



the ukpms user manual
Volume 3: Machine Data Collection for UKPMS
Chapter 10: Ground Radar

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1. Preamble

This chapter is intended to provide a brief overview of Ground Radar and is aimed at those who require an appreciation of the principles behind the test method and the factors involved in the analysis and processing of results for utilisation within UKPMS. It also directs the reader, where appropriate, to other references for more detailed information.

2. Background and Introduction

Ground Radar is the abbreviated term used within this chapter to describe the Ground-Penetrating Impulse Radar survey technique. Ground Radar offers rapid, non-destructive survey capabilities to establish sub-surface profiles. Survey apparatus and methodologies have been developed over recent decades and acceptance of the technique has now been gained in a wide range of applications; including:

- Pavement investigations.
- Structural investigations.
- Archaeological surveys.
- Buried pipe and cable detection.
- Ordnance location.

This chapter considers Ground Radar's capabilities in the field of pavement investigation only.

The current UKPMS specification does not include functionality for dealing with Ground Radar data. However, the existence of a defined HMDIF format (see Section 6) means that it can be imported into a UKPMS system where it may then be combined with other pavement data collected against the same network model. Subsequently exporting the data to a Geographical Information System provides a useful viewing facility.

2.1 Network Level Surveys

Network level surveys are used to determine material types and layer thicknesses. These provide a general knowledge of the asset and assist in the interpretation of survey data obtained from other sources (e.g. Deflectograph – see Chapter 4 of Volume 3 of the UKPMS User Manual).

The UKPMS Owners Forum (2004) identified that a network-wide representation of Ground Radar data also offered potential benefits for the management of streetworks. This would provide the facility to advise streetworks contractors of a pavement's construction in advance of their works so that excavation and reinstatement could be programmed more effectively; thereby reducing waste and disruption.

2.2 *Project Level Surveys*

Ground Radar can also be used for more detailed analysis of pavements at a project level to investigate the underlying causes of deterioration and to provide information for scheme design. Examples include:

- Determination of moisture profiles within the sub-base.
- The identification of sub-surface defects including voiding, de-lamination, de-bonding, cracking and consolidation.
- Quality control of steel reinforcing and dowel bar placement in rigid or composite pavements and the investigation of corrosion and defective joints.
- Identification of buried features that could impact on planned maintenance (e.g. tram tracks).
- Providing construction data transversely across the carriageway (particularly on sections of road that have been widened or subject to utility works).

Project level surveys generally require higher quality data than network level surveys and this is reflected by differing survey methodologies. The end-use of the Ground Radar must therefore be considered when specifying and procuring surveys to ensure that the obtained data is suitably accurate and detailed (see Section 4.1).

2.3 *Advantages and Limitations*

The advantages of using Ground Radar include:

- Measurements are relatively easy to make, are rapid and non-intrusive.
- Network level surveys are undertaken at traffic speeds (typically 50 to 80kph) with no requirement for traffic management.
- The equipment is portable, rugged and poses no hazards to operatives (in so far as it uses only very low power radio waves).
- Surveys are effective through multi-layer pavements.
- The achievable accuracy of layer depth measurement reported by contractors and industry bodies varies. A figure in the region of $\pm 10\%$ appears typical for pavement applications.
- Survey results can be reported in various formats (including HMDIF – see Section 6)

The limitations of Ground Radar include:

- Its performance is site-specific.
- Calibration is required against construction data obtained from cores (or other sources).
- The raw data is complicated and requires expert analysis and interpretation.

- Project level surveys are undertaken at typical speeds of between 0.5 and 20kph. This would normally require traffic management.
- The effective total depth of measurement is limited to approximately 1500mm (when using standard pavement application apparatus).
- Accurate network data is required before undertaking a survey.
- It is unsuited for reporting absolute measurements.
- Its performance can be compromised by highly conductive materials such as closely spaced reinforcement, mineralogical clays and saline pore fluids.

3. Test Principles

For a full description of the test principles and apparatus, reference should be made to HD 29/94 “*Structural Assessment Methods*” (DMRB. Volume 7. Section 3. Part 2. Chapter 6 and Annexes 5 to 7).

