APPENDIX A

SITE CHARACTERISATION STUDY
PROJECT BRIEF

CONTENTS

A.1 OBJECTIVE

To assess the capability of new investigation methods, or enhanced existing methods, in order to obtain better information on the geometry of old retaining walls and ground conditions behind slopes and walls.

A.2 BACKGROUND

One of the recommendations in Volume 1 of the Report on the Kwun Lung Lau Landslide of 23 July 1994 (Hong Kong Government, 1994) was :

> "The GEO should undertake and support elsewhere in Hong Kong research into improved means of site characterisation focused on the factors that affect slope instability in Hong Kong. The Writer does not think that the development of slope warning systems for the conditions found in Hong Kong is promising. The critical features are small and numerous and instability often develops in an abrupt manner. However, there are a number of new developments in geophysics such as radar and non-contact resistivity that might be found useful in discovering subsurface defects and enhanced moisture zones."

The opinion on slope warning systems given above is supported. It is not proposed to consider such methods further.

Research should be aimed at identifying improvements to existing ground investigation techniques used in Hong Kong and the testing of newly-developed techniques. There are two main areas of application, viz. (a) improved means of assessing the geometry of retaining walls and related structures (e.g. hard slope surfaces, masonry and other facings) and (b) better understanding of ground conditions behind slopes and walls, with emphasis on how the ground may deteriorate with time through sub-surface erosion, weathering, saturation or volume change.

Given the large numbers of old slopes and walls in Hong Kong, and the difficult ground access in many cases, new or improved existing investigation methods should ideally be quick to apply and easily transportable. Indirect non-contact and non-intrusive methods based on remote measurements or soundings are the most attractive; however any results from such methods should be readily interpretable by non-specialist geotechnical engineers.

A.3 CURRENT METHODS OF CHARACTERISING SLOPES AND WALLS

"Site characterisation" for the purpose of this project is interpreted as meaning all the work done in investigating, describing and classifying the condition of retaining walls and the ground behind slopes and walls. The traditional means of characterising sites in Hong Kong is well established in Geoguides 2 and 3 (GCO, 1987; 1988). It usually consists of four main steps :

(a) Desk study, including aerial photograph interpretation, inspection of old maps, plans, drawings and existing records of ground investigations on the site or adjacent sites.

(b) Site inspection/reconnaissance, involving a walkover of the site and its surroundings and gathering information on relevant surface features.

(c) Ground investigation, including some or all of geological mapping, geophysical survey, drilling or boring, trial pitting, sampling, *in situ* testing and laboratory testing.

(d) Reporting, to cover preparation of field reports, maps, plans, and borehole logs, interpretation of data obtained and preparation of final site investigation report.

In the context of the KLL landslide, where there were no obvious signs of surface distress prior to failure, and other recommendations in the KLL Landslide Report which address integration of information from surrounding sites, it is not proposed to undertake research for this project under (a) and (b) above. Research should be devoted to methods of ground investigation (item (c) above). Following on from Section 2 above, it is proposed that the research be concentrated on geophysical survey methods, but other methods may also be examined.

A.4 EXISTING INVESTIGATION METHODS USED IN HONG KONG AND POSSIBLE IMPROVEMENTS

One of the main difficulties in the investigation of old masonry walls is to determine the wall thickness. The conventional methods used in Hong Kong and their weaknesses are :

	Method	Weaknesses
(a)	Approved building plans, records	Some have been found to be unreliable
(b)	Probing weepholes	Weepholes often blocked by rubbish or debris
(c)	Coring through wall	Poor sample recovered due to single tube drilling
(d)	Horizontal drilling	Expensive, and mobilisation difficult

In view of the demonstrated unreliability of some approved building plans, research is needed into ways of improving the other techniques.

The usual practice of weephole probing should be reviewed. Initial ideas for improvement are to require weepholes to be cleared of debris and rubbish before probing, and to take a driven sample at the end of some holes to ensure they are cleared and to determine the geological materials behind the wall. In the longer term, other improvements might be feasible through liaison with ground investigation equipment manufacturers, such as :

(a) developing remote-control downhole viewers to examine the insides of weepholes,

(b) improving core recovery technique in coreholes, and

(c) reducing the rig size for drilling short horizontal holes through masonry walls in Hong Kong's congested conditions.

A.5 POSSIBLE NEW METHODS

While conventional drilling and other field test techniques are well-established in Hong Kong, engineering geophysical methods are not commonly used for investigation of slopes and retaining structures. At present, seismic refraction is the only popular on-land geophysical method. Ground radar, cross-hole seismic tomography, electromagnetic tomography and well-logging techniques have been tested in a few projects but with limited success and little reporting in the technical literature.

The application of modern engineering geophysics to Hong Kong conditions should be further explored. In view of rapid recent developments in geophysical equipment, data logging and limits of resolution, a detailed literature review is warranted as the first step.

The next stage is likely to be field trials of some non-contact methods aimed at rapid coverage of whole slopes and structures, with a view to identifying anomalies such as voids, zones of increased moisture and materials of relatively low strength or stiffness. Based on an initial literature review and discussions, the following techniques are likely to be worth pursuing :

(a) Ground radar.
This provides a record of continuous electromagnetic subsurface probing. The technique may be useful in detecting cavities, identifying buried services and groundwater tables, and determining the thickness of retaining walls. Initial trials carried out in GEO in 1991-2 were generally unsuccessful in identifying variations in soil and rock materials. Further trials are warranted.

(b) Relative ground resistivity survey.
This is a rapidly-applied non-contact technique based on current induction using portable equipment. It has been found effective elsewhere in detecting cavities, groundwater and subsurface profiles.

Other techniques which may warrant further study and possibly trials are time domain reflectometry (TDR) and spectral analysis of surface waves (SASW). Consideration will also be given to density and magnetic methods, and to relatively new insertion techniques, such as the seismic cone penetration test, although the initial view is that such methods are likely to be less attractive due to difficult access, variable penetrability of decomposed igneous rocks and colluvium, etc.

One of the important findings in the Kwun Lung Lau failure investigation was the presence of groundwater flow pathways into the landslide site. Research into the use of tracing methods to identify groundwater flow lines will also be considered.

A.6 PROCUREMENT OPTIONS

The main options are :

(a) In-house research by GEO using existing ground investigation and geophysical term contractors and/or other specialist contractors by invitation.

(b) Funded external research by a local consultant or tertiary institution employing their own contractors, with overall management by GEO.

The project cannot be specified precisely at the outset. The research is best done in several phases, involving field trials of techniques with a review of findings before proceeding to the next phase.

Option (a) is preferable in order to preserve flexibility, but option (b) may be more expedient if adequate GEO professional staff resources are not identified. Both options will be fully explored.

A.7 INFORMATION SOURCES

A full review of previous trials of novel investigation techniques carried out in Hong Kong by or on behalf of GEO will be conducted and a written summary provided. Initial suggestions for other literature to be reviewed are as follows : Geological Society Engineering Group Working Party (1988), Proceedings of the Annual Symposia on the Application of Geophysics to Engineering & Environmental Problems (SAGEEP 1-6, 1989-1994), Proceedings of the Waterloo Conference on Ground Penetrating Radar (GPR, 1994) and Woods (1994).

A.8 PRELIMINARY THOUGHTS ON FIELD TRIALS

An initial phase of field trials should be set up in two stages :

(a) The first stage should be on sites where a detailed, high-quality ground investigation (GI) has already been carried out. The GI results will form the basis for correlation with non-contact geophysical survey results. Contractors will be given access to the existing GI records. This will assist them in calibrating their equipment and appreciating local ground conditions.

(b) The second stage will involve trials carried out as properly-controlled research experiments using "class A" prediction wherever practicable, i.e. the contractor undertaking the non-contact survey, and any other party assisting in interpretation of the results, should have no prior knowledge of ground conditions behind the structure or slope under investigation. This may be difficult to achieve in practice, but could be feasible if suitable sites with minimal previous investigation records can be identified. In this situation the GEO would arrange independent conventional GI, for correlation with the results of non-contact methods, either concurrently or shortly after the work done by the geophysical contractor. Alternatively, sites already investigated by detailed conventional GI would be used but the results would not be made available to the geophysical contractor.

An additional option to be considered, although more complicated and time-consuming, is to modify an existing site by deliberately forming anomalies such as voids and weak zones near the surface of the slope or structure and then reinstate the surface prior to geophysical survey. Minor site formation works by another contractor will be required. This may prove difficult to arrange in respect of lands matters and safety aspects.

Further phases of fieldwork would only be contemplated if the first phase produces promising results.

A.9 PROJECT MANAGEMENT

Overall management of the project will be through a small working party chaired by GGE/Development, with representatives from the Planning Division, Special Projects and Materials Divisions of GEO. CGE/Planning is the proposed project manager.

A.10 RESOURCES

The preliminary estimate for professional staff resources is 6 man-months of GE input spread over the full study period, assisted by a TO(G) for an equivalent period. SGE/EG will oversee the day-to-day running of the project. Regular liaison with Materials Division staff on employment of contractors is anticipated.

Approval will be sought to fund the research from existing GEO R&D funds under the Capital Account, or from the Landslip Preventive Measures Block Vote. If existing funds cannot be identified, a request will be made to the Finance Branch for new funds. The final expenditure will depend on the scope of field trials attempted. $2-3M should be sufficient for the first phase.

A.11 OUTLINE PROGRAMME

It is estimated the project will be completed within 12-18 months. The literature review will be carried out within the first two months. Consultant selection, if required, would need a minimum of three months. The time for site selection and arranging the first field trials, including resolving lands/access matters, will be of a similar order.

A.12 REFERENCES

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APPENDIX B

GEOPHYSICS LITERATURE REVIEW

CONTENTS

B.1 LAND-BASED ENGINEERING GEOPHYSICS PRACTICE IN HONG KONG

B.1.1 General

A summary of all land-based geophysics made for the Geotechnical Engineering Office (GEO) since 1987 is presented in Table B1. This list broadly represents engineering geophysics practice in Hong Kong in both the private and public sectors. Electronic and Geophysical Services (EGS) has been the GEO term geophysical contractor exclusively since 1987, apart from a brief period in 1993 when the term contract was awarded to Geoteam (HK) Ltd but was later novated to EGS.

The land-based techniques carried out for GEO have generally been limited to seismic refraction, gravity and resistivity surveys. Seismic tomography has been attempted at two sites in Hong Kong. Information obtained from the EGS data base, which extends back to 1973 indicates that pre-1987 land geophysics for both public and private clients was limited to seismic surveys. This is similar to the practice up to the early 1980s described by Ridley-Thomas (1982). Several trials of the more modern invasive and non-invasive techniques such as ground penetrating radar (GPR), geophysical borehole logging, thermography, seismic reflection, magnetometer and gravity surveys have been made by GEO over the past few years (see Section B.1.6.).

B.1.2 Seismic Refraction

Seismic refraction surveys in Hong Kong are generally made to assist in selection and development of land borrow areas. The depth of weathering and P-wave velocity are the main site characteristics for which seismic refraction has been utilised. Twelve, and more recently 24 channel seismographs are used for data acquisition. The most commonly-used energy source is a 8kg sledge hammer and plate; however, from 1991 onwards explosives have been used. In wet ground conditions a Buffalo gun is used as the energy source.

Unsatisfactory results due to low signal to noise ratios are common in Hong Kong. This is mainly due to environmental noise and the low energy source. This problem has been overcome by the use of explosives as the energy source and carrying out the surveys at night when the environmental noise is low. Another limitation is the complex weathering profile which commonly exists in Hong Kong. This makes interpretation of the refraction data difficult if a simple, planar, non-dipping, layer cake model with linearly-increasing velocity with depth is assumed in the analysis. The simple intercept-time methods of analysis generally used are not valid in such complex geological situations.

B.1.3 Cross-Hole Seismic Survey

Cross-hole seismic investigations have been made at two sites in Hong Kong for engineering purposes. They were used in an attempt to delineate fault or shear zones at the Tsing Ma Bridge tunnel anchorage’s and to map caverns within buried marble below a housing development site in Ma On Shan, Area 90.

Acoustic P-wave velocity measurements were made between three boreholes using EG&G ES 2401, 24-channel seismographs, 24-element hydrophone streamers and a BOLT 2000 psi borehole airgun at the Tsing Ma Bridge anchor site. Tomographic construction was made on the p-wave velocity data using a Perkin Elmer 3212 and a ICC DRS 6000 mini main-frame computer. Poor results were obtained due to low signal to noise ratios (blamed mainly on high environmental noise despite the surveys being done at night) and poor grouting of the plastic liners into the boreholes. To overcome the environmental noise problem, the seismographs were fitted with variable high cut, low cut and notch filters so that the gain of the individual traces could be increased or decreased. The results were still less than satisfactory.

A cross-hole seismic survey was made in 118 borehole pairs at the Ma On Shan housing project using the same equipment as at the Tsing Ma Bridge anchor site. The survey was also carried out at night. Several low velocity zones were detected, and were interpreted as cavities within the marble which would tend to cause dispersion, attenuation and delay to the P-waves. The low velocity zones were not investigated using physical techniques; therefore the accuracy of the seismic survey could not be verified.

B.1.4 Gravity Surveys

Gravity surveys have been carried out for the Hong Kong Geological Survey of the GEO with the aim to produce a Bouguer Anomaly Map of Hong Kong. The final survey was carried out by EGS in conjunction with the British Geological Survey (BGS) in 1990-91. Evans (1990) reports that four new gravity base stations were established in Hong Kong by BGS for the regional gravity survey.

B.1.5 Resistivity Survey

Simple applications of resistivity surveys to determine the soil corrosivity have been made in connection with water supply pipelines. The Wenner electrode configuration is generally used with stainless steel electrodes.

B.1.6 Previous Engineering Geophysics Trials by GEO

B.1.6.1 Ground Penetrating Radar

A ground penetrating radar (GPR) trial was made in August and September 1991. The objective was to determine the effectiveness of GPR in Hong Kong in the detection of corestones, weathering interfaces to 20m, retaining wall thickness and location of services. The trial was made by EGS who sub-contracted the works to a Canadian geophysical company multi-VIEW Geoservices Incorporated. The GPR used was the pulseEKKO IV Radar of Sensors & Software (Canada) using 50, 100 and 200MHz antennas.

