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Planning and Design of Site Investigations

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Abstract

Guidance on planning and design of site investigations is not explicitly included in the Code of Practice for Site Investigations (1981). Insufficient emphasis is given to developing a strategy and a programme of activities which is relevant to the proposed development and ground conditions.

A more formal approach to the organisation of these preliminary stages is presented and an outline given for a planned programme of administration.

Guidelines are given on how to develop an appropriate strategy including categorisation of investigation, preliminary design assessment and detailing site work. The need for records and refinement is highlighted.

Introduction

Site investigation is part of the design process. Arguably, the investigation is the key to adequate and economic design because the data collected forms the basis of the site assessment and the foundation solutions subsequently produced.

Successful investigations only result from thorough planning and design. Lack of planning is probably the prime contributory factor leading to poor or inadequate foundation solutions, and also to additional construction costs. Long term maintenance liabilities may also result.

Unfortunately, the Code of Practice for Site Investigations (1981) does not lay sufficient emphasis on these important aspects. If they featured prominently in the Code, it would encourage promoters to:

1. Demand that qualified and experienced geotechnical engineers control the investigation and closely supervise the field works. This involvement should commence during the initial planning and should ideally continue throughout construction.
2. Increase the degree of supervision on site by both the controlling engineer and the contractor.
3. Allocate more realistic funds to enable sufficient planning, ground investigation, reporting and monitoring. Any additional costs should be more than compensated through improved efficiency and economy of construction.

Such a course would help improve the quality and standard of site investigations, thereby avoiding many of the common shortcomings presently associated with the ground investigation industry.

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Assessment of Early Sections of the Code

The Code concentrates primarily on providing guidance on the scope and detail of the ground investigation (i.e. site works). The site investigation, which embraces site selection, identification of environmental constraints, method of administration, and other essential preliminary assessments, is assumed to have been previously carried out.

Section Two claims to provide guidance on matters relating to site selection and to works design preparations, but in reality is a superficial collection of 'general considerations'. Similarly, Section Three aims to set out the essentials of planning and of investigation selection methods, but instead only contains a shopping list of aspects that need to be assessed. The order of this Section is not presented in a logical, balanced, or easy to follow manner, and constantly leap-frogs from aspects of ground works to requirements for the various types of developments.

The Code treats site appraisal and ground investigation as a series of isolated tasks and events with no development or discussion of an overall strategy. Planning and design of investigations is covered only by implication. There is no explicit guidance for formulating a plan, for establishing a programme, or on how to produce a structure for the administration of investigations.

Although the Code covers different types of development and types of investigation related to the various soils or rocks to be encountered, it does not set out a unified approach that will link the investigation requirements with those of the structure.

Code Sequences

The sequences recognised are represented as Table I. Site investigation essentially covers the Desk Study, Reconnaissance, Planning and Controls, although the latter is mentioned only superficially (Sub-section 7.2). Unfortunately, it is stated that the first stage of any project is the Desk Study (rather than Planning and Control).

TABLE I. *Summary of sequences identified by the Code*

Site investigation		Ground investigation		Reports
Desk study	►	Preliminary	►	Presentation of data
Reconnaissance		Main		Factual
Planning and control		Special studies		Interpretation

Ground investigation, including Preliminary, Main and Special Studies, represents the main thrust of the Code. This is augmented by Reporting which relates purely to the presentation of data and the subsequent final report.

Proposed More Formal Approach

The early sections of the Code could be rationalised to cover, more explicitly, the planning and design aspects of investigations. Detailed guidance on the various aspects would be referred to by identifying published material as References that the promoter or controlling engineer should consult. Presently, only one such reference is included (Dumbleton and West, 1976) but is not identified in the text.

A more rational approach for organising site investigation assessment is presented as Table II. Planning includes the Desk Study but also considers all the other necessary activities that are prerequisites for a thorough preliminary assessment. Design is concerned with provisionally detailing the site works to produce the necessary information for foundation analysis and recommendations.

