THE USE OF GROUND PENETRATING RADAR FOR ASSET MANAGEMENT AND UTILITY DETECTION

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Abstract

Ground Penetrating Radar (GPR) is a reliable and efficient method of locating any target or ground layer which is different in nature to its surrounding environment. Although it cannot determine the exact nature of the target material because every signal returned to the radar is the product of 2 or more materials rather than a signature frequency from 1 material, it is extremely useful for understanding a wide range of engineering and structural problems.

Although there are intrusive methods of investigating these problems, these are usually expensive in terms of both cost and time. There is also often an associated risk in terms of health and safety. GPR represents a very cost effective method of non-destructive testing which can enable asset owners to reach essential management decisions with regard to the preservation or repair of those assets.

The use of GPR for locating subsurface utilities; for verifying the integrity of road structures, for examining structural problems, including the detailed investigation of historical buildings and the assessment of airport runways is illustrated.

Keywords: *GPR, utility detection, road composition, structural engineering, airport runway integrity, civil engineering.*

1 GROUND PENETRATING RADAR

Ground Penetrating Radar (GPR) works by emitting a series of radio waves across a pre-determined frequency band. As the radio waves meet with changing conditions below the ground surface, portions of the signal are returned to a receiver antenna. The signals returned to the radar give information about the changing conditions below ground as well as the depth and, sometimes, an indication of the size of any buried anomalous objects. Although we generally talk about applying GPR to the ground, it can also be applied to walls, ceilings and other built structures where it is more commonly referred to as WPR (wall probing radar).

GPR is a relative investigation tool. Signals are only returned if the conditions or materials below the surface change. Where there is no change, there will be no returned signal. It follows that every signal is therefore the product of the interface of two or more materials. It is therefore not possible to use GPR to identify a single specific substance although, in the case of water or metal, there are sometimes ancillary clues.

The advantage of the method, however, is that it does not depend on the targets being made of conductive material for successful detection. In simple terms this means that targets do not require to be metal. Provided that the target(s) sought are made of different material, there should be a difference in their electromagnetic properties with respect to their surrounding environment, In these circumstances, they should be visible to the radar. This applies to a very wide range of applications, for example, utility detection, structural investigations, verification of roads, environmental investigations (including mining), security and forensic searches and archaeology.

2 UTILITY DETECTION

One of the principal uses of GPR is to locate pipes and cables either in advance of construction (for the sake of avoidance) or in order to be able to access these either for repair and maintenance work (e.g. tracing water leaks) or in order to add in additional utilities. Utility detection is the largest sector of GPR use.

2.1 The problems of utility detection

It is vital for safety's sake that utilities can be accurately located. Historically the position of utilities has often been recorded schematically rather than precisely. With the growth of pipes and cables built into the subsurface of our city streets, there is now a major problem in being able to locate utilities so that either additional pipes and services can be laid or repairs carried out or other construction work can be carried out safely around the existing services.

It is now routine for GPR to be deployed alongside Electromagnetic Location (EML) to detect pipes and services. The great advantage of using GPR is that it can detect utilities regardless of the material they are made from. Plastic pipes, metal pipes, fibre optic cables all differ from the soil that surrounds them and the tarmac or concrete which covers them. They are therefore visible to the radar.

It is important, however, that the GPR operator understands fully the way in which his equipment works, its limitations and also the limitations of the ground in which the utilities are buried. A competent operator needs to know when to use different frequencies of antenna, what survey parameters will allow him or her to detect the targets and how to assess the probability of detection.

Such decisions are important not only for obtaining accurate information but also, ultimately, for the safety of all those involved in the construction project. Cutting through power cables, gas pipelines and even water pipes may be lethal.