Nine sites were surveyed. The general conclusions were that the maximum penetration obtainable, regardless of frequency of the antennas, was about 10m. The location of corestones within a slope could be postulated, however their presence was not confirmed by subsequent physical exploration. Two reinforced concrete walls were tested but the determination of wall thickness was not successful. It should be noted that reinforcement bars can completely attenuate electromagnetic waves, thus resulting in no reflections beyond the bars embedded in the concrete. The GPR had limited success in locating near-surface utilities, including water-bearing pipes.

A GPR demonstration was made for GEO in December 1994 by Forest Engineering Geophysics Exploration Co., in conjunction with the Chinese Academy of Geoexploration, at an LPM site being investigated by the Design Division of GEO. The purpose of the test was to determine the thickness of a thin masonry retaining wall (feature no. 8SW-C/R1) behind a village house in Sai Kung. The radar equipment used in the demonstration was the SIR Systems 10A manufactured by Geophysics Survey System Inc. A 500MHz antenna was used in both the pulse and continuous profiling mode. Five vertical and two horizontal traverses were made at the site. The thickness of the retaining wall in question was determined to be between 0.35m and 0.50m thick using GPR. This correlated well with corehole information.

B.1.6.2 Geophysical Borehole Logging Trial

A trial was made in December 1989 in the Yuen Long Scheduled Area of Hong Kong to evaluate whether geophysical borehole logging techniques could help in the interpretation of the complex geology which consists of marble, meta-sediments and metamorphosed volcanic rock intruded by granites. EGS carried out the trial for the Geotechnical Control Office using an EG & G Mount Sopris Model II logging system. Three techniques were used, namely natural gamma, self potential and single point resistivity, all housed in a single probe. The natural gamma technique measures the natural radioactivity of the rock mass and is traditionally used in oil exploration to determine the percentage shale content. As the probe measures natural radiation it can be used in cased boreholes. The self potential and single-point resistivity methods measure the natural potential resistivity between the logging tool and an electrode at the ground surface. Self potential is sensitive to fluid flow that produces electrical currents in the ground and hence can be used to detect open fissures or permeable zones. Resistivity is sensitive to changes in moisture content and clay content and can be used to detect permeable zones, rock quality and formation fluid.

Twenty boreholes were logged; however no additional information, other than that which could be gained from the borehole logs themselves, was obtained from the trials.

B.1.6.3 Thermography

A thermography demonstration was made by Materials Laboratory for the Design Division of GEO in September and October 1993. The objective was to demonstrate whether thermography would be able to detect voids and ground water behind hard slope surface coverings in Hong Kong. There is no report on the trials, however notes from a meeting to discuss the trials indicate that the technique was unsuccessful. Two slopes (one a cut slope and one a fill slope) and one wall were investigated. The main points of the note state that the technique did not work on the vegetated fill slope and there was insufficient space available in front of the wall to obtain a clear thermographic image of the feature. Thermographic images of a cut slope were successfully made in Siu Sai Wan. "Hot" and "cold" areas were identified but no interpretation was made because no physical data were available.

B.1.6.4 Seismic Survey of Wall Thickness

Shelton (1980) and Chan (1982) (see Section 6.) both refer to a field demonstration of a seismic method for the determination of wall thickness made by Integrity Testing Services. The seismic reflection method was used but was unsuccessful due to the seismic velocity variation in the different wall components not being accurately quantified.

B.1.6.5 Magnetometer and Gravity Survey Trials

Both magnetic and gravity trial surveys have been made in Yuen Long in an attempt to map the shallow cavitous marble subcrop. Between 1987 and 1989 a large number of magnetometer measurements were made in the Yuen Long Industrial Estate (Langford, 1990). The instrument used was the Geometrics Unimag Proton procession magnetometer. The survey did not show a correlation between a negative anomaly and the presence of marble at depth. Significant sources of error were the unquantifiable anomalies related to the fill platform and more importantly the influence of steel H-pile foundations in the area. Collar et al (1990) conducted a detailed trial gravity anomaly survey of the Yuen Long area. They had some limited success in correlating gravity anomalies with the approximate extent of the buried marble formation.

B.2 INTERNATIONAL ENGINEERING GEOPHYSICS PRACTICE

B.2.1 Introduction

This Section summarises a review of the available literature in Hong Kong on non-invasive engineering geophysics and its applicability in identifying the features described in the main body of the report in Section 2. Geophysical methods identified as not being applicable to the project, such as induced polarisation, gravity and magnetic methods, are not discussed further. Each geophysical method is discussed separately, beginning with a brief explanation of the theory, followed by selected case histories and comments on the applicability of the method in identifying instability indicators.

Papers and articles concerning engineering geophysics are contained in a wide variety of English language publications, ranging from journals such as Geoexploration and Geophysical Prospecting to Geotechnique and the Quarterly Journal of Engineering Geology. However, since the late 1980s the Society of Engineering and Mineral Exploration Geophysics (SEMEG), now known as the Environmental and Engineering Geophysical Society (EEGS) has been sponsoring an annual Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP), which has published many useful papers in their proceedings. General texts by Dobrin & Savit (1988) and Griffiths & King (1983) describe the theory and general application of geophysical prospecting, the latter being directed towards geologists and engineers. Another valuable source of information is the collection of papers edited by Ward (1990) focusing on theory and practice in geotechnical and environmental geophysics.

The reference list in Section B3 is split into references cited in the text and others which have been reviewed as part of the project but not cited.

B.2.2 The Seismic Method

B.2.2.1 Shallow Seismic Reflection

Seismic reflection methods exploit subsurface acoustic impedance contrasts which reflect body waves back to geophones located at the surface (Figure B1). Acoustic impedance is the product of related parameters, seismic velocity and density.

Non-invasive, high-resolution seismic reflection is mostly used to identify interfaces between soft or loose sediments and underlying consolidated soil or bedrock. In such geological conditions the impedance contrast is large and therefore the reflected p-wave energy is high. Miller et al (1990) describe a case history where seismic reflection was successful in imaging an alluvial bedrock interface as shallow as 4m below the ground surface. The standard common depth point (CDP) method (Figure B1(a)) was used with an air rifle as the energy source. This produced a repeatable high frequency wave for CDP stacking. The use of an air rifle as the energy source also reduces the amount of ground roll and air wave noise. Long spiked geophones helped improve ground coupling in areas of dry, loose, rocky ground.

Pullan & Hunter (1990) describe the Optimum Offset Technique (Figure B1(b)) of shallow seismic reflection and illustrate its usefulness with three case histories where bed rock was delineated below saturated sediments. They note that the high frequencies required for high resolution are preferentially attenuated, especially if the surface layers are dry and coarse grained and that high resolution seismics are best suited to bedrock mapping where bedrock is overlain by fine-grained saturated soils. They also note that even if small amounts of gas are present in the near surface sediments, seismic signals are subject to extreme attenuation. This could be significant in partly-saturated soils in Hong Kong.

High resolution seismic reflection may be successful in mapping fill bodies. Although environmental noise may be a problem, the use of CDP, stacking and other modern methods of analysis may allow the method to be utilised in certain circumstances in Hong Kong.

B.2.2.2 Seismic Refraction Method

As noted in Section B1, the refraction method (Figure B2) is used in Hong Kong to determine bedrock depth and form with variable success. Its use in identifying instability indicators other than mapping simple stratigraphy is considered limited.

B.2.2.3 Surface Wave Methods

There are two main surface wave methods in use, depending on the energy source. Impact sources, such as a hammer or a drop weight, produce a transient impulse, while vibrators produce continuous waves. The choice of source affects the details of the way in which field data is acquired and processed. The data from impact sources is processed using the Spectral

Analysis of Surface Waves (SASW). The vibrator source data is processed using the Continuous Wave Method (CWM) (Matthews et al in press[a]). Stokoe et al (1994) describe the fundamentals of SASW and Matthews et al (in press[b]) describe in detail the CWM.

Surface wave methods have been extensively used as a non-destructive test to determine the shear stiffness and thickness of concrete pavements. An annotated bibliography by Hiltumen & Gucunski (1990) contains over 40 references on SASW, most of which are concerned with concrete pavement measurements; however, case histories where the method has been used to monitor the effectiveness of ground improvement and in liquefaction studies are also included. With advancement in the understanding of small strain stiffness of soil and rock, surface wave methods have been used to determine ground stiffness profiles for use in geotechnical design. This is because the strain associated with a seismic wave propagating through soil or rock is in the order of about 0.001% (Matthews et al in press[b]), which is comparable with the strains measured around excavations and below foundations. Al-Shayea et al (1994) suggest that there should be further development of the SASW method for the purpose of locating voids. They present research in which the dispersion curve showed marked differences for free field lines and lines over voided areas.

Although no case histories have been found which relate directly to features associated with slope instability in Hong Kong, the determination of stiffness-depth profiles using surface seismic methods could be useful if the profiles can be correlated with typical weathering grades of local granitic and volcanic rock found in Hong Kong. SASW may also be useful in determining the thickness of masonry retaining walls.

B.2.3 Electrical

B.2.3.1 Electrical Resistivity Surveying

Ward (1990) describes the fundamentals of resistivity surveying, data acquisition and processing, including detailed discussion of the pros and cons of various electrode configurations (Figure B3). He also describes case histories where the resistivity method has been used to detect unfilled and filled cavities in limestone, where a marked resistivity high was associated with an air-filled void and resistivity lows associated with clay-filled voids.

Resistivity image profiling utilises the dipole-dipole electrode configuration (Figure B4) which produces a 2D apparent resistivity pseudo section. The pseudo section is then inverted to produce the final resistivity section. Hiromasa & Hideki (1990) present a case study of a rock investigation in which resistivity imaging was used to characterise the ground along a proposed tunnel route. The technique was used to identify faults, fracture zones and altered zones along a 1600m long survey line. The depth of investigation was about 300m in weathered and fresh granite. Zones of different resistivity values were identified and related to weathering grade and alteration of the granite rock mass. With the aid of air photo interpretation, the locations of major faults, shear zones and altered zones were identified.

Northmore & Jackson (1995) successfully used a British Geological Survey-designed resistivity imaging system (RESCAN) to monitor moisture migration in a soil embankment in Kenya to obtain an understanding of the mechanisms which trigger landslides and serious cracking in the embankments.

Resistivity methods may be useful in mapping fault or shear zones, zones of elevated moisture content and possible voids. The method has a distinct disadvantage over other electromagnetic methods as it requires insertion of electrodes into the ground, but has the marked advantage of being able to produce a 2-D resistivity section of the site.

B.2.3.2 Self Potential Method

The self-potential (SP) is based on surface measurement of natural differences in electric potential resulting from subsurface electrochemical reactions. SP anomalies are generated by subsurface currents in the earth. SP investigations have been used to help locate and delineate the sources responsible for the production of such flows. As the method offers relatively rapid field data acquisition and the ability to respond directly to flows of interest, it is a cost effective reconnaissance investigation method prior to more intensive studies (Corwin, 1990).

SP surveys are conducted by measuring the potential difference in the ground using a pair of non-polarising electrodes and a high-impedance voltmeter. Corwin (1990) recommends the fixed-base configuration which uses a stationary electrode and a moving measuring electrode. The advantage of the fixed base configuration over the gradient configuration (which utilises two electrodes and a connecting wire of fixed length equal to the separation between measurement stations) is that errors associated with the gradient configuration such as soil contact effects, electrode polarisation and time varying potentials, are not cumulative.

For engineering purposes the SP method is used almost exclusively to study of ground water movement. Corwin (1990) cites many examples of SP investigations of dam seepage. Geological features such as faults, shear zones and major discontinuities, which tend to form preferential paths for water flows, have also been identified using the SP method.

SP data are qualitative and are often severely affected by spatial factors and errors caused by large time-varying potentials such as those generated by corrosion or telluric currents. In engineering applications the severity of these effects is compounded by relatively low SP anomaly levels and high artificial noise sources in urban areas (Corwin, 1990).

The SP method may be useful in Hong Kong to detect water flow associated with leaking services, if the problems associated with noise can be overcome.

B.2.4 Electromagnetic

B.2.4.1 Introduction

Electromagnetic methods are used to determine ground conductivity by measuring the response of the ground to induced electromagnetic fields. The advantage over conventional resistivity methods is that they are non-invasive and measurements are relatively quick and easy to make. Measurements can be either made in the frequency domain or the time domain, which have different applications. Comprehensive reviews of electromagnetic methods and their applications to environmental and engineering problems are given by Nobes (1994) and McNeill (1995).

B.2.4.2 Frequency-Domain Electromagnetics

Frequency-domain electromagnetic measurements are primarily used for profiling to detect and map lateral changes in conductivity. A typical conductivity meter such as the Geonics EM-31 (McDowell, 1981) consists of transmitting and receiving coils located at the ends of a 4m-long boom. Surveys are carried out by one person taking readings of direct conductivity on a set of parallel traverses or a grid of stations. McDowell (1981) notes that the orientation of the boom relative to the traverse direction depends on the nature of the target, also that the readings are a measure of the conductivity of the ground between the ends of the boom and could vary with boom orientation where lateral inhomogeneity exists. The basic principle of the equipment is to pass an alternating current of a certain frequency through a transmitter coil which induces circular eddy current loops into the earth. The magnetic field at the surface, as measured by the receiving coil, is the combination of the secondary field created by the induced current loops and the primary field. Normally, there is both a difference in direction and phase between the primary and secondary fields. The magnitude of the magnetic generated in one of these eddy loops is proportional to the value of the current within the loop, which inturn is directly proportional to the terrain conductivity. The second component is the in-phase component, the ratio of the secondary to primary magnetic field measured in parts per thousand of the primary field. This component is useful because it is very sensitive to metallic objects.

