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*The paper was published in the proceedings of the 7<sup>th</sup> Australia New Zealand Conference on Geomechanics and was edited by M.B. Jaksa, W.S. Kaggwa and D.A. Cameron. The conference was held in Adelaide, Australia, 1-5 July 1996.*

# Non-Intrusive Investigative Technology For Geotechnical and Environmental Assessment

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**Summary:** Non-intrusive survey systems developed for mineral exploration can now be made available to the geotechnical and environmental industries to ensure more rapid and accurate progress in sub-surface detailing. Geological or artificial hazards may now be fully documented to allow for commercial developments within or near environmentally and culturally sensitive sites. In particular all legal, technical, and financial risks must be fully assessed prior to installation of new facilities. A comprehensive understanding and appreciation of these aspects is essential for engineers and project managers who wish to make crucial and timely decisions and ensure smooth and cost effective progress of their projects. A variety of geophysical systems (radar, seismic, electrical, etc.) have now been optimised for numerous applications and final resolution can be greatly improved by post-survey processing. However, preliminary results can be obtained on site and initial targets such as sub-surface services, hazardous ground conditions or stratigraphic profiles can be readily identified. Voiding, deconsolidation, slope or embankment stability, landfill delineation and other general data can be made available. Site conditions have a direct affect on the signal quality and it is therefore essential to select the most appropriate technology available. Electrical and electromagnetic techniques are commonly affected by conductive ground conditions while seismic reflection suffers poor resolution of fine detail. Carefully selected techniques may provide information to a depth of 50m and resolutions of up to 10cm. It is not possible to maximise depth at the same time as maximising resolution. Thus, as a result optimum conditions for either must be pre-determined.

## 1. INTRODUCTION

A decade of system development and adaptation of standard geophysical exploration techniques to engineering requirements has been at the forefront of Rock Solid Australia's research and development program. Existing survey techniques have been customised and improved in order that they may become more user friendly and sensitive to the types of anomalies sought as well as applicable in hazardous working environments. Inspections have moved from the common ground condition evaluation to the assessment of structural integrity. It is no longer sufficient to assess that a site may have collapsing or saturated soils. The owner of the utility system or building structure must obtain qualitative data about the current condition of the entire system so that informed decisions may be made about what to do, where to do it and how best to allocate limited budgets.

As the owners' priorities change due to changes in organisational structures as well as organisational duties, more importance is placed in "balancing the books" at the end of the financial year or meeting the quoted price. Companies both public and private operate on a lean budget and it is important that constructional and maintenance decisions are made on the most accurate and up-to-date information. Systems are now available to provide a full range of inspection techniques enabling the project manager

to make informed decisions about particular site conditions.

## 2. TECHNIQUE OVERVIEW

Engineering geophysics is now more than ever before able to target and assess critical aspects of structural integrity and geotechnical stability. More and more project managers need information about the whole site or structure before they feel confident and sufficiently well informed to make judgements about further action. The aim must be to maximise the quality of data to become well informed while at the same time minimising the outlay in obtaining it. Many sophisticated survey techniques have been developed for non-destructive testing. Only seismic refraction techniques have been previously available for geotechnical studies, ultra-sonics for structural evaluations and magnetic surveys for location of metallic artefacts.

### 2.1 Ground Penetrating Radar

Ground Penetrating Radar (GPR) surveys require a transmitting antenna which emits electromagnetic pulses into the target medium. The pulses reflect off sub-surface boundaries before detection by a receiving antenna. The time between emission and detection of pulses are recorded with the type and pattern of reflections. Processing and interpretation by skilled operators provides an engineering profile

of the surveyed section.

Rock Solid Australia uses highly portable GPR equipment comprising independent battery powered antennas connected by fibre optic cables to a control console. A schematic of the system is shown in Figure 1. Operation of the survey is controlled from a portable computer, which records test data in digital format. Preliminary results can be displayed on site and critical targets (e.g. geological stratigraphy, services) can be readily identified. These results are represented as time profiles, or wiggle traces, resembling seismic reflection sections.

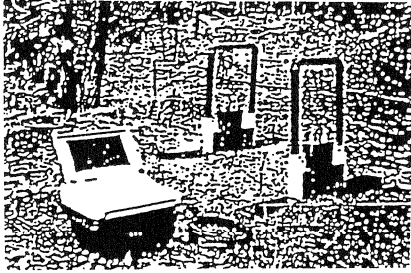


Figure 1. Schematic of GPR system.

