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The ground: clients remain exposed to unnecessary risk

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The ground remains the greatest source of risk to construction projects. In spite of a wealth of freely available information and guidance on the central importance of adequate site investigation in managing ground risk, many clients remain unnecessarily exposed to risk due to inadequate site investigation. The Federation of Piling Specialists undertook a comprehensive survey of geotechnical designers within its membership to evaluate the usefulness of site investigation information routinely provided to them. For nearly a third of all the piling and specialist geotechnical contracts surveyed, the site investigation information provided was poor, preventing optimisation of the foundation solution. The cost to clients arising out of poor site investigations far exceeds the savings that could be made by following good practice when investing in a site investigation. The survey indicates that good practice guidance is not being followed, resulting in investigations that are not adequately designed, specified or supervised.

1. INTRODUCTION

All construction projects have temporary and permanent works built on or in the ground, and it is well known that the ground usually presents the greatest risk to a construction project.[1] Comprehensive studies[1,2] undertaken in the 1980s and early 1990s demonstrated the scale and cost of ground-related problems affecting highway, industrial, commercial and housing projects. Alhalaby and Whyte[3] published quantative data on the additional costs that could have been avoided by adequate and full site investigation. Ashton and Gidado[4] surveyed construction professionals and found that over 56% of respondents reported major difficulties when carrying out substructure works, solely as a result of inadequate site investigation procedures. BRE Digest 472, *Optimising Ground Investigation*,[5] stated that ground investigation practice had changed little since the 1980s. This is in spite of the wealth of published guidance relating to site investigation best practice, and the penalties affecting projects that proceed on the basis of poor ground information. Looking to the future, the Eurocodes are set to take precedence as design standards, and Eurocode 7[6] recognises the crucial importance of the quality of ground investigation information, stating that

> Knowledge of the ground conditions depends on the extent and quality of the geotechnical investigations. Such knowledge and the control of workmanship are usually more significant to fulfilling the fundamental requirements than is precision in the calculation models and partial factors.

This paper presents the results of a comprehensive survey undertaken by members of the Federation of Piling Specialists (FPS) to evaluate the usefulness of site investigation information routinely provided to them.

The FPS membership comprises 18 piling and specialist geotechnical contractors who between them carry out approximately 80% by value of UK piling and specialist geotechnical contracts. This survey therefore constitutes a substantive stocktake of the effectiveness of the site investigation process.

2. THE SURVEY

Between July and September 2006 members of the FPS were invited to complete a questionnaire designed to evaluate the adequacy of site investigation information received for piling and specialist geotechnical contracts. The questionnaires were completed at the time of contract award by the designers responsible for the geotechnical design.

The survey required respondents to provide details of the type of geotechnical product or process, and the value of the geotechnical works, as summarised below.

(*a*) Product type/process, under the broad headings of piling, ground improvement and other geotechnical processes (the categories of geotechnical product and processes used in this paper are described in Table 1).
(*b*) Market sector, categorised as housing, private industrial, private commercial and public non-housing.
(*c*) Details of reports received: factual, interpretative or other reports.
(*d*) Investigation techniques used, and their usefulness in relation to the foundation solution required.
(*e*) The adequacy of the investigations undertaken, and their coverage of the proposed development with regard to plan area, depth and sampling and testing of the ground.
(*f*) Questions on the provision of basic data and the general adequacy of the information provided.
(*g*) An overall rating of the information received, from the perspective of an end user/designer.

Space for general comment was also provided.

Geotechnical process/product categories	Description
Piling	Includes driven, CFA, bored and sheet piling. Bearing piles and embedded retaining walls
Ground improvement	Includes vibro replacement stone columns, vibro compaction, vibro concrete columns and dynamic compaction
Other	Includes any geotechnical product or process not covered by piling and ground improvement: e.g. grouting, soil nailing, ground anchors and slope stabilisation

Table 1. Geotechnical process/product categories

To preserve commercial and contractual confidentiality the project name or details of the FPS member were not recorded. This was to encourage candid and open responses to the questionnaire.

In total, 221 responses (29% of all contracts awarded to FPS members over the survey period) were received, as shown in Figs 1 and 2 by type of geotechnical product and contract value. (Table 2 shows a detailed breakdown of the data by type of contract, the value of geotechnical work, and the market sector in which the work was undertaken.)

