—	3·3	125	3·14	—	0·73	Default value	Mayne [t]
025	Mobile Bay	AL 1	S	C	324	25·4	15·2	0	C	—	1·25	24	1·25	—	0·71	Default value	Mayne [t]
026	Mobile Bay	AL 2	S	C	324	25·4	42·7	0	C	—	3·38	96	3·35	—	0·71	Default value	Mayne [t]
027	Dublin	S3	S	C	340	14	7	13	T	13	0·67	59	0·67	—	0·73	From ring shear test	Gavin *et al.* (2013)
028	Horstwalde	P2B	S	C	711	12·5	20·7	0	T	—	1·40	NA	1·40	—	0·86	Default value	Rücker *et al.* (2013)
029	Horstwalde	P2D	S	C	711	25	20·7	0	T	—	1·40	NA	1·40	—	0·85	Default value	Rücker *et al.* (2013)
030	Horstwalde	P5B	S	C	711	12·5	20·7	0	T	—	1·42	NA	1·42	—	0·86	Default value	Rücker *et al.* (2013)
031	Horstwalde	P5D	S	C	711	12·5	20·7	0	T	—	0·95	NA	0·95	—	0·86	Default value	Rücker *et al.* (2013)
032	Horstwalde	P4B	S	C	711	12·5	20·7	0	T	—	1·55	NA	1·55	—	0·86	Default value	Rücker *et al.* (2013)
033	Horstwalde	P4D	S	C	711	12·5	20·7	0	T	—	1·25	NA	1·25	—	0·86	Default value	Rücker *et al.* (2013)
034	Horstwalde	P3D	S	C	711	12·5	20·7	0	T	—	1·12	NA	1·12	—	0·86	Default value	Rücker *et al.* (2013)
035	Larvik site	L1	S	C	508	6·3	21·5	2	T	43	0·98	18	0·98	—	0·80	Default value	Karlsrud *et al.* (2014)

Table 2. Continued

Test ID [a]	Site [b]	Pile no. [c]	Pile material [d]	Pile shape [e]	B or D: mm [f]	t: mm [g]	z_{tip}: m [h]	Water table depth: m [i]	Test type [j]	Age: d [k]	Max Q_m: MN [l]	w: mm [m]	0·1D Q_m: MN [n]	Clay contribution Q_{sc}: MN [o]	Average IFR (if available) [p]	Interface friction angle δ_f [q]	Source [r]
036	Larvik site	L7	S	C	508	6·3	21·5	2	T	30	0·6	38	0·6	—	0·80	Default value	Karlsrud *et al.* (2014)
037	Jackson County	JCE	S	C	273	—	17·8	16	C	—	1·09	12	1·09	—	—	Default value	Mayne and Elhakim *et al.* (2002)
038	Lafayette BRG	PAT	S	C	356	—	20·3	5	C	54	2·23	20	2·23	—	—	Default value	Komurka and Grauvogl-Graham (2010)

[a] ID number for case in ZJU-ICL database
[b] Site name shown in source
[c] Pile ID number
[d] Material from which pile was made: C = concrete; S = steel
[e] Exterior shape of pile: C = circular; S = square
[f] Outer width of square pile or octagonal piles or diameter of circular piles
[g] Wall thickness for open-ended pile
[h] Tip depth of pile
[i] Depth to water table at time of driving
[j] Compression or tension test; C = compression; T = tension
[k] Time of load testing after pile driven
[l] Maximum load measured in pile load test
[m] Maximum displacement measured in pile load test
[n] Measured pile capacity at $w = 0{\cdot}10D$
[o] Predicted clay shaft capacity contribution
[p] Incremental filling ratio of open-ended pile
[q] Interface friction angle with default value of 29°; ideally obtained from ring shear test or estimated by grain size distribution (GSD) (Jardine *et al.*, 2005)
[r] Source of the pile load test information
[s] Private communication, C. H. C. Tsuha, 2012, Companhia siderúrgica do atlântico, Rio de Janeiro
[t] Private communication, P. W. Mayne, 2013, FHWA Deep Foundation Load Test Database (DFLTD)
[u] Not loaded to failure

Table 3. Summary of ZJU-ICL database (pile age = 10–100 d)

	Closed	Open	All
Number of piles	48	32	80
Steel	18	26	44
Concrete	30	6	36
Tension tests	8	16	24
Compression tests	40	16	56
Average length L: m	18·9	26·0	21·8
Range of L: m	6·18–45·00	5·3–79·1	5·3–79·1
Average diameter D: m	0·422	0·667	0·520
Range of D: m	0·2–0·7	0·324–2·000	0·2–2·0
Average density D_r: %	54	61	57
Range of D_r: %	31–89	30–87	30–89
Average test time after installation: d	43	28	35

the age is uncertain are assumed to fall in the usual range of 10–100 d.

