# BEM & WIP Technology for Condition Assessment of Pipelines & other Engineering Assets

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## Abstract

Rock Solid Group (RSG) has been using specially configured micro-geophysical techniques combined with its understanding of geotechnical and geochemical issues in the study of various sub-surface and surface engineering structures eliminating the need for destructive sampling and testing.

To successfully apply suitable technology for condition assessment a clear understanding of the techniques' limitations and manipulation of recorded data is essential. Lack of suitable and efficient methods for assessment of pipelines, commonly forming parts of urban water, sewer and gas infrastructure, has lead RSG to develop unique technology to tackle this issue.

Key issues are the pipeline itself as well as the embedment of buried infrastructure.

Pipes form an integral part of the life-line to all major towns and cities. They carry water or gas to, and sewerage away from, these centres. Their failure in many instances is unacceptable to the communities they service. The ability to accurately assess their current condition and continue monitoring any condition changes during their life cycle is essential to enable the development of a budgeted and targeted maintenance program.

The application of RSG's patented Wave Impedance Probing (WIP) and Broadband Electromagnetic (BEM) technology has found a large range of applications globally. The flexibility and ease of use of these technologies has seen the development of both in-line as well as external inspection methods of buried as well as exposed pipelines.

BEM technology is now also being applied to a variety of other engineering structures such as underground tunnels and bridges where wall linings and supports are constructed from ferrous materials.

## Introduction

This paper aims to identify the reasons for the development of the BEM & WIP technology as well as highlighting benefits of these techniques over other conventional testing methods.

As part of any condition evaluation program of engineering networks such as pipelines or tunnels, the need to obtain accurate data about the current state of the network is essential. Too often, and for too long, engineers have been attempting to develop condition

assessment models based predominantly on visual inspections (manned entry or CCTV) and historical performance indicators.

With the evolution of ever more powerful computer systems, the ability to perform a greater number of, and more complex tasks on site is allowing non-destructive testing (NDT) to establishing itself as a viable and integral part of any condition evaluation projects.

RSG has been performing geophysical and NDT inspections for over 22 years and experience has taught us that conventional assessment techniques frequently yield ambiguous, or unreliable data.

Commonly used techniques such as ultrasonics or other seismic derivatives, although commonly referred to as non-destructive, actually involve some level of infrastructure destruction. This may be as minor as removing surface protective coatings for sensor contact to emitting potentially destructive 'shock waves' into the sub-strata or wall.

Yet other systems such as magnetic flux leakage devices, commonly referred to as MFL, have serious limitations in their ability to survey through thick or uneven surfaces limiting their applicability and often rendering their survey results meaningless.

Still another family of NDT tools, which uses eddy currents or electromagnetic derivatives as their means of assessment (e.g. ground penetrating radar), too often struggle to achieve their specified levels of accuracy because of corruption of received signal. The corruption or 'noise', is common in most urban environments where stray electromagnetic fields effect the emitted or received signal frequencies on which the evaluation accuracy depends.

It is essential to understand the way NDT techniques function as well as where and when they are applicable to truly appreciate the unique position that the WIP and BEM technology holds in the field of condition evaluation tools.

## WIP & BEM Technology

Both WIP and BEM technology fall under an umbrella group of devices commonly referred to as 'pulse EM' systems. These techniques are derivatives of geophysical equipment which has been used in the Australian exploration industry for more than 80 years and are therefore based on well established physics principles.

RSG's background knowledge of this technology and experience in its use in the exploration industry has allowed us to modify it for NDT inspections, suitable for acquiring detailed information about the current condition of surface or sub-surface pipelines as well as embedment of infrastructure.

It can be said that the fields of geophysics and materials or non-destructive testing merge. The point of commonality is the field of physics. At one end are geophysical techniques such as seismology, magnetics and electromagnetics while at the other end are non-destructive testing techniques such as ultrasonics, magnetic flux leakage and eddy currents. From a physics view point these techniques are based on the same principles.