From a number of case histories McDowell (1981) compares three types of electromagnetic devices: the terrain conductivity meter, conventional resistivity meter and the fluxgate magnetic field gradiometer. He notes that use of the conductivity meter such as the Geonics EM-31 is quick and inexpensive as compared with conventional resistivity measurements. At two sites where resistivity and magnetic surveys were impossible due to concrete and metal surface cover, the electromagnetic survey was relatively unaffected. Conductivity surveys have been successful in locating sand lenses in clays, mine shafts, backfilled basements and cess pits.

Anon (1988) describe several applications of the frequency-domain electromagnetic method. Where low resistivity bedrock is overlain by clay-rich soils, the depth to bedrock can be mapped because conductivity can be crudely related to clay thickness. They note that measurements made with the Geonics EM34 and EM31 compared very closely with the results obtained with conventional resistivity profiling. There is little reason to consider resistivity profiling , therefore , if ground conductivity surveys can be carried out with approximately the same depth of penetration. Faults and shear zones can be located owing to the different electrical properties within such zones as compared with the surrounding rock (normally conductivity highs due to deep weathering), or of one rock being faulted against another. Ground conductivity profiling methods are commonly used in Africa to locate water-bearing shear zones in basement areas for water supply. The location of either air-filled (conductivity lows) or clay-filled (conductivity highs) voids is more cost effective than resistivity profiling for depths in the range of 0m to 30m.

Electromagnetic profiling can be considered as a favourable means of investigation in Hong Kong since it is truly non-invasive, quick and relatively inexpensive. It is potentially useful for mapping high moisture content zones, voids and altered shear zones or weathered dykes.

B.2.4.3 Time-Domain Electromagnetics

Time-domain electromagnetics (TDEM) involves measuring the electrical conductivity of soil and rock by inducing pulsating currents in the ground with a large transmitter coil and then monitoring the decay of the secondary eddy current between the pulses with a separate receiver coil (Figure 5B(a & b)). TDEM is primarily used to the determine depth and thickness of soil and rock layers (Frischnecht & Raab, 1984).

Nelson & Haigh (1990) describe a case history where TDEM was used in conjunction with high resolution seismic methods to delineate the location of sinkholes in lateritic terrain. Whiteley (1983) describes a joint TDEM and resistivity sounding to locate bedrock and to resolve a thin saline layer above bedrock. The TDEM gave a better estimate of bedrock depth whilst joint inversion of both methods gave accurate estimates of the saline layer and depth to bedrock. Hoekstra & Blohn (1990) describe a case history where two thin basalt flows were identified using shallow TDEM surveys. Changes in resistivity profile correlated well with the interface between the two basalt flows and the underlying tuff.

Time Domain Electromagnetics has possible applications in Hong Kong in the determination of stratigraphy as different weathering grades in either granite or volcanic rocks contain different clay contents. It may also be possible to use TDEM to determine high moisture zones and ground water table conditions and, to a lesser extent, altered zones and embedded clay lenses.

B.2.5 Ground Penetrating Radar (GPR)

B.2.5.1 Introduction

Due to its popularity and growing importance a separate section has been devoted to GPR instead of including it as a sub-section under B.2.4. Ground Penetrating Radar uses the principle of reflected electromagnetic waves to locate buried objects (Figure B6). The basic principles and theory of GPR are given in many technical papers, notably Daniels (1989) and Daniels & Roberts (1994). Over the past five years GPR has improved significantly mainly due to advances in electronic signal processing. Data acquisition and analysis have taken advantage of powerful, quick and portable computers. Since GPR and seismic survey share the same principles, much of the software used to perform CDP stacking, migration and deconvolution can be applied to the GPR signals. GPR and seismic surveys complement each other since one is sensitive to contrasts in electromagnetic properties and the other to contrasts in mechanical properties.

Siggins (1990) and Daniels & Roberts (1994) recommend measurement of the site-specific electrical properties of representative soil and rock prior to carrying out the GPR survey, especially at sites with deep weathering as GPR may not yield good results in clay-rich soils. Annan & Chua (1992) used three types of modelling to help evaluate GPR success in a particular situation. Radar range predictions were used to predict depth of penetration. Synthetic radargrams were used to assess the type of response from a given target. Simple two-dimensional ray tracing was used to determine two-way travel times to evaluate the effect of antenna separation, depth of target and radius of target on the observed response.

The depth of penetration of a radar wave depends upon the electrical properties of the ground, centre band frequency of the antenna and the power output of the antenna. Dry homogenous rock can be penetrated up to 35m but 10m-15m is more common. Conversely the maximum penetration though a montmorilonite-rich clay could be as small as 50mm. Roggenthen (1993) demonstrates that by using higher power output to the antennas deeper penetration can be obtained in highly conductive soils. Gogh et al (1994) suggest that, based on the pulseEKKO IV system, penetration of 10m to 25m can be obtained with 25-100MHz antennas and 1m to 5m penetration can be obtained with 300-1000MHz antennas. They suggest using 100MHz antennas for investigations up to 10m deep. Grasmueck (1994) reports 40m to 50m penetration in dry granite using a GSSI SIR-3 unit with 100MHz antenna. Siggins (1990) reports penetration of about 10-15 wavelengths in high resistivity rocks and about 1 wavelength in conductive materials. Generation of very low frequency waves is not feasible due to the large antennas required for long wavelength production.

Conventional GPR equipment offers antennas with fixed centre-band frequency and hence a fixed range and resolution. Frequency selection for a given survey is a function of range, resolution, field conditions and what is available to the end user. Often the user requires several antennas with different centre frequencies to perform a survey. Economic constraints will result in the geophysicist only owning a certain number of antennas with a range of commonly-used frequencies. The variable frequency antenna helps solve some of these problems. Thomas (1992) describes an antenna with a variable frequency capability. Both Noon et al (1994) and Steven & Michael (1992) describe the development of the step frequency GPR. This system synthesises a step frequency which matches the spectrum of the antenna band width. It has advantages over conventional impulse systems, e.g. the control of the signal waveform leads to better target resolution, ringing is reduced through the use of windowing, and penetration is improved as the signal bandwidth matches the antenna frequency and energy contained in the lower frequencies is not lost.

The following features have a high dielectric contrast and are therefore potentially detectable with GPR: cavities; changes in rock porosity; water table; plastic containers; concrete foundations; oil and petroleum spills and geological contrasts. Other features which are highly conductive and therefore also detectable by GPR are barrels, tanks, pipes, clay and salts dissolved in the ground water.

B.2.5.2 Case Histories

A summary of case histories obtained from published literature on GPR in identifying both man-made and natural sub-surface anomalies is contained in Table B2.

B.2.5.3 Applications in Hong Kong

GPR has potential applications to determine the thickness of retaining walls, and detect clay-filled discontinuities, hydrothermally altered zones, voids and zones of enhanced moisture content. The combined use of GPR and thermography may also be useful in mapping voids and elevated zones of moisture behind hard surface protection to slopes (see Table B2, Gourry et al., 1995)

B.3 CONCLUSIONS

The main conclusions from the review of relevant literature are as follows:

(i) Shallow seismic reflection may be useful in mapping the base of extensive fill bodies. Seismic refraction is unlikely to be successful in identifying instability indicators other than the bedrock level. Surface wave methods could be useful in the mapping of weathering profiles if a relationship exists between stiffness and weathering grade.

(ii) Resistivity imaging may be useful in the location of shear zones or faults and the mapping of zones of elevated moisture content and high clay content. Void mapping may also be possible. The self potential method could be utilised in the detection of leaking services.

(iii) Both frequency-domain and time-domain electromagnetic methods could be utilised in the mapping of zones of high moisture content, location of voids and the location of shear zones and altered dykes.

(iv) It is unlikely that gravity or magnetic methods would be particularly useful in Hong Kong.

(vi) It is possible that GPR will be able to determine the thickness of retaining walls, detect clay filled discontinuities, hydrothermally altered zones, voids and zones of enhanced moisture content. The combined use of GPR and thermography may also be useful in mapping voids and elevated zones of moisture behind hard surface protection to slopes.

B.4 RECOMMENDATIONS

(a) The applicability of the following non-invasive engineering geophysical methods should be tested in Hong Kong:

(i) Shallow Seismic Reflection;

(ii) Spectral Analysis of Surface Waves;

(iii) Resistivity Imaging;

(vi) Self Potential;

(v) Electromagnetic Methods;

(vi) Ground Penetrating Radar; and

(vii) Thermal Imaging.

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No.	W.O.No.	Period of Fieldwork	Project Title	Objective of Survey	Geophysical Method	<Client> Contractor	Remarks	Report No.
1	(GC/87/01) Q7/2/20.1	28/08/87 to 20/09/87	West Kowloon Reclamation Potential Borrow Area Study Silver Mine Bay - Area KS	Determination of depth to bedrock for fill borrow area.	S.Rr	<GCO> EGS	Good borehole correlation. Some poor record quality due to noise from wind and passing vessels.	11077
2	Q7/2/20.2	26/10/87 to 11/12/87	Yuen Long - Tuen Mun Eastern Corridor, Tai Tong East Borrow Area Land Seismic Refraction Surv.	Determination of depth to bedrock for fill borrow area.	S.Rr	<GCO> EGS	Using Hagedoorn Plus-minus method having reasonable bore-hole correlations. Evidence of faulting identified.	10494
3	Q7/2/20.5	13/07/87 to 23/09/87	Tates Cairn Tunnel (Shatin Portal) Additional Site Investigation Land Seismic Refraction Survey	Determination of depth to bedrock for fill borrow area.	S.Rr.	<GCO> EGS	Hammer was used as energy source. Reasonable result and good borehole correlation.	9644
4	Q7/2/20.8	06/09/87 to 08/10/87	Tsz Wan Shan Area 13 Reclamation Feasibility Study Land Seismic Refraction Survey	Determination of depth to bedrock for fill borrow area.	S.Rr.	<GCO> EGS	Poor correlation with borehole data due to high ambient noisy level, great depth to bedrock and possibility of a low velocity hidden layer.	11078
5	Q7/2/20.11	28/09/87 to 20/10/87	West Kowloon Reclamation N. Tsing Yi Land Seismic Refraction Survey	Determination of depth to bedrock for fill borrow area.	S.Rr.	<GCO> EGS	Good borehole correlation with 2 out of 3 boreholes. Deeper zones of weathering identified probably associated with faulting.	11114
6	Q7/2/20.20	14/04/88 to 20/04/88	Trial Gravity Survey at Yuen Long	Trial Gravity Survey to contribute to understanding & concealed geology at Yuen Long.	G	<GCO> EGS	Highly anomalous zone was identified but the syrvey area not large enough for proper interpretation.	10837
7	Q7/2/20.20 S1	09/07/88 to 21/10/88	Geophysical Surveys High Density Gravity Survey Map Sheet 6NW-B	Bouguer anomaly map of study area to enable extent of Marble inlier to be determined	G	<GCO> EGS	Gravity survey to form part or proposed Gravity Map of Hong Kong. Seven gravity base stations also established.	11655
8	Q7/2/20.20 S2	11/1988	Geophysical Surveys Interpretation of High Density Gravity Survey, Map sheet 6NW-B	Interpretation	G	<GCO> EGS	Moderately successful in outlining areas of known Marble subcrop. Errors mainly from assuming a uniform density contrast.	11774
9	Q7/2/20.28	25/01/89 to 17/02/89	NWNT Sewage Scheme Land Seismic Refraction Survey	Determination of depth to bedrock for pipe route design.	S.Rr.	<GCO> EGS	Poor correlation with boreholes due to complex weathering profile, environmental noise, low energy source. Buffalo gun was used as energy source in marsh areas.	12184
10	PW7/2/20.35	-----	Designated Areas- Borehole Logging Applications - Logging Trial.	Geological evaluation of the Marble formation in Yuen Long.	BH.L	<GCE> EGS	Natural Gamma, Self Potential and Single Point Resistivity logging used. Geophysical logs did not expand on existing knowledge.	-----

Table B1 - Summary of Land Geophysics Carried Out for GEO to 1995 (Page 2 of 4)

No.	W.O.No.	Period of Fieldwork	Project Title	Objective of Survey	Geophysical Method	<Client> Contractor	Remarks	Report No.
11	(GC/89/01) PW7/2/25.15	19/03/90 to 25/03/90	Tai Lam Chung Ridgeline Seismic Refraction Survey	Determination of depth and state of weathering to determine cost of ridge line lowering for Chek Lap Kok Airport.	S.Rr.	<GCO> EGS	Not able to transmit enough energy into ground using 8kg hammer with plate leading to low signal to noise ratio and poor record quality.	13301
12	PW7/2/25.23	04/07/90 to 25/04/91	Regional Gravity Survey of Hong Kong	Production of Bouguer anomaly gravity map of Hong Kong.	G	<GCO> EGS/BGS	Gravity base stations established by BGS. General survey consisted of 133 marine and 507 land measurement stations.	14311
13	PW7/2/25.39	4/1991 to 5/1991	Tsing Chau Tsai Borrow Area Seismic Refraction Survey	Determination of quantity & quality of suitable fill.	S.Rr.	<GCO> EGS	Because of the wet conditions, buffalo gun was used as a stronger source. Good correlation with boreholes.	14362
14	PW7/2/25.43	18/03/91 to 26/03/91	Water Supply from China Beyond 1994 Ground Resistivity Survey	Determination of soil corrosivity for cathodic protection of water pipeline.	R	<GCO> EGS	The data gave a reasonable clear picture of the geo-electric layering at the measurement location.	14265
15	(GC/91/01) PW7/2/31.1	12/1991	Lantau Fixed Crossing Tsing Ma Bridge Tunnel Anchorage Tomographic Survey	Define & delineate areas of geological anomaly at anchor location.	S.T. & BH.L.	<GCO> EGS	Low signal to noise ratio resulted in poor data. Ground coupling may also have been poor as a result of substandard grouting of borehole linner.	15988
16	PW7/2/31.3	02/11/91 to 14/11/91	Green Island Link Preliminary Feasibility Study - Kau Yi Chau Land Seismic Refraction Survey	Determination of depth to grade I, II and III rock.	S.Rr.	<GCO> EGS	Low velocity zone (LVZ) due to deep weathering, faults and lithological boundary were identified. Reasonable borehole correlation. HDP primer explosive used as energy source.	15935
17	PW7/2/31.5	27/08/91 to 06/09/91	Ground Penetrating Radar Pulse EKKO IV System Trial Survey	Use of GPR in locating of coretones weathering interfaces, retaining walls thickness and location of services.	G.P.R.	<GCO> EGS/MGI	Frequency used 50, 100, 200 MHz. Max penetration is about 10m. Wall thickness determination failed and corestone postulated but not confirmed. Success with utilities.	15827
18	PW7/2/31.9	2/1992 to 3/1992	Route 3 Interchange Advanced Earthworks in North West Tsing Yi Seismic Refraction Survey	Determination of seismic velocity & thickness of strata.	S.Rr.	<GCO> EGS	Very good borehole correlation because of the use of large quantities of explosives as an energy source Depth of weathering and fault zone determined.	16232