- All entries must include records from high-quality (ideally load-controlled) first-time axial tests to failure, including load–displacement curves that continue until either peak loads or axial displacements have developed. Tests equipped with strain gauges and tension tests to failure are particularly valuable for isolating the shaft-to-base capacity splits from compression tests.

Applying the above filters to the baseline dataset led to 37 entries being adopted from the ICP database along with five additional cases from the UWA set. To date, the ZJU-ICL team has also assembled 38 further new test entries from the literature, their own projects (including four open-ended concrete piles with outer diameter ranging from 600 to 800 mm (Yang *et al.*, 2015)) and through acknowledged communication with other research groups worldwide. The new cases contribute a 90% increase in the total population of tests that meet the criteria outlined above. Table 1 summarises the characteristics of the ICP, UWA and ZJU-ICL databases, while Tables 2 and 3 give details of the new entries and characteristics of the combined ZJU-ICL database.

Ideally, test piles should be instrumented to allow the shaft load distributions to be defined and the base capacities isolated in compression tests. A good spread of tension tests is also desirable. All of the ICP database entries adopted involved either strain gauged piles or tension tests. However, only three of the five new entries from the UWA database and 14 of the 38 new ZJU-ICL cases (including tension tests) allow shaft and base capacities to be separated. The new database will be made available from a website hosted by Zhejiang University (http://mypage.zju.edu.cn/en/zxyang/682156.html) that is under construction and will be appearing in March 2015, with a hard copy version being published simultaneously by Zhejiang University and Elsevier Joint Press. Each case will be entered in the format similar to that adopted by Niazi (2014). An example entry from the authors' research at the Wuhu Yangtze River Bridge site in China (Yang *et al.*, 2015) is given in the Appendix.

Figure 1 illustrates the geographical distribution of the new combined dataset, which increases the number of countries considered from 10 to 13. The ZJU-ICL team will update the database periodically and the authors welcome the submission of any new test entries that meet the above criteria and data quality levels illustrated in the Appendix. All such entries will be acknowledged fully and will increase the value of this inclusive and freely available international research resource.

PRELIMINARY FINDINGS

The remainder of this paper outlines some preliminary findings from the database. Far more detailed studies

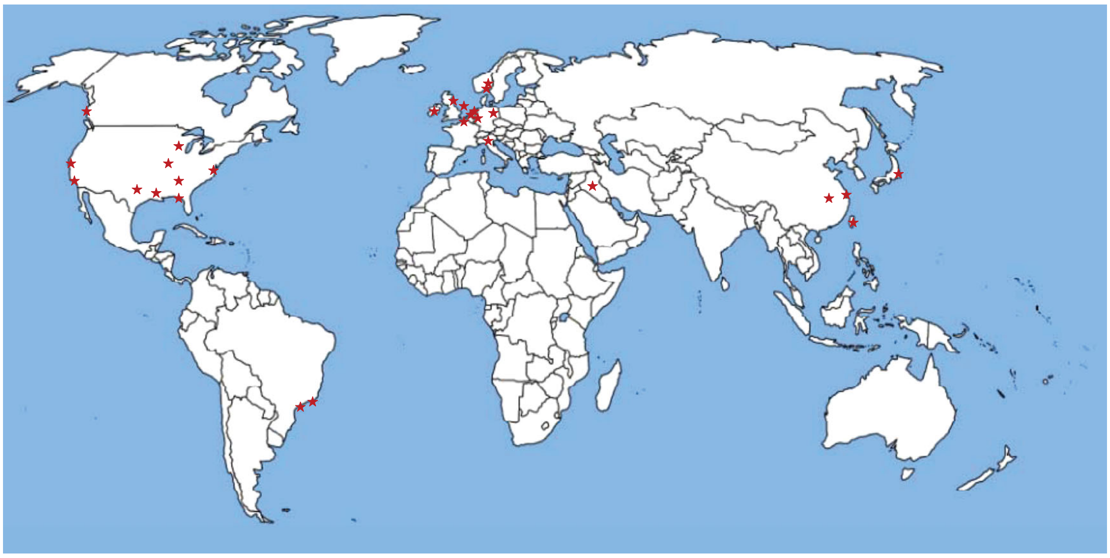

Fig. 1. Geographical distribution of ZJU-ICL database

Table 4. Summary of statistics (mean $\mu \pm$CoV) of API and CPT methods (pile age = 10–100 d)