The overall evaluation of the survey data will first be discussed, before considering the detailed messages communicated by the survey responses.

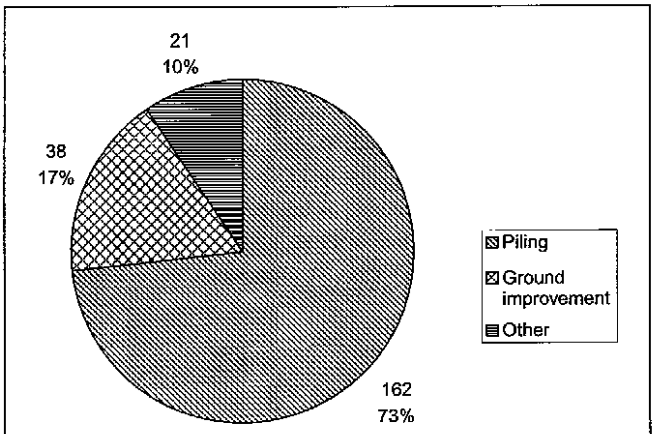

Fig. 1. Summary of questionnaire responses by geotechnical product

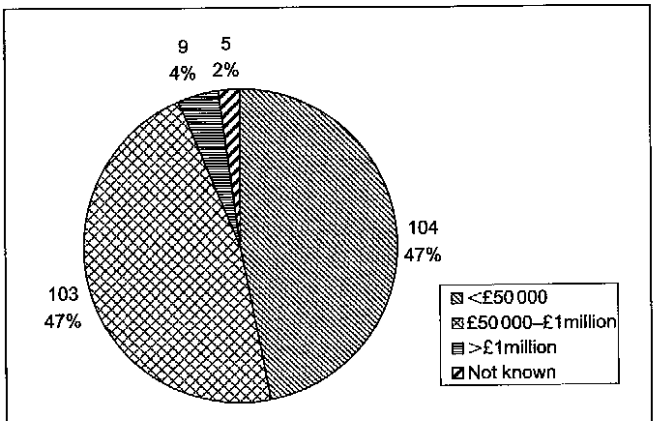

Fig. 2. Summary of questionnaire responses by contract value

3. OVERALL EVALUATION

The results to the specific question 'Overall, how do you as the end user, rate the investigation?' are shown in Fig. 3. (Table 3 breaks down the data further by market sector.) The data show the following trends.

(*a*) Overall, in 42% of projects the site investigation information was considered satisfactory, 27% was poor or very poor, and 31% good or very good.
(*b*) In general the housing market had the poorest standard of investigation, with 35% of cases being judged poor or very poor and only 20% good or very good, the remaining 45% being satisfactory.
(*c*) Private commercial projects fared slightly better, with 28% marked poor or very poor but 36% marked good or very good.
(*d*) Public non-housing and private industrial projects had better information with, respectively, 18% and 14% marked poor or very poor and 35% and 38% marked good or very good.

The same data are considered by the value of the geotechnical work in Table 4. A very clear trend of improving quality with increasing value of geotechnical work is evident. Although relatively small in number, projects with a value of over £1 million had significantly better information provided than smaller projects. The exception was the one project worth more than £1 million that was undertaken in the housing sector, where the information was judged to be poor.

3.1. Summary by value and market sector

It appears that the lower the value of the geotechnical works, the poorer the site investigation information is likely to be. When considering market sector, housing and private commercial schemes were most likely to have the poorest information.

4. USEFULNESS OF INVESTIGATION TECHNIQUES

The usefulness of various different investigation techniques was compared in the survey.

Tables 5 and 6 show how the various techniques were rated across all projects surveyed. For many projects a number of different investigation, sampling and testing methods were adopted.

4.1. Cable percussion boreholes and rotary boreholes

Boreholes may be undertaken for different purposes. However, for the geotechnical designer their main purpose is to allow a description of the ground to be made, and to facilitate in situ