Table B1 - Summary of Land Geophysics Carried Out for GEO to 1995 (Page 3 of 4)

No.	W.O.No.	Period of Fieldwork	Project Title	Objective of Survey	Geophysical Method	<Client> Contractor	Remarks	Report No.
19	PW7/2/31.11	14/01/92	Water Transfer to North Lantau and Raw Water Transfer to Silvermine Bay Treatment Works (Tung Chung)	Determination of the thickness and type of overburden and the level of the solid geology over the survey area.	S.Rr.	<GEO> EGS	Hammer and shot plate as energy source, good correlation with 12 boreholes.	16252
20	PW7/2/31.12	17/03/92 to 19/03/92	Water Transfer to North Lantau and Raw Water Transfer to Silvermine Bay Treatment Works (Siu Ho Wan)	Determination of the depth of overburden along selected traverses.	S.Rr.	<GEO> EGS	Low signal to noise ratio resulted in confused data mainly due to low energy source - 8kg hammer and plate.	16238
21	PW7/2/31.13	18/03/92 to 20/03/92	Water Transfer to North Lantau and Raw Water Transfer to Silvermine Bay Treatment Works (Pui O)	Determination of the depth of overburden and soil corrosivity for cathode protection of the proposed water pipe.	S.Rr. & R.	<GEO> EGS	Seasonal high water table affected the Geo-electric layering.	16231
22	W7/2/31.20	6/1992 to 8/1992	Feasibility Study at Kau Shat Wan Land Seismic refraction Survey	Examination of the probable zones of geological variance and determination of bulk seismic velocity.	S.Rr.	<GEO> EGS	Using of high velocity explosives and multiple coverage gave high quality data.	17121
23	PW7/2/31.27	10/1992 to 12/1992	Proposed Housing Development at Ma On Shan Area 90 - Phase 2 Cross hole Seismic Survey	To define and delinlate cavernous horizons between borehole pairs.	C.H.S.	<GEO> EGS	Extremely sensitive hydrophones and cables were used and the field works were done at night to reduce the noise level, reasonable results obtained.	17239
24	PW7/2/ 31.44A,B	22/08/93 to 24/08/93	North Lantau Geophysical Survey Land & Marine Gravity Survey	To define the dominant geological structures in the area.	M. & G.	<GEO> EGS	Gravity data suggested the presence of fold-belt of carboniferous sediments.	18143 to 18146
25	GE/93/05.14	23/03/94 to 27/03/94	FMS - Phase IV Land Borrow Area Investigation Fat Tong Chau (Junk Bay)	Determination of the depth of bedrock which is defined at the top of Grade III or better.	S.Rr.	<GEO> GT	Error in bedrock determination between 1 and 29m.	19194
26	GE/93/05.16	9/1994 to 10/1994	FMS - Phase IV Land Borrow Area Investigation Sunshine Island (Chau Kung To)	Delineate the level of the soil geology "top of rock" and to determine the seismic velocity of the various horizons encountered.	S.Rr.	<GEO> EGS	Good general correlation between the result and borehole data. Explosive used as energy source.	19479
27	GE/93/05.17	15/08/94 to 17/11/94	FMC - Phase IV Land Borrow Area Investigation Yam O Wan	Determination of the depth of bedrock which is defined at the top of Grade III or better.	S.Rr.	<GEO> GT	Seismic velocity of the grade III rock requires determination so that refractor identified can be termed ' bedrock '.	19408-09

Table B1 - Summary of Land Geophysics Carried Out for GEO to 1995 (Page 4 of 4)

No.	W.O.No.	Period of Fieldwork	Project Title	Objective of Survey	Geophysical Method	<Client> Contractor	Remarks	Report No.
28	GE/93/05.23	31/08/94 to 8/12//94	FMC - Phase IV Land Borrow Area Investigation, Hillslope Area at South of Penny's Bay	Determination of the depth of bedrock which is defined at the top of Grade III or better.	S.Rr.	<GEO> GT	Error in bedrock determination between 0 and 25m.	19477
29	GE/93/05.24	7/03/94 to 20/06/94	FMS - Phase IV Land Borrow Area Investigation Hillslope Area at Mong Hau Shek	Determination of the depth of bedrock which is defined at the top of Grade III or better.	S.Rr.	<GEO> GT	Error in bedrock determination between 0.5 and 27m.	19165
30	GE/93/05.38	1/1995	Route 16 West Kowloon - Shatin	Determination of the seismic velocity of the solid geology and location of Low Velocity Zone.	S.Rr.	<GEO> EGS	Shots were fired when the noise level was low. Generally good quality data. Explosives used as energy source.	19721
31	-----	2/05/90 to 21/05/90	CAP20 Cavern Studies - Shai Wan and Mount Davis Sites.	Delineation of weathered zones, fault and shear zones.	S.Rr.	<GEO> G.M.	Shear zones and depth to highly weathered to moderately weathered rock determined. Explosive sourse used.	-----
32	-----	12/94	Working Report of GeoRodar Detection of Retaining Wall 8SW-C/R1, Sai Kung, Hong Kong.	Determine the thickness of a thin masonry retaining wall.	GPR	<GEO> F.E.	Retaining wall thickness determined to be 0.5m which correlates well with borehole information.	-----

Footnote :

B.G.S. - British Geological Survey
BH.L - Bore Hole Logging
C.H.S. - Cross Hole Seismic
E.G.S. - Electronic and Geophysical Services
F.E. - Forest Engineering Geophysics Exploration Co.
G - Gravity Survey
G.C.O. - Geotechnical Control Office
G.E.O. - Geotechnical Engineering Office
G.M. - Geomap
G.P.R. - Ground Penetrating Radar
G.T.- Geoteam (H.K.) Ltd.
M - Magnetic Survey
M.G.I. - Multiview Geoservices Incorporated
R - Resistivity
S - Seismic
S.Rl - Seismic Reflection
S.Rr - Seismic Refraction
T - Tomography

Table B2 - A Summary of GPR Case Histories

Authors	Year	Equipment	Features Detected	Comments
Daniels & Roberts	1994	Not given in paper.	Stopes, drifts and rises in a sulphide mine in Montana.	Voids detected to a depth exceeding 10m.
Gogh et al	1994	pulseEKKO IV	(i) Loosely backfilled mine shafts. (ii) Cellars and a cave system in Budapest. (iii) Junction between limestone, clay and sandy sediments along a 200m length of highway. (iv) Seismics combined with GPR - fault system below a proposed power station. (v) Buried bunkers at a disused military site.	(i) Combined approach using electrical, electromagnetic and GPR. (ii) Cellars detected 1.5 to 2m b.g.l. and the caves to about 15m b.g.l. (iii) 100MHz antennas to map the layer to about 10m. (iv) Fault system mapped to 100m using the combined approach.
Roggenthen	1993	GSSI, Inc. with 100MHz antenna.	Old mine stopes and caves.	High power output to the antennas produced 10m penetration at sites with highly conductive soils.
Vaish & Gupta	1994	pulseEKKO III with 200MHz antennas.	Depth and lateral extent of abandoned mica and kaolin mine in south Delhi.	Mining works located to 3m b.g.l.
Deng et al	1994	pulseEKKO IV	Karstic features in dolomite.	Voids within Quaternary superficials together with karstic features within dolomite were identified to 14m b.g.l.
Beck & Ronen	1994	SIR-10 with 500MHz and 100MHz antennas.	(i) Dolomite cave system in Israel. (ii) Location of a smugglers tunnel. (iii) Concrete road pavement thickness.	(i) GRP towed across survey area using an ATV at 15km/hr. (ii) Tunnels located 3.5m b.g.l. in a sandy clay.
Davis & Annan	1992	pulseEKKO III with 100MHz antennas.	(i) Bedrock surface. (ii) Fractures and dykes in granite.	Bedrock surface mapped through saturated sands to 20m.
Bjelm et al	1983	Not given in paper.	Bedrock and water table below glacial till in Sweden.	Good correlation with excavations to 5m. Ground water at 11m b.g.l.
Robillard et al	1994	SIR 10	Bedrock along a cable route to 2m.	Mapped alternating limestone and marl beds and identified a fault. Penetration greatly reduced when soils were clay rich.
Grasmueck	1994	SIR 3 with 100MHz antennas.	Sub-horizontal stress relief discontinuities in dry granite.	Penetration depths of 50m achieved. CDP and migration techniques were used to obtain better depth resolution and signal to noise ratio.
Siggins	1990	SIR 8 WITH 500MHz antennas	Clay filled sheeting joints in a granite quarry.	Sheeting joints identified to 6m.
Sasahara	1995	SIR 10 with 100MHz to 900MHz antennas	Landslip prevention study to locate potential critical rock mass discontinuities in a tuff quarry.	Only clay filled discontinuities or discontinuities with water percolation were identified.
Scullion & Saarenketo	1995	Various GPR systems	Various types of road damage.	Investigate frost damage, subgrade compressibility, cracks, stripping and voids.
Piccolo & Zanelli	1994	SIR 10 with 100MHz and 500MHz antennas	Cavities and fractures behind concrete tunnel lining.	Delamination of the rock concrete interface, geo-structural features, open fractures, voids and honeycomb alteration identified.
Gourry et al	1995	pulseEKKO 1000 with 275MHz to 900MHz antenna.	Location of anomalies behind a masonry tunnel lining.	Thermography was used to detect small voids in the masonry only, GPR located voids at the masonry host rock interface.

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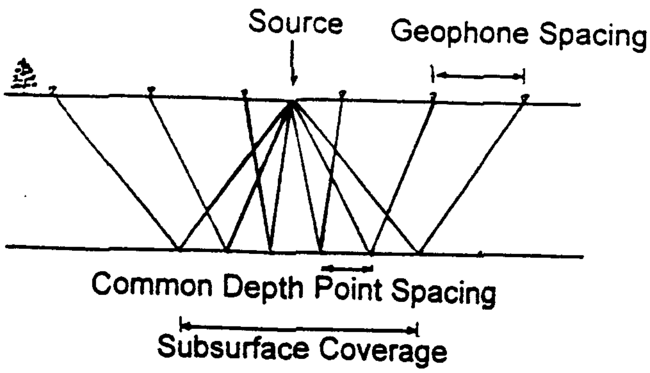
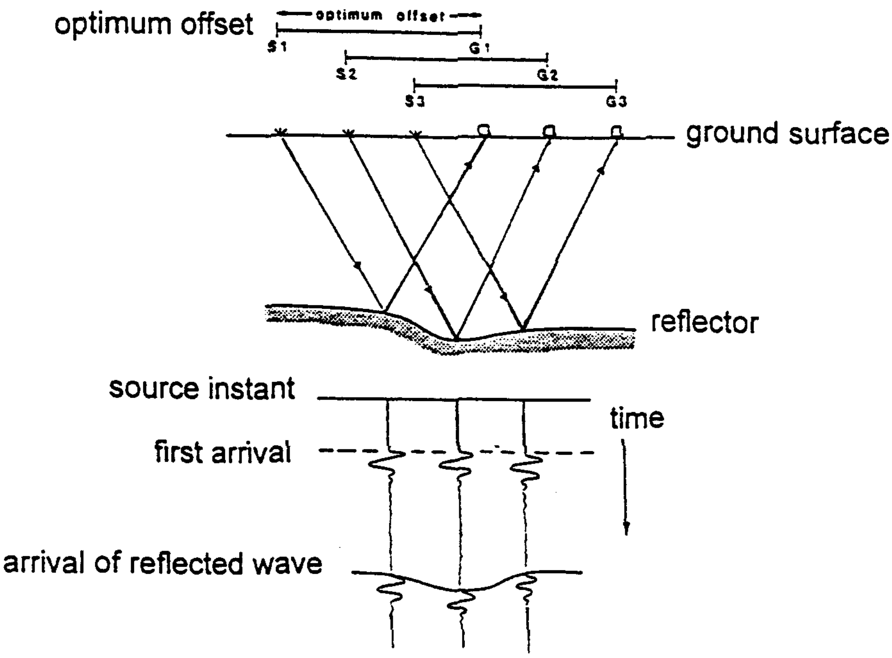
Simple Reflection Ray Paths

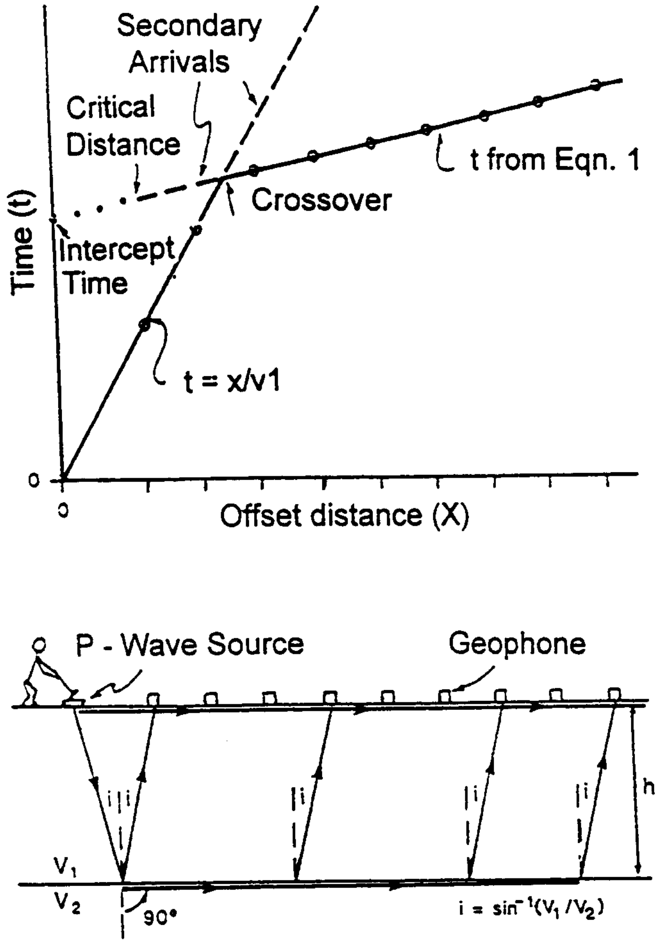


(a) Schematic view of reflection ray paths in a single layer case for a six-channel seismograph. Note that the common-depth-point spacing is exactly half the geophone spacing after Steeples and Miller (1990)



(b) The schematic optimum offset section shown at the bottom of the figure was produced by shooting first from S1 (source position 1) and recording the output from G1 (geophone 1), then from S2 to G2, and finally from S3 to G3 after Pullman and Hunter (1990)

Figure B1 - Shallow Seismic Reflection Ray Paths



Time-distance graph and direct and critically refracted raypaths in the ideal two-layer case. First break times are noted by large circles on the time-distance graph. Solid lines are defined by first breaks. Dashed lines on the time distance graph are secondary arrivals that might not be visible on a field record or might be difficult to time accurately.The dotted line is the projection to the intercept time based on critically refracted arrival times.

