The Use of Ground Penetrating Radar to Detect Vertical Subsurface Cracking in Airport Runways

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Abstract: **In January 2007 the GPR crack detection equipment was used on the runway of a military airfield to locate the joints between the underlying concrete slabs, and to identify reflective cracking developing from the joints into the overlying asphalt, or to confirm the integrity of the asphalt. A system of "traffic light" reporting was used to enable the structural engineers to evaluate the extent of damage to the runway [2].**

A second, more extensive investigation has now been completed on the runway of another military airfield. Multi-channel GPR using 2 crack detection heads simultaneously with a traditional pair of 1GHz antennas was used alongside the traditional methods of visual inspection and coring.

The GPR survey successfully identified the location of subsurface cracks although, in this instance, the majority of these were in the vicinity of visible cracks. The additional assurance provided by the GPR data allowed the engineers to propose a repair programme for the worst affected areas rather than a full scale reconstruction, resulting in a significant saving of client resources. The survey also successfully identified the bay geometry and reinforcement density in the first layer of concrete.

Crack detection with an adapted GPR antenna provides a new more comprehensive method of assessing the condition of airport runways. Although validation with sample cores is recommended, the technique is essentially non-intrusive and provides more information on which to base re-construction decisions than traditional methods.

Keywords - **Reflective cracking, runway maintenance, airfield maintenance, pavement engineering, concrete joints, GPR, Georadar, Composite Pavement Structure.**

1. INTRODUCTION

Ground Penetrating Radar (GPR) surveys of airport pavements are becoming increasingly common. They offer non-intrusive and rapid data acquisition methods and can provide invaluable information to the pavement engineer regarding construction types, material thickness and defect location in the form of delamination particularly between asphaltic layers and between concrete and asphalt interfaces. The identification of other failure modes, most notably reflective cracking, are undertaken by visual inspection and coring. Traditional GPR antennas are not normally capable of detecting subsurface vertical cracks. When reflective cracks are not visible at the surface traditional methods of assessment based on visual inspection and coring are ineffective.

Reflective cracking is a defect associated with composite pavements. Cracks reflect the location of slab joints in the concrete below the asphalt. It is thought they propagate vertically through the asphaltic overlay. Reflective cracking is also known as *Bottom-up cracking*.

An adapted GPR antenna, the crack detector head (CDH), has been developed in order to measure crack depths in flexible pavement construction [1]. These cracks develop at the pavement surface and permeate downwards. This is known as *Top-down* cracking. The vertical extent of cracking beneath the surface is a determinant of the need for pavement re-surfacing.

Using the same GPR technology and adapting data acquisition and processing methodologies, it has been possible to locate vertical cracks emanating from concrete slab joints before they reach the pavement surface and provide information regarding their depth and extent across the runway structure.

A simple reporting format was developed to convey the wealth of information made available. This information was used in evaluating rehabilitation options with massive cost saving implications.

2. BACKGROUND TO INVESTIGATION

In January 2007, after a demonstration of the ability of the crack detection head to detect concealed cracking, the Defence Estates Prime Contractor commissioned a GPR survey of the main runway at a UK military airfield. Since this was the first occasion on which this type of survey had been attempted, it was accepted that part of the two working days spent on site would be dedicated to developing an efficient methodology for this type of survey as well as collecting as much relevant data as possible. The runway was about to undergo extensive reconstruction so the principal brief was to provide engineers with an understanding of the slab geometry beneath he asphalt overlay and highlight the areas of increased subsurface cracking so reconstruction methods could be adapted and specific problem areas prioritised.

With the data acquisition method honed, the second investigation, also at a UK military airfield, was commissioned at the beginning of the rehabilitation planning stage. Full reconstruction had been recommended but after visual inspection pavement engineers were not convinced reconstruction was necessary. Independent evidence was required to add weight to proposals that rehabilitation of the existing runway would be sufficient to extend the operational life of the structure.

3. GPR SURVEY METHODOLOGY

3.1 Survey 1.

For the preliminary investigation in January 2007, the GPR equipment was set up, as illustrated in Figure 1, with a Groundvue 3 multi-channel radar system equipped with 2 crack detection heads at 0.5m separation from each other and a central traditional 1.5GHz antenna to provide simultaneous construction information. The traditional data serves as a useful comparison for the person interpreting data, particularly in any area where the boundary between the asphalt and the concrete is not clear from the crack depth data.