Geotechnical product	Market sector	Value of geotechnical work				Total
		<£50 000	£50 000–£1 million	>£1 million	Not known	
Piling	Housing	29	21	1	1	52
	Private commercial	21	17	3	1	42
	Private industrial	3	9	1	1	14
	Public non-housing	11	9	–	–	20
	Not known	7	24	2	1	34
	Subtotal	71	80	7	4	162
Ground improvement	Housing	5	5	–	–	10
	Private commercial	5	–	–	–	5
	Private industrial	12	2	–	–	14
	Public non-housing	7	1	–	–	8
	Not known	–	1	–	–	1
	Subtotal	29	9	–	–	38
Other	Housing	1	2	–	–	3
	Private commercial	2	6	1	–	9
	Private industrial	–	1	–	–	1
	Public non-housing	1	5	1	–	7
	Not known	–	–	–	1	1
	Subtotal	4	14	2	–	21
	Total	104	103	9	5	221

Table 2. Summary of responses to FPS ground investigation survey

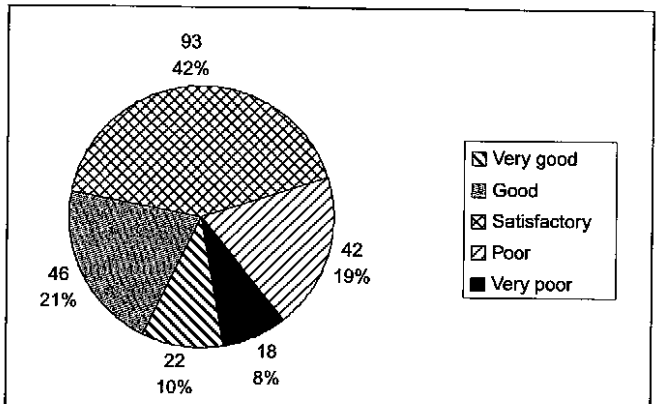

Fig. 3. Overall rating of investigation information

testing and the collection of samples for laboratory testing. Geotechnical design parameters are then derived using the test data, and with reference to the description of the ground profile. Cable percussion and rotary boreholes were carried out most often, and were judged to be very useful or useful in 95% and 85% of cases where they were provided. This result is of little surprise, as the use of boreholes is well established, and they provide (if done with adequate care) a well-understood technique for collecting information.

4.2. Cone penetration testing

The data relating to cone penetration testing present a curious picture, with only 19 out of 221 projects recording its use. The collective view of designers completing the survey regarding the usefulness of the cone penetration test (CPT) was ambivalent, with 47% of respondents judging it of little use and 53% useful or very useful. Possible reasons for the low rating of the CPT are advanced below.

(*a*) There is a reluctance to use this test because of the perceived lack of experience in the UK of the use of cone test results in design.

(*b*) UK pile design practice relies heavily on the SPT. Some designers may choose to ignore the CPT in design if they have SPT information.

(*c*) The output traces from CPT tests are more complex to evaluate than numerical data (SPT, undrained shear strength and unconfined compression strength, etc.) presented at discrete locations in a borehole. The greater

Market sector	Very good		Good		Satisfactory		Poor		Very poor	
	No.	% of market sector	No.	% of market sector	No.	% of market sector	No.	% of market sector	No.	% of market sector
Housing	3	4·6	10	15·4	29	44·6	17	26·2	6	9·2
Private commercial	8	14·0	13	22·8	20	35·1	12	21·1	4	7·0
Private industrial	3	10·3	8	27·6	14	48·3	4	13·8	0	0·0
Public non-housing	4	11·7	8	23·5	16	47·0	2	5·9	4	11·7
Not known	4	11·1	8	19·4	14	38·9	7	19·4	4	11·1
Total	22	10·0	46	20·8	93	42·1	42	19·0	18	8·1

Table 3. Respondents' overall rating of investigation information received for projects awarded by market sector

Value	Very good		Good		Satisfactory		Poor		Very poor	
	No.	% of market sector	No.	% of market sector	No.	% of market sector	No.	% of market sector	No.	% of market sector
<£50 000	8	7·7	23	22·1	44	42·3	18	17·3	11	10·6
£50 000–£1 million	10	9·7	20	19·4	46	44·7	21	20·4	6	5·8
>£1 million	4	44·4	3	33·3	1	11·1	1	11·1	–	0·0
Not known	–	0·0	–	0·0	2	40·0	2	40·0	1	20·0
Percentage of all GI	22	10·0	46	20·8	93	42·1	42	19·0	18	8·1

Table 4. Respondents' overall rating of investigation information received for projects awarded by contract value