Planning

The first decision that has to be made at the outset of any investigation is to identify the type of administration that is appropriate. The client or developer may retain the necessary expertise in-house or may wish to appoint a project co-ordinator. A multi-disciplinary team could be commissioned or a single controlling engineer.

The role of the geotechnical engineer should be identified, and those of the specialist and civil contractor.

The detail of the Desk and Reconnaissance Studies will depend on the type of development required. Different objectives result depending on whether the study relates to:

(i) feasibility of works,
(ii) assessment of a failure (serviceability or limit state),
(iii) a new development or redevelopment,
(iv) impact on environment,

or any combination of these.

All types of constraints should be identified, particularly those that are most critical to the project.

(i) Financial restraints often dictate the scope and method of operation; the exceptions being where a failure has taken place or if there is a high risk to life.
(ii) Developers often see the investigation process as an unnecessary delay which does not often provide a tangible benefit. Too often, the time allocated to this exercise is insufficient.
(iii) The risks to life or adjacent property need to be clearly defined.
(iv) There is a belief that the method of procurement of ground investigation has a profound effect on the quality of the information produced and is the main contributory factor which has led to the present decline of standards.

The choice of procurement method could be a lump sum sub-contract based on a schedule of activities; by negotiated or selective tendering based on detailed requirements with a Bill of Quantities; or a consortium bid on a 'design and investigate' basis.

TABLE II. *Suggested approach for organising a site investigation assessment*

Site investigation			Ground investigation			Records and reports	
Planning	Administration Desk study Reconnaissance Constraints Procurement method	►	Preliminary	Feasibility	►	Preliminary assessment	Planned strategy and programme contingency proposals
			Main study	Geotechnical evaluation — profiling — material and ground-water characteristics		Field data presentation	as per Code
Design	Foundation design assessment Development of Investigation strategy Programme of site activities		Specialised studies	Geophysics Dynamic and static probes Pressuremeters/dilatomaters Hydrographic		Factual/Interpretive report	as per Code

Redevelopment evaluation

Site selection has become more restricted because of the lack of suitable development sites. As a result, there is now a requirement to redevelop or consider marginal sites with poor engineering properties. This necessitates a more specialist evaluation of ground characteristics and potential remedial measures.

(i) Industrial sites are likely to have buried foundations, various fills and are often chemically contaminated. Ground beneath existing buildings is likely to behave in a different manner to surrounding areas.
(ii) Rebuilding or refurbishment sites can have access problems and the foundations may need to be uprated.
(iii) Waste land, tips and filled areas may vary enormously and haphazardly in their properties and often overlie ground with poor characteristics.
(iv) Undermined sites present additional difficulties because it is not usually possible to fully define the extent and form of mining nor its affect on the overlying ground. General guidelines on planning and design for mining investigations are presented in a PSA/CIRIA report (Healy & Head, 1984).
(v) If a site is contaminated then a separate chemical investigation is necessary and a Code of Practice is presently being developed to cover this aspect (Draft Code of Practice for Identification and Investigation of Contaminated Land, 1983). Foundation durability aspects for aggressive ground conditions has been reported separately (Barry, 1983).

Design

Detailed design of site activities for the ground investigation is fully reported in the PSA/CIRIA Site Investigation Manual (Weltman & Head, 1983). The basic strategy and the programme of site works is developed for the following two functions:

1. **Ground profiling,** including determination of structure and fabric.
2. **Sampling and testing** to determine material and groundwater characteristics. Testing includes both *in-situ* and in the laboratory.

In order to assist in the development of a strategy and programme, a system of site categorisation is proposed, represented as Table III. Categorisation, in terms of the structure on the one hand, and ground complexity on the other, appears to be a reasonable method for measurement. This approach forms the basis of a more rational method for identifying sensible levels of investigation. However, the proposals should not be employed rigidly because there are always dangers in prescription.

The concept of Geotechnical Categories is also being considered by the Eurocode Drafting Committee on Foundations. It has identified three categories and those presented have been restricted to the same amount to maintain compatibility.