2.2 GPR used for utility detection

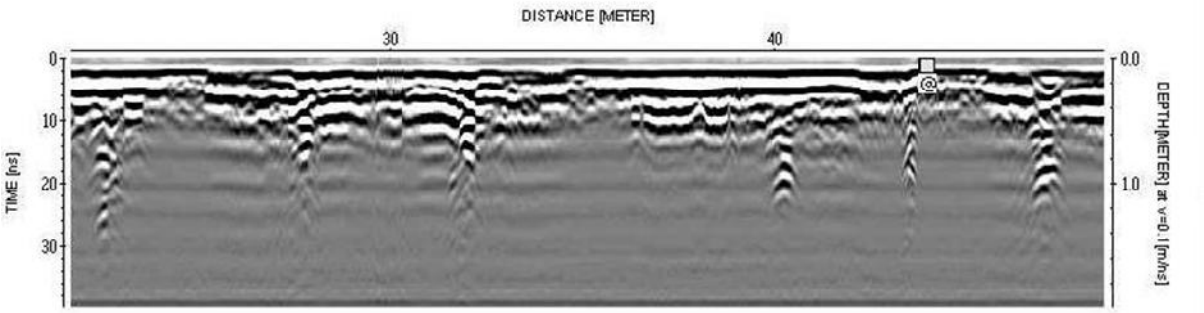


Figure 1: GPR Image of a series of utilities below an urban pavement.

The basic data produced by a GPR shows the equivalent of a vertical section below ground. Figure 1 illustrates this. The axis along the top of the image shows the distance travelled by the radar. The axis to the left hand side shows the time in nanoseconds to reach any given depth. This is translated on the right hand side into metres. Radars measure very accurately in time but the velocity at which radio waves are transmitted depends upon the electromagnetic properties of the material through which they pass (Daniels, 2004). The transmission velocity therefore has to be calibrated for each investigation so that the depth in metres can be worked out.

Where a series of such radar profiles is collected either along parallel lines or using GPS, it is possible to form a 3-dimensional data block from which horizontal time slices can be extracted (Figure 2). These can be used to form plans of the utilities buried in the subsurface by importing the images into drawing packages such as AutoCad.

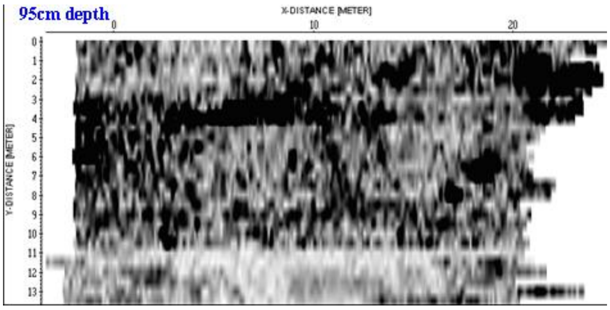


Figure 2: Time Slice showing the outline of buried utilities as straight dark lines.

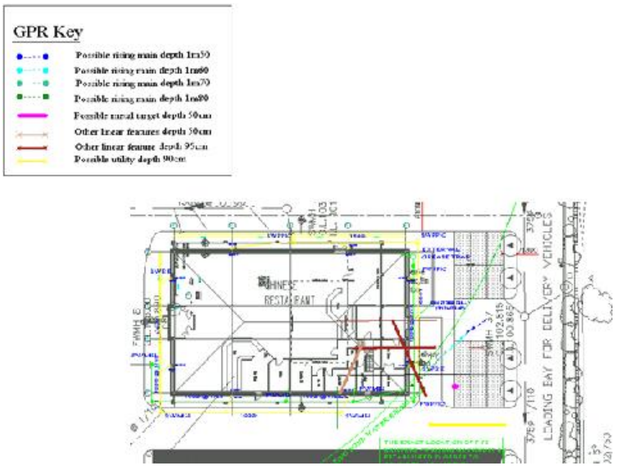


Figure 3: Plan incorporating GPR results including those of Figure 2.

3 STRUCTURAL INVESTIGATIONS

The same general principles apply to structural and other civil engineering investigations. Provided that the target information required by the engineers is different from its immediate surrounding environment, the GPR can provide useful information on buried structures of all varieties.