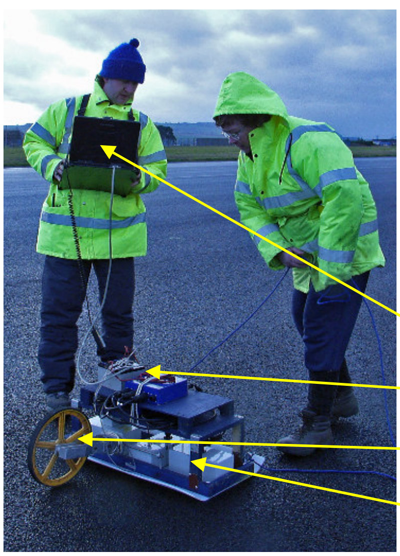

Figure 1. Overview of GPR System

The control system of the radar lies directly above the sled containing the antennas. A distance measuring instrument consisting of a wheel, fitted with an optical encoder, measures the linear distance travelled by the GPR system and also provides the prompt for the radar to transmit, based on the sampling distance selected by the operator. A laptop computer is used to select the survey parameters, which control the radar's operation, and to store the data collected.

All profiles were acquired along the length of the runway as the path of the CDH needs to be perpendicular to the orientation of the crack it is detecting.

Two acquisition methods were used to determine which would provide the most effective use of time on site.

3.1.1 Method 1

This consisted of five parallel GPR profiles acquired from locations across the runway width. These locations were along the centre line of the runway and at points 10m and 18m either side of the centreline.

Joints in the concrete were identified below the asphaltic overlay and marked alphabetically on the runway surface with marker paint. These locations were also marked in the data for reference when interpreting the data in the office. Evidence of vertical cracking was noted and marked. This method was found to be slow and time consuming on site with little time saving benefit back in the office.

3.1.2 Method 2.

This consisted of data acquired from the same five locations across the runway width, but involved continuous data collection without location and marking each joint. This proved to be a rapid method of data acquisition covering a large proportion of the runway within the working day. Post acquisition interpretation time was increased due not only to the quantity of data acquired but because no structural elements of the runway (e.g. joints) were identified.

Other factors encountered with the first investigation included the need for two GPR operators; One to tow the sled and the other to operate the system via the laptop. Also, the strain of carrying a ruggedized laptop computer all day was considerable.

3.2 Survey 2.

The second investigation adapted the GPR equipment set up making it only necessary for one GPR operator to use the system and reduced any physical stress on that individual.

The primary adaptation was to suspend the sled containing the antenna beneath a hand pushed trolley and to mount the GPR control systems and laptop computer on top as seen in Figure 2.

This enabled a greater degree of flexibility for the operator as well as increasing the operating parameters of the GPR system as space was available for extra battery's to power both the GPR system and the laptop computer.

The method of acquiring data on site was also improved by utilising the ability of the CDH to locate longitudinal concrete slab joints in real time. This meant that the bay geometry of the slabs beneath the

asphalt could be ascertained and parallel GPR profiles acquired down the midpoint of each slab.
Within 5 minutes of turning the GPR system on it was possible to calculate that each slab was 6m wide and the runway had eight slabs across its width.

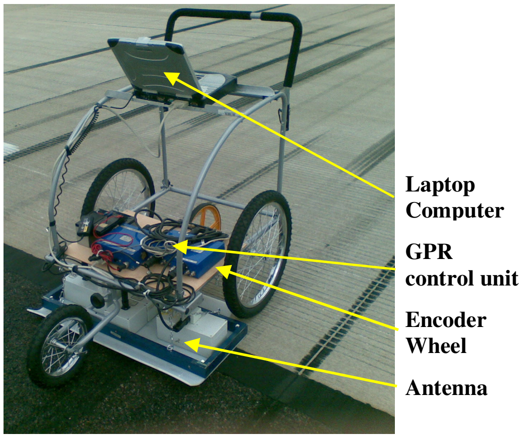

Figure 2. Adapted GPR system overview

With this information it was possibly to acquire data from the mid point of each slab across the width of the runway. A total of eight profiles each approximately 1200m long. All data was collected in one 8 hour shift which was a threefold increase in the distance covered when using the previous methods.

4. DATA INTERPRETATION

Data from the CDH is interpreted in much the same way as with traditional GPR and because during these investigations a traditional antenna has been used in parallel with the two CDH antennas, it is possible to view and compare the information to gain a complete picture of the pavement structure.

