THE IMPORTANCE OF UTILITY DETECTION

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Abstract

In the modern world the space beneath the ground is increasingly being filled with pipes and services supplying the world's population with power in various forms (e.g. gas, electricity, light), with water supplies, with telecommunication links and computer connections. There is, however, a large and increasing problem with the recording of the position of these various services. As a result, there is a significant lack of certainty over the precise location of essential services and an increasing risk of accidental damage to the buried infrastructure when either more material has to be buried or repairs carried out to existing pipes and services.
The costs associated with burying or repairing pipes and cables can be very high and include the cost of traffic congestion in the streets while the work is being completed. However, if a breach of the utility occurs, due to unexpected positioning, the costs in both economic and social terms can be immeasurably higher.
The Malaysian Government has taken a very important step forward in getting to grips with these problems in supporting a specialised training programme for members of the Association of Land Surveyors of Malaysia (Persatuan Juruukur Tanah Bertauliah Malaysia or Pejuta) in utility detection. This course focusses primarily on two complementary techniques: Ground Penetrating Radar (GPR) and Electro-Magnetic Location (EML).
Land Surveyors are learning to locate the buried infrastructure using appropriate techniques and modern equipment. They are also instructed in what constitutes unsuitable equipment and a range of more specialised, less often used tools. Their training programme includes at least 30 hours of practical experience and both practical and theoretical examinations.
Although both GPR and EML are widely used throughout the world as techniques for locating pipes and services, Malaysia is the first country to seek accreditation for its practitioners in advance of this work being carried out. This is an important first step in improving the database of buried utilities and in reducing the risk to those involved in repair and construction.

Keywords: *utility detection , Ground Penetrating Radar , GPR , Electro-Magnetic Location, EML.*

1 THE NEED FOR UTILITY DETECTION

The modern world has an enormous and growing appetite for services many of which are delivered via pipes and cables, generally referred to as utilities, through the subsurface of the ground. We light our homes and cook our meals with electricity or gas. The business sector requires telephones, faxes and, increasingly, internet access. In spite of the growth of the mobile phone networks, many homes also require telephone and internet services. Water is brought in to both homes and businesses by pipeline and sewage pipes are used to transport grey water away. The result of all of these activities is a growing conglomeration of pipes and cables buried beneath our feet. Obviously not all are at the same depth and equally obviously not all travel in the same direction. However, just as in our cities there is a limit to the space available for houses, shops and other buildings above ground, the space below ground is also limited both for access and also for the amount of utilities that it can contain. Figure 1 shows the exposed utilities in a typical urban street (Shepherd, M. 2010).

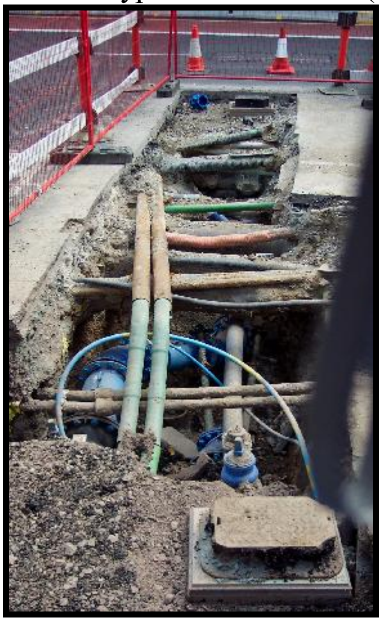

Figure 1: Buried Pipes and Services

With each passing year the population of buried utilities grows, particularly in urban areas. Given this crowding beneath our streets, we have created a series of problems. How do we know where it is safe to add in more utilities? How do we repair pipes which are broken or have corroded? Where can we dig safely? Can we tell one utility from another?

Although digging deeper into the levels below our existing utilities is an option, it is inherently evident that this will simply remove the problem into a deeper level. We have the technical capability to do this: directional drilling allows us to penetrate the subsurface below the level of existing utilities (Figure 2).

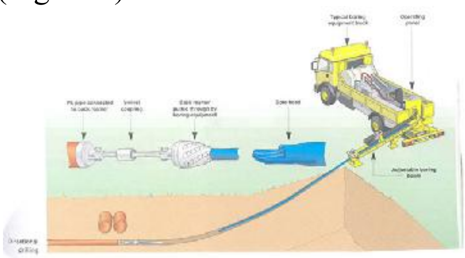

Figure 2: Diagram of Directional Drilling (HSE 2012)

Presumably, given enough time, we will fill this deeper level also so that although this provides a solution, it is effectively a temporary one. Whatever level we require to access and whether this is for the purpose of insertion of new utilities or the repair of older ones, it is essential that we can identify what already lies buried in the ground accurately both in terms of position and of the nature of the utility.