## 2.2 Wave Impedance

Impedance testing involves the propagation of electrical signals within or through the medium under investigation. It is non-directional but, preferred signal paths may be selected depending on the orientation and size of the impedance device. The amplitude and polarity of the complex signal is measured in relation to the generating source. This data is directly related to the physical properties of the medium in which the wave is established. Sub-surface soil conditions or buried artefacts have a distinct effect on the signal response. Saturated soil layers will commonly provide low impedance paths for the propagating wave. Polarity flips are also common where significant contrasts exist. The steepness and shape of the responses provide accurate electrical definitions of geological profiles.

Specially designed impedance devices provide more flexibility for surveys within confined spaces. Units are lightweight and demountable for easy pipeline access. This flexibility also accommodates varied current loop sizes which may be used for differing sensitivity levels. The impedance unit operates on a 12 volt power pack feeding the data directly into a dedicated console. Data is fed to a surface computer capable of processing and displaying results. The unit may be carried, dragged or floated through pipes while linked to the console (internal or external) by an electrical cable. Results are recorded in a digital format and are difficult to interpret prior to complex processing. They are represented as a set of peaks and troughs indicating areas of anomalous electrical activity. An example of typical wave impedance data is shown in Figure 2.

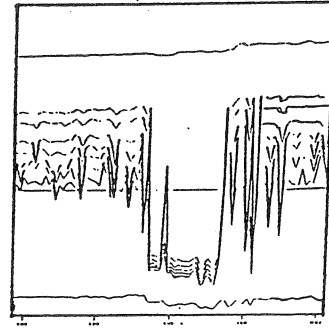


Figure 2. Typical impedance data.

## 2.3 Seismic Resonance

Seismic surveying is often not suitable for detailed and accurate system assessment. However, a seismic derivative called resonance may be successfully used to provide information about a pipeline wall and its embedment. Generating shorter seismic waves for increased resolution has necessitated development of a unique anvil and geophone device. This unit is also small enough to operate in confined spaces and its lightweight, demountable construction allows easy pipeline access. The resonance device consists of a manually triggered, spring loaded piston which generates a vibrational wave within the pipe wall itself. The strength of the signal and rate of attenuation are recorded by a displaced geophone. Assuming a homogeneous pipeline structure and consistent contact behind the pipe wall, the seismic response may be assessed for structural and foundation conditions. As this technique is directional, the number of shot locations selected determines the resolution. Structural contact conditions significantly effect signal response. Poor contact causes rapid attenuation of the signal. Typical seismic data are shown in Figure 3.

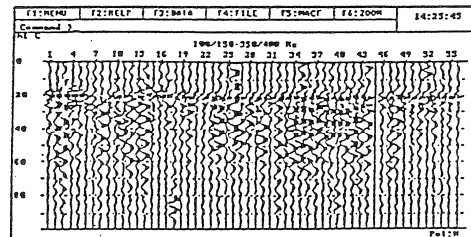


Figure 3. Typical seismic data.

Deteriorated structural material, voiding, slumping and deconsolidation of foundation materials also cause signal attenuation. The manually triggered system must be carried along the surveyed surface because placement of the anvil and geophone requires accurate sighting. The system is powered by a portable 12 volt power pack and the signals are converted to digital form and subsequently transferred to a portable computer for storage and display. The results appear as wiggle traces on the computer screen. However, as complex processing is required, conclusive results are not available on site.

## 2.4 Dipole Excitation

The Dipole Excitation (DIPEX) technique allows real time detection and location of re-inforcing steel in any concrete structure. No surface contact is required and there is no physical damage to the material. The depth of penetration depends upon the physical configuration adopted for each survey. However, for compact systems wire centres can be readily identified at depths of several centimetres in concrete pipes. This method relies on direct excitation of metal particles at the molecular level. The magnitude of the resulting resonant energy levels can then be correlated with particle density giving an immediate indication of anomaly location using audio and visual output on a portable computer. Housings can be adapted for remote sensing using cables extending over 100m.

## 2.5 Vibration Analysis

Using specifically designed high frequency seismic systems, data can be analysed by looking at the time-domain or frequency-domain properties of the waves propagated within the wall structures. For accurate time-domain analysis, the signal must be generated by a source capable of supplying constant strength impacts at constant distance. When studying the frequency domain, impacts need not be consistent and distance between source and receiver can vary. Special data processing systems are available to compensate for the variations.