TABLE III. *System of site investigation categorisation*

Category	Structure	Ground conditions
1	Small Simple Straightforward	Uniform Adequate characteristics
2	Conventional	Varied
3	Large Unusual	Complex Problematic Poor characteristics

Tables IV to VI summarise the features of each Investigation Category in terms of typical structure types, foundation types, effect on environment and appropriate types of ground conditions.

The Categories are presented to help define the minimum requirements in terms of investigation extent, quality of data to be produced and the level of control necessary. In general, increasing the Category from 1 to 3 requires increased proportion of supervision, level of specialisation, extent of investigation and higher costs.

If the proposed structure naturally falls within Category 1 but the effect on environment or ground conditions suggest, say, Category 2, then the higher category should be chosen. Similarly, if the proposed structure falls within Category 2 but the ground conditions are expected to be particularly difficult, then a Category 3 investigation is more appropriate.

Foundation design assessment

Once the ground investigation has been categorised it will then be necessary to carry out a preliminary foundation design assessment to identify the broad requirements of the field works. Although in some circumstances it will be possible to precisely identify at the outset the type of foundations to be constructed, it is more likely that a series of options will be considered. The final decision on the choice will probably be made on the basis of economy, behaviour, and ease of construction.

1. The **types of foundations** being considered will depend on the overall loads and their distribution, the ground and groundwater conditions, and any special requirements. It is important to consider alternatives and to design the investigation to provide the appropriate information. If, for example, ground improvement techniques are envisaged, the method finally chosen might only be decided after detailed discussions with various ground improvement specialists after the final reports have been produced.

TABLE IV. *Features of Category 1 investigations*

Structure types	Low rise Lightly-loaded	Includes housing, industrial buildings, offices and shops
Foundation design	Routine	Based on empiricism, and engineering experience. Simple formulae appropriate.
Effect on environment	No risk	Will not affect adjacent structures or utilities.
Ground conditions	Known Original materials	Will have adequate strength and low compressibility.

TABLE V. *Features of Category 2 investigations*

Structure types	Conventional Standard foundations	No abnormal loads. Includes buildings, retaining walls, embankments, roads and bridges.
Foundation design	Formal design Quantitative data required	The foundations should be engineered and be based on experience and judgement.
Effect on environment	Avoid or accommodate risks	Careful study required.
Ground conditions	Partly known Varied	Field and laboratory tests required. May be specialised investigation aspects.

TABLE VI. *Features of Category 3 investigations*

Structure types	Unusual Complex foundations	Abnormal loads or abnormal risks can be identified. Includes high-rise structures, reservoirs, dams, deep excavations, underground works, large scale civil works and offshore construction.
Foundation design	Specialised Multiple aspects Interactive soil-structure design	Could be multi-disciplinary.
Effect on environment	High risks	Affects life or adjacent property.
Ground conditions	Unknown Difficult/problematic Specialised	Specialised activities would probably be included.

2. The **level of theory** to be used for the final design assessment needs to match the sophistication and quality of the investigation. Although a simplistic approach may be used to carry out the initial foundation assessment based on desk studies, the degree of sophistication of the subsequent foundation design process varies enormously from empirical formulae to complex analytical approaches using computers. The design may require a refinement and optimisation process and so the tests should cover the whole site and also outside the construction area. The aims and objectives of the ground investigation should be tailored precisely to the subsequent requirements of the foundation design.

   For example, SPT values coupled with undrained shear strength estimates would be totally inappropriate for a complex soil-structure interaction problem associated with a tower block. Similarly, complex and expensive *in-situ* tests in dense sands for lightly-loaded buildings are unnecessary.
3. Once the appropriate design theory has been identified the **relevant soil/rock parameters and characteristics** can be identified. The range of parameters required, and the relevant stress and strain levels, can then be matched to the details of the ground investigation. For example, pressuremeter tests to determine shear modulus values would be irrelevant in anisotropic soils and where the test direction is at right angles to the imposed building loads.
4. **Special requirements** such as foundation material

durability in contaminated ground, or construction difficulties, should also be considered.

