THE PRACTICAL APPLICATION OF A SITE INVESTIGATION RISK EVALUATION SYSTEM

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Geotechnical data gathered during the design phase of a typical UK construction contract is often made available to bidders, but, with a disclaimer absolving them from risk associated with inadequate or misinterpreted information. Contractors with neither the time nor the expertise to fully appreciate the implications of such data incur substantial difficulties. New guidelines and technical reports, such as the Geotechnical Baseline Report for Underground Construction (Essex 1997), are currently being used on some large infrastructure projects, however, this research aimed to address the problems caused to SME's resulting from an inappropriate allocation of sub-structural risk. A Site Investigation Risk Evaluation System (SIRES) has been developed in order to improve site investigation procedures, thereby, reducing and identifying the risk associated with uncertain site conditions. The SIRES has been used during the site appraisal, design and construction phases on four construction projects, in South East of England. The findings from this research provide overwhelming evidence endorsing the application of SIRES as a means to objectively measure the level of risk associated with inadequate site appraisal data.

Keywords: SME's, case studies, risk management, site appraisal procedures.

INTRODUCTION

Whilst 'expert' sources, such as BS5930 (1999) (formally 1981) Code of Practice for Site Investigations, provide a literary base for current site and ground investigative procedures, their use to determine the adequacy of site investigative work, needed to satisfy design requirements, have been identified as failing clients of the construction industry.

The impact of computer technology in the 1980's increased the capability of risk analysis and management, none more so than CASPAR (Willmer 1988). Most systems emulate a basic risk management exercise, following three stages; Risk Identification, Risk Analysis and Risk Response (Hayes *et al.* 1987: 8). These three stages used tools and techniques to form a systematic approach to assist the effective management of an increasingly complex construction process. However, the underlying trend identified by the thirty-five case studies used within this research, signify that despite these new technologies and state-of-the-art site investigative tools, the failure to implement an effective risk management system during the Site Investigation (SI) process, led to uncertain site and ground conditions and an increase in risk exposure.

Despite the level of sophistication available for the determination of risk and uncertainty associated with ground work operations, this research identified that over

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80% of contractors had sought redress, in one form or another, for difficulties faced during sub-structure work as a direct consequence of inadequate SI information (Ashton 1996: 160). This work subscribes to the ethos that "risk exists as a consequence of uncertainty" (Perry and Hayes 1985: 42-45) and in order to reduce the risk, uncertainty must be reduced or eliminated.

RELEVANT LITERATURE AND NEED FOR THE RESEARCH

Many sub-structural related problems seems to hinge on lack of reliable information and until clients are made aware of the economic risk that uncertain ground conditions pose, clients will remain unwilling to commit adequate funds at the appropriate time for this vital work.

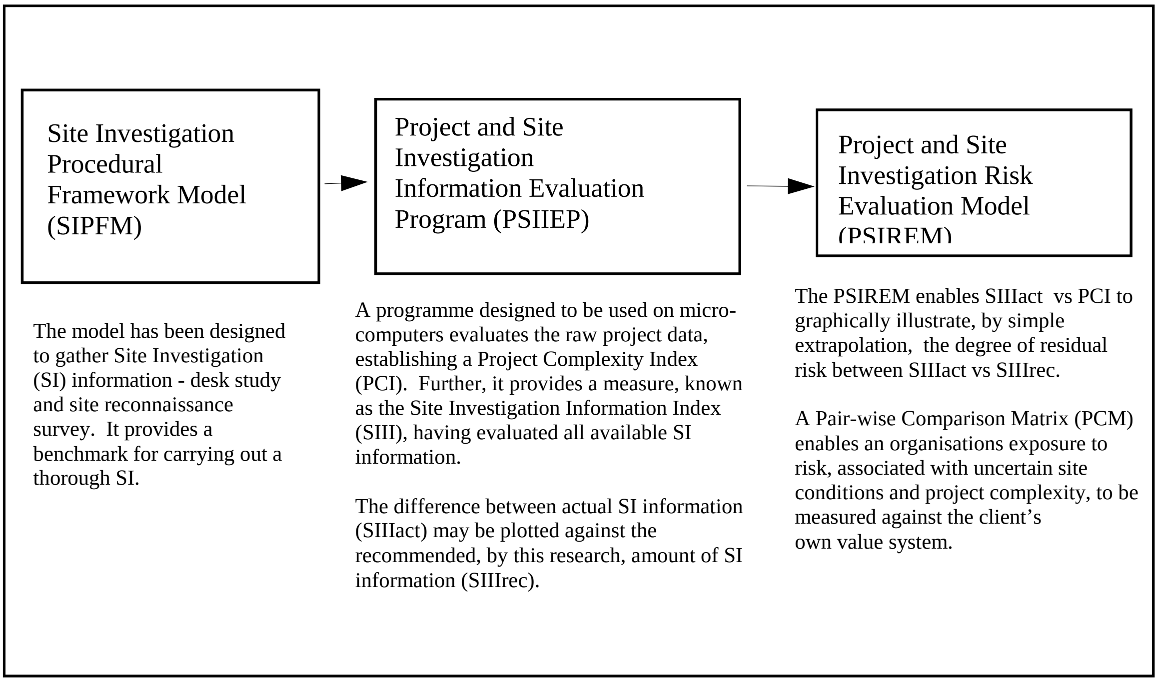
The following facts demonstrate a systematic failure to achieve adequate SI information under present procedural conditions. Further, these records highlight the construction industries inability to address the fundamental errors that occur during the site and ground investigative process.