3.1 Reinforced Concrete

GPR is often used either to define the type of reinforcement used in concrete or to look for targets such as utilities below the reinforcement. It is also used to define the depth of concrete cover and to look for underlying causes of the concrete breaking up. This is usually a high frequency investigation. The wavelengths must be short enough to pass through the reinforcement mesh in order to detect any targets. If the wavelengths emitted are not sufficiently short, the radar will effectively detect a large metal object and be unable to penetrate below the surface.

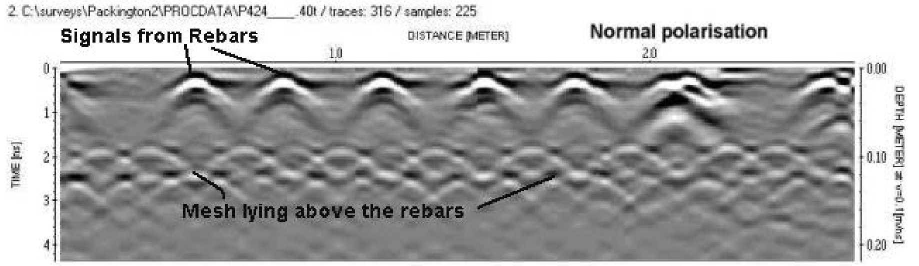


Figure 4: Data from GPR investigation of concrete ceiling showing the location of reinforcement bars (rebars) and the overlying metal mesh (Utsi et al, 2004).

Figure 4 shows an example of the examination of reinforced concrete, in this instance, in a ceiling. The purpose of the investigation was to identify the reinforcement pattern in a series of modular built blocks of flats so that the structural engineers would have evidence on which to base their judgement as to whether the buildings could potentially withstand the effects of a gas explosion (Utsi et al, 2004).

3.2 Historic Buildings

Depending on the frequency of antenna deployed and the survey parameters applied, it is possible to obtain very detailed pictures of subsurface features. A good example of this is the investigation of the 13th Century Cosmati mosaic which covers the floor immediately in front of the High Altar of Westminster Abbey in London. Beautiful as this mosaic was, it had suffered considerable damage over the centuries since it was first completed. In 2004 the Dean and Chapter of the Abbey decided that it should be restored. As part of this process, a GPR survey of the area was carried out in order to gain information as to how the mosaic had been constructed, to identify any near surface voids which might result in more pieces of the mosaic detaching and to identify any remains of an earlier church known to have existed before the extensive rebuilding in the 13th Century.

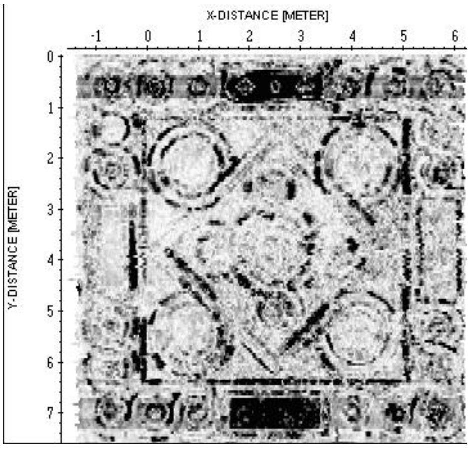


Figure 5: Time Slice from the High Frequency GPR Investigation of the Cosmati Pavement showing the position of two burials.

Not only was it possible to examine in some detail how the mosaic had been built from the series of time slices extracted from a 3-dimensional data block, it was confirmed that there were two burials, one to the North and the other to the South, effectively built in to the underside of the mosaic (Figure 5).

Because one of the GPRs used was very high frequency (4GHz), it proved possible to image both grave goods and irregularities in the fabric of the mosaic, caused by repair work carried out in the past.

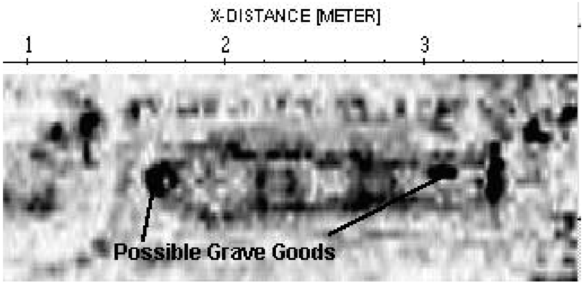


Figure 6: Extract from Time Slice showing some of the buried grave goods.