Geotechnical product	Investigation technique	Very useful	Useful	Little use	No use	Total
Piling	Cable percussion	43	78	5	0	*126*
	Rotary	15	39	2	5	*61*
	Sub total	*58*	*117*	7	*5*	*187*
	CPT	3	4	8	0	*15*
	Trial pit	1	26	48	16	*91*
	Window sample	0	8	25	5	*38*
	Dynamic probe	0	6	11	1	*18*
	Geophysical	0	4	14	0	*18*
Ground improvement	Cable percussion	17	9	3	0	*29*
	Rotary	0	3	4	0	*7*
	Sub total	*17*	*12*	7	*0*	*36*
	CPT	1	1	0	0	*2*
	Trial pit	13	11	3	0	*27*
	Window sample	2	13	0	0	*15*
	Dynamic probe	1	1	0	0	*2*
	Geophysical	0	0	0	0	*0*
Other	Cable percussion	4	6	0	0	*10*
	Rotary	1	3	0	0	*4*
	Sub total	*5*	*9*	*0*	*0*	*14*
	CPT	0	1	1	0	*2*
	Trial pit	0	4	1	0	*5*
	Window sample	0	1	0	0	*1*
	Dynamic probe	0	0	0	0	*0*
	Geophysical	0	1	0	0	*1*

Table 5. The usefulness of investigation technique, shown by geotechnical product

time and effort required to evaluate and use CPT data, compared with, say, SPTs, becomes a barrier outweighing the benefits. A common approach is to correlate the CPT data to equivalent SPT values, which are then correlated to the relevant pile design parameters. This seems a backward step, going from carefully acquired cone and sleeve resistance through two sets of correlations to get to the required pile design parameters. For the reasons discussed above, this may be expedient but may militate against the wider acceptance of the CPT in UK practice.

4.3. Trial pits

Trial pits proved popular, although slightly less so than cable percussion boreholes, with 123 incidences of their use recorded.

At face value, the survey respondents were ambivalent about trial pits, with 44% finding them useful or very useful and 55% finding them of little or no use. Table 6 shows the survey responses broken down by the different investigation techniques used and geotechnical product categories, and expressed as a percentage. Trial pits were considered to be of much less use for piling projects (71% of little or no use) compared with ground improvement projects (89% useful or very useful). This is not surprising, given the depth limitation of trial pits compared with the usual pile length. On the other hand, ground improvement is usually (although not exclusively) implemented to treat near-surface soils, which can be effectively investigated by trial pits.

In spite of the obvious limitations of trial pits for pile design, their importance in providing data on near-surface soils, crucial for temporary works (platform design), should not be overlooked.

4.4. Lightweight investigation techniques

Over the whole number of projects, window samples were provided on 54 projects (24%) and dynamic probes on 20 projects (9%). Across all of the geotechnical products, window sampling data and dynamic probing data were found very useful or useful for 45% and 40% of the time respectively. However, these lightweight (and comparatively cheap)

Geotechnical product	Investigation technique	Very useful	Useful	Little use	No use
Piling	Cable percussion	34	62	4	0
	Rotary	25	64	3	8
	Sub total	31	63	4	3
	CPT	20	27	53	0
	Trial pit	1	29	53	18
	Window sample	0	21	66	13
	Dynamic probe	0	33	61	6
	Geophysical	0	22	78	0
Ground improvement	Cable percussion	59	31	10	0
	Rotary	0	43	57	0
	Sub total	47	33	19	0
	CPT	50	50	0	0
	Trial pit	48	41	11	0
	Window sample	13	87	0	0
	Dynamic probe	50	50	0	0
	Geophysical	0	0	0	0
Other	Cable percussion	40	60	0	0
	Rotary	25	75	0	0
	Sub total	36	64	0	0
	CPT	0	50	50	0
	Trial pit	0	80	20	0
	Window sample	0	100	0	0
	Dynamic probe	0	0	0	0
	Geophysical	0	100	0	0

Table 6. The usefulness of investigation technique, expressed as a percentage of contracts where the technique was used

investigation techniques were considered much less useful for pile design.

This reinforces the point that specifiers of ground investigation must be aware of the advantages and limitations of investigation techniques relevant to the foundation solution likely to be adopted for the project.

4.5. Geophysical investigation

Respondents were asked to comment on the provision of geophysical investigations. They were undertaken on only 19 out of the 221 projects reported, and were considered to be of little use in 74% of cases. Whatever the merits of geophysical investigation techniques, their popularity in terms of provision and acceptance by those in the FPS who design geotechnical products was limited.