- 37% of 5,000 Industrial Building projects suffered delays due to ground related problems (N.E.D.O.: 1983)
- 50% of 8,000 Commercial Buildings were found to have suffered unforeseen ground conditions (N.E.D.O.: (1988)
- Geotechnical inadequacies were considered the major concern and reason for 210 premature failures costing an estimated £260 million (N.A.O.: 1994)
- 90% of risk to projects originated from unforeseen ground conditions which could often have been avoided by adequate and full Site Investigation (Alhalby and White1994)
- 80% of contractors taken from a University of Brighton questionnaire survey had sought redress in one form or another for difficulties faced as a direct consequence of an inadequate site investigation (Ashton and Gidado (2001a).
- On average 0.004% of the total contract sum establishes as being spend on site and ground investigative work and analysis. The SI percentage was identified from an accumulative total of construction projects equalling £39,943,000 (Ashton 1998).
- From a 1,000 questionnaire survey, 87% of the respondents sighted insufficient tendering periods in which to conduct additional investigative work required to support their method statements and clarify SI data. (Ashton 2002).
- This research identified that a significant factor that obstructs the successful transmission and communication of SI data was the construction industry's failure to subscribe to a standard, universally recognised system to describe and translate site appraisal information. (Ashton 2003).

AN OVERVIEW OF THE SITE INVESTIGATION RISK EVALUATION SYSTEM (SIRES)

Although previous research attempts have been made to improve site investigation procedures (Weltman and Head 1983); illustrated in a conceptual model, outlined in Figure 1.0**,** the SIRES has provided a new system developed, in collaboration with construction professionals. The robust testing within professional practice was regarded an integral part of the research aim and necessary to achieve an endorsement and industry acceptance. Whilst Ashton and Gidado (2003: 403-411) have previously reported upon the development and testing of the SIRES, the current paper details four case studies that were carried out following the completion of the global research programme. These case studies chart the application and implementation of the system used by professionals while tendering for four different Design & Build construction contracts. The findings of the study provided overwhelming evidence endorsing the application of SIRES as a means to objectively measure the level of risk associated with inadequate site appraisal data, thereby enabling proactive decision making related to and at key tender evaluation stages.

Figure 1.0 Site Investigation Risk Evaluation System (SIRES)



TESTING THE SIRES IN PROFESSIONAL PRACTICE

A thorough site investigation has been regarded by Hayes, Perry, Thompson and Willmer (1987) as being a key element to improving project success. The importance of carrying out a thorough desk and site reconnaissance survey, (ensuring adequate funding, appointing specialist geotechnical expertise, and facilitating a flexible working environment) met with universal approval from construction professionals. However, this research clearly established that practitioners do not use available resources to assists in this fundamental identification process.