Figure B2 - Seismic Refraction Ray Paths and Time-Distance Graph after Larkston (1990)

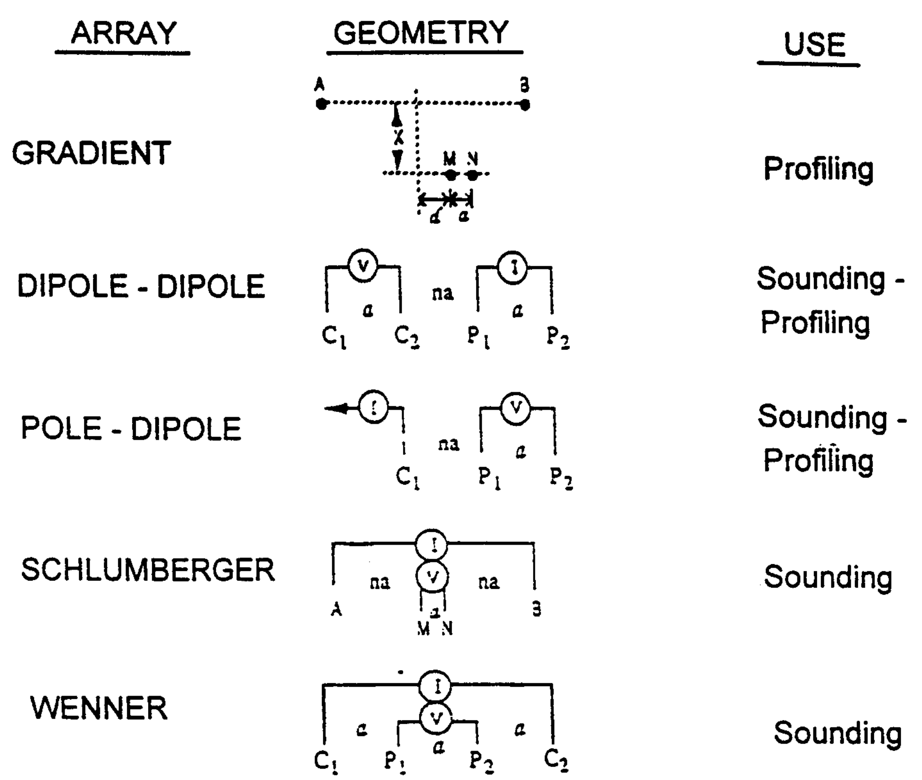


Figure B3 - Common Arrays Used in Resistivity and Induced-Polarisation after Ward (1990)

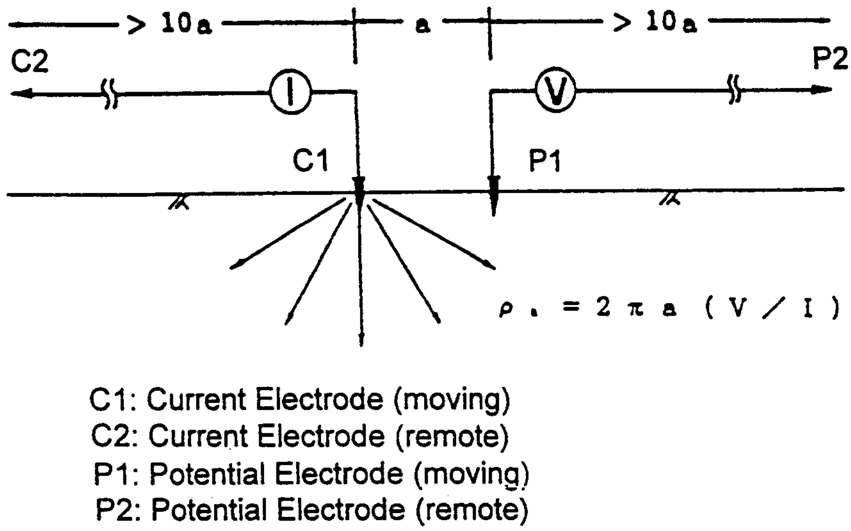


Figure B4 - Pole-Pole Electrode Array used in Resistivity Imaging after Shima et al (1990)

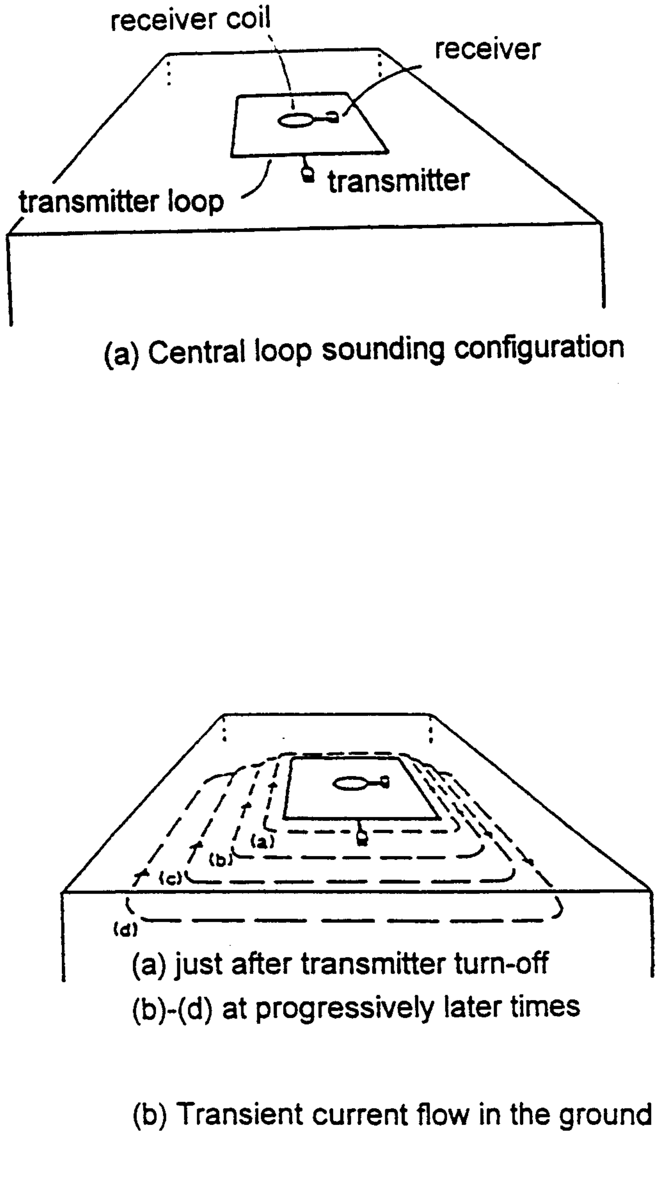
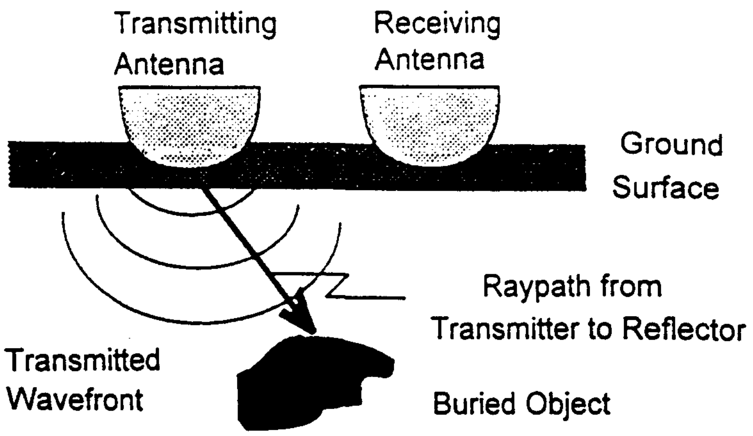
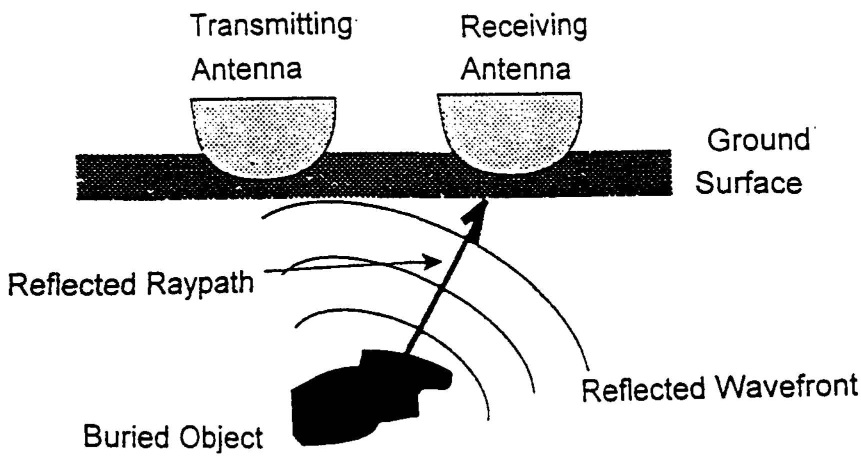


Figure B5 - Sounding Configuration and Transient Current Flow in TDEM after McNeil (1994)



(a) Radar wave transmitted as cylindrical spreading wave.



(b) Reflected wave from a point on a buried object.

Figure B6 - The GPR Reflection Process after Daniels and Roberts (1994)

APPENDIX C

PROFILES OF CONTRACTOR AND FIELD WORK PROGRESS

CONTENTS

C.1 PHASE 1 FIELD TRIALS

Bachy Soletanche (BS) tested seven geophysical methods between 5 and 13 December 1995. The contractor completed the trials eight days ahead of programme. The field team consisted of four geophysicists and two labourers. The exact location of the additional traverses made by BS can be found in the contractors report (Bachy Soletanche, 1996[a]). During the GPR survey at Sites A and B the contractor combined different frequency antennas in bistatic mode. The lower frequency (500MHz) antenna was used as the transmitter in order to obtain better penetration and the higher frequency (900MHz and 1GHz) antenna was used as the receiver to obtain higher resolution. The contractor profile and field records for Phase 1 can be found on Tables C1 and C2 respectively.

Fugro Geotechnical Services (HK) Ltd (FGS) tested three geophysical methods between 6 and 13 December 1995 (Fugro Geotechnical Services (HK) Ltd, 1996[a]). FGS completed the trials on programme. The field team consisted of three geophysicists and two labourers. FGS were the only contractor to use two different types of GPR equipment. They used the SIR 2 system manufactured by Geophysical Survey Systems Inc. and also the pulseEKKO 1000 system manufactured by Sensors and Software Inc. They also used a 35MHz antenna manufactured by Swedish firm Radarteam with the SIR 2 system. The contractor profile and field records for Phase 1 can be found on Tables C3 and C4 respectively.

Guandong South China EGTD Co.(GSC) tested four geophysical methods between 10 and 17 January 1996. They completed all the works one day ahead of programme. They had twelve geophysicists on site working in teams of three to four with one senior geophysicist in charge of each method. The exact location of the additional traverses made by GSC can be found in the contractor's report (Guandong South China EGTD Co., 1996[a]). The contractor profile and field records for Phase 1 can be found on Tables C5 and C6 respectively.

The Institute of Geophysical and Geochemical Exploration (IGGE) tested five geophysical methods between 15 to 29 January 1996. They completed all the works on programme. They had fifteen personnel on site split into five teams. Each team had a senior geophysicist dedicated to one of the geophysical methods. The exact location of the additional traverses made by IGGE can be found in the contractor's report (Institute of Geophysical and Geochemical Exploration, 1996[a]). For the GPR survey, the contractor used the SIR 10 system which is designed for mounting into a vehicle for highway investigations and can utilise up to 4 channels, allowing simultaneous operation of antennas with different frequencies. The system is not as compact as the SIR 2 system which is designed for field use. The contractor profile and field records for Phase 1 can be found on Tables C7 and C8 respectively.

Meinhardt Works (MW) tested five geophysical methods between 15 and 27 January 1996. They completed the trials on programme. The field work team consisted of two geophysicists and three labourers. The exact location of the additional traverses made by MW can be found in the contractor's report (Meinhardt Works, 1996[a]). The contractor profile and field records for Phase 1 can be found on Tables C9 and C10 respectively.