Generally the faster the time of flight of the generated signal the better the quality of the pipe inspected. A detailed study of the frequency spectrum provides information about quality of the pipe material as well as the condition of the embedment of the pipeline.

Some surface preparation of the area to be tested may be required. All systems operate on a 12 volt power pack and a portable is used for waveform storage.

## 2.6 Electrical Analysis

Analysis of subtle electrical properties is possible by using a miniaturised version of the wave impedance system (ripple). This system provides a means of detecting the thickness of the concrete by indirect means. The dominant source of the response is often the reinforcing steel. However, it is possible to neglect the effect of the steel if the spacing of the reinforcing steel bars is smaller than the size of the sensor. Alternatively, it may be possible to avoid the steel where the spacing is further apart than the size of the sensor by locating the steel using the DIPEX meter.

Signal strength is proportional to the amount and distance of the steel reinforcement from the receiver.

Consequently, increased signal levels may imply a thinning of the concrete. The system can be automated to trigger at a set distance ensuring a high resolution survey. The advantage of having an external trigger is that the entire system is waterproof.

As the amount of data against which results can be calibrated increases so the accuracy of the results improves. Rock Solid Australia is now developing systems which allow rapid on-site processing of data.

## 3. TECHNIQUE SELECTION

To be able to provide investigative technology for the extensive spectrum of required applications, a complete understanding of the wide range of geophysical instrumentation is essential. Too many operators depend on one technique with which they are familiar. This ultimately leads to poor quality data since no one particular instrument will operate satisfactorily under all ground conditions. Features such as soil type, soil saturation levels, salinity levels, groundwater quality and site structures all have an impact on equipment operation and data acquisition.

## 4. SITE SURVEY PARAMETERS

Survey parameters must be tailored to meet the specific requirements of each site or structure under investigation.

### 4.1 Frequency

Unless the operator is working within a narrow range of applications the frequency of the electromagnetic or vibrational pulse will require change to suit the specific task. This can be achieved with most geophysical instruments by interchanging various emitting antenna or vibration generating source.

For example a ground penetrating radar can be set for;

1. High frequency (800-1000MHz). These relatively short wavelengths are best suited to high resolution work such as concrete testing.
2. Medium frequency (200-500MHz) is used for work requiring greater penetration and less detail such as obstruction searches and locating voids.
3. Low frequency (50-100MHz) offer greater depth of penetration (depths up to 25m) for uses that include landfill boundary mapping and hydrogeological mapping.

Seismic surveying also covers a broad range of applications through its ability to lend itself to a variety of frequencies. Ultra-sonics which is the high end of the vibrational wavelengths (short) is typically applied to condition evaluation while the

longer wavelengths are employed to probe deeper into the subsurface.

With many geophysical techniques the anomalous signature is related to the number of wavelengths perturbed or altered as they pass through a variable zone. Hence, it is easier to identify subtle changes using short wavelengths.

#### 4.2 Sampling Interval

The distance along the survey traverse between recordings of pulse reflections is influenced by the size and depth of the target being identified, the required output detail and the capabilities of the NDT unit. Typically, intervals would be 1.0m for low frequency surveys, down to 50mm for high frequency detailed work.

The mode of setting the sampling interval can be by time interval or measured distance. Most geophysical units can be run in continuous mode whereby the readings are taken at relatively short time intervals with the sampling interval determined by the speed of traverse. This method reduces the ability to stack return pulse signals.

#### 4.3 Pulse Stacking

All geophysical units generally have the capacity to stack pulses to obtain strengthened signal definition. This involves sending a series of pulses (typically up to 4000) at each traverse point and stacking the reflected signals to obtain a clearer defined signal relative to the normal recorded background interference (“noise”).

Experienced operators can assess the relative merits of increased stacking against reduced sampling intervals to determine the optimum relative levels.

### 5. OPERATOR SKILLS

Survey techniques require operators who have been suitably trained and experienced in geophysical surveys. The setting up of the equipment, conducting of the survey, the post processing and interpretation all require specialist skills.

Surveys can be severely influenced by items adjacent to the survey area such as buildings, steel fences, powerlines, etc. It is essential that the operator is suitably trained to identify these possible interference source and is aware of the effect that they can have on the output data. At times such interference may totally mask the results from the target and render the survey useless while on other occasions post-survey processing of field data may eliminate the interference and provide the desired results.