2 THE PROBLEM OF UTILITY DETECTION

2.1 Position

Recording accurately the position of utilities has not always been seen as a critical function. In the early days of laying water supply pipes, it would have been difficult to foresee the explosion of other utilities that would eventually be stored underground. As a result, although the installation would have been recorded, the position information is sometimes schematic rather than accurate. In addition, over the years, other errors have crept in. Records have been lost, the units in which measurements were recorded have been incorrectly translated from one system to another (e.g. feet and inches into metres), and improvements and additions have not always been added to the original drawings.

It has also happened that cables have been placed incorrectly and that contractors attempting to access one utility have cut through another either because of the incorrect installation or because they had not checked the position of other utilities.

The end result is that it is not always possible to recreate the history of buried pipes and cables and a significant degree of doubt attaches to their precise position although this information is vital if repairs and new installations are to be carried out safely.

2.2 The Safety Aspect

If we do not know where our utilities are in the ground, then we cannot either repair them, replace them or add to them without risking life and limb. If a street plan of services shows an electricity cable running down the centre of the road but this is not its real location, the person excavating the road is quite literally exposing him or herself to potential death or serious injury while carrying out the excavation. The effects of cutting through an existing utility can be quite literally devastating. At best a ruptured gas main results in gas supplies to homes and businesses being cut off. At worst, there is a risk of explosion, death and destruction of the infrastructure, possibly for miles around. Fluids under high pressure, such as water or gas, released suddenly impact directly on their environment. Flooding ruins property, closes roads and has also been known to kill when people become trapped (IoL News, 2012). Water main bursts have damaged gas pipes in many locations around the world (for example KentOnLine, 2012; The Standard, 2012). Figures 3, 4 and 5 illustrate some of these effects.

Figure 3: Devastation caused by a recent gas explosion (Telegraph, 2012)

Figure 4: Burst Water Main (BBC, 2010)

Figure 5: Road collapse caused by Water Main Burst (Fenland Citizen, 2012)

3 ECONOMIC COSTS

Installing and maintaining our subsurface utilities is an expensive business. Any work which involves digging into the ground carries a high direct cost in terms of labour and equipment. The indirect costs, however, are even greater. Road closure is generally necessary to carry out the work. This increases traffic congestion, already a major problem in most major cities worldwide. In turn, this has a knock on effect in terms of business hours lost by society as a whole. In 2012, the UK government estimated that the cost of congestion, caused by street works, was of the order of £4.3billion per year just for the UK (UK DoT IA, 2012).

Where damage has occurred to persons or property, the direct and indirect costs are of a much higher order of magnitude. The same agency estimated the daily cost of emergency repair work as over seven times the cost of routine works (UK DoT IA, 2012).

These costs can be reduced if we have a non-intrusive method of a) locating the utilities and b) assessing their condition, particularly if we can avoid having to close the roads to traffic while the work is being carried out. There are major research programmes being directed towards these goals (for example, Mapping the Underworld in the UK).

4 METHODS OF UTILITY DETECTION

There are a number of accepted methods of utility detection of which the two most common are Electromagnetic Location (EML) and Ground Penetrating Radar (GPR). Of these, EML is the primary method.

4.1 EML

EML works by detecting specific radiated frequencies, either generated by the utility itself or induced into the utility for the purposes of detection. By establishing the maximum signal strength at a series of locations, underground utilities can be tracked. The main disadvantage of EML is that it cannot be used in all cases. It is best used in conjunction with metallic pipes and it cannot be used at all where there are other blocking transmissions in the immediate neighbourhood.

4.2 GPR

GPR is a complementary technique but equally important in utility detection. The method relies, as do all other radar detection strategies, on the emission of radio waves, in this case into the ground. As the subsurface conditions change, portions of the signal are returned to the receiver antenna, indicating the depth and something of the nature of the buried materials.