3.1 Theory

Ground Radar operates by transmitting pulses of low power radio wave energy into a pavement. As the energy wave radiates downwards its velocity and strength is affected by the electrical properties of the materials through which it travels. Contrasts in the electrical properties of different pavement layers (or buried objects) cause a proportion of the wave energy to be reflected back to the surface when a boundary is encountered (whilst the remainder continues onwards through the pavement). The reflected wave energy is measured and recorded by an antenna at the road surface. The strength of the reflected wave energy and the time taken to travel through the pavement can be analysed to generate a cross-section of the sub-surface materials and to provide indications of their condition.

3.2 Apparatus

Typical Ground Radar survey apparatus consists of a control unit, transmitting/receiving antennae and a data storage device.

For network level surveys, antennae are fitted to a trailer (coupled to a road-going vehicle) and are positioned at a height of approximately 15mm above both wheeltracks. The transmitting frequencies of the antennae differ between the two wheeltracks to enable accurate measurement throughout the depth of the pavement.

Data is referenced to a highway network in the form of links and sections. A wheel with a shaft encoder is fitted to the antennae to measure chainage within each section. (Modern developments in Global Positioning Systems offer the potential for improvements in the accuracy and repeatability of location referencing).

The shaft encoder can also be used to control the rate at which wave energy is pulsed. In urban environments, constant speeds may not be maintainable



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within the normal traffic flow and so the rate at which the Ground Radar antennae transmit wave energy is best governed by distance measurement (as opposed to time interval). For network level surveys, layer thicknesses are typically determined at fixed intervals of around 2m.

Project level surveys generally require a higher resolution of sub-surface features. To achieve this, the Ground Radar apparatus can be towed at slow speed or alternatively pushed across the road surface by hand whilst the antennae transmit wave energy at more frequent intervals (typically 0.5m). Increasing the sampling of Ground Radar measurements in this way can, however, result in very large data files and can give rise to problems with graphical representation of the data (see Section 4.2)

Ground Radar is still a developing technology and survey equipment and data analysis techniques are continually being refined. In the future this may prevent the current need for different survey methodologies for network and project level surveys.

3.3 Calibration

Interpretation of the reflected wave energy received by the Ground Radar antennae requires an understanding of the electrical properties of the constituent materials within a pavement.

A preliminary analysis of the Ground Radar data is undertaken to identify apparent changes in pavement construction (or defects/anomalies). Site specific data is then provided by targeting coring (or other exploration techniques) within key areas to confirm layer thicknesses and material types. This is then used to validate the interpretation of the Ground Radar data.

Reference should be made to Annex 6 of HD 29/94 “*Calibration of radar for determination of layer thickness*” (DMRB, Volume 7, Section 3, Part 2.) for a more detailed description.

4. Test Considerations

4.1 Procurement of Ground Radar Surveys

Ground Radar data is a useful tool for network and project level applications. However, different survey methodologies may be required depending upon the level of detail and accuracy required. The intended use of the obtained Ground Radar data should therefore be considered when specifying and procuring surveys.

To ensure the accuracy and reliability of the information provided from a Ground Radar survey, HD 29/94 requires contractors to produce a Survey Plan as part of their tender submission. The Survey Plan should address the following:

- Previous experience etc.
- Equipment specification.
- Calibration of the radar system.
- Quality control procedures for both survey and analysis.
- Work programme.
- Survey procedure.
- Risk assessment of the site work.
- Presentation of the ground radar results (see Section 4.2).

The requirement for pavement construction details from coring (or other sources) to calibrate Ground Radar data (see Section 3.3) can introduce additional costs if not included within the Survey Plan/Tender of the Ground Radar contractor. The number and location of core samples should be carefully considered to maximise the achievable confidence in the Ground Radar data.

4.2 *Sample Frequency*

The distance interval at which the Ground Radar apparatus transmits wave energy pulses as it travels along the road can vary according to:

- The survey level (i.e. Network or Project Level).
- The survey methodology and apparatus used.
- The intended end-use of the data.

Recording measurements at closely spaced intervals can result in large data files. Interpretation of closely spaced data can be difficult when analysed at map scale. In such cases, pre-processing to merge the data into contiguous lengths of consistent construction and condition may be appropriate. Consideration of the rate of Ground Radar sampling and the presentation format of the results should be considered when specifying surveys.

