Exploration Geophysics (1990) **21**, 125–127

Integrated Site Investigation

J. P. MacGregor
Coffey & Partners Pty. Ltd.
12 Waterloo Road
North Ryde NSW 2113
Australia

Present address:
Snowy Mountains Engineering Corp. Ltd.
161 Clarence Street
Sydney NSW 2000
Australia

Abstract

Engineering requirements for project development should be met by a combination of investigation methods including both geology and geophysics. The integration of different techniques may lead to successful analysis in situations where separate methods would provide misleading results.

Key words: Site investigation, engineering geology, engineering geophysics, geotechnical model.

Introduction

I wish to consider briefly the objectives of a site investigation and illustrate these objectives using some examples from my experience. In some cases the integration of geological, geophysical and engineering techniques has contributed to the satisfactory assessment of site conditions, and in order cases the lack of co-ordination of the site investigation programme has led to problems and sometimes to costly contractual disputes.

Objectives of Site Investigation

Any engineering project involves some modification of existing site conditions and could include excavation, filling, addition or removal of a resource, building of a structure which may be rigid or flexible, and may range from limited to extensive dimensions. Even without modification of the foundation profile there may be significant changes in the stresses on the foundation materials.

For design purposes the engineer requires to know details of the existing site conditions and their response to the modifications proposed in the project development. For contractual reasons it is desirable to assess the practical problems involved in the removal and placement of material, the stability of excavated slopes and the control of water, whether surface or underground.

As natural conditions may be complex, the assessment involves the establishment of a geotechnical model of site conditions. In this model the site is divided into units, with each unit assigned boundaries and engineering parameters considered typical of the materials within the unit. The boundaries provide the basis for quantity estimation, and the engineering parameters the assessment of performance.

The role of the engineering geologist and the engineering geophysicist is to use their expertise to determine the features which control the geotechnical model relevant to the particular project and establish the boundaries and parameters which provide the most practical solution to the engineer's problems. The investigation techniques used must be appropriate to the problem.

As every site is different, the project planning should consider the relevance of each investigation method and the cost benefit of each method to the project as a whole. This planning requires close consultation between the design engineer and the investigation team. In theory the results of site investigations follow the law of diminishing returns, and there must be a point where little useful information is obtained from more investigations. Restrictions on time and expenditure ensure that this point is rarely reached.

Engineering geological investigations involve the determination of facts which represent relatively reliable and accurate data on a minute proportion of the site. Investigation methods include regional terrain studies and mapping of surface features, supplemented by subsurface investigations, either using shallow test pits or deep drill holes. *In situ* testing and laboratory testing of samples recovered during the investigation programme provide data on engineering parameters at the specific locations sampled.

The skill in engineering geology is in the interpretation of the situation between the points with known data to form the geotechnical model. In this analysis it is assumed that sufficient investigation has been carried out to identify and quantify all the units present, that the investigation points are representative, and that boundaries between known points are essentially linear.

Engineering geophysical investigations delineate different areas, each with consistent physical properties. The analysis assumes that these properties are relevant to the geotechnical model which applies to the site. Without control, the model produced by geophysical methods may differ significantly from the model indicated by geological investigations.

Geophysical investigations indicate parameters which may be general and represent average properties of materials with a wide range in specific parameters. Indicated boundaries may be approximate. The particular value of most geophysical techniques is that, provided sufficient field traverses are completed, the survey provides an assessment of uniformity over a significant area, and can indicate local anomalies which could otherwise be missed.

One feature which is distinctive of many geophysically based models, is the presence of several layered units with boundaries subparallel to the ground surface and an increase in material strength with depth. While there are many instances where the actual subsurface profile is similar to this model, there are also many cases where a geophysical model of this type can be misleading. Where the properties of a particular site are governed by a material with dominant horizontal defects, it is more likely that a layered geophysical model would provide a more accurate assessment of site conditions, than in the situation where the controlling feature is vertical foliation or weathering along vertical defects in an otherwise uniform material.