4.6. Summary of usefulness of investigation techniques

For pile design, boreholes should always be provided, by cable percussion in soils and rotary coring in rock. Dynamic probing, window sampling and trial pitting, although provided to varying extents, were of little use in pile design.

For ground improvement contracts, window sampling and trial pits may supplement boreholes to good effect. However, deep boreholes should also be provided to confirm ground conditions below probable treatment depths.

Cone penetration tests, although cost-effective, were undertaken relatively infrequently. At present the use of cone data in foundation design within the FPS membership appears limited.

Whatever foundation solution is being proposed, the site investigation information acquired must consider the needs of the temporary and permanent works designer. In particular, pertinent data on the near-surface ground conditions must be provided where a temporary working platform is required.

5. COVERAGE OF INVESTIGATION

Progressing from questions about the investigation techniques used, the survey also asked questions to find out how well site investigations covered the proposed plan area of the development, and whether they were undertaken to adequate depth.

It was clear from the responses that the requirements set out in published guidance was routinely ignored.

(*a*) There were frequently insufficient boreholes, or boreholes that did not go deep enough.
(*b*) In many cases, adequate in situ and laboratory testing was not available to enable the optimum selection of design parameters.

Basic information was also frequently missing, as indicated by the response to the questions shown in Table 7.

(*a*) In 16% of cases there was no borehole location plan, rendering virtually useless any other borehole information provided.
(*b*) In 73% of cases boreholes were not levelled, and in 59% of cases adequate topographical information was not provided.
(*c*) Only 17% of investigation holes had coordinates provided.
(*d*) In 25% of projects the information did not allow the adequate derivation of design parameters. In such cases, designers presumably had to make assumptions—hopefully conservative.
(*e*) The provision of best-value foundation solutions must be

Survey question	Yes		No	
	No.	% of Responses	No.	% of Responses
Was there a borehole location plan?	185	84	36	16
Were the investigation holes levelled?	60	27	161	73
Was there adequate topographical information?	90	41	131	59
Was there enough information to adequately derive design parameters?	165	75	56	25
Does the information provided allow optimum judgement of ground conditions?	116	52	105	48
Was the balance between the environmental and geotechnical information right?	100	45	121	55

Table 7. Measure of the provision of basic data supplied with ground investigation information

based on optimisation of the geotechnical solution based on careful evaluation of the performance or load-carrying capability of the ground. In 48% of cases respondents did not think the information provided enabled optimum judgement of ground conditions to be made. This implies that nearly half of the time clients were not benefiting from optimum foundation solutions being provided for their schemes.

(*f*) In recent years the size of site investigation reports has grown to incorporate test data to satisfy statutory and environmental requirements. In contrast, the quality of information necessary for cost-effective geotechnical design has not improved, and has even deteriorated in the face of the increased environmental effort. Respondents to the survey judged the balance between the environmental and geotechnical elements of reports to be wrong in 55% of cases. Many clients will be unaware of this subtle, but potentially costly, trend.

6. PROVISION OF SITE INVESTIGATION DATA

Out of the 221 projects considered in the survey, a factual report was not received in 32 cases (14%), raising the question of the level of risk inherent in these projects, which at face value proceeded without even basic site-specific information.

It is possible to speculate on a wide variety of scenarios to explain why the 32 projects appeared to proceed in this way. Perhaps the contracts were additional work on sites where information was already in the hands of the piling contractor. Possibly the site was adjacent to other sites worked on, and believed to be underlain by 'well known' conditions. Whatever the reason, this behaviour runs the risks of propagating the message to clients that their sites do not all need site-specific investigation. This is at complete odds with published guidance. In defence of this situation it is probable that there are projects where the piling contractors know what they are doing, and are managing the risk (and getting paid for doing so) in other ways.

7. DATA FORMAT

Site investigation data may be disseminated in one of three main formats

(*a*) hard copies of reports
(*b*) electronically scanned copies of reports (typically in pdf format)
(*c*) AGS data files.

Of the 189 factual reports and 77 interpretative reports received, the majority were received as 'hard copy' (88%), with only 41 (15%) in electronic scanned format. Very surprisingly, no one reported receiving data in AGS format.

The reported benefits of using the AGS data transfer format are clearly not being realised by piling contractors. It is beyond the scope of this paper to consider why this is the case. However, the cost of data-handling software and the expense of maintaining trained users appear to present significant barriers at present.