Whilst robust testing was carried out throughout the development and evaluation phase to establish the PSIIEP and PSIREM, the ultimate test for any new practical and applied system, according to Peacock and Whyte (1992), is through use by professional practitioners who need specific and direct results. The following four case studies detail the SIRES performance and scope.

Case Study 1.01/03/PA/SE

The Situation

The first case studied was managed by a major construction company, which had recorded a turnover of £185million. It employed over one thousand staff and operated from twelve regional offices around the UK. This case focussed upon a housing development situated to the West of Sussex, on the rolling South Downs. During this study, the organisation and the site received extensive coverage in local and national newspapers, following a dramatic incident as a result of unstable ground conditions.

Difficulties arose only three weeks into the contract whilst forming the site access road. The SI report had led the project team to design the site using V-grade chalk (completely weathered) to BS5930:1999. This material was said to exist on the site and therefore an extensive cut-and-fill operation had been planned for the first eight weeks of the contract programme. It was discovered that the decision to use the existing material had been based upon the experience of an engineer within the project team who had worked in the area and had used a cut-and-fill system. BS1377:1990 had not been used nor any of the recommendations regarding part 2-9 soils testing procedures for engineering purposes.

The second and catastrophic failure was due to slope failure or hillside creep. During the early months of the project a terrace of six house units moved significantly and as a result the entire terrace had to be demolished.

Situation Analysis

Following the process outlined by the Site Investigation Procedural Framework Model (SIPFM) and application of the Project and Site Investigation Information Evaluation Program (PSIIEP), a subsequent investigation of the Local Authority records suggested that the site and the sub-structure material would not be suitable for compacted fill.

The projects economic success was reliant on using vast amounts of '*existing*' site material in a 'cut-and-fill' construction proposal. It would have been prudent perhaps to have checked that the weathered chalk was actually present and in the required quantity, supported by BS1377:1990 testing procedures. The SIPFM direct the user to identify *Mining and Mineral Deposits* specifically for the purpose of ensuring engineering materials were fit for their intended use. Failing this oversight *Ordinance Survey* data records and/ or aerial photographic would have highlighted undulating features synonymous with the South Downs area in Sussex. An expert appraisal of *Drift and Solid* maps and their associated *Sheet Memoirs* would have undoubtedly indicated that the fabric of this site would not fulfil the requirements of BS1377:1990.

Results from the PSIIEP and the PSIREM established a very high Project Organisation's Risk Exposure (PORE) reading. The PORE 25.6 score was clearly identifying the difficulties with proceeding in a project with either extremely limited site investigation information or inadequate information in relation to an extremely complex construction project.

Case Study 1.02/03/PA/SE

The Situation

A SI investigation, which comprised of two Boreholes (BH) and one Trial Pit (TP) in a site approximately 130 x 62 meter's suggested that contaminated ground was not a consideration based upon the results of the soils analysis carried out on material taken from one TP. The BH log recorded fill material 250mm, Brown silty clay 400mm and then Firm to stiff brown clay for a further 20m, which was the point at which the BH log stopped. Having signed a design-and build JCT '81 building contract with a reputable building company based in Kent, work began in 2003 to construct a four-storey block of flats. The pad foundation system encountered medium dense, silty-sandy gravel; synonymous with river or stream deposits, it was established that the founding shear strength of the material was too weak for a traditional pad foundation solution. The central pads were eventually cast on a piled system, a last minute decision made in order to resolve the situation as quickly as possible so as not to prolong the construction programme.

Situation Analysis

The original SI was carried out in June 1990 and was intended to accompany an outline design proposal for Local Authority (LA) planning approval. The SI had fulfilled the early clients brief and the intended use for this particular investigation. This initial report even drew attention to the limitations of the report and the extent to which it should be used for detailed design. Unfortunately, neither the client or the design-and build contractor carried out further SI work, both failing review Local Authority reports regarding the sites history. The SIPFM advocates an examination of *Ordinance Survey* and *Local Authority* records which had the client or the contractor done so would have established the possibility of there being water in the area and/or the existence of a stream in the vicinity or within the site boundary.

This case study established that the foundation system finally used was probably not the most appropriate because; the structural engineer had designed the foundations using huge factors of safety as a result of inadequate site investigation information. The structural engineer drew attention to the issue that despite all existing recommendations time after time design solutions were completed based upon incomplete site investigation data and that ultimately it was the structural engineer's liability that was in jeopardy.