Although it may seem at first glance that material testing and mineral exploration are worlds apart, the fact is that identical physics is used for exploration geophysics as for non-destructive testing (NDT).

- Seismology = Ultrasonics
- Magnetics = Magnetic Flux Leakage

- Electromagnetics = Eddy Current

## Need for a New Technology – Ferrous Wall Condition

**Ultrasonics:**
Ultrasonic testing, or UT as it is commonly referred to, is probably the best established material testing technique for assessing ferrous pipe wall conditions. They have been around for may years and manufacturers have driven this technology to a level where anyone can appear to be an ultrasonic expert. The requirement is to simply place the sensor on the pipe surface and record a wall thickness.

Unfortunately it is just not that simple. When one studies the complexity of how a vibrational wave propagates through materials, major issues become evident about the application ultrasonic applications. The technology is also not truly non-destructive. There are very few applications of ultrasonic testing where the coating, lining or metal surfaces do not have to be removed or 'polished' to allow for satisfactory sensor contact essential to ensure generation of meaningful data.

The fact is that many of the established companies or contractors providing UT also provide a re-surfacing or repair of the coatings or linings. These are obviously not supplied as a free service but as a stand-alone service. The cost of re-surfacing should correctly be included as part of UT inspections. This typically does not happen giving an incorrect impression as to the true cost of UT surveys. Since in many instances the UT provider also provides re-surfacing it is not in their interest to limit the destructive impact on the asset under inspection.

Nonetheless, this technology is well established and limitations are excepted. For the most part, the owner of the asset under inspection or the operator of the ultrasonic system is not aware that there is anything else available to do the required measurements so the limitations are ignored. Even worse still is that particular industry standards specify the inspection technique not allowing introduction or use of different techniques without significant risks to the proponent.

**Magnetic Flux Leakage:**
Magnetic Flux Leakage, or MFL as it is commonly referred to, has also become well established. It is far more flexible in its application than the UT but is a lot more complex and therefore more expensive to obtain. Devices utilising MFL are available on the market in many forms ranging from simple hand held devices to complex in-line probes known as smart 'pigs' (or pipe inspection gauges).

The benefit of MFL over UT is that it is truly a NDT technique requiring little or no surface preparation prior to application. Although this benefit is significant when dealing with relatively 'smooth' and thin coatings or linings such as painted surfaces, the truth is that few buried pipelines, when exposed, provide a sufficiently 'smooth' surface for MFL application.

MFL utilises magnetic flux typically generated by strong rare earth magnets. While this physics principle is highly sensitive to ferrous wall thickness variations it is also extremely sensitive to variations in sensor displacement off the pipe wall. In fact, the majority of standard MFL equipment available on today's market can provide confident data only when displacements off the ferrous surface is no more than 6mm (0.25"). Beyond this elevation the variations in MFL are greater due to displacement variations than due to changes in ferrous wall conditions.

Since many of the pipelines, especially those which are buried, have thicker or uneven coatings (e.g. bituminous paint), the benefit of the MFL technique cannot be fully utilised and the surface of the pipes is again scrapped and cleaned prior to scanning. Although this is destructive it is an essential component of the surveys to ensure confidence in data collected.

Just like UT, major suppliers of MFL to markets, where surface pre-survey preparation is required, provide the re-surfacing as a service. Again the true cost of undertaking MFL in these circumstances should include the cost of re-surfacing. Instead it is provided as a stand-alone service resulting in an unrealistic pricing of MFL surveys.

It is important to note however that MFL is a truly NDT technology when applied in circumstances where surface pre-survey preparation is not required such as in-line surveys of transmission oil & gas lines.

**Eddy Current:**
Eddy current devices make use of electromagnetic fields (EMF). There are many devices on the market today and many are being successfully applied right now. This technology is marketed under a large range of names and acronyms such as RFT (Remote Field Testing), NFT (Near Field Testing) and Pulsed Eddy Currents. In principle these techniques all use the same physics principles. There are significant variations in the format of the sensor configuration and frequencies that these devices operate at.