Database	ICP-05		UWA-05		Fugro-05	NGI-05	API
	Full	Simplified	Full	Offshore			
ICP	0·97±0·35	0·69±0·38	1·00±0·32	0·84±0·38	1·11±0·41	1·16±0·50	0·87±0·66
UWA	0·96±0·33	0·69±0·37	1·00±0·32	0·85±0·38	1·12±0·41	1·19±0·49	0·87±0·63
New ZJU-ICL data	0·96±0·22	0·72±0·30	1·12±0·32	0·96±0·41	1·32±0·46	1·27±0·44	0·93±0·43
Total ZJU-ICL data	0·96±0·28	0·70±0·34	1·05±0·32	0·90±0·40	1·21±0·45	1·23±0·47	0·90±0·55

remain to be made by the authors and other workers regarding axial capacity and stiffness behaviour. Here, only some broad checks are offered on the overall predictive performance of the Main Text API method and the four cited CPT-based approaches, considering for the UWA and ICP procedures both the 'full' versions and the 'offshore' and 'simplified' formulations listed by API RP2GEO. The latter procedures are included in the API GEO commentary section, but do not appear to have been tested systematically in earlier database studies. Q_c/Q_m ratios were established for each database entry for the capacities calculated by each method and that measured. Simple arithmetic statistical means (μ) and CoVs are presented. Noting that some methods employ relative density (D_r) values for parts of their calculations, the latter were derived from the CPT q_c relationship given by Jamiolkowski *et al.* (2003)

$$D_r = 0{\cdot}35 \ln(q_{c1N}/20) \qquad (1)$$

where $q_{c1N} = (q_c/p_A)/(\sigma'_{v0}/p_A)^{1/2}$, p_A = 100 kPa.

The cases adopted from the ICP and UWA databases outlined above were recalculated to ensure that the calculations for each case are as consistent as possible, adopting more refined CPT q_c values and calculation resolution where possible. This step also provided a means of checking the results obtained and eliminating any errors.

Table 4 compares the preliminary statistical summary, listing mean and CoV Q_c/Q_m values of the API Main Text and CPT methods, considering the ICP, UWA, new ZJU-ICL data entries and the combined ZJU-ICL datasets. Inspecting the results obtained with seven methods and four databases shows the following broad trends.

- Broad agreement with the trends reported by Jardine *et al.* (2005) and Schneider *et al.* (2008).
- The 'simplified' ICP and 'offshore' UWA methods give lower mean values μ and larger CoVs than their 'full' versions. The authors suggest that there is no benefit in applying the simplified ICP approach in place of the full version as it gives an unnecessarily conservative μ and a larger CoV. However, the 'full' UWA version appears marginally non-conservative and the UWA 'offshore' method may be preferable, despite its higher CoV.
- The mean Q_c/Q_m values range from 0·69 to 1·32 over all the cases covered and the CoVs from 0·22 to 0·66, with the Main Text API method giving consistently higher CoVs than the CPT approaches.
- The 'full' UWA and ICP methods give lower CoVs (0·22 to 0·35) than the other CPT approaches (0·41 to 0·50) and mean Q_c/Q_m values close to unity.

SUMMARY AND CONCLUSIONS

This paper reviews the background for developing high-quality pile test databases and shows that there is a critical need to develop such resources for driven piles. The characteristics of two leading datasets were considered before outlining the Zhejiang University/Imperial College London (ZJU-ICL) database, reporting how it was assembled and describing how it may be accessed by other workers. The paper also sets out the key quality parameters adopted, the population of current entries and the reporting format. Preliminary results obtained from comparisons of axial capacities calculated by various approaches and site measurements confirm key points identified in earlier ICP and UWA studies.

- The existing Main Text API procedures are subject to far larger predictive CoVs than the alternative CPT methods.
- The UWA and ICP procedures appear to offer the least scatter and little bias in predictions for the axial capacities of the piles included in the current ZJU-ICL database.

A new point to emerge is that the 'simplified' ICP variant is over-conservative in the cases considered. It is thus recommend that future onshore and offshore applications should adopt the 'full' formulation set out by Jardine *et al.* (2005), as in the multiple offshore projects reported by Overy (2007).