At the time the one and only site investigation was carried out, the client had a preconceived idea for the design of the development. Rough sketches had been used by the client to explain and develop the project brief. It would have been beneficial had the bore holes been positioned on each gridline of the proposed building. Instead the two bore holes were positioned at opposite ends of the site and bore no relation to the 'footprint' of the building.

In February 1987 the Building Research Establishment (p.6) published a digest in which a case study taken from Clayton, Simons and Matthews research (1982) identified a similar situation to that described above. A disturbing fact, therefore, must be why are current guidelines and recommendations been ignored remained out of reach from those clients and contractors most needing assistance?

With a project complexity index of just 3, the development should have been relatively straight forward. With a pad foundation system considered in a green field site and a site team that were experienced with the type of construction and the method statement proposed the project should have gone without problems. However, the SIII was 50.8, which was only just beyond an acceptable SI index range. Subsequently, it should have been evident that several investigative aspects were overlooked, importantly and critically these omissions were in areas that would have identified the presence of ground water.

Case Study 1.03/03/PA/SW

The Situation

The third case study describes a project undertaken by an organisation that specialised in developing self-contained retirement flats. The development was for a five-storey block of flats with retail units beneath and car parking at the rear and in the basement. The project required an extensive concrete retaining structure and used both an RC frame and load bearing masonry with concrete floors provided the buildings structural stability.

Following the appointment of new organisational management, this research was asked to carry out a Site Investigation Risk Evaluation on a project in the South East of England. A subsequent second site investigation was commissioned aimed at obtaining appropriate soil properties, in order to facilitate an appropriate design solution. Several changes were made to the original SI design and seven boreholes were drill, targeted by the building ‘footprint’. The samples were laboratory tested to determine the nominal allowable bearing capacity of the soil (kPa). The earlier relatively low allowable bearing capacity 55-65kPa that had been reported to be present the SI was in stark contrast and in discrepancy to the second investigative report and the actual ground condition. The new soil results indicated that the allowable bearing pressure was 105kPa and the anticipated settlement under imposed loads were within acceptable limits (less then 25mm) unlike the previous site investigation report. Perhaps the most surprising fact, not mentioned thus far, came from the discovery of contamination within the soil. Although the soil samples were within the acceptable limits established by the Inter-Departmental Committee for the Redevelopment of Contaminated Land (ICRCL, 1983), it identified the possibility of further contamination from oil containers once situated within the site boundary.

The project foundation system was redesigned using a simple RC pad and beam system and linked to the RC retaining wall and into the building design. The total cost of the redesign process and the delay in construction operations was borne by the savings made as a consequence of rejecting the piling option, simplifying and easing the method and sequence of construction and the availability of the workforce to carry out the work.

Situation Analysis

The second site investigation provided a comprehensive profile of the site and its environment. However, one properly designed and executed SI could have provided adequate information in order to design the built solution prior to the commencement of construction work on site.

This research programme applied the SIPFM to the earlier site investigation in order to establish which of the tasks within the study had not been carried out satisfactorily. The first site investigation had been little more than a scope study carried out by the client having asked a few questions at the Local Authority (LA) office, general building contractors who had worked in the area and from survey data held at the LA office building control. This initial site investigation served little purpose, not even assisting in the design and development of future site investigative work.

The Project and Site Investigation Information Evaluation Program (PSIIEP) provided a numerical indices and a means by which to demonstrate the reduction of risk associated with the acquisition of more SI data. Local Authority records of this site and the surrounding area were well documented, yet, the early SI failed to check LA records regarding the history of the area and the previous land use, and therefore this information remained undiscovered. No evidence existed to suggest or support whether Local Memoirs had not been sought nor local knowledge explored; despite the experience and qualifications shared within the structural engineering practice and the site investigation organisation, there was little geological, mining and mineral deposit data or references to further information.

Local memoirs can often reveal vital data and provide an insight to a site’s history. These facts may have been stumbled upon whilst searching more conventional records and archives, however, conversation with local residents, shopkeepers and local historians often yield results. Two local residents to this project not only knew about the oil tanks that remained in the ground, but, that the demolition contractor had buried large quantities of the existing site rubbish, removing soil at a cheaper rate and levelled the rubble over the site.