Golder Associates (GA) tested eight geophysical methods between 16 January and 12 February 1996. They completed the trials on programme. The field trial team consisted of two geophysicists and one labourer. The exact location of the additional traverses made by GA can be found in the contractor's report (Golder Associates, 1996[a]). The field work team made detailed site plans for each traverse, identifying every source of potential noise that could influence the geophysical results. They also used magnetic and electromagnetic utility detectors to locate metallic services which ran close to or across the traverse lines. The contractor profile and field records for Phase 1 can be found on Tables C11 and C12 respectively.

C.2 PHASE 2 FIELD TRIALS

Golder Associates carried out the full suite of tests between 1 and 10 October 1996. The works were carried by one senior geophysicist and a graduate geotechnical engineer. The preliminary results and interpretation based on the geophysics only can be found in the contractor's preliminary report (Golders, 1996[b]). The equipment and site methodology used was essentially the same as described in Appendix D apart from the following; the AGI model Sting R1 Earth Resistivity Meter was combined with the Swift system of 28 smart electrodes for the RI which improved the speed of the survey, and the seismic data for the SASW were collected using an Iotech Wavebook 512 instead of a spectral analyser. The team completed the works to programme. The contractor profile and field records for Phase 2 can be found on Tables C13 and C14 respectively.

Bachy Soletanche Group carried out the full suite of tests between 5 and 16 October 1996. The works were carried out by three geophysicists and two labourers. The preliminary results and interpretation based on the geophysics only can be found in the contractor's preliminary report (Bachy Soletanche, 1996[b]). The equipment and site methodology used was essentially the same as described in Appendix D. The contractor profile and field records for Phase 2 can be found on Tables C15 and C16 respectively.

Fugro Geotechnical Services (HK) Ltd. carried out GPR, RI and FDEM between 10 and 22 October 1996. The works were carried out by one senior geophysicist, graduate geophysicist and one labourer. The preliminary results and interpretation based on the geophysics only can be found in the contractor's preliminary report (Fugro, 1996[b]). The equipment and site methodology used was essentially the same as described in Appendix D apart from the following; the pulsEKKO 1000 GPR equipment was not used, and the Geopulse resistivity metre combined with an Imager 50 control module was used for the RI which improved the speed of the survey. Due to problems with the resistivity equipment the team completed the trials three days later than programmed. The contractor profile and field records for Phase 2 can be found on Tables C17 and C18 respectively.

Guandong South China EGTDC carried out GPR, RI and SASW between 22 and 29 October 1996. The RI survey was carried out at their own cost since they did not use this method in the Phase 1 trials. The works were carried out by a team of eight geophysicists. The preliminary results and interpretation based on the geophysics only can be found in the contractors preliminary report (Guandong South China EGTDC, 1996[b]). The equipment and site methodology used was essentially the same as described in Appendix D, apart from the RI equipment which is described in Table C19. The contractor also carried out SASW at all four sites at his own cost. The field trials were completed on programme. the contractor profile and field records for Phase 2 can be found on Tables C19 and C20 respectively.

The Institute of Geophysical and Geochemical Exploration (IGGE) carried out GPR, RI and SASW between 24 October 1996 to 1 November 1996. The works were carried out by a team of nine geophysicists. The preliminary results and interpretation based on the geophysics only can be found in the contractor's preliminary report (Institute of Geophysical and Geochemical Exploration, 1996[b]). The equipment and site methodology used was essentially the same as described in Appendix D. SASW was carried out at all four sites at the contractors own cost. The field trials were completed to programme. The contractor profile and field records for Phase 2 can be found on Tables C21 and C22 respectively.

C.3 REFERENCES

Bachy Soletanche (1996[a]) Site Characterisation Study Phase 1 Field Trials Engineering Geophysical Methods. Dated June 1996.

Bachy Soletanche Group (1996[b]) Preliminary Report, Site Characterisation Study Phase II Field Trials Engineering Geophysical Methods, 34p, 65 Figures, 2 Appendices.

Fugro Geotechnical Services (HK) Ltd. (1996[a]) Final Interpretative Report Site Characterisation Study Non-Invasive Engineering Geophysical Field Trials Phase I. Report No.572048, Revision No.02, dated 19 April 1996.

Fugro Geotechnical Services (HK) Ltd. (1996[b]). Preliminary Interpretative Report, Site Characterisation Study Non-invasive Engineering Geophysical Trials Phase II, in four Volumes, Vol.1 13p, 22 Figures, Vol.2 6p, 34 Figures, Vol.3, 6p, 25 Figures, Vol.4 7p, 33 Figures.

Golder Associates (1996[a]) Final Report to Government Engineering Office of Hong Kong - Field Trial of Eight Geophysical Techniques to Investigate Retaining Walls and Man-Made Slopes in Hong Kong. Dated May 17 1996, Reference 959-1029/IC3-1216.

Golder Associates Inc. (1996[b]). Preliminary Interpretative Report to Government Engineering Office of Hong Kong. Site Characterisation Study Non-Invasive Trials Phase II Field Trials Hong Kong, 969-1010/IC3-1278, 39p, 48 Figures, 1 Appendix.

Guangdong South China EGTDC. (1996[a]) Site Characterisation Study Phase 1 Field Trials Engineering Geophysical Methods Final Interpretative Report of GPR, SASW, HRSR and TDEM on Site "A", "B", "C" and "D". Dated March 1996.

Guandong South China EGTDC (1996[b]). Preliminary Interpretative Report of GPR, SASW and RI on Site E, F, G and H. Site Characterisation Study Phase 2 Field Trials Engineering Geophysical Methods, 19p, Appendix 1-48 Figures, Appendix 2-71 Figures.

Institute of Geophysical and Geochemical Exploration (1996[a]) Final Interpretative Report on Engineering Geophysical Methods. Dated June 3, 1996.

Institute of Geophysical and Geochemical Exploration (1996[b]). Preliminary Interpretative Report, on Site Characterisation Study - Phase 2 Field Trials Engineering Geophysical Methods. 23p, 120 Figures.

Meinhardt Works (Hong Kong) Ltd. (1996) Final Report Site Characterisation Study Geophysical Field Trials - Phase 1. Dated January 1996.

LIST OF TABLES

Table C1 - Contractor Profile - Phase 1 Field Trials

1. Main Contractor :
   Bachy Soletanche Group (BSG)

2. Joint Venture Companies :
   Europeanne De Geophysique (EDG)

3. The Non-invasive techniques used :
   a) Ground Penetrating Radar
   b) Spectral Analysis of Surface Waves
   c) Electromagnetic Method
   d) High Resolution Thermal Imaging
   e) Resistivity Imaging
   f) Self Potential
   g) Acoustic/Sonic Tool *(To be carried out at the contractor's own cost)

4. Names of Staff to be Employed on the Site Trials :
   - F. Lantier (EDG) - S. Geophy. & Geologist, ENSG NANCY, 28 years exp.
   - R. Foillard (EDG) - Geophysical Engineer, ENSG NANCY, 18 years exp.
   - M. Lassoved (EDG) - Physics degree, 4 years exp.
   - H.T. Burbidge (BSG) - Geotechnical Engineer, MSc, 12 years exp.

5. Equipment Details :

Technique	Manufacturer	Type
a) Ground Penetrating Radar	Geophysical Survey Systems Inc.	- SIR 2 System - 500, 900 and 1000MHz antenna's
b) Spectral Analysis of Surface Waves	Metravib Scientific Atlanta Metravib	- RAIO Seismograph - Spectral Dynamics SD380 Signal Ana. - CSH 05 Piezoelectric Accelerometer
c) Electromagnetic Method	Geonics	- EM38 terrain conductivity meter
d) High Resolution Thermal Imaging	AP PAAR	- IRS 3
e) Resistivity Imaging	EDG	- Multiplex voltmeter - Non-polarizing Electrodes
f) Self Potential	Geoinstrument Geotrode	- Millivdtmeter - Non-polarizing Electrodes
g) Acoustic/Sonic Tool	Metravib Scientific Atlanta PUNDIT	- RAIO Seismograph - Spectral Dynamics SD380 Signal Ana. - 24 & 54 kHz Transducers

Table C2 - Field Records - Phase 1 Field Trials - Bachy Soletanche Group

Geophysical Methods	Trial Site	Start Date	End Date	Person In Charge	Remarks
GPR	A	06.12.95	06.12.95	R. Foillard	Problems encountered at sites B and C with scaffolding obstructing the lowerin of antenna's down the wall profiles.
	B	08.12.95	08.12.95		
	C	05.12.95	05.12.95		
	D	07.12.95	07.12.95		
SASW	A	06.12.95	07.12.95	M. Lassoved	Metravib CSH 05 (3KHz) piezoelectric accelerometers used.
	B	08.12.95	08.12.95		
	C	05.12.95	05.12.95		
	D	07.12.95	07.12.95		
EM	A	06.12.95	06.12.95	F. Lantier	Initial site reading influenced by surface metallic objects such as manhole covers, drain pipes and metal window frames.
	B	09.12.95	09.12.95		
	C	05.12.95	05.12.95		
	D	07.12.95	07.12.95		
HRTI	A	10.12.95	10.12.95	F. Lantier	Surveys made between 00:00hrs and 02:00hrs.
	B	10.12.95	10.12.95		
	C	10.12.95	10.12.95		
	D	09.12.95	09.12.95		
RI	A	06.12.95	07.12.95	F. Lantier	Hilti Bolts used as electrodes. Dipole-dipole electrode array adopted.
	B	09.12.95	09.12.95		
	C	05.12.95	05.12.95		
	D	07.12.95	08.12.95		
SP	A	06.12.95	07.12.95	F. Lantier	Geotrode non-polarising copper sulphate electrodes with sponge soaked in copper sulphate attached to base to ensure good contact. Fixed base electrode configuration adopted.
	B	08.12.95	08.12.95		
	C	05.12.95	05.12.95		
	D	08.12.95	08.12.95		
(AST)	A	06.12.95	07.12.95	M. Lassoved	PUNDIT equipment used to measure seismic velocity in masonry wall facing and concrete tie beams.
	B	08.12.95	08.12.95		
	C	05.12.95	05.12.95		
	D	07.12.95	07.12.95		

Key :

Trial Site "A" - Kennedy Town Police Quarters
Trial Site "B" - Eliot Hall, University of Hong Kong
Trial Site "C" - Sir Ellis Kadoori School, So Kan Po
Trial Site "D" - Cape Collisinson Crematorium, Chai Wan
GPR - Ground Penetrating Radar
SASW - Spectral Analysis of Surface Waves
HRSR - High Resolution Seismic Reflection
EM - Electromagnetic Method
HRTI - High Resolution Thermal Imaging
RI - Resistivity Imaging
SP - Self Potential
(AST) - Acoustic/Sonic Tool
(SR) - Seismic Refraction
(MEMUS) - Magnetic/EM Utility Scan
( ) - To be carried out at the contractors own cost

Table C3 - Contractor Profile - Phase 1 Field Trials

1. Main Contractor :
   Fugro Geotechnical Services (HK) Ltd. (FGS)

2. Joint Venture Companies :
   British Geological Survey (BGS)

3. The Non-invasive techniques used :
   a) Ground Penetrating Radar
   b) Electromagnetic Method
   c) Resistivity Imaging

4. Names of Staff to be Employed on the Site Trials :
   - A. K. Whittle (FGS) - Geophysicist, 20 years exp.
   - D. A. Pearks (FGS) - BSc, MSc(Geophy)
   - Dr J. P. Busby (BGS) - BSc, PhD, 12 years exp.

5. Equipment Details :

Technique	Manufacturer	Type
a) Ground Penetrating Radar	Geophysical Survey Systems Inc. Radarteam Sensors & Software Inc.	- SIR 2 System - 500 MHz antenna - 35 MHz antenna (2no.) - pulsEKKO 1000 console - 225, 450 and 900 MHz antenna's
b) Electromagnetic Method	Geonics	- EM31 conductivity meter
c) Resistivity Imaging	ABEM Instruments AB	- Terrameter SAS 300B - Steel electrodes

Table C4 - Field Records - Phase 1 Field Trials - Fugro Geotechnical Services (HK) Ltd.

Geophysical Methods	Trial Site	Start Date	End Date	Person In Charge	Remarks
GPR	A	08.12.95	09.12.95	Dr. J.P. Busby and A.K. Whittle	A.K. Whittle in charge of the SIR 2 system and Dr. J.P. Busby in charge of the pulsEKKO 1000. 35 MHz anten. used in bistatic mode at site C.
	B	06.12.95	07.12.95		
	C	11.12.95	12.12.95		
	D	13.12.95	13.12.95		
EM	A	08.12.95	08.12.95	Dr. J.P. Busby	Scaffolding at site B and C interfered with the lowering of the EM31 down the wall profile (3.6m boom). High levels of interference caused by surface metallic objects noted.
	B	06.12.95	06.12.95		
	C	11.12.95	11.12.95		
	D	13.12.95	14.12.95		
RI	A	09.12.95	09.12.95	Dr. J.P. Busby	10mm diameter stainless steel pins inserted into pre-drilled holes used as electrodes. Dipole-dipole electrode array utilised.
	B	07.12.95	07.12.95		
	C	12.12.95	12.12.95		
	D	13.12.95	14.12.95		

Key :

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Trial Site "D" - Cape Collisinson Crematorium, Chai Wan
GPR - Ground Penetrating Radar
SASW - Spectral Analysis of Surface Waves
HRSR - High Resolution Seismic Reflection
EM - Electromagnetic Method
HRTI - High Resolution Thermal Imaging
RI - Resistivity Imaging
SP - Self Potential
(AST) - Acoustic/Sonic Tool
(SR) - Seismic Refraction
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( ) - To be carried out at the contractors own cost

Table C5 - Contractor Profile - Phase 1 Field Trials

1. Main Contractor :
   Guangdong South China EGTD Co.

2. Joint Venture Companies :
   None

3. The Non-invasive techniques used :
   a) Ground Penetrating Radar
   b) Spectral Analysis of Surface Waves
   c) Electromagnetic Method
   d) High Resolution Seismic Reflection

4. Names of Staff to be Employed on the Site Trials :

- Lin Youcong	- Sen. Geophysic Engineer, MCSST, MCSG, 30 years exp.
- Huang Weiyi	- Sen. Geophysic Engineer
- Zhang Xihong	- Sen. Geophysic Engineer
- Zhao Ming	- Geophysic Engineer
- Huang Jianxin	- Geophysic Engineer

5. Equipment Details :

Technique	Manufacturer	Type
a) Ground Penetrating Radar	Geophysical Survey Systems Inc.	- SIR 2 and SIR 10H System - 100(2no.), 500 and 900MHz antenna's
b) Spectral Analysis of Surface Waves	Geometric	- Strata View R24 signal seismograph - 10 and 60 Hz geophones
c) Electromagnetic Method	He Caoming Specialist Group	- WDC-2 Time Domain Electromagnetic Observing System
d) High Resolution Seismic Reflection	Geometric	- Strata View R24 signal seismograph - 60 ~ 100 Hz geophones

Table C6 - Field Records - Phase 1 Field Trials - Guangdong South China EGTD Co.