The new database adds significantly (by 90%) to the population of high-quality pile load tests that meet the criteria set to test capacity and stiffness design methods. This resource offers scope for evaluating potential prediction biases relating to a wide range of soil and pile parameters. Colleagues are encouraged to consider submitting further high-quality tests for inclusion into the database so that the value of this freely accessible research resource can continue to grow.

APPENDIX

See Figure A.1 for an example of one data entry in the ZJU-ICL database, which will be released with a web-based version and in print.

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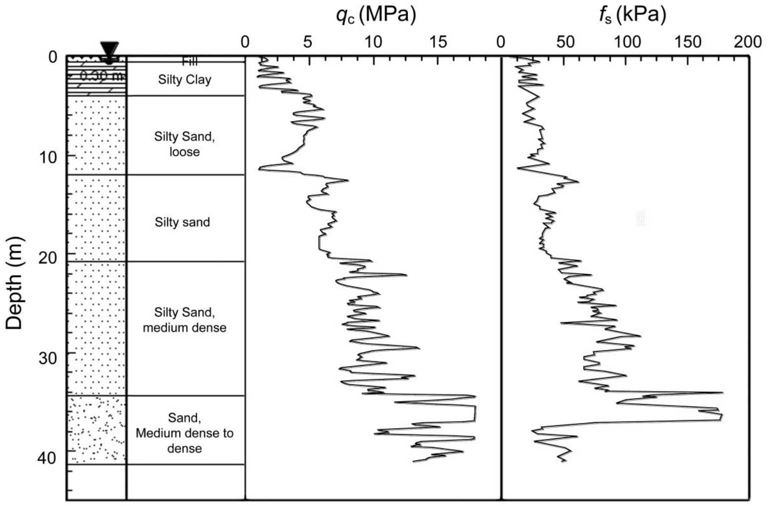
Site ID No. 3: K27, Wuhu, China

Cone penetrometer data	Detail	Description
	Site name and location	Wuhu Second Bridge over the Yangtze River Test site: K27
	Soil type(s)	Silty sand and fine sand
	Water table depth (m)	0.3
	Pile type(s)	Pre-cast Hollow Concrete (PHC)
	Type of cone penetrometer testing	Electric CPT
	Number of pile load tests	1, with 3 others at other locations
	Comments	The q_c profile has one straight line segments of 1 to 2m length where qc exceeds the 18 MPa capacity of the CPT deployed. These sections are considered as q_c = 18 MPa in the analysis performed. Interface friction angle estimated with GSD, and soil unit weight applies default value.

Pile ID: Wuhu K27-1

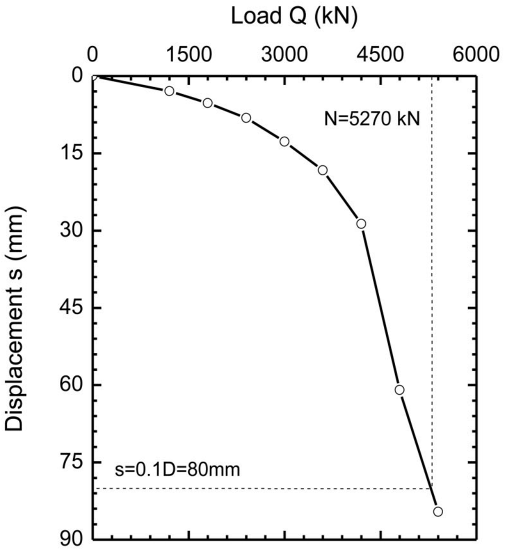
Load-displacement data	Detail	Description
	Pile type/material	Open-ended concrete pile
	Length, L (m)	29.2
	Outer diameter, D (mm)	800
	Wall thickness, t (mm)	130
	Installation method	Driven
	Set up time, days	13
	$Q_{max\text{-}measured}$ (kN)	5400
	Q_m (kN)	5270
	Q_s (kN)	Not isolated
	Q_b (kN)	Not isolated
	API Q_c (kN)	3607
	Q_c/Q_m	0.68
	UWA Q_c (kN)	4536
	Q_c/Q_m	0.86
	ICP Q_c (kN)	5053
	Q_c/Q_m	0.96
	Fugro Q_c (kN)	6006
	Q_c/Q_m	1.14
	NGI Q_c (kN)	4282
	Q_c/Q_m	0.81

Fig. A.1. An example description of test site and pile load test (Yang *et al*., 2015)

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