As with all GPR investigations a request for historic construction information is important. Any information regarding the construction history of an airfield is useful as it may provide clues to the responses identified in the GPR data.

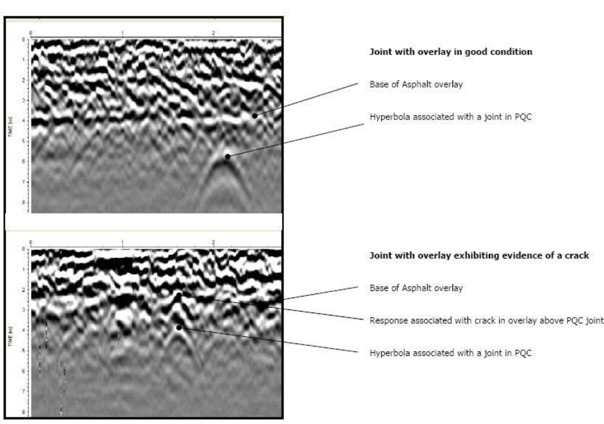

Figure 3. Comparative example of a joint with and without vertical cracking associated with it.

Identification of the transverse slab joints is paramount to the success of the crack detection survey as the locations above these joints contain the areas where vertical cracking is most prevalent. It should be noted that in many cases, the concrete slabs will have been constructed with imperial measurements therefore it is important to identify the regular pattern of joints in the GPR data before zooming into the fine detail. It is possible to locate cracks in slabs and mistake them for joints; these also may have cracks reflecting through the asphalt.

Once the joints in the concrete are located, it is simply a case of analysing the GPR response of the asphaltic material overlaying it. The typical response from a crack is that of a small air-filled or water-filled void as seen in figure 3.

For the initial investigation the interpretation of the results from the first method of data acquisition was rapid as the joint locations had been marked in the data during collection. However, observations made on site regarding the joint locations that might have vertical cracking associated with them were spurious. It was only after processing the data and taking time to look carefully at the response that a proper and correct interpretation of the data could be made. This effectively discredited the method as a way of locating reflective cracks in real time in the airfield environment.
The data from the second method of acquisition proved to be far more effective as joint patterns could be identified. Once the joints were identified a detailed analysis of the area surrounding the joint could be made.

This method of interpretation was adopted for the investigation of the second military runway.

The results from the two CDH antennas are all that is required for reporting. The traditional antenna is only used as a baseline reference to aid in the interpretation of the CDH data.

5. REPORTING THE RESULTS

The preliminary results are recorded as the data is interpreted. The results from each CDH antenna were recorded in a simple table format. The chainage to each joint was recorded and the depth to any crack associated with that particular joint was recorded. Joints that had no evidence of vertical cracking associated with them were also noted.
There were some instances where an anomalous response was identified in the vicinity of the joint but did not have the characteristics of a vertical crack. These were also highlighted with an annotated note and a question mark placed by them for further investigation.

This method of gathering the preliminary results lent itself to a reporting format using Microsoft Excel. This format uses a column for each profile for each antenna plotted next to a chainage. Each cell is colour coded GREEN for a joint with no evidence of vertical cracking, RED for a joint with some evidence of vertical cracking and YELLOW for joints with an ambiguous or unidentified response associated with them. Microsoft Excel allows comments to be associated with individual cells so extra information could be included such as depth to the top of the crack or an explanation of any ambiguous or unidentified response. An example of the reporting format is presented in figure 4.

RAF ********* CRACK INVESTIGATION

All values are depths in metres below ground level.