Unlike UT or MFL these systems are truly NDT techniques. Elevations or off-sets of the sensors from the ferrous surfaces can be in orders of 50mm (2") or more and still yield meaningful results when analysed and processed correctly. Variations in elevation due to uneven surfaces is also not an issue since this too can be compensated for confidently. With access to sophisticated data analysis software, condition assessment of ferrous materials, with these devices, can be achieved without any impact on the pipe whatsoever.

Unfortunately most of these devices are dependent upon the frequency of EMF emitted and recorded. The principle is that the recorded EMF should be a certain fingerprint of the EMF emitted. Any change in the recorded EMF is deemed a change in the ferrous wall that the EMF resides in. The principle is very sound and in most instances works perfectly well especially where the environment in which it is being used is consistent e.g. laboratory or manufacturing plant set-up. Unfortunately environments such as urban centres are awash with stray currents and noise emitted by other EMF sources. These include power lines and cables, trains, trams and any other electrical source in close proximity. The result is that many of the frequency depended EMF devices cannot determine if a change in a fingerprint of EMF is due to anomalous conditions of the ferrous wall under inspection or an affect of a stray current from outside sources. This results in decreased or lost confidence in recorded data.

**New Technology - Broadband Electromagnetics:**
Having used and evaluated many of the commercially available devices, which make use of the physics principles described above (UT, MFL, Eddy Currents), and identifying the short comings of each technique, RSG embarked on a process of developing new technology.

The development of this new technology (BEM) was not the result of wanting to develop technology for the sake of it. It costs many millions of dollars to bring new technology to the market so it is not something considered lightly. BEM was developed because existing and available techniques and devices could not give the level of detail and data confidence required for assessments of assets without misrepresentation or unacceptable commercial risk.

As mentioned earlier, many of the devices used as NDT are actually destructive because they have some level of impact on the pipeline. Hence to call these techniques NDT is really a misrepresentation. To not remove coatings or linings or to not 'polish' surfaces for good sensor contact means yielding low confidence data. Furthermore, acquiring data using frequency dependent devices in regions know to be 'infested' with stray fields, potentially altering recorded frequencies unexpectedly, give rise to recording of inaccurate results. These limitations added up to unacceptable commercial risk for RSG.

**External Inspections:**
External pipe wall condition assessments are typically carried out on all types of ferrous pipelines to explore the integrity of the ferrous pipe wall. Tunnel wall inspections have also been undertaken with this technology.

**Figure 1** NDT setup for exposed pipeline surveys.

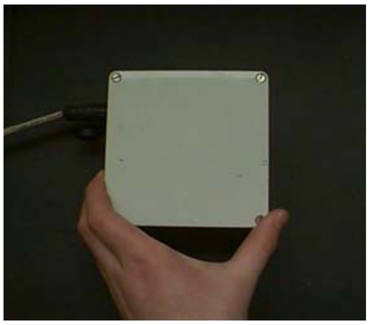

**Figure 2** Hand held NDT sensor.

Pipe scanning is undertaken using HSK (Hand Scanning Kit) non-destructive testing (NDT) technique. Individual readings are taken along the surface of a pipe. With the aid of a temporary paper grid wrapped around the outside of the pipe allowing for accurate positioning of each reading taken. Following post survey data processing this allows a presentation of results in an easy to understand and accurate colour contour plot shown below. The plot contours are a representation of the variation of the ferrous thickness or condition across the contoured area.

**Advantages**

- Scanning is not limited by the diameter of the pipe.
- The equipment has the ability to survey through thick coatings (50mm+/2"+) of materials such as paint, tar or concrete commonly found on many buried and exposed pipelines.
- The line does not have to be taken off-line, as readings are taken from the outside of the pipe. The technique scans through the full wall of the pipe registering corrosion or flaws within the full wall thickness.

- Negligible affect of outside stray current fields potentially contaminating resulting data. Where stray fields are identified – these can be clearly seen in captured data – variations in data capture parameters are possible since the device is non-frequency dependent.