4.3 *Management of Data*

Commissioning a Ground Radar survey can represent a significant investment. A data management regime should be implemented to ensure that the maximum benefit is realised. This should include:

- Mechanisms for refining, augmenting and validating Ground Radar data with construction information from other sources.
- Processes for maintaining and updating the construction information to reflect changes on the highway network.

4.4 *Frequency of Survey*

Consideration should be given to the required frequency of Ground Radar surveys.

By assessing the strength and scatter of reflected signals received at the pavement surface an indication of moisture content can be derived. Although unable to provide an absolute measure of the moisture content of the sub-grade, the surveys can highlight wet areas. These may be caused by a high water table or defective drainage. Comparisons between results obtained in “wet” and “dry” seasons may then be used to suggest the possible source of the water and highlight areas for further investigation.

4.5 *Material Classification*

At present, the classification of material types encountered by Ground Radar are assigned by the survey contractor (or consultant undertaking the survey analysis and interpretation). If different contractors (or consultants) are used within a highway network then issues of consistency can arise. This can complicate the interpretation and reporting of the final data. A standardised approach across a network is recommended.

One approach could be to produce a material classification based upon three levels of description detail:

- Generic – *a broad material identification from Ground Radar alone.*
- Categorized – *an identification of the material type from core inspections.*
- Specific – *a more detailed identification of the material type from as-built records or sample analysis.*

Table 1 provides a proposed material classification system based upon the varying levels of information that may be available.

Generic	Categorized	Specific
Surface Dressing	Surface Dressing	Surface Dressing
		Friction Surface
Asphalt	Dense Macadam	DBM, HDM, HMB
	Hot Rolled Asphalt	High Stone Surfacing Low Stone Surfacing HRA Base
	Porous	PA, OGM
	Thin Surfacing	TS, SMA
PQ Concrete	PQ Concrete	CRCP, CRCR, JRC, URC
Block Paving	Granite Setts, Cobbles, Bricks, Paviers	~
Bound Mixtures	Hydraulically Bound Mixtures	Cement, Slag, Fly Ash, Hydraulic etc.

	Unbound Deteriorated Mixtures	Granular sunk into clay, Degraded granular
Subgrade	Unbound soils	Clay, Gravel, Silt, Chalk, Hard Rock
Bridge Deck	~	~
Interface Layers	Reinforcement, Geogrid, Geotextile	~

Table 1 Proposed Material Classification System

4.6 Weather

Undertaking Ground Radar surveys in heavy rain (or when there is standing water on the pavement) is not advisable. The presence of water can affect the transmitted/reflected signal and can complicate the calibration process.

5. Processing of Test Results

The current UKPMS specification does not provide functionality for processing or viewing Ground Radar data. However UKPMS is regarded as a “convenient repository” for such data because of the commonality with the location referencing systems used for other pavement data.

Externally to UKPMS, specialist software is used to refine the raw data and to eliminate external “noise” and interference. Significant reflections at layer boundaries are then identified and reported upon.

It is unlikely that highway engineers will have sufficient experience or expertise to process and interpret raw Ground Radar data. This task is normally undertaken by either the contractor who undertook the survey or by a specialist consultant.

6. Ground Radar HMDIF

An example of the typical structure and content of a Ground Radar HMDIF file that would be produced by a contractor is provided in Table 2. The HMDIF contains pavement construction data only (drainage, utilities, moisture contents, sub-surface defects etc. are not included).