The combination of all appropriate techniques, with continual review of the model as additional data is obtained, is the desirable approach. Unfortunately in practice, in many cases and for many reasons, this does not occur.

Geophysics and Geology in the Service of Engineering

The advantages of co-ordination between geology and geophysics and the correct selection of investigation methods are illustrated by reference to several projects with which I have been involved.

My first example is the development of a groundwater source for Nicosia, Cyprus, in the 1950's, where surface mapping, followed by drilling established the general subsurface profile. Resistivity surveys located buried gravel beds deposited by ancient rivers in an area of extensive clay formations and enabled the optimum siting of pump wells which were then tested and connected to the city reticulation system.

The importance of accurate co-ordination of the different components of an investigation was highlighted during a mineral investigation programme in Uganda, in 1961, where an airborne geophysical survey identified significant electromagnetic and magnetic anomalies. Test drilling struck sulphides, but subsequently it was found that a survey error had indicated a wrong ground location, by about 15 km, for the airborne anomaly.

During a study tour of hydro-electric schemes in the north of Scotland in 1962 a single-channel engineering seismograph was used to test embankment and spillway foundations. These traverses showed that high velocities are recorded in intact fresh granite and that a significant reduction in velocity is caused by the presence of even one weathered sub-vertical joint. While the extent of this problem is obvious in an area of complete rock outcrop, alternative interpretations for the same apparent seismic velocity in an area with soil cover could be:

(a) a uniform medium-strength unfractured rock,
(b) a high-strength rock with many tight joints,
(c) a high-strength rock with several widely spaced, open or clay filled joints, or
(d) a combination of (b) and (c).

Each of these situations could result in a different assessment of the practicability of machine excavation of the rock.

In 1964, a groundwater survey in the Markham Valley in Papua New Guinea involved a similar approach to the Cyprus survey, but was less successful as the resistivity could not identify the different components in a much more complex subsurface profile, and the exploration drilling was widely spaced. A magnetometer survey along the alignment of the proposed high-level pressure tunnel for the Upper Ramu hydroelectric scheme was used in an attempt to locate igneous dykes, but it was found that the dyke rock gave lower magnetic values than the meta-siltstone country rock. Investigations for a proposed hydroelectric development on the Warangoi River in New Britain included seismic refraction over karst limestone with little success in the location of solution cavities.

Investigations for thermal power station development in New South Wales between 1967 and 1978 included geophysical surveys using different techniques, including single-channel and multi-channel seismic and sparker. Water-borne sparker surveys provided a valuable indication of the overburden/rock interface level under Lake Macquarie, and seismic refraction traverses were extensively used to indicate probable ripping depths in excavations. The use of a constant separation traverse enabled the extension of an igneous dyke located in the chimney stack foundation for Munmorah power station to be traced. Unsuccessful surveys included the attempt to use seismic methods to determine the density of coal compacted by bulldozer in a storage area, and the location of saturated sand/weathered sandstone boundaries in bridge foundations by seismic methods.

A proposal for a systematic investigation of transmission tower foundations using a combination of drilling and seismic traverses appeared attractive, but it was found that the additional cost of the mobilisation of two investigation methods was more expensive than extra drilling.

The rocks in the Sydney basin are essentially sedimentary, with near horizontal layering, and geotechnical mapping supplemented by limited drilling usually provides the necessary control for a geotechnical model which can be infilled by geophysical survey. The accuracy of depth determination is not commonly sufficient for building foundation design, but the appropriate geophysical method provides a relatively inexpensive method of comparing alternative sites at the feasibility stage.

As a consultant it appears that economic pressures to produce results at lower cost sometimes result in ineffective investigations. This is usually due to:

* too little geological data to define the geotechnical model
* too little geophysical data to enable a confident interpolation of the model boundaries and engineering properties.

Although it is desirable that the geological and geophysical work is coordinated, it is obvious that in many cases the programme for each method is selected and carried out separately without cross-reference. On several major investigations it has been found that the geophysical field work and interpretation was completed before the results of the drilling investigation were available.