It is essentially a relative method i.e. it indicates where there is a change in the subsurface materials. Every returned GPR signal is from an interface between two or more materials which differ from each other in electromagnetic properties. Unlike EML there is no change in technique for plastic pipes as opposed to metal ones. All that is required is that the utilities should have different electrical and magnetic properties from those of their immediate environment. An example of a GPR profile taken from a utility detection survey carried out in an urban location is shown at Figure 6.

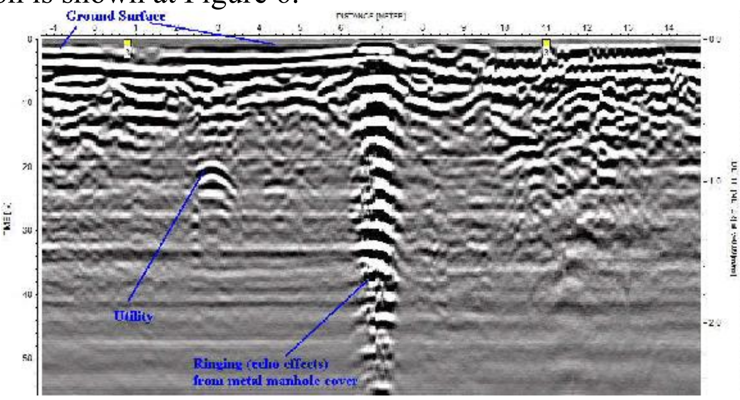

Figure 6: Typical Utility Detection Data

The scale along the top of the plot is the distance travelled by the radar. The vertical scales show the depth below ground to the various targets. On the right hand side the measurement is in metres and, on the right, in nanoseconds time. Radars measure very accurately in units of time. Since radio waves do not travel at a constant speed their velocity of transmission, which varies with the materials through which they pass, has to be known or calibrated in order for the depth in metres to be calculated (Daniels, 2004).

It is immediately apparent from Figure 6 that not only is the subsurface as complicated in structure as one might imagine, but the interpretation of the data requires some knowledge on the part of the person(s) using the equipment. It should also be clear that this is one vertical snapshot but that the operator really requires to detect the line along which the various pipes and cables lie, in other words a horizontal view of the data is required.

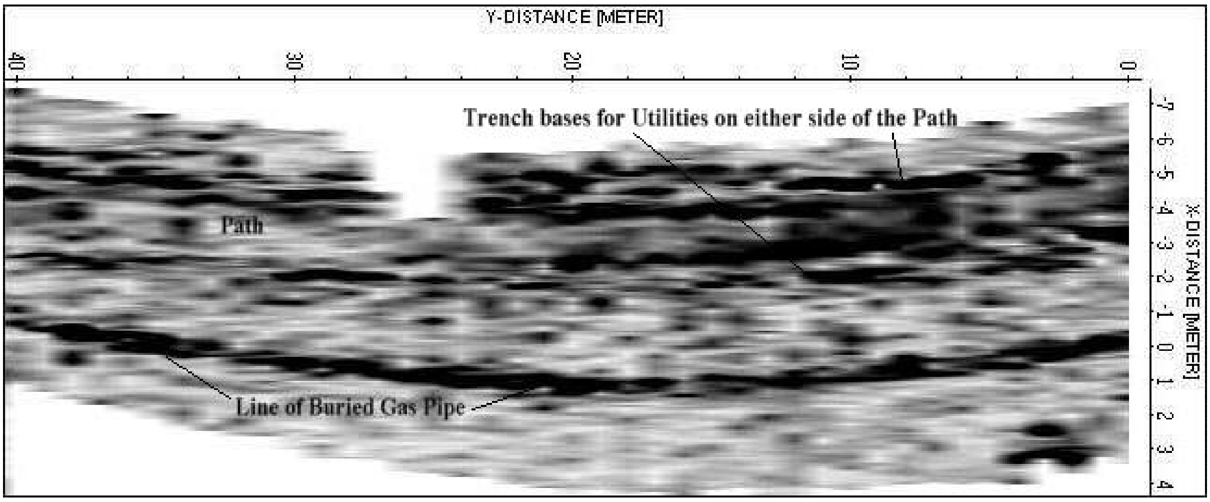

Figure 7: Time Slice showing a number of buried utilities

To achieve this, the operator records a number of repeat parallel lines across his/her survey area, each at a set distance from the other. In this way, a 3-dimensional data block can be built up from which the line of the various utilities may be deduced. Figure 7 shows one horizontal time slice extracted from a 3-dimensional data block. Time slices are effectively maps of the location of utilities and can be incorporated into AutoCad drawings. There are interpretative software packages available, some of which are incorporated into GPR equipment which allow the operator to produce plans in a similar manner immediately after survey (Figure 8).