People untrained and inexperienced in geophysical surveys generally find little of relevance when viewing the data produced during the surveys. This is because many of the features are represented by subtle changes in the output data and physical shapes of features are often not readily discernible.

### 6. APPLICATIONS OF GEOPHYSICS

Rock Solid Australia now provides a full range of modern survey techniques suitable for advanced condition assessment. These techniques lend themselves to a broad spectrum of applications in the mining, environmental, geotechnical, civil and structural engineering fields. Some of the current areas of use include: site investigations; structural analysis; environmental auditing and geological surveys.

#### • Site Investigations

- Obstruction searches.
- Location of cavities and sink holes.
- Soil profiling.

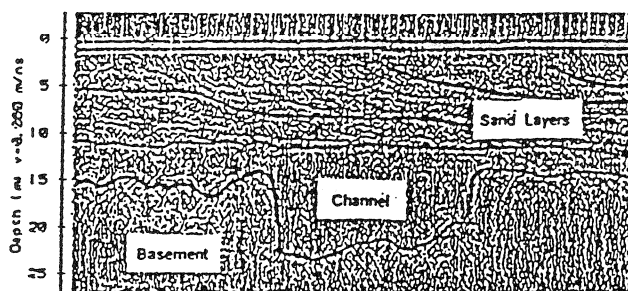


Figure 4. Radargram showing basement rhyodacites overlain by silty clays.

#### • Structural Analysis

- Tunnel inspections.
- Brick and masonry condition.
- Embankment stability.
- Reinforced concrete.
- Construction monitoring.
- Void detection adjacent to sewers & pipelines.
- Foundation evaluation.
- Pavement analysis.
- Seepage path mapping.

#### • Environmental Auditing

- Landfill mapping.
- Buried waste and chemicals.
- Leakage plume mapping.

#### • Geological Survey

- Mine and quarry planning.
- Soil profiling.
- Hydrogeological mapping.

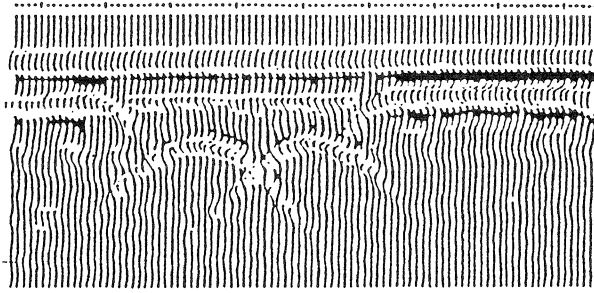


Figure 5. Detection of buried pipe and waterway.

## 7. CASE HISTORIES

### 7.1 Slope Stability Assessment - Braemar College, Woodend

Braemar College is located on the heavily wooded slopes of Mt. Macedon. A large gymnasium development had resulted in an extensive slope instability which is currently being studied and solutions to stabilise the slip are still being sought.

A new proposed library building had the potential of destabilising another slope due to the necessary earthworks. However, in an attempt to study the slope stability and target the areas of utmost concern an extensive ground penetrating radar and wave impedance study was carried out.

These surveys successfully located deep saturated clay zones in the proposed building area and these could then be studied in greater detail by drilling the locations and setting up monitoring wells.

As a result the building was relocated to a new site decreasing the risk of slope destabilisation.

### 7.2 Hamilton Siphon Inspection - Brisbane

Located some 100m below the Brisbane River, this tunnel carries two large sewer pipes critical to the sewer network of Brisbane.

A minor earthquake resulted in a number of fractures in the tunnel structure and attempts to pressure grout the structure to stabilise it, preventing water inflow and further collapses.

Rock Solid Australia used a combination of GPR, Wave Impedance, Ripple Impedance and Sonic Resonance to develop an understanding of the condition of the siphon, locate zones along the tunnel worthy of further detailed studies and map the geology behind the tunnel to understand the cause of the movement. All results clearly identified a faultline running centrally along the bottom of the river.

## 8. CONCLUSION

Geophysical inspection technology is ideally suited to the requirements of design and construction engineering by providing a non-destructive and non-invasive testing tool. The ongoing development of geophysics for engineering, together with the acquired skills of operators, is increasing users' confidence.

The ability to obtain continuous profiles across a test target provides owners and managers with far greater detail than previously available. Failure to use this available technology may lead to a lack of essential information and could at times be deemed a lack of due diligence. Applications of geophysics will continue to grow as clients become aware of and comfortable with the capabilities of these relatively new survey, inspection and assessment methods.