Longitudinal Chainage (m)	South Shoulder 27m South of CL		21m South of CL		15m South of CL		9m South of CL		3m South of CL		3m North of CL		9m North of CL		15m North of CL		21m North of CL		North Shoulder 27m North of CL		100m group
	Ch.1	Ch.2	Ch.1	Ch.2	Ch.1	Ch.2	Ch.1	Ch.2	Ch.1	Ch.2	Ch.1	Ch.2	Ch.1	Ch.2	Ch.1	Ch.2	Ch.1	Ch.2	Ch.1	Ch.2	
1365	0.01	0.01									0.06										
1375				0.12							0.09	0.09									
1384													0.09	0.09							
1396	0.06	0.06																			
1403.5													0.12								
1411			0.07											0.13	0.13						
1421					0.09	0.06															
1427	0.01	0.01																			
1437														0.1							
1439											0.14	0.14									
1453.5			0.05	0.05																	
1457	0.02	0.02									0.08	0.12									
1457.4											0.1	0.1									
1466.5			0.13	0.13	0.10																
1469	0.01	0.01																			
1471.5											0.14										
1475.8											0.01	0.01									
1480			0.06	0.06	0.06	0.06															
1483.6											0.13	0.13									
1487	0.01	0.01									0.12	0.12									
1517										0.07	0.1	0.1									
1523.8											0.05										
1530	0.03	0.03																	0.02	0.02	
1539.6											0.15	0.15									
1541.8													0.08	0.05							
1546	0.02	0.02																			
1556											0.08	0.08									
1568.7													0.06								
1576																	0.07				
1578	0.02	0.02											0.09	0.09							
1582												0.07									
1590													0.06								
1600											0.1										
1609	0.02	0.02									0.06	0.06									
1613																			0.02	0.02	
1620												0.06									
1639.5	0.01	0.01																			
1656													0.09								
1666											0.11										
1674																			0.03	0.03	
1693.9																	0.1				
1699.7													0.05								
1700.6			0.1																		
1705																			0.02	0.02	
1716	0.01	0.01										0.05									
1739																	0.12	0.12			
1742											0.08	0.08									
1745									0.04	0.04									0.06	0.06	
1747								0.6													
1751											0.18	0.18									
1756			0.1								0.13										
1761.4	0.02	0.02																			
1763.5											0.11				0.14						
1765.4													0.11	0.13							
1782									0.09	0.09											
1789					0.1	0.1															
1791	0.02	0.02															0.07	0.07			
1794															0.13	0.13					

Figure 4. Reporting format used to simplify GPR data

The results for the first investigation showed subsurface cracking to be widespread. Some areas appeared to have a greater proportion of vertical cracks associated with them. It was possible to locate the areas with the highest density of defects thus allowing pavement engineers to evaluate different strategies for dealing with them.

In the case of the second investigation surprisingly few joints show evidence of vertical cracking above them. This proved interesting as initial surveys undertaken by traditional methods some time ago had condemned the runway to reconstruction.

The CDH results concluded that any vertical cracks that exist within the pavement structure have already breached the surface and have been recognised by visual inspection.
This has enabled engineers to amend the maintenance strategy from reconstruction to rehabilitation by overlaying the existing structure.

6. VARIFICATION OF RESULTS

As with most non-intrusive investigations, the results can only be assumed unless there is physical evidence that verifies their credibility.

For the purpose of the first investigation, there was no direct core calibration. Evidence of vertical cracking was moderately widespread which fitted with the models and assumptions engineers had previously made.

The second investigation had the benefit of a number of cores located over joints in the concrete slabs which verified the results and gave them credibility. However there were issues getting the cores in exactly the right place. If a 100mm diameter core barrel is displaced by 50mm, there is every chance it will miss the crack identified by the GPS.

7. CONCLUSIONS

These investigations have demonstrated that crack detection with an adapted GPR antenna could provide a new more comprehensive method of assessing the condition of composite airfield pavements. However, the investigation also highlighted some of the limitations of this type of survey and based on this information the paper proposes a methodology for undertaking this type of investigation and highlights were additional research is needed.

This type of investigation is still in its infancy. Data acquisition and interpretation methodologies are being refined. The introduction of RTK-GPS into the GPR data will be a great benefit as a precise location for any failed joint could be given. If necessary a coring rig could be guided to the location and verification of the result could be gathered swiftly. In future investigations it may be possible to utilise an array of CDH antennas rather than just two. This would enable coverage of a much larger area and build a bigger picture of subsurface vertical cracking within the airfield pavement.

ACKNOWLEGMENTS

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REFERENCES

[1] Forest, R & Utsi, V (2004), "Non destructive crack depth measurements with Ground Penetrating Radar" in Slob, E, Yarovoy, A and Rhebergen, J (eds) *The Proceedings of the Tenth International Conference on Ground Penetrating Radar*, Vol 2, pp799-802.

[2] Utsi E, Birtwisle A & Cook, J "Detection of Subsurface Reflective Cracking using GPR" (forthcoming).

[3] Birtwisle, A & Cudworth "Validating the use of Ground Penetrating Radar to Detect Vertical Subsurface Cracking in Composite Pavements" (forthcoming)