Although SIRES was finally used to design and deliver the second investigation and ultimately it provided a guide to produce a PORE reading of just 4.1 within a 10.1~20 Project Complexity range, all the additional costs of the design changes, removal of the tanks and the extra over cost to clear unwanted material from the site were met by the developer. Close working relationships between the project team and the consulting structural engineering organisation were tarnished following allegations of improper site investigation and design practice.

Case Study 1.04/04/PA/SE

The Situation

The final case presented in this paper chronicles the evolution of a site investigation carried out by a design and build construction company, who won the contract to construct several four-storey block units divided into twenty-four self-contained dwellings, including four specially designed for high levels of disability. Within the contract six retail shop units and ground level parking together with both an extensive hard and soft landscape conclude the scheme.

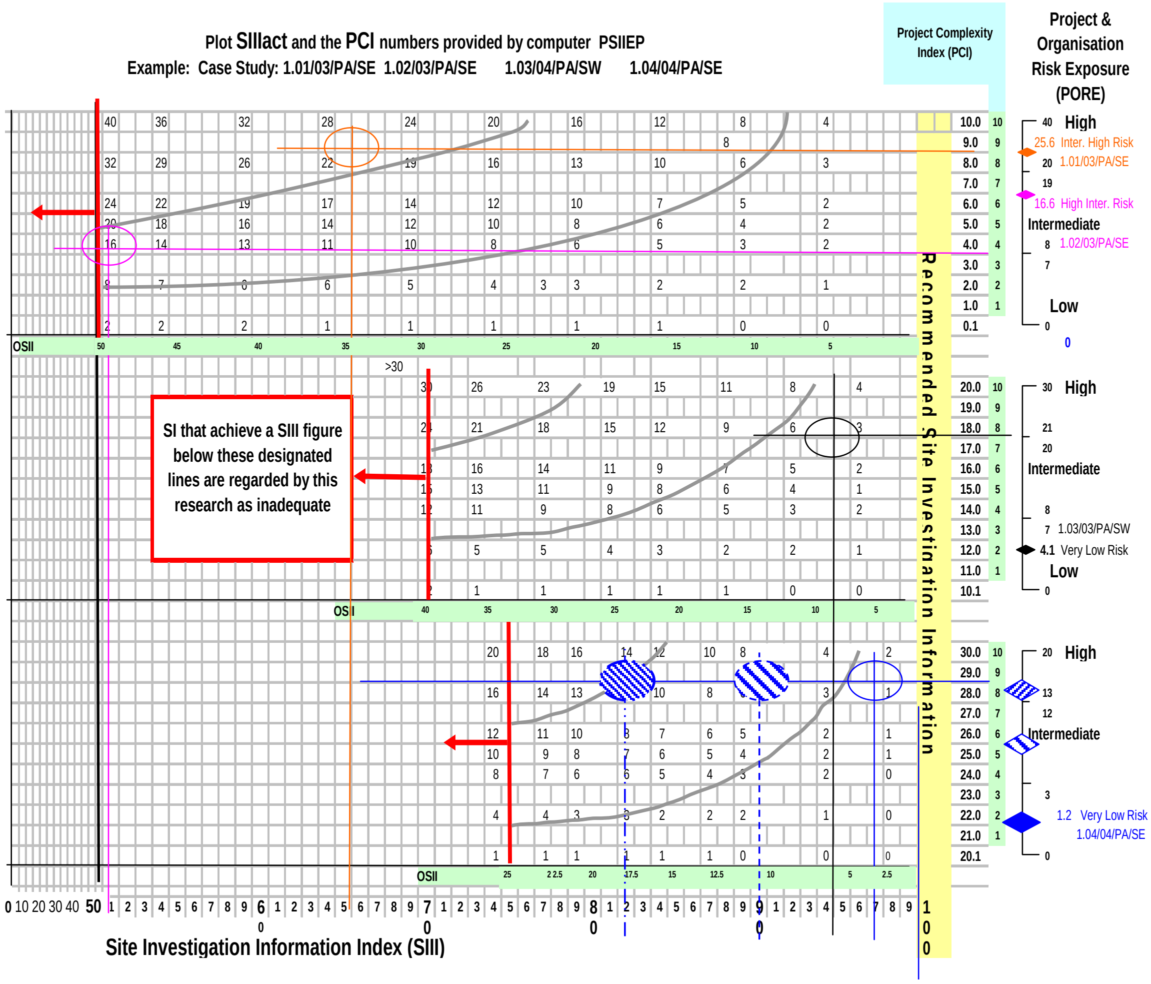
Situation Analysis

All available project data was used to carry out the PSIIEP exercise and the following results were recorded; PCI~28.6 and SIII~82.4, the PORE factor was 12.8 within the 20.1~30 Project Complexity graphical range. This placed the project in the very highest risk scale; refer to Figure 2.0, and resulted in the project being rejected. The organisation chose to reject the project because the PORE factor was too high and the client insisted on a time scale which eliminated the possibility of carrying out further site investigation work.

Having turned down the project the research carried out a second SI using the SIPFM and discovered vital information regarding the history of the site. New information drew attention to the fact that wells existed and the potential for ground contamination at the formation level. A second investigation enabled the PSIIEP exercise to record; PCI~28.6 and SIII~90, the PORE factor was 7.2 within the 20.1~30 Project Complexity (PC) graphical range; the PC range remains the same because in this case the complexity of the project could not be altered. Although the project PORE factor had been reduced considerably to 7.2 and was now in the medium to low range within an intermediate risk exposure category, it was still considered too high to meet the client's brief.

Whilst Ashton and Gidado (2003) described the development process of the Project and Site Investigation Risk Evaluation Model (PSIREM). For the first time, this research has identified where the SIRES was used to design a third site investigation with the specific aim of achieving a PORE reading. The PSIIEP exercise established that with a PCI of 28.6 the required SIII reading would need to be 94 or above in order to achieve a PORE factor of between 0~3 within the 20.1~30 Project Complexity (PC) graphical range. The SIRES provided the means by which professional practitioner could determine the level and extent to which to design the SI in order to meet the desired outcome.