Developing an investigation strategy

The objective of a well planned and designed investigation is to identify a provisional programme of works that will form the basis of the site assessment. The programme will identify the minimum requirements in terms of location, depth and quantity of probes and holes, and select appropriate sampling and testing schedules for on site and in the laboratory.

A schedule of ground profiling via probes, boreholes and drillholes can be selected which compliments the ground and structural complexity. The scope of the sampling and testing will depend on the type and succession of strata and the parameters required.

Monitoring of the ground, groundwater and structure is often important and should be integrated into both the investigation and construction processes.

Once a strategy has been developed it will then need to be constantly reassessed and refined as the site work proceeds.

Reports and Records

All too often the site supervising engineer is appointed immediately prior to the site works, when the investigation contractor has been identified and the provisional programme has been established. Lack of involvement in the planning and design by those responsible for the supervision of field works often restricts the flexibility of the work because the reasoning behind the programme has not been clearly established. This situation is not desirable and is often made even worse if the supervisor is then subsequently despatched to other ground investigations without being involved in the foundation designs in the office.

To clarify this aspect it is recommended that a record be produced of the reasoning behind the planning and strategy of the investigation programme. The report should specify the detailed requirements and any contingency proposals thought desirable. The information could then be consulted at all stages of the investigation and the field works realistically re-appraised at regular intervals, yet maintain a sensible scope and balance.

Conclusions

1. Section Two and Three of the Code should be rationalised to cover, more explicitly, the planning and design process necessary for the successful implementation of ground investigations. Detailed guidance on various aspects should be referred to through a list of References. Such references could be presented in a Bibliography which could be updated at regular intervals. Those relevant to planning and design have been presented at the end of this Paper.
2. A more formal approach to planning and design than is presently contained within the Code is considered necessary. Details of a rational and logical approach are outlined, including site investigation categorisation, followed by a preliminary foundation design assessment and guidelines for developing an investigation strategy.
3. Detailed records of the planning and design aspects should be produced as a preliminary report which can then be used throughout the field works to control the scope of the investigation process. Continual reassessment and re-appraisal of the scope is required during site works.

References

BARRY, D. L. (1983): Material durability in aggressive ground, CIRIA Report 98, 60 pp.

BRITISH STANDARDS INSTITUTION (1981): Code of Practice for Site Investigation, BS 5930, HMSO, London.

BRITISH STANDARDS INSTITUTION (1983): Draft Code of Practice for the Identification and Investigation of Contaminated Land, document 83/55992, 124 pp.

DUMBLETON, M. J. & WEST, G. (1976): A guide to site investigation procedure for tunnels, DoE/DTp, Transport and Road Research Laboratory Report LR 740, 24 pp.

HEALY, P. R. & HEAD, J. M. (1984): Construction over abandoned mine workings, PSA Technical Guide 34, CIRIA Special Publication 32, 94 pp.

WELTMAN, A. J. & HEAD, J. M. (1983): Site investigation manual, PSA Technical Guide No. 35, CIRIA Special Publication 25, 144 pp.

Additional Bibliography

CIRIA (1978): Tunnelling—improved contract practices, Report 79, 70 pp.

CLAYTON, C. R. I., SIMONS, N. E. & MATTHEWS, M. C. (1982): Site investigation—a handbook for engineers, Granada Publishing, 423 pp.

DUMBLETON, M. J. & WEST, G. (1974): Guidance on planning, directing and reporting site investigations, DoE/DTp, Transport and Road Research Laboratory Report LR 625.

TYRRELL, A. P., LAKE, L. M. & PARSONS, A. W. (1983): An investigation of the extra costs arising on highway contracts, DoE/DTp, Transport and Road Research Laboratory Report No. 814, 22 pp.

WEST, G. (1983): Comparisons between real and predicted geology in tunnels: examples of recent cases, *Q. J. Eng. Geol.* London, Vol. 16, pp 113–126.

WEST, G., CARTER, P. G., DUMBLETON, M. J. & LAKE, L. M. (1981): Site investigation for tunnels, Rock Mech. Review, *Int. J. Rock Mech. Min. Sci.* Vol. 18, pp 345–367.