Figure 8: On screen plotting of a single utility

There are, however, limits to what can be achieved with a GPR. There are conditions for which the method is unsuitable such as any highly ionized solution (such as sea water or certain waterlogged clays). It is also possible for one target to be hidden by others in its immediate vicinity.

Other specialist knowledge which is not so immediately apparent is the need to know the effects of freshwater on detection. As explained above, the transmission velocity of the radio waves varies with the material it passes through. In air the transmission velocity is c. 0.3m/ns. Through dry soils this velocity falls to 0.1m/ns. In waterlogged soils, the velocity may be as low as 0.035m/ns (Utsi, 2001). An understanding of the inter-relation of frequency, target size and depth penetration is also essential.

4.3 Survey Results

The final step in the utility mapping process is to produce a report and a scaled plan including all of the results of the detection, both from EML and from GPR. This map will indicate the type of utilities present and their measured depths, taking into account the differences in measurement. For example, GPR measures to the top of the utility whereas EML measures to the centre.

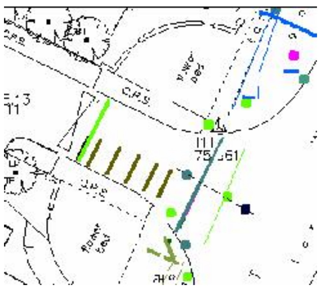

Figure 9: A simple utility map (Utsi, 2004)

Other factors such as certainty (data quality), when the work was completed, by whom etc will also be covered. It is this end product which allows further ground investigation to take place in safety or, alternatively, for a decision to be taken to avoid the area altogether.

5 THE IMPORTANCE OF TRAINING

Both EML and GPR rely on the operator understanding how to use the equipment effectively and efficiently. It is important to know the correct way to operate the equipment, the limitations of both the equipment and the method of detection and to apply the use in a manner likely to ensure accurate results. Inappropriate use of genuine equipment can result in highly inaccurate results. The working protocol has to ensure accuracy of location and of survey reference positions. Failure to adhere to these principles not only brings the reputation of both the techniques and the operator(s) into question but also raises the probability of a utility breach, potentially an extremely dangerous result.

In addition to this, there is a small but persistent amount of equipment available worldwide for which the claims outstrip its capabilities, to the point where the laws of physics would be broken if those same claims could be met. It is worth noting in passing that manufacturers of bona fide equipment (and many reputable surveyors also) belong to professional organisations such as the European GPR Association.

6. THE MALAYSIAN INITIATIVE

In 2011, with the backing of the Malaysian Government, the Association of Land Surveyors of Malaysia (Persatuan Juruukur Tanah Bertauliah Malaysia or Pejuta) set up its first professional utility detection course so that its members could qualify in advance of undertaking non-intrusive detection of pipes and cables. This recognition that training was required in advance of undertaking utility detection work represents an important step which has not generally been applied in other countries, until recent times. Many western countries are now awash with operator courses, with affiliation to different professional bodies. Excellent as many of these courses are, most suffer from the problem of having been set up after the initial award of utility detection contracts. This timing has been critical since, alongside good professional work, it also allowed inexperienced users to make mistakes or cut corners inappropriately with correspondingly poor results. In most cases, the search for appropriate training and setting up suitable affiliation is a result of observing the problems that arise when utility detection work is not carried out properly. It is further fuelled by the desire to distinguish professionalism from a more ad-hoc approach.

The first intake of prospective candidates began their studies in October 2011. The theoretical modules cover principles of measurement, measurement tools, the fundamentals of Geophysics, data management, processing and interpretation, and data analysis. In the practical part of this course, all candidates spend a minimum of 4 weeks studying the theory and methodology of both EML and GPR. As well as learning the appropriate application of these utility detection tools, they are also instructed in the limitations of each method and, as part of this exercise, to be able to identify inappropriate equipment.

There is a heavy emphasis on applying appropriate principles in practice and all participants are required to produce a detailed utility detection log of at least 30 hours practical experience, carried out in their own time and covering both GPR and EML. At the end of the course, they sit a short exam in each of the techniques and also carry out a practical exercise to demonstrate that they fully understand how utility detection is to be achieved in practice. This latter exercise also requires the candidates to demonstrate a proper understanding of on-site procedures, including Health and Safety aspects. The practical exam results of the first intake were of a satisfyingly high standard.