Although it was not possible to be certain what the item to the right of the coffin interior was, the returned radar signals from the head of the coffin, on the left in Figure 6, suggested the presence of a chalice and paten, both common items in the burial of an abbot. GPRMax was used to develop the GPR signals from a model of a chalice and paten for which the dimensions were provided by the Abbey archaeologist, Professor Warwick Rodwell (Giannopoulos, A., Figure 7)

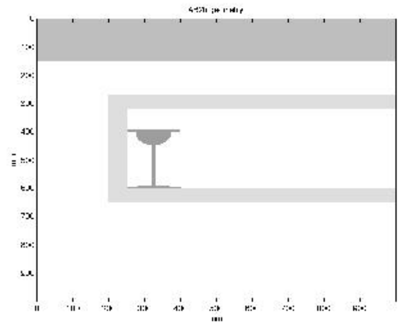


Figure 7: Design of Simulated Chalice and Paten

This model was then adjusted until the signals both in the 2-d generated data and the time slices extracted from the 3-dimensional data cube matched. These results are seen in Figure 8. The chalice model which fitted the initial signals from the survey was 5cm longer in the stem and 2cm smaller in the diameter of the paten than the original design. On the basis of the radar data and the computer simulations, it is possible to say that this grave contains at least a chalice and a paten. On the basis of Figure 8, it is also clear that there is considerably more material than this remaining in the inside of the tomb (Utsi, 2006).

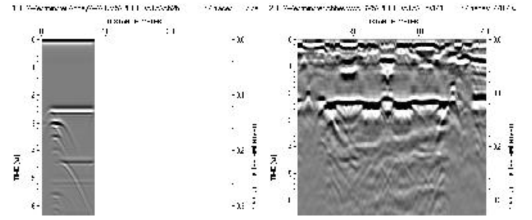


Figure 8: Simulation using GPR Max (left) compared with the survey data (right)

3.3 Bridge and Road Structures

GPR is also commonly used for the investigation of road integrity and bridge structures, surveys which are typically carried out from a vehicle at road speeds in order not to impede the normal flow of traffic or to add to urban congestion.

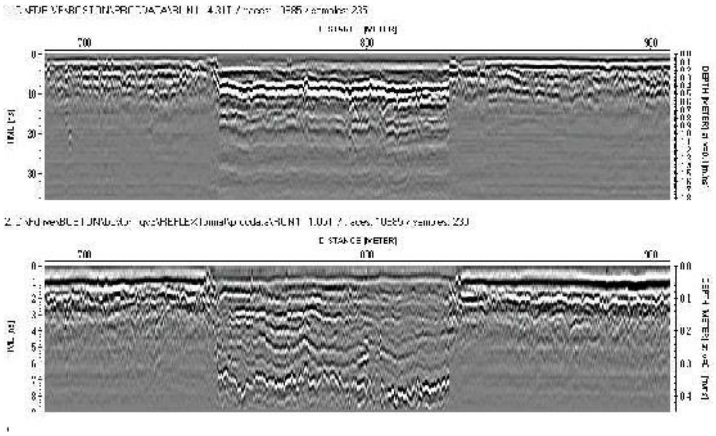


Figure 9: Data extracted from a Major Road survey

For road integrity, the radars are attached to vehicles and run along the carriageway along predetermined tracks in order to demonstrate the integrity or otherwise of the road. Figure 9 illustrates the use of a multi-channel radar for this purpose. The two traces illustrate the same stretch of major road. The upper trace was generated by a low frequency antenna and can therefore penetrate a greater depth. The lower trace was generated by a high frequency antenna with lesser depth penetration but greater capability in target definition. More detail is therefore generated by this higher frequency antenna at the same time as the lower frequency antenna examines the road to a greater depth. The results can either confirm or disprove that the road has been constructed as designed or can be used to examine why surface problems develop at particular points along the route.