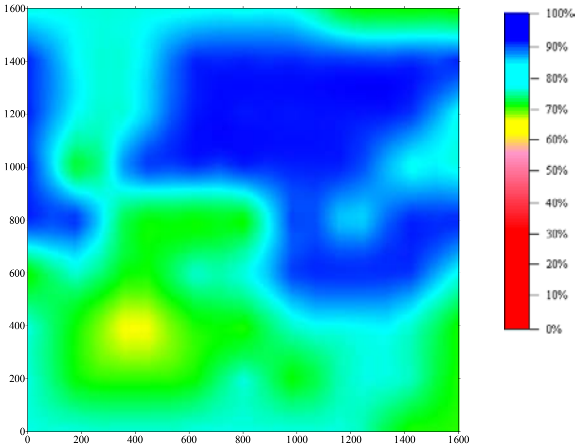


**Figure 3** Colour contour plot representing variations in pipe wall thicknesses. The plot is represented as if the pipe is sliced open (typically along the crown) and flattened out.

**In-Line Inspections:**

**Figure 4** Launching an in-line Smart Pig.

Internal pipe wall condition assessments have been carried out on any diameter of pipe 80mm upwards. Continuous data can be recorded along extensive lengths of pipeline.

During in-pipe data acquisition the NDT probes are either winched or rodded through the pipe. Due to the large volumes of data recorded as part of any scan, distances surveyed along smaller diameter pipes are typically 500m - 600m per day while in large diameters only tens of metres per day can be scanned.

Data acquired is generally represented graphically or as colour contour plots. The graph below is actual data collected along a series of cast iron pipe sections.

**Advantages**

- Ideal for extensive pipe surveys where the probe can be inserted into pipe hatches or cuts eliminating the need for extensive excavations or physical pipe sampling.

- Can be operated in full or partially filled non-pressurised pipelines eliminating the need for total dewatering of the pipeline.

- Can survey through all known internal linings including thick layers of cement.

- Probes can be customised to fit a variety of pipe diameters starting as small as 40mm.

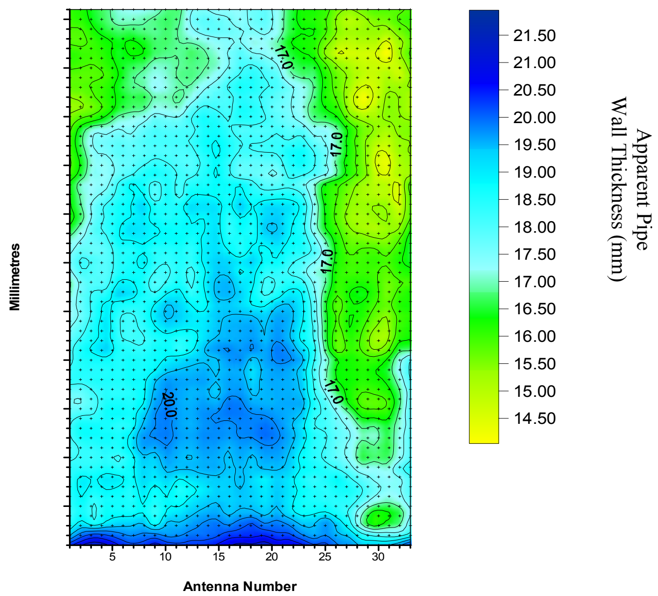


**Figure 4** Condition contour plot of a vertical cast iron pipeline 750mm in diameter, approximate segment length of 3m. Contours and image map provide information against apparent wall thickness scale along the side.

## Need for a New Technology – Pipe Embedment Condition

**Seismic Testing:**
Seismic testing is probably the most common geophysical technique used in engineering for ground assessment today. It has been used for geotechnical investigations for many years and is a documented technique in many sub-surface investigations for medium to large scale structures.

Seismic testing makes use of energy or vibration waves pulsed into the substrata. These waves travel through the ground and their characteristics change depending upon the characteristics of the medium that they happen to be passing through. It is the study of the

resulting affect on the pulsed wave that yields the required information about the geological environment.