Geophysical Methods	Trial Site	Start Date	End Date	Person In Charge	Remarks
GPR	A	13.01.96	13.01.96	Huang Jianxin	SIR 2 system only used at site D where access was difficult down the fill slope. 100MHz antenna's used in both monostatic and bistatic mode.
	B	17.01.96	17.01.96		
	C	11.01.96	11.01.96		
	D	10.01.96	10.01.96		
SASW	A	13.01.96	13.01.96	Zhang Xihong	Multiple geophone array utilised in conjunction with Strata View 24.
	B	17.01.96	17.01.96		
	C	11.01.96	11.01.96		
	D	10.01.96	10.01.96		
EM	A	13.01.96	13.01.96	Huang Weiyi	Time domain electromagnetic method tested. Electrical interference from metallic objects noted during field work especially at sites A, B and C.
	B	17.01.96	17.01.96		
	C	11.01.96	11.01.96		
	D	10.01.96	10.01.96		
HRSR	A	13.01.96	13.01.96	Zhang Xihong	
	B	17.01.96	17.01.96		
	C	11.01.96	11.01.96		
	D	10.01.96	10.01.96		

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GPR - Ground Penetrating Radar
SASW - Spectral Analysis of Surface Waves
HRSR - High Resolution Seismic Reflection
EM - Electromagnetic Method
HRTI - High Resolution Thermal Imaging
RI - Resistivity Imaging
SP - Self Potential
(AST) - Acoustic/Sonic Tool
(SR) - Seismic Refraction
(MEMUS) - Magnetic/EM Utility Scan
( ) - To be carried out at the contractors own cost

Table C7- Contractor Profile - Phase 1 Field Trials

1. Main Contractor :
   Institute of Geophysical and Geochemical Exploration, China (IGGE)

2. Joint Venture Companies :
   Forest Engineering Geophysics Exploration Co. (FEGE)

3. The Non-invasive techniques used :
   a) Ground Penetrating Radar
   b) Spectral Analysis of Surface Waves
   c) Electromagnetic Method
   d) High Resolution Seismic Reflection
   e) Resistivity Imaging

4. Names of Staff to be Employed on the Site Trials :

- Yi Yongsen	(IGGE)	- Senior Geophysicist, Director of IGGE
- Yie Shumin	(IGGE)	- Senior Geophysicist, deputy Director of IGGE
- Yang Piyuan	(IGGE)	- Senior Geophysicist
- Zhou Anchang	(IGGE)	- Senior Geophysicist
- Wu Zhiping	(IGGE)	- Senior Geophysicist
- Hu Ping	(IGGE)	- Senior Geophysicist
- Xu mingcai	(IGGE)	- Senior Geophysicist

5. Equipment Details :

Technique	Manufacturer	Type
a) Ground Penetrating Radar	Geophysical Survey Systems Inc.	- SIR 10A System - 100(2no.), 500 and 900, MHz antenna's
b) Spectral Analysis of Surface Waves	Hewlett-Packard Hewlett-Packard Hewlett-Packard Hewlett-Packard	- Dual-channel Dynamic Singal Analyzer - Computer - Thermo printer - Ploter with six pen
c) Electromagnetic Method	Crone Geophysics & Exploration Ltd.	- Digital pulse EM system
d) High Resolution Seismic Reflectio	Geometrics	- ES-2401 Seismograph - 100 Hz geophones
e) Resistivity Imaging	Zonge Engineering & Research Organization	- GRP-32 wide-band electric survey system

Table C8 - Field Records - Phase 1 Field Trials - Institute of Geophysical and Geochemical Exploration

Geophysical Methods	Trial Site	Start Date	End Date	Person In Charge	Remarks
GPR	A	24.01.96	24.01.96	Wu Zhiping	100Mhz antenna's used in both monosatic and bistatic mode.
	B	19.01.96	19.01.96		
	C	16.01.96	16.01.96		
	D	18.01.96	18.01.96		
SASW	A	25.01.96	25.01.96	Yang Piyuan	SASW tried along concrete tie beam at site B.
	B	19.01.96	29.01.96		
	C	15.01.96	16.01.96		
	D	27.01.96	27.01.96		
EM	A	24.01.96	24.01.96	Hu Ping	Time domain electromagnetic method tested.
	B	19.01.96	19.01.96		
	C	16.01.96	16.01.96		
	D	17.01.96	17.01.96		
HRSR	A	24.01.96	24.01.96	Xu Mingcai	At site B, geophones set up along TB03 with energy source initiated at increasing distances from wall along the May Hall platform.
	B	20.01.96	29.01.96		
	C	16.01.96	16.01.96		
	D	18.01.96	18.01.96		
RI	A	25.01.96	25.01.96	Zhou Anchang	Dipole-dipole electrodes array utilised with both stainless steel and copper electrodes.
	B	20.01.96	20.01.96		
	C	15.01.96	16.01.96		
	D	27.01.96	27.01.96		

Key :

Trial Site "A" - Kennedy Town Police Quarters
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Trial Site "C" - Sir Ellis Kadoori School, So Kan Po
Trial Site "D" - Cape Collisinson Crematorium, Chai Wan
GPR - Ground Penetrating Radar
SASW - Spectral Analysis of Surface Waves
HRSR - High Resolution Seismic Reflection

EM - Electromagnetic Method
HRTI - High Resolution Thermal Imaging
RI - Resistivity Imaging
SP - Self Potential
(AST) - Acoustic/Sonic Tool
(SR) - Seismic Refraction
(MEMUS) - Magnetic/EM Utility Scan
( ) - To be carried out at the contractors own cost

Table C9 - Contractor Profile - Phase 1 Field Trials

1. Main Contractor :
   Meinhardt Works

2. Joint Venture Companies :
   Fong On Construction (FOC) , Bay Geophysical Associates Inc., (BG) and Works Consultancy Service. (W)

3. The Non-invasive techniques used :
   a) Ground Penetrating Radar
   b) Spectral Analysis of Surface Waves
   c) Electromagnetic Method
   d) Resistivity Imaging
   e) Self Potential

4. Names of Staff to be Employed on the Site Trials :

- A. J. Sutherland	(W)	- NZCScience(Geo), 12 years exp.
- S. Mcquown	(BG)	
- S. Lai	(FOC)	- HD(Eng), 5 years exp.

5. Equipment Details :

Technique	Manufacturer	Type
a) Ground Penetrating Radar	Geophysical Survey Systems Inc.	- SIR 2 System - 200, 400, 500MHz antenna's
b) Spectral Analysis of Surface Waves	Toshiba Metrabyte Bruel & Kjaer Bruel & Kjaer	- T4700CS laptop computer - DAS 1602 A/D board - Model 4384 Accelerometer (Piezoelectric transducer) - Model 2635 Charge Amplifier
c) Electromagnetic Method	Geonics	- EM 31-D terrain conductivity meter
d) Resistivity Imaging	ABEM	- Terrameter (SAS 300) resistivity meter - 24 no. 6mm diameter stainless steel tube electrodes
e) Self Potential	ABEM	- Terrameter (SAS 300) resistivity/SP meter - Copper-copper sulphate non-polarizing electrodes

Table C10 - Field Records - Phase 1 Field Trials - Meinhardt Works

Geophysical Methods	Trial Site	Start Date	End Date	Person In Charge	Remarks
GPR	A	22.01.96	23.01.96	S. Mcquown	Problems encountered on sites B and C with scaffolding obstructing to lowering of the antenna's down the wall profiles.
	B	15.01.96	18.01.96		
	C	17.01.96	18.01.96		
	D	19.01.96	20.01.96		
SASW	A	20.01.96	20.01.96	A. Sutherland	Voids below surface slabs at sites A and B caused coupling problems. No spectral analysis made on site, only data collection.
	B	24.01.96	25.01.96		
	C	26.01.96	27.01.96		
	D	23.01.96	23.01.96		
EM	A	22.01.96	23.01.96	S. Mcquown	High level of interference caused by surface metallic objects, especially at sites A, B and C.
	B	16.01.96	16.01.96		
	C	N.A.	N.A.		
	D	20.01.96	20.01.96		
RI	A	19.01.96	20.01.96	A. Sutherland	Dipole-dipole electrode array used.
	B	24.01.96	25.01.96		
	C	26.01.96	26.01.96		
	D	22.01.96	22.01.96		
SP	A	19.01.96	19.01.96	A. Sutherland	Fixed base and gradient array electrode configuration used.
	B	24.01.96	25.01.96		
	C	26.01.96	26.01.96		
	D	23.01.96	23.01.96		

Key :

Trial Site "A" - Kennedy Town Police Quarters
Trial Site "B" - Eliot Hall, University of Hong Kong
Trial Site "C" - Sir Ellis Kadoori School, So Kan Po
Trial Site "D" - Cape Collisinson Crematorium, Chai Wan
GPR - Ground Penetrating Radar
SASW - Spectral Analysis of Surface Waves
HRSR - High Resolution Seismic Reflection

EM - Electromagnetic Method
HRTI - High Resolution Thermal Imaging
RI - Resistivity Imaging
SP - Self Potential
(AST) - Acoustic/Sonic Tool
(SR) - Seismic Refraction
(MEMUS) - Magnetic/EM Utility Scan
( ) - To be carried out at the contractors own cost

Table C11 - Contractor Profile - Phase 1 Field Trials

1. Main Contractor :
   Golder Associates (HK) Limited (GAL)

2. Joint Venture Companies :
   Dr. Soheil Nazarian Independent Consultant (SNIC) and Testconsult (HK) Ltd. (TCL)

3. The Non-invasive techniques used :
   a) Ground Penetrating Radar
   b) Spectral Analysis of Surface Waves
   c) Seismic Reflection
   d) Electromagnetic Method
   e) Infrared Thermography
   f) Resistivity Imaging
   g) Self Potential
   h) Seismic Refraction *

   * (carried out at the contractor's own cost)

4. Names of Staff to be Employed on the Site Trials :

- G. Schneider	(GAL)	- MSc, (Geophysics)
- Dr. I. Bishop	(GAL)	- MSc, PhD(Geophysics), 10 years exp.
- Dr. S. Nazarian	(SNIC)	- PhD, 13 years exp.
- C. Stanley	(TCL)	- 30 years exp. in infra-red thermograph

5. Equipment Details :

Technique	Manufacturer	Type
a) Ground Penetrating Radar	Geophysical Survey Systems Inc. EPC Seiko	- SIR 2 & SIR 8 Systems - 100, 300, 500, 900 and 1000MHz antenna's - 8700 Thermal Printer - SII printer
b) Spectral Analysis of Surface Waves	Tektronix	- 2630 Fourier Analyser - 1 Hz , 4.5Hz and 30Hz geophones - 1000Hz seismic accelerometers - Geological pick or sledge hammer
c) High Resolution Seismic Reflection	Bison Instruments Mark Products	- 24-channel Bison 7024 digital instantaneous Floating point stacking seismograph - 30Hz geophones
d) Electromagnetic Method	Geonics	- EM 31-D and EM38 terrain conductivity meter
e) High Resolution Thermal Imaging	AGEMA	- Thermovision 880 longwave infrared scanner
f) Resistivity Imaging	Advanced Geoscience Inc.	- Sting R1 Earth Resistivity Meter - 30 cm long steel electrodes
g) Self Potential	Advanced Geoscience Inc.	- Sting R1 Earth Resistivity Meter - Non-polarizing Electrodes
h) Seismic Refraction	Bison Instruments Mark Products	- 24-channel Bison 7024 digital instantaneous Floating point stacking seismograph - 30Hz geophones

Table C12 - Field Records - Phase 1 Field Trials - Golder Associates (HK) Ltd.