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```
HMSTART UKPMS 001 " "; \
TSTART;
SSEC\NETCODE,SECTLAB,SURVEY DATE;
RADARRECORD\FEATURE,START CHAINAGE,END CHAINAGE,CROSS SECTION POSITION,REPORT DATE,DATA
SUPPLIER;
RADAR RECORD LAYER\ LAYER NUMBER,LAYER THICKNESS,LAYER DESCRIPTION,INTERPRETATION
CONFIDENCE,CONDITION;
TEND\5;
DSTART;
SSEC\UKPM2,20302882/15,060900;
RADAR RECORD\CW,0,0,CL1,070900, "ACONTRACTOR";
RADAR RECORD LAYER\1,150,"BITUMINOUS MATERIAL",80,"";
RADAR RECORD LAYER\2,200,"LEAN MIX CONCRETE",60,"";
RADAR RECORD LAYER\3,300,"SUBBASE",30,"";
RADAR RECORD\CW,0,5,0,5,CL1,070900, "ACONTRACTOR";
RADAR RECORD LAYER\1,155,"BITUMINOUS MATERIAL",80,"";
RADAR RECORD LAYER\2,204,"LEAN MIX CONCRETE",60,"";
RADAR RECORD LAYER\3,312,"SUBBASE",30,"";
RADAR RECORD\CW,1,1,CL1,070900, "ACONTRACTOR";
RADAR RECORD LAYER\1,160,"BITUMINOUS MATERIAL",80,"";
RADAR RECORD LAYER\2,204,"LEAN MIX CONCRETE",60,"";
RADAR RECORD LAYER\3,308,"SUBBASE",30,"";
RADAR RECORD\CW,1,5,1,5,CL1,070900, "ACONTRACTOR";
RADAR RECORD LAYER\1,163,"BITUMINOUS MATERIAL",80,"";
RADAR RECORD LAYER\2,204,"LEAN MIX CONCRETE",60,"";
RADAR RECORD LAYER\3,307,"SUBBASE",30,"";
RADAR RECORD\CW,2,2,CL1,070900, "ACONTRACTOR";
RADAR RECORD LAYER\1,155,"BITUMINOUS MATERIAL",80,"";
RADAR RECORD LAYER\2,204,"LEAN MIX CONCRETE",60,"";
RADAR RECORD LAYER\3,312,"SUBBASE",30,"";
RADAR RECORD\CW,2,5,2,5,CL1,070900, "ACONTRACTOR";
RADAR RECORD LAYER\1,153,"BITUMINOUS MATERIAL",80,"";
RADAR RECORD LAYER\2,204,"LEAN MIX CONCRETE",60,"";
RADAR RECORD LAYER\3,308,"SUBBASE",30,"";
RADAR RECORD\CW,3,3,CL1,070900, "ACONTRACTOR";
RADAR RECORD LAYER\1,250,"BITUMINOUS MATERIAL",90,"";
RADAR RECORD LAYER\2,340,"SUBBASE",40,"";
RADAR RECORD\CW,3,5,3,5,CL1,070900, "ACONTRACTOR";
RADAR RECORD LAYER\1,253,"BITUMINOUS MATERIAL",90,"";
RADAR RECORD LAYER\2,335,"SUBBASE",40,"";
RADAR RECORD\CW,4,4,CL1,070900, "ACONTRACTOR";
RADAR RECORD LAYER\1,256,"BITUMINOUS MATERIAL",90,"";
RADAR RECORD LAYER\2,324,"SUBBASE",40,"";
RADAR RECORD\CW,4,5,4,5,CL1,070900, "ACONTRACTOR";
RADAR RECORD LAYER\1,258,"BITUMINOUS MATERIAL",90,"";
RADAR RECORD LAYER\2,315,"SUBBASE",40,"";
RADAR RECORD\CW,5,5,CL1,070900, "ACONTRACTOR";
RADAR RECORD LAYER\1,270,"BITUMINOUS MATERIAL",90,"";
RADAR RECORD LAYER\2,320,"SUBBASE",40,"";
SSEC\UKPM2,20302882/20,060900;
RADAR RECORD\CW,0,235,CL1,070900, "ACONTRACTOR";
RADAR RECORD LAYER\1,150,"BITUMINOUS MATERIAL",80,"";
RADAR RECORD LAYER\2,200,"LEAN MIX CONCRETE",60,"";
RADAR RECORD LAYER\3,300,"SUBBASE",30,"";
RADAR RECORD\CW,235,367,CL1,070900, "ACONTRACTOR";
RADAR RECORD LAYER\1,155,"BITUMINOUS MATERIAL",80,"";
RADAR RECORD LAYER\2,204,"LEAN MIX CONCRETE",60,"";
RADAR RECORD LAYER\3,312,"SUBBASE",30,"";
RADAR RECORD\CW,367,781,CL1,070900, "ACONTRACTOR";
RADAR RECORD LAYER\1,160,"BITUMINOUS MATERIAL",80,"";
RADAR RECORD LAYER\2,204,"LEAN MIX CONCRETE",60,"";
RADAR RECORD LAYER\3,308,"SUBBASE",30,"";
DEND\55;
HMEND\62;
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Table 2 Example Ground Radar HMDIF