This method has been used for condition evaluation of embedment surrounding pipelines. The aim of these investigations is typically to identify undesired substrata conditions such as voids, deconsolidation, slumping soils or general poor structural support of pipelines. These sub-surface features can result in settlements and collapses of embedment support compromising the functionality of pipelines. This is most commonly evident in gravity pipes such as sewer and stormwater drains.

Although relatively inexpensive, the difficulty of using seismic testing arises primarily from its classical 'long wavelength' pulses. Any geophysical measurement which studies wave propagation assesses the wave pattern. Each wave cycle consists of a peak and a trough. In a very simplistic assessment the analysis of a seismic wave consists of comparing one wave pattern to the next. When the wave pattern changes then this is taken as a change in the medium through which it is travelling at that time.

The problem with seismic testing is that the wavelength is typically in the order of a metre (3 feet) or more. For a wave cycle to change pattern it must pass through an area that has significant variation to change the wave pattern. Furthermore, it is very difficult during analysis to draw conclusions from one wave cycle only. Typically wave pattern changes need to occur across numerous consecutive cycles before it is accepted as an anomalous signature.

The result of this is that seismic testing is unlikely to provide sufficient sensitivity to locate anomalies less than a metre (3 feet) in cross-section. From an engineering point of view this is too crude an analysis and many significant anomalies are likely to be missed.

Another issue of seismic analysis of the substrata, particularly in urban environments, is that of excessive vibrational 'noise'. As mentioned previously, the method uses pulsed vibrational waves induced into the ground and an analysis of the wave cycle changes. The problem however is that many of the pipelines requiring assessment run below or along major roads. Traffic travelling along these roads induces its own vibrational waves into the substrata. These intermittent and arbitrary pulses are referred to as 'noise'. Since it is not know what the 'noise' levels are and therefore cannot be easily filtered out they corrupt the seismic data collected often rendering the results meaningless.

**Conductivity/Resistivity Measurements:**
Resistivity is the inverse of conductivity so any geophysical techniques measuring resistivity or conductivity analyse one and the same thing. These techniques 'inject' an electrical current into the substrata and classically have one point as the emitter and another as the receiver. As the current passes through the earth the 'ease' with which the current is transmitted through the substrata allows for the assessment of the likely sub-surface conditions leading to the recorded conductivity or resistivity.

Until recently it was imperative that good contact is made between the emitter (and receiver) and the substrata under investigation. This meant that metal rods had to be driven into the ground prior to undertaking the surveys resulting in very slow progress not to mention the difficulty of driving stakes through road surfaces. Recent developments in this technology have seen the development of capacitive coupling eliminating the need for direct contact.

An added problem with these measurements is that of signal channelling. When an electrical field is injected into the substrata encounters a saturated zone (e.g. wet soil layer), perhaps not even close to the pipeline, the injected signal will have a tendency to 'short circuit' through this zones. This has two detrimental effects; (i) unless this zone is know to

exist inappropriate modelling of the current flow is likely to result, and, (ii) when this occurs, limited or no signal may reach the desired location, (i.e. in proximity of the pipeline) resulting in a lack of information from the zones of most interest.

Besides these complications urban environments have proved hostile to these techniques. There are many conductive elements in the urban environment and substrata (e.g. other pipes and cables). The conductive nature of these items leads to channelling of injected signal rendering the results meaningless. Furthermore, many roads have a layer of re-inforced concrete layer below the surface bitumen finish. The re-inforcing mesh effectively 'swamps' the injected signal, obliterating any response form anomalous sub-surface conditions.

**Ground Penetrating Radar:**
Ground penetrating radar, also commonly referred to as ground probing radar or GPR, is probably the most versatile geophysical technique for sub-surface scanning and inspection. The top end products provide for a range of different antennae and configurations allowing a variety of selections to be made to ensure the most appropriate tool for the site conditions and targets.

Regrettably the GPR is commonly abused. This is a result of the provider or contractor attempting to apply the unit to surveys and in environments unsuited to the unit or configuration. It is also the consequence of a lack of understanding how the technology works and what its true limitations are. This leads to inappropriate and inaccurate promises of deliverables.