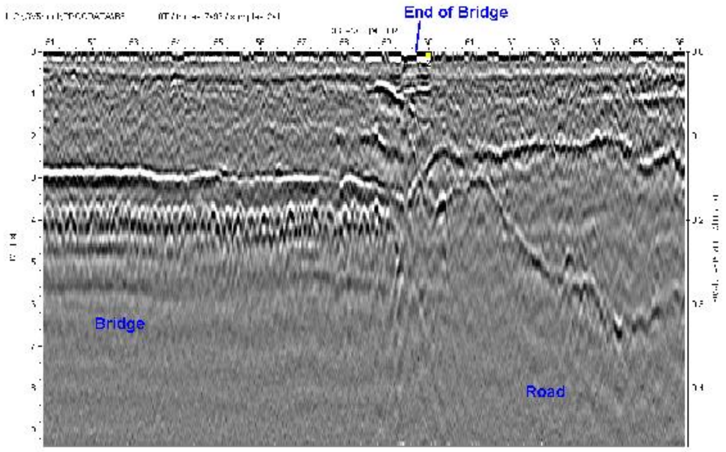


Figure 10: Extract from a road survey showing the different compositions of a bridge and the road beyond it.

Bridge construction requires to be monitored since problems can develop over time, particularly if there is any ingress of water. GPR is commonly used to monitor bridge conditions over the life of the structure. Figure 10 shows part of a bridge and the point at which it ends, with the road continuing beyond it. The reinforced concrete at the base of the bridge is particularly clear: the individual reinforcement bars show as small hyperbolas. Obviously the analysis of this type of data is a specialised business but the information that can be gained from it is vital to good asset management.

3.4 Airport Runways

The same principles of investigation are applied in the survey of airport infrastructures of which the runways are typically the most critical. Here GPR is applied in the same manner as for a road to examine the integrity of the layers below ground, including the use of a survey vehicle. It can also be used to identify the buried cables and other utilities which it is vital should not be disturbed when additional construction work is carried out.

A relatively recent development is the use of GPR for the detection of subsurface cracking. Typically an airport runway is made up of reinforced concrete with an overlay of tarmac. As the runway is used two types of cracks develop. Surface cracks develop from the daily wear and tear of the runway and permeate down into the subsurface. These cracks can obviously be seen. Subsurface cracking typically develops at the joints in the reinforced concrete slabs and permeates upwards into the tarmac. Provided that the cracks have not actually reached the surface these are invisible to the human eye but not to the radar.

The decision whether to refurbish the tarmac by creating another layer on top or to replace the existing tarmac depends on an assessment of the relative proportions of surface cracking down into the subsurface and subsurface cracking reaching up towards the surface. The structural engineer can be greatly assisted in this decision by using an adaptive GPR based tool to measure the existence of subsurface cracking. This type of investigation cannot be carried out on a vehicle as the measurements are too small scale to be done accurately at speed. Verification of layers can be done from a vehicle but crack depth determination is done on foot at a slow walking pace.

Figure 11: Crack detection and traditional GPR equipment in use on a military airport runway.

The operator uses a combination of traditional antennas and adapted antennas of the same high frequency (1.5GHz) to survey the runway on foot (Figure 11). The traditional antennas provide layer information for the tarmac and the underlying concrete. The adapted antennas are optimised to detect anomalous objects rather than layer changes. From these, the operator can detect the joints in the concrete and also any subsurface cracking.

The top image in Figure 12 shows GPR data from an intact joint where no cracking has developed. The single hyperbola is generated by the joint. No second hyperbola above indicates that the concrete/tarmac interface is intact. In fact this can also be seen in the clarity of the layer signal which indicates the position of this interface.

The second image in Figure 12 shows the result of surveying across a crack. In this case there are two hyperbolas. The lower one indicates the position of the joint in the concrete as can be seen from the fact that it lies below the level of the tarmac. The second hyperbola lies directly above the first but within the tarmac layer. This indicates that a crack has developed above the joint and that this crack extends into the tarmac. Each of these results is then plotted using a "traffic lights" system where green indicates no cracking, red indicates the development of one or more cracks and amber indicates either an anomalous result or some other potential problem at the investigation point (Figure 13). This allows the structural engineers to measure the extent of the development of subsurface cracking which, in turn, makes it easier both to take and to justify a decision to repair, refurbish or replace the runway surface (Birtwisle et al, 2008; Utsi et al, 2008).