8. DISCUSSION

It is clear from the survey that for a significant proportion of projects (approximately 30%) the site investigation information provided to piling and specialist geotechnical contractors was, in some significant way, inadequate. As a consequence, clients are exposed to unmanaged ground risk, and are unlikely to be getting the most cost-effective foundation solution appropriate for the prevailing ground conditions and proposed development. It is beyond the scope of this paper to quantify the overall cost to the construction industry of this parlous state of affairs. It is, however, smaller projects (implying a large number of clients) that are exposed to the greatest risk.

There are a wide range of opinions within the geotechnical community as to the exact causes of the problem of poor site investigation, but very little published quantative data to support them. The following factors are, however, frequently attributed as reasons for poor site investigation.

Procurement of site investigation purely on price. This is often associated with a poor or absent specification for the investigatory work, allowing investigation contractors to undercut each other on the basis of what they will leave out (levelling and coordination of boreholes, site supervision and desk study etc.). Approximately half of the investigations reported in the Association of Geotechnical and Geoenvironmental Specialists' (AGS) benchmarking exercise undertaken in 2006/2007 were less than £20 000.[7] The margin separating competing contractors' tender prices may be less than £1000, and can be the difference between including or omitting a significant activity in the investigation. Frequently, the need for the phasing of site investigation is not understood by clients or their advisers. The criteria for an adequate investigation to fulfil the client's needs at the time of a speculative land deal are different from those required for detailed foundation design, and this must be recognised.

There is ample anecdotal evidence that the majority of site

investigations are procured by non-geotechnical specialists, who are not conversant with the needs of the geotechnical process. This leads to poor or absent scoping of investigations in tender enquiries sent to investigation contractors. When the subsequent tenders are awarded on the basis of price, rather than value, the recipe for disaster is complete. Overemphasis on the environmental element of an investigation at the expense of the geotechnical requirements serves to exacerbate the situation. In the survey, 55% of respondents felt there was an overemphasis on the environmental aspects, to the detriment of geotechnical information. Are clients aware of these deficiencies, and the cost implications flowing from them?

9. ADDING VALUE TO THE STATUS QUO

It is clear from the FPS survey that the status quo regarding the provision of site investigation information is unsatisfactory, in spite of there being a wealth of good guidance on the topic. There clearly exists a difficulty in getting across to clients and their principal advisers the message of how important adequate site investigation is in managing ground risks .

The problem is not new, and it appears that the initiatives promoted by the geotechnical community to educate and inform clients of the crucial importance of adequate site investigation information in managing ground risks have had limited impact in most market sectors.

It is not the purpose of this paper to consider how the status quo can be improved, but it is hoped that, by attempting to measure the usefulness of site investigation information routinely provided to a significant group of end users, quantitative evidence to the current state of affairs will be useful in future initiatives.

10. CONCLUSIONS

It is nearly 15 years since the *Site Investigation in Construction* series of documents were produced.[8] These outlined the critical importance of undertaking adequate site investigation in order to manage the ground risks inherent in all construction projects. The documents also provided best-practice guidance on the planning, specification and procurement of investigations.

In spite of this wealth of best practice guidance, many clients are not reaping the benefits of adequate investigation of the ground in reducing the risk of unforeseen conditions or inappropriate overdesign of foundations. It is questionable whether the implementation of the Eurocodes will alter the current situation.

It is concluded that, in a third of projects, the site investigation information provided hampers selection of the optimum foundation solution. The costs to clients of inefficient design, or the disruption caused by unforeseen ground conditions arising out of inadequate investigations, far outweigh the apparent additional cost of undertaking a well-thought-out and competent investigation in the first place.

The warning sounded by Littlejohn *et al.*[2] in 1994 remains valid, and is worth repeating.

> Now and in the future, it is vital that financial decision-makers appreciate that you pay for a site investigation whether you have one or not, and you are likely to pay considerably more if you do not, or if it is inadequately designed, executed or interpreted.

ACKNOWLEDGEMENTS

The author recognises that this paper could not have been produced without the willing participation of the many unnamed respondents to the survey, and their effort is acknowledged. The work reported in this paper was undertaken on behalf of the Federation of Piling Specialists, and the comment and helpful advice received by many industry colleagues, without whom this paper would not have been produced, is also appreciated.

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