An added level of complication with the GPR is that it is a highly sophisticated technology requiring advanced geophysical knowledge and field experience to ensure accurate data analysis. Too often this equipment is purchased by well meaning contractors who have neither the background knowledge nor the skill to operate GPR effectively.

The result of this common inappropriate use and application of GPR has lead this technology into disrepute. There are many instances where GPR is simply no longer welcome.

Further proof of this has been the attempt to implement this technology from the in-side of a pipeline. For many years basic surface systems have been rehoused to enable their insertion into pipelines. The result has been that much of the system does not operate effectively because the antennae are not appropriately shielded, but more importantly, much of the delicate electronics and wiring has not been designed for corrosive environments such as those found in 'hot' and humid sewer lines.

**New Technology – Wave Impedance Probing:**
Since the late 80's RSG has been aware that to be able to correctly assess pipeline embedment conditions new robust NDT technology had to be developed.

While the GPR overcame many of the complexities associated with long wavelengths of seismic testing allowing the identification of relatively small yet important anomalies as well as ensuring penetration of substrata in favourable conditions, it became evident that to be able to effectively provide this service, highly skilled and well educated operators were required. It was also evident that to allow a GPR system to work in hostile environments such as sewers there was a further need for technology re-configuration and re-packaging.

The result was a drive to develop a relatively rapid scanning tool which would allow fast scanning of many miles of pipeline providing accurate yet simple analysis of the embedment.

The technology had to be robust enough to work in sewer environments yet simple enough to allow mid-level skilled operators to undertake surveys confidently.

It was not the intention to develop a tool to compete with advanced systems like GPR. The idea was to develop a technology which could work in tandem with advanced geophysical systems but limit the regions where the advanced systems would be required. This gave birth to the wave impedance technology.

**Surface Surveys:**
Surveys from the surface can be undertaken along paved or unpaved finishes and along grassed terrain. Typically inspection depths vary from 500mm (20") to 3m (10') depending upon site conditions and antennae selection.

**Figure 5** NDT set-up for exposed pipeline surveys.

Ground profile surveys are undertaken using the GAP non-destructive testing (NDT) technique. Individual readings are taken along the surface traverse. Readings can be collected as frequently along the traverse line as necessary but are usually spaced every 1 to 2 metres (3' to 6'). Basic on-site assessment is possible with identification of major anomalies probable. Post-survey analysis of the data collected allows for the detection of subtle changes in the geological profile.

**Advantages**

- Scanning is non-invasive and penetrations of between 2 to 3 metres are commonly achieved.

- The equipment can be used for scanning through both paved and grassed surfaces.

- The line does not have to be taken off-line, as readings are taken from the outside of the pipe.

- Able to survey kilometres daily the technology is safe for use in the environments selected.

**In-Line Surveys:**
Depending upon the surface and near surface conditions as well as the depth of burial of the pipeline, in-line survey configuration may be preferred. The benefit of in-line surveys is that the scanning is in close proximity to the pipe wall and primarily of the embedment material. This means that the emitted signal does not need to penetrate through significant soil layers or overcome effects of shallower infrastructure but can focused on the primary target.

**Figure 6** Deploying Ground Inspection Gauge (GIG) into a manhole.

The GIG in-line configuration is water resistant. This means that while the probe cannot be employ in surcharging or pressure pipes it can be used in operating gravity flow pipelines. During in-pipe data acquisition the NDT probes are either winched or rodded through the pipe. The speed of survey is largely independent of pipe diameter but surveys of pipes as small as 180mm (7") have been successfully completed. Typically pipe diameters surveyed in the past range between 600mm to 1200mm. Distances of around 1km (0.6miles) are achievable daily.
Data acquired is generally represented graphically or as colour contour plots. The graph below is actual data collected along a series of cast iron pipe sections.