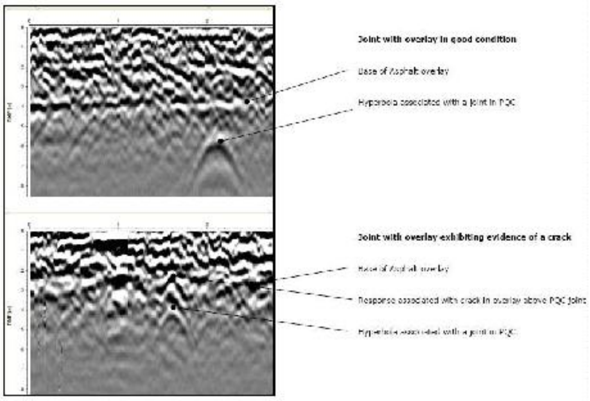
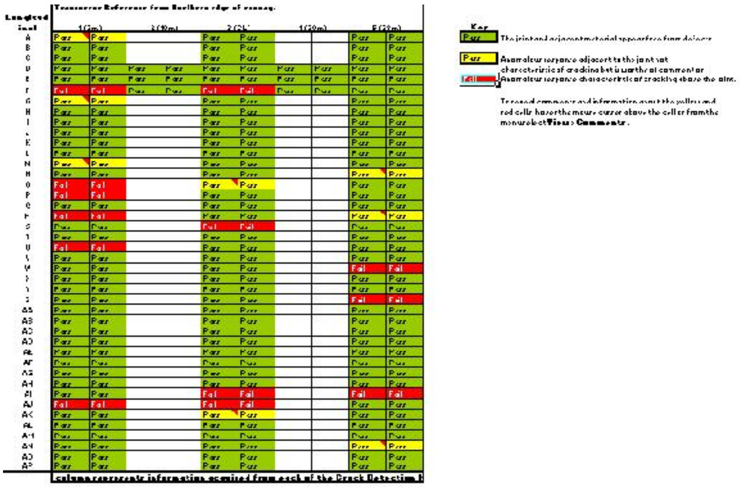


Figure 12: An example of a clean joint (above) and one which has developed cracking (below).



Transverse Reference from Northern edge of runway.

Longitudinal	1(5m)		3(10m)		[illegible]		4(20m)		5(25m)	
A	Pass	Pass			Pass	Pass			Pass	Pass
B	Pass	Pass			Pass	Pass			Pass	Pass
C	Pass	Pass			Pass	Pass			Pass	Pass
D	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
E	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
F	Fail	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Pass	Pass
G	Pass	Pass			Pass	Pass			Pass	Pass
H	Pass	Pass			Pass	Pass			Pass	Pass
I	Pass	Pass			Pass	Pass			Pass	Pass
J	Pass	Pass			Pass	Pass			Pass	Pass
K	Pass	Pass			Pass	Pass			Pass	Pass
L	Pass	Pass			Pass	Pass			Pass	Pass
M	Pass	Pass			Pass	Pass			Pass	Pass
N	Pass	Pass			Pass	Pass			Pass	Pass
O	Fail	Fail			Pass	Pass			Pass	Pass
P	Fail	Fail			Pass	Pass			Pass	Pass
Q	Pass	Pass			Pass	Pass			Pass	Pass
R	Fail	Fail			Pass	Pass			Pass	Pass
S	Pass	Pass			Fail	Fail			Pass	Pass
T	Pass	Pass			Pass	Pass			Pass	Pass
U	Fail	Fail			Pass	Pass			Pass	Pass
V	Pass	Pass			Pass	Pass			Pass	Pass
W	Pass	Pass			Pass	Pass			Fail	Fail
X	Pass	Pass			Pass	Pass			Pass	Pass
Y	Pass	Pass			Pass	Pass			Pass	Pass
Z	Pass	Pass			Pass	Pass			Fail	Fail
AA	Pass	Pass			Pass	Pass			Pass	Pass
AB	Pass	Pass			Pass	Pass			Pass	Pass
AC	Pass	Pass			Pass	Pass			Pass	Pass
AD	Pass	Pass			Pass	Pass			Pass	Pass
AE	Pass	Pass			Pass	Pass			Pass	Pass
AF	Pass	Pass			Pass	Pass			Pass	Pass
AG	Pass	Pass			Pass	Pass			Pass	Pass
AH	Pass	Pass			Pass	Pass			Pass	Pass
AI	Pass	Pass			Fail	Fail			Fail	Fail
AJ	Fail	Fail			Fail	Fail			Pass	Pass
AK	Pass	Pass			Pass	Pass			Pass	Pass
AL	Pass	Pass			Pass	Pass			Pass	Pass
AM	Pass	Pass			Pass	Pass			Pass	Pass
AN	Pass	Pass			Pass	Pass			Pass	Pass
AO	Pass	Pass			Pass	Pass			Pass	Pass
AP	Pass	Pass			Pass	Pass			Pass	Pass