Geophysical Methods	Trial Site	Start Date	End Date	Person In Charge	Remarks
GPR	A	16.01.96	18.01.96	Dr. I. Bishop	SIR 8 system with thermal printer used initially to obtain a feeling for ground Condition. Majority of work done with SIR 2 system.
	B	22.01.96	27.01.96		
	C	19.01.96	23.01.96		
	D	24.01.96	24.01.96		
SASW	A	31.01.96	31.01.96	Dr. S. Nazarian	Accelerometers used for small spacing ie. high resolution high freq. waves. Geophones used for large spacing low frequency waves. Voids below surface slab caused some problems.
	B	31.01.96	31.01.96		
	C	01.02.96	01.02.96		
	D	30.01.96	30.01.96		
HRSR	A	18.01.96	18.01.96	G. Schneider	On site inspection of the seismic records indicated that no reflected waves were being recorded only direct and air waves and possibly refracted waves.
	B	27.01.96	27.01.96		
	C	20.01.96	20.01.96		
	D	25.01.96	25.01.96		
EM	A	16.01.96	16.01.96	G. Schneider	Only success was at site D where the EM31 was used to survey the horizontal platform at a 1m grid spacing.
	B	22.01.96	29.01.96		
	C	19.01.96	23.01.96		
	D	24.01.96	24.01.96		
HRTI	A	31.01.96	07.02.96	C. Stanley	Surveys made during late part of afternoon to ensure surfaces had been exposed to max. amount of sunlight apart from site C which was surveyed in the morning.
	B	12.02.96	12.02.96		
	C	12.02.96	12.02.96		
	D	N/A	N/A		
RI	A	17.01.96	17.01.96	G. Schneider	Both the Wenner and Dipole-dipole electrode arrays were used during the trials.
	B	29.01.96	29.01.96		
	C	23.01.96	23.01.96		
	D	26.01.96	26.01.96		
SP	A	N/A	N/A	Dr. I. Bishop	Self potential method only made at site D where direct contact with the soil could be made with the electrodes. Fixed base electrode configuration used.
	B	N/A	N/A		
	C	N/A	N/A		
	D	25.01.96	26.01.96		
(SR)	A	18.01.96	18.01.96	G. Schneider	Refraction data collected during HRSR survey. Good refraction data collected at site D.
	B	27.01.96	27.01.96		
	C	20.01.96	20.01.96		
	D	25.01.96	25.01.96		

Key :

Trial Site "A" - Kennedy Town Police Quarters
Trial Site "B" - Eliot Hall, University of Hong Kong
Trial Site "C" - Sir Ellis Kadoori School, So Kan Po
Trial Site "D" - Cape Collisinson Crematorium, Chai Wan
GPR - Ground Penetrating Radar
SASW - Spectral Analysis of Surface Waves
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EM - Electromagnetic Method
HRTI - High Resolution Thermal Imaging
RI - Resistivity Imaging
SP - Self Potential
(AST) - Acoustic/Sonic Tool
(SR) - Seismic Refraction
(MEMUS) - Magnetic/EM Utility Scan
( ) - To be carried out at the contractors own cost

Table C13 - Contractor Profile - Phase 2 Field Trials

1. Main Contractor : Golder Associates (HK) Limited		
2. Joint Venture Companies : None		
3. The Non-invasive techniques used : a) Ground Penetrating Radar b) Spectral Analysis of Surface Waves c) Resistivity Imaging d) Spectral Analysis of Surface Waves		
4. Names of Staff to be Employed on the Site Trials : - Dr. I. Bishop - MSc, PhD(Geophysics), 10 years exp.		
5. Equipment Details :		
Technique	Manufacturer	Type
a) Ground Penetrating Radar	Geophysical Survey Systems Inc. Seiko	- SIR 2 Systems - 100, 500 and 900 MHz antenna's - SII printer
b) Spectral Analysis of Surface Waves	Tektronix	- 2630 Fourier Analyser - 4.5Hz geophones - sledge hammer
c) Resistivity Imaging	Advanced Geoscience Inc.	- Sting R1 Earth Resistivity Meter - 30 cm long steel electrodes
d) Electromagnetic Method	Geonics	- EM 31-Dterrain conductivity meter

Table C14 - Field Records - Phase 2 Field Trials - Golder Associates (HK) Ltd.

Geophysical Methods	Trial Site	Start Date	End Date	Person In Charge	Remarks
GPR	E	01.10.96	01.10.96	I. Bishop	Bamboo scaffolding at site G obstructed the antenna's steady movement along the horizontal traverses.
	F	03.10.96	03.10.96		
	G	07.10.96	07.10.96		
	H	09.10.96	09.10.96		
SASW	H	09.10.96	09.10.96	I. Bishop	
EM	G	05.10.96	08.10.96	I. Bishop	Surveys made at 1m centers in a grid pattern at both sites.
	H	09.10.96	09.10.96		
RI	E	02.10.96	02.10.96	I. Bishop	Steel nails used as electrodes.
	F	04.10.96	04.10.96		
	G	08.10.96	08.10.96		
	H	09.10.96	09.10.96		

Key :

Trial Site "E" - North of Stubbs Villa, Stubbs Road
Trial Site "F" - Police Quarters, Block B, Hollywood Road
Trial Site "G" - Blue Pool Road
Trial Site "H" - Sze Yu House, Choi Wan Estate

GPR - Ground Penetrating Radar
SASW - Spectral Analysis of Surface Waves
EM - Electromagnetic Method
RI - Resistivity Imaging

Table C15 - Contractor Profile - Phase 2 Field Trials

1. Main Contractor :
   Bachy Soletanche Group (BSG)

2. Joint Venture Companies :
   Europeanne De Geophysique (EDG)

3. The Non-invasive techniques used :
   a) Ground Penetrating Radar
   b) Electromagnetic Method
   c) Resistivity Imaging
   d) Spectral Analysis of Surface Waves

4. Names of Staff to be Employed on the Site Trials :

- F. Lantier	(EDG)	- S. Geophy. & Geologist, ENSG NANCY, 28 years exp.
- R. Foillard	(EDG)	- Geophysical Engineer, ENSG NANCY, 18 years exp.
- M. Lassoved	(EDG)	- Physics degree, 4 years exp.
- J.M. Ragot	(EDG)	- Geophysical Engineer, BSc, 14 years exp.

5. Equipment Details :

Technique	Manufacturer	Type
a) Ground Penetrating Radar	Geophysical Survey Systems Inc.	- SIR 2 System - 500, 900 and 1000MHz antenna's
b) Electromagnetic Method	Geonics	- EM38 terrain conductivity meter
c) Resistivity Imaging	EDG	- Multiplex voltmeter - Non-polarizing Electrodes
d) Spectral Analysis of Surface Waves	Metravib Scientific Atlanta Metravib	- RAIO Seismograph - Spectral Dynamics SD380 Signal Ana. - CSH 05 Piezoelectric Accelerometer

Table C16 - Field Records - Phase 2 Field Trials - Bachy Soletanche Group

Geophysical Methods	Trial Site	Start Date	End Date	Person In Charge	Remarks
GPR	E	05.10.96	05.10.96	R. Foillard	Bamboo scaffolding at site G obstructed the antenna's steady movement along the horizontal traverses.
	F	08.10.96	08.10.96		
	G	09.10.96	10.10.96		
	H	07.10.96	07.10.96		
SASW	H	10.10.96	12.10.96	M. Lassoved	Generator used to produce constant frequency vibrations.
EM	G	10.10.96	10.10.96	J.M. Ragot	Anomalies caused by fence, vehicles and a Towngas pipe.
	H	07.10.96	07.10.96		
RI	E	05.10.96	05.10.96	J.M. Ragot	Hilti-bolts used as electrodes.
	F	08.10.96	08.10.96		
	G	09.10.96	10.10.96		
	H	07.10.96	07.10.96		

Key :

Trial Site "E" - North of Stubbs Villa, Stubbs Road
Trial Site "F" - Police Quarters, Block B, Hollywood Road
Trial Site "G" - Blue Pool Road
Trial Site "H" - Sze Yu House, Choi Wan Estate

GPR - Ground Penetrating Radar
SASW - Spectral Analysis of Surface Waves
EM - Electromagnetic Method
RI - Resistivity Imaging

Table C17 - Contractor Profile - Phase 2 Field Trials

1. Main Contractor :
   Fugro Geotechnical Services (HK) Ltd.

2. Joint Venture Companies :
   None

3. The Non-invasive techniques used :
   a) Ground Penetrating Radar
   b) Electromagnetic Method
   c) Resistivity Imaging

4. Names of Staff to be Employed on the Site Trials :
   - A. K. Whittle - Geophysicist, 20 years exp.
   - D. A. Pearks - BSc, MSc(Geophy)

5. Equipment Details :

Technique	Manufacturer	Type
a) Ground Penetrating Radar	Geophysical Survey Systems Inc. Radarteam	- SIR 2 System - 500 MHz antenna - 35 MHz antenna (2no.)
b) Electromagnetic Method	Geonics	- EM31 conductivity meter
c) Resistivity Imaging	ABEM Instruments AB	- Terrameter SAS 300B - Steel electrodes

Table C18 - Field Records - Phase 2 Field Trials - Fugro Geotechnical Services (HK) Ltd.

Geophysical Methods	Trial Site	Start Date	End Date	Person In Charge	Remarks
GPR	E	10.10.96	10.10.96	A.K. Whittle	G.P.R. over heating problem at site G. Only relatively low frequency antenna's used 200MHz + 35MHz
	F	12.10.96	12.10.96		
	G	15.10.96	15.10.96		
	H	16.10.96	16.10.96		
EM	G	15.10.96	16.10.96	A.K. Whittle	EM surveys carried out at 1m grid at both sites
	H	17.10.96	17.10.96		
RI	E	11.10.96	18.10.96	A.K. Whittle	Delays in RI survey caused by equipment failure
	F	19.10.96	19.10.96		
	G	22.10.96	22.10.96		
	H	17.10.96	17.10.96		

Key :

Trial Site "E" - North of Stubbs Villa, Stubbs Road
Trial Site "F" - Police Quarters, Block B, Hollywood Road
Trial Site "G" - Blue Pool Road
Trial Site "H" - Sze Yu House, Choi Wan Estate

GPR - Ground Penetrating Radar
SASW - Spectral Analysis of Surface Waves
EM - Electromagnetic Method
RI - Resistivity Imaging

Table C19 - Contractor Profile - Phase 2 Field Trials

1. Main Contractor :
Guangdong South China EGTD Co.

2. Joint Venture Companies :
None

3. The Non-invasive techniques used :
a) Ground Penetrating Radar
b) Spectral Analysis of Surface Waves
c) Resistivity Imaging

4. Names of Staff to be Employed on the Site Trials :

- Lin Youcong	- Sen. Geophysic Engineer, MCSST, MCSG, 30 years exp.
- Huang Weiyi	- Sen. Geophysic Engineer
- Zhang Shihong	- Sen. Geophysic Engineer
- Zhao Ming	- Geophysic Engineer
- Ge Rubing	- Geophysic Engineer
- Meng Fangiang	- Assist Geophysic Engineer
- Zhang Yuming	- Assist Geophysic Engineer

5. Equipment Details :

Technique	Manufacturer	Type
a) Ground Penetrating Radar	Geophysical Survey Systems Inc.	- SIR 2 and SIR 10H System - 100(2no.), and 500 MHz antenna's
b) Spectral Analysis of Surface Waves	Geometric	- Strata View R24 signal seismograph - 4.5, 10 and 60 Hz geophones
c) Resistivity Imaging	Machinery & Electron. Institute, Ministry of Geology & Mineral Resources, PRC.	- MIS-2 Multi-electrode Switch - MIR-1C Voltmeter

Table C20 - Field Records - Phase 2 Field Trials - Guandong South China EGTD Co.

Geophysical Methods	Trial Site	Start Date	End Date	Person In Charge	Remarks
GPR	E	22.10.96	23.10.96	Zhao Ming	Both continuous profiling and point by point profiling was used.
	F	24.10.96	24.10.96		
	G	26.10.96	28.10.96		
	H	29.10.96	29.10.96		
SASW	E	22.10.96	22.10.96	Zhang Shihong	Contractor experienced problems with noise from traffic at sites E, F & G and from construction plant at Site H.
	F	24.10.96	24.10.96		
	G	26.10.96	28.10.96		
	H	29.10.96	29.10.96		
RI	E	22.10.96	23.10.96	Huang Weiyi	Three different electrodes configurations were used at each site - Wenner, Dipole - Dipole and Differential.
	F	24.10.96	24.10.96		
	G	26.10.96	28.10.96		
	H	29.10.96	29.10.96		

Key :

Trial Site "E" - North of Stubbs Villa, Stubbs Road
Trial Site "F" - Police Quarters, Block B, Hollywood Road
Trial Site "G" - Blue Pool Road
Trial Site "H" - Sze Yu House, Choi Wan Estate

GPR - Ground Penetrating Radar
SASW - Spectral Analysis of Surface Waves
EM - Electromagnetic Method
RI - Resistivity Imaging

Table C21 - Contractor Profile - Phase 2 Field Trials

1. Main Contractor :
Institute of Geophysical and Geochemical Exploration, China (IGGE)

2. The Non-invasive techniques used :
a) Ground Penetrating Radar
b) Spectral Analysis of Surface Waves
c) Resistivity Imaging

3. Names of Staff to be Employed on the Site Trials :

- Luo Zhuangwei	(IGGE)	- Senior Geophysicist, deputy Director of IGGE
- Zhou Anchang	(IGGE)	- Professor in Geophysics
- Yang Piyuan	(IGGE)	- Professor in Geophysics
- Hu Ping	(IGGE)	- Senior Geophysicist
- Yuan Shoucheng	(IGGE)	- Senior Geophysicist
- Yuan Guanding	(IGGE)	- Senior Geophysicist
- Feng Nian	(IGGE)	- Senior Geophysicist
- Zhong Qing	(IGGE)	- Senior Geophysicist
- Liu Feng	(IGGE)	- Senior Engineer

4. Equipment Details :

Technique	Manufacturer	Type
a) Ground Penetrating Radar	Geophysical Survey Systems Inc.	- SIR 10A System - 100(2no.), and 500 MHz antenna's
b) Spectral Analysis of Surface Waves	Hewlett-Packard Hewlett-Packard	- Dual-channel Dynamic Singal Analyzer - Computer
c) Resistivity Imaging	Zonge Engineering & Research Organization China Geology Univer China Geological Inst.	- GRP-32 wide-band electric survey system - DUM-1 Swith

Table C22 - Field Records - Phase 2 Field Trials - Institute of Geophysical and Geochemical Exploration

Geophysical Methods	Trial Site	Start Date	End Date	Person In Charge	Remarks
GPR	E	26.10.96	28.10.96	Yuan Shoucheng	
	F	29.10.96	29.10.96		
	G	31.10.96	31.10.96		
	H	25.10.96	25.10.96		
SASW	E	28.10.96	28.10.96	Yang Guanding	
	G	31.10.96	31.10.96		
	H	25.10.96	25.10.96		
RI	E	15.10.96	28.10.96	Yang Guanding	
	F	29.10.96	30.10.96		
	G	31.10.96	31.10.96		
	H	24.10.96	24.10.96		

Key :

Trial Site "E" - North of Stubbs Villa, Stubbs Road
Trial Site "F" - Police Quarters, Block B, Hollywood Road
Trial Site "G" - Blue Pool Road
Trial Site "H" - Sze Yu House, Choi Wan Estate

GPR - Ground Penetrating Radar
SASW - Spectral Analysis of Surface Waves
EM - Electromagnetic Method
RI - Resistivity Imaging