In some cases selling geophysics as an exploratory tool for engineering projects has been too successful, and clients

without appreciating the limitations of the methods, expect a complete evaluation of site conditions based entirely on geophysical surveys.

Assessment of rippability is the most common area where geophysics provides a regular contribution to site investigation. The interpretation of the extent of practical ripping using a combination of engineering geology and geophysics is discussed in several papers in this volume. The different methods of assessment place emphasis on different factors. In marginal conditions the practicability of ripping with a given machine depends on the nature, orientation and spacing of rock defects which are close to vertical. Most investigation methods provide little data on these defects. As stated above, the same velocity may represent different site conditions, and the particular defect combination which applies to the specific site should be established before estimating the limit of rippability.

Contractual disputes on rippability form a major proportion of claims in earthworks contracting. Several methods are used to estimate rippability but each suffers from a lack of feed-back on ripping performance in the actual site conditions which were encountered. There is a requirement for a study which includes:

* the data available as a result of the site investigations,
* the interpreted subsurface profile,
* the actual subsurface profile,
* the detailed performance of the machine used in the excavation.

This type of study, carried out for a range of rock types, could enable refinement of the present level of analysis and a realistic assessment of the accuracy of prediction in this area.

Two recent dredging projects in the northwest of Western Australia illustrate the necessity of integrating site investigation methods. Although in an apparently similar environment, the excavation problems were different, and an appreciation of the situation by all groups involved in the investigation could have clarified the problem areas before the stage of contractual problems.

At King Bay, near North West Cape, the sea bed in the area proposed for a harbour development was underlain by several coral reef horizons over high strength, jointed basalt. The possible effect of basalt boulders on the dredging programme did not appear to have been considered. It was difficult to identify these boulders in the drilling investigation, but the boulder-strewn foreshore should have suggested that the hashing on the sparker profile represented a similar situation offshore.

In the deepening of the approach channel to Port Hedland harbour coral reef horizons were identified above calcareous sediments, sandy clay and weathered sandstone. Although the drilling showed reasonably uniform conditions, the geophysical interpretation identified areas with significantly different properties and contributed to a confused appreciation of the situation by the dredging contractor.

The use of geophysical methods to locate subterranean cavities is a source of continued speculation. Which method provides the most cost-effective answer? In the selection of a route for the Alice Springs to Darwin natural gas pipeline, which crosses about 200 km of karst limestone terrain, most geophysical methods were considered. It appeared that Sirotem had the most potential but the cost and time involved in 200 km of systematic ground traverses was unacceptable.

A study of regional geology, and photogeological interpretation of several possible routes, indicated that areas of concentrated subsidence were associated with structural geological features, particularly the intersection of major jointing. A route was selected which avoided these areas as much as practicable, with provision for ground Sirotem traverses in areas of potential concern. The pipeline was constructed without the location of major cavities.

The Royal Australian Air Force base at Tindal, near Katherine in the Northern Territory, is close to the gas pipeline route and is underlain by limestone. Areas of surface subsidence appear related to solution cavities and, over a period of more than 20 years, there have been many extensive geophysical surveys using several methods in a systematic attempt to locate other cavities beneath the property.

Although the geophysical effort in this area has been considerable, there has been relatively little engineering geological input. The subsidence features appear to occur in specific geological situations with solution along joint intersection, followed by the collapse of erodible soil infilling during rain storms. Geotechnical mapping of the area could have reduced the amount of geophysical survey and enabled the concentration of investigation in areas of significant risk. Relatively few cavities have been identified at Tindal, possibly because most of the area does not have cavities, rather than a limitation of the methods used.

Conclusions

The design engineer requires a clearly defined geotechnical model of site conditions. It may be possible to obtain this model by geological investigations alone — in some circumstances the required accuracy dictates a high proportion of factual data. The use of geophysical methods alone is unlikely to define the model.

In most cases the integration of engineering geology and appropriate geophysical methods provides the most accurate and cost-effective representation of site conditions. The co-operation of all disciplines is required, and most importantly, sufficient time to consider and review the investigation data, before finalising the geotechnical model.

(Paper received: 1/2/88; revised: 1/5/90)