column represents information acquired from each of the Crack Detection

Key

Pass The joint and adjacent material appear free from defects

Pass Anomalous response adjacent to the joint not characteristic of cracking but is worthy of comment or

Fail Anomalous response characteristic of cracking above the aim.

To read comments and information about the yellow and red cells hover the mouse cursor above the cells or from the menu select **View > Comments**.

Figure 13: "Traffic Light" report of subsurface cracking

4 CONCLUSIONS

GPR is a valuable non-destructive tool for the investigation of hidden material, including the vital technique of utility detection and structural investigations of a wide variety of built structures. Being able to accurately locate utilities is vital in order that the support and technological base of our cities can continue to provide the facilities that a modern population requires. It is also essential to ensuring that any current or future construction may be completed in safety.

The examples of structural surveys discussed above include roads, bridges, airport runways and historic buildings. The same principles of investigation are regularly applied to other types of investigation such as forensic searches for weapon caches, analysis of glacier composition, geological searches for minerals, including petroleum, or in order to understand the environment and even archaeological investigations.

It is, however, vital that the operator and analyst engaged in using GPR understands the use of the equipment he/she is using and the potential limitations of its deployment. This is particularly true when it comes to understanding and analysing the survey results.

4.1 Acknowledgements

The author would like to thank Alex Birtwisle of Atlas Geophysical for permission to use the photograph at Figure 11 and the data examples in Figures 12 and 13.

4.2 References

Birtwisle, A. & Utsi, E. 2008. *The Use of Ground Penetrating Radar to detect Vertical Subsurface Cracking in Airport Runways.* Rogers, C.J. & Chignell, R.J. (eds) GPR 2008, the Proceedings of the 12th International Conference on Ground Penetrating Radar, June, Birmingham University, Birmingham, UK.

Daniels, D. 2004. *Ground Penetrating Radar – 2nd Edition,* The Institution of Electrical Engineers, London, UK, pp24 – 27.
Giannopoulos, A. GPR Max. http://www.gprmax.org.

Utsi, E. & Utsi, V. 2004. *Measurement of Reinforcement Bar Depths and Diameters in Concrete*. Slob, E, Yarovoy, A & Rhebergen, J (eds) Proceedings of the Tenth International Conference on Ground Penetrating Radar, Delft, The Netherlands, June 2004, pp659 - 662.

Utsi, E. 2006. *Improving Definition: GPR Investigations at Westminster Abbey.* Daniels, J.J. & Chen, C (eds) GPR 2006, the Proceedings of the 11th International Conference on Ground Penetrating Radar, June 19-22, Ohio State University, Columbus, Ohio, 2006.

Utsi, E., Birtwisle, A., & Cook, J. 2008. *Detection of Subsurface Reflective Cracking using GPR.* Forde, M (ed) Proceedings of the Structural Faults and Repair Conference, June 2008, Edinburgh, UK.