Figure 2.0 The Project and Site Investigation Risk Evaluation Model



Having analysed the four case studies, it appears that Local knowledge was often over looked during routine site investigative work. These cases highlight the instances where local residents knew of a disused service lines that had not been identified during the review of utility data, yet, caused considerable delays during construction operations. Although often these delays do not result in financial or a time related

contractual problems, the re-scheduling of work, materials and labour was a difficulty the site team could have eliminated with prior knowledge and forethought.

CONCLUSION

The aim of this research has been to develop a system, to be used by construction practitioners, to identify where the shortfalls in available site investigation information occur; thereby providing opportunities to objectively establish whether to procure further SI work, in order to reduce risk associated uncertain site conditions.

This research has identified that an entire project design and philosophy may be based upon site investigation data and information gathered at a very early stage within the project inception. (Ashton 2003: 189-190). The SIRES focuses on achieving adequate site investigation information from ‘Desk Study’ and ‘Site Reconnaissance’ elements within the SI investigative process, answering most of the issues raised by construction professionals responding to the questionnaire survey (Ashton and Gidado

2001), which suggested significant problems originate from the failure to carry out rudimentary SI principles.

Whilst the four case study reports outlined within this paper provide continued evidence to support the effectiveness of the SIRES, it is worthy to note other outcomes of the research which need to be addressed in order to further improve the service the industry aims to provide tomorrows clients.

A significant outcome from the global research programme is that it has producted a system, comprising of three elements, which when combined, provide the construction practitioner with an effective management tool designed to identify the project organisation's exposure to risk, resulting from any given amount of SI information. It has developed and delivered a SIRES that is both simple and effective. Unlike existing models and risk analysis techniques, this work has used an industrial input, case studies and the client's own set of values to determine a Project Organisation's Risk Exposure (PORE).

The SIRES is currently being developed in association with perhaps one of the worlds leading engineering design and geotechnical specialist organisations in an effort to disseminate the research outcome to a worldwide audience. It is anticipated that the SIRES will, unlike so many previous attempts, provide the industry with an affordable user–friendly system to reduce risk associated with inadequate site investigation information.

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