Finally they are required to produce a dissertation on a topic derived from the course. Only when they have satisfactorily completed all sections of the course, do the surveyors gain their licence to practice utility detection. This process should ensure that those responsible for utility detection in Malaysia have a good understanding of how to accomplish this task. It should also reduce the number and range of potential pitfalls in establishing the location of national and regional subsurface utilities.

Figure 9: Course participants demonstrating use of EML for utility detection

Figure 10: Course participants demonstrating Use of GPR for utility detection

Figure 11: Combining EML and GPR techniques for utility detection

A simple example in GPR detection illustrates this. As discussed above, the transmission velocity of radio waves varies with the material through which those waves pass. Malaysia is a country subject to sudden and torrential downpours. This means that a dry, well-drained soil can quickly become saturated. Water affects the operation of a GPR in two ways. Firstly it significantly slows down the transmission of radio waves and secondly, it can free up ion content of the soil. The latter effect is extremely important. GPR will not work at all in salt water and is heavily attenuated in some wet clays. In these circumstances the radio waves pass into the wet ground or salt water, set up a weak electric current which then dissipates. As no signal is returned to the radar receiver antenna, it is impossible to tell anything about the subsurface, let alone any objects contained within it. An inexperienced or inadequately trained operator therefore runs the risk of either promising results which cannot be delivered or, worse, carrying out a full survey at the expense of his/her client without being able to deliver any meaningful results.

However there is a potential solution to this problem. Malaysia’s qualified surveyors would realize that they should consider using a lower frequency antenna than the one they would normally deploy. A utility buried in this suddenly waterlogged environment will not have changed its depth. From the radar's perspective, it effectively has. Since the radio waves travel more slowly, it takes longer for the signal to reach the pipe or cable. Lower frequency antennas have a greater depth capability. They also suffer less loss in an ionized environment. Training will have equipped the surveyor to calculate the relative increase in time. He or she will also know how to calibrate the changed transmission velocity so that this increased time will be corrected by the slower speed to give an accurate indication of depth. He or she will also be competent to brief the client in a realistic fashion on the risks of not obtaining the required results and be able to suggest potential alternative strategies.

It is obviously a much better solution for the Malaysian Government, the ultimate end-user of the mapped utility information, to have the option of using the services of someone who fully understands what they are doing and why they are doing it and is capable of taking an informed decision in order to obtain an optimal outcome. The alternative is a price based tender in which the cheapest quote wins but with no guarantee of a successful outcome and little or no means of holding the winning tenderer to account for the standard of his or her work.

7. FUTURE DETECTION POSSIBILITIES

As described above, there is now a strong worldwide impetus for the development of processes and equipment which will allow both the detection and also condition monitoring of buried infrastructure. GPR and EML are essential components of this on-going research. The present situation allows proper detection, provided that both methods are used in a professional and complementary fashion, based on a viable survey strategy.

That said, there are still multiple occasions when the presence of utilities may need to be inferred, because of the limitations either of the equipment or the environment, the chief problem being the suitability or otherwise of the surrounding soils. Governments including those in the UK and the USA are now funding research to try and improve detection by both engaging in soil science research and also structuring which types of detection methods should be favoured in terms of their soil response. As an example the Mapping The Underworld project, led by the University of Birmingham in the UK, is working on integrating GPR, EML, Acoustic and Magnetic detection methods into a single working device which will rely most heavily on whichever technology best suits the ground conditions of the site being surveyed (Mapping the Underworld).

This research, particularly into soil electromagnetic responses, has been invaluable in understanding not only results from utility detection surveys but also the otherwise apparently anomalous results from other types of surveys (Thomas et al, 2006, Utsi, 2012).

Alongside this research there are also efforts to identify buried utilities, for example, by electronic tagging.

Future research is also under consideration to see whether or not it is possible to make an assessment of the condition of buried utilities using non-intrusive testing. This is a challenging aim and it is not certain that it will be achievable.

8. Acknowledgements

The author would like to thank Alex Birtwisle of Atlas Geophysical Ltd for permission to use Figure 6 and Alan Jones of Pipehawk plc for permission to use Figure 8.

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