**Advantages**

- Ideal for extensive pipe surveys where the probe can be inserted into a manhole eliminating the need for extensive excavations or pipe modifications.
- Can be operated in empty or partially filled non-pressurised pipelines eliminating the need for the pipeline to be off-line during survey.
- Can survey through non-ferrous pipeline materials even when re-inforced.
- Probes can be customised to fit a variety of pipe diameters starting as small as 185mm.

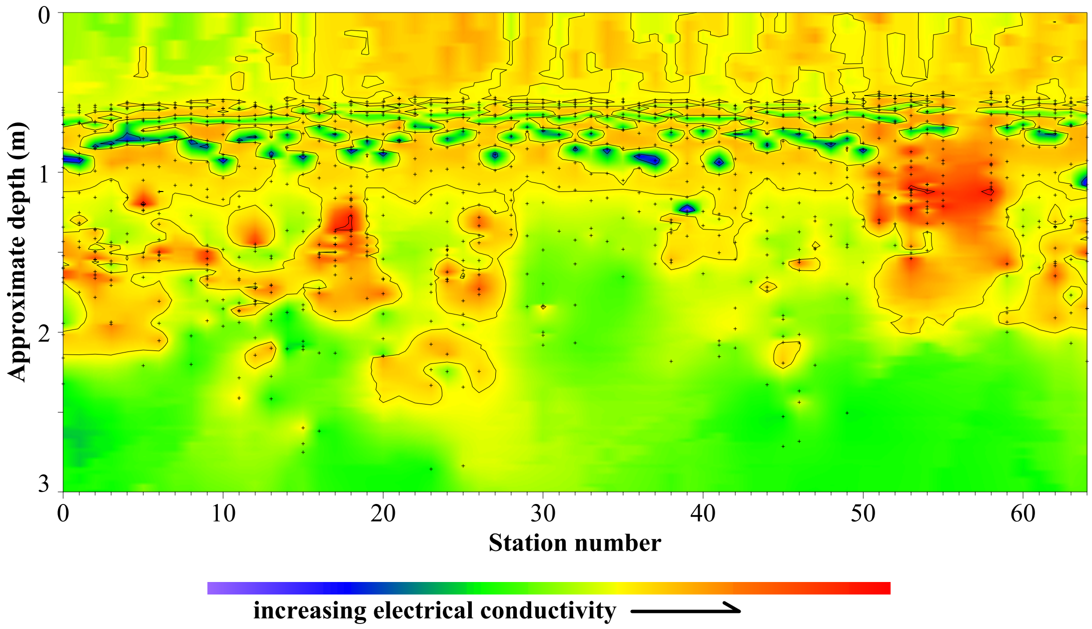


**Figure 7** Example of typical data plot possible if 3D data is collected.

## Conclusion & Summary

In order to meet today's demands for non-destructive, accurate, cost-effective methods of evaluation, a clear understanding of a broad range of NDT methodologies is essential to allow one to take advantage of what the technologies offer.

Using existing, modified and new techniques, such as BEM or WIP, an appropriate and cost-effective assessment programme can be designed to suit a range of under and above-ground pipes, conduits, tunnels, and other structures.

BEM is now commonly applied to studying and assessing ferrous water main supply pipes, sewers and gas lines. It can be used in both surface, and in-pipe systems. One of the main benefits provided by this technique is its ability to survey *through* ferrous pipe external coatings or internal linings. To date, successful surveys have been conducted through coatings in excess of 100mm thick.

Recent enhancements to the BEM and WIP technologies have also increased their sensitivity. New probe configurations for medium-large diameter pipes are becoming available as the inventory of probe increases allowing for detailed in-pipe inspections and the possibility to construct a project specific probe is there.

In order to design an appropriate condition assessment testing programme, it is essential to determine;

- the physics associated with the techniques available; including limitations and application,
- the geotechnical, geological and groundwater conditions in the area where the pipeline or other structure resides,

- the civil aspects of the infrastructure; how it was constructed, what it is made of, and so on,
- specific client needs; including micro/macro data required about the asset, and
- project constraints; for example, restricted access to the asset, or budgetary limitations.

Assessment results enable the owner to safely and cost-effectively protect and maintain these valuable assets.