VOLUME 7	PAVEMENT DESIGN AND MAINTENANCE
SECTION 3	PAVEMENT MAINTENANCE ASSESSMENT

PART 2

HD 29/08

DATA FOR PAVEMENT ASSESSMENT

SUMMARY

This Standard describes the data required for pavement assessment and the data collection methods that are currently approved by the Overseeing Organisations. These methods cover measurement of the construction and condition of different types of pavements, except skidding resistance which is covered in HD 28 (DMRB 7.3.1). This revision has been updated to reflect current practice and includes requirements previously issued in IAN 42/05.

INSTRUCTIONS FOR USE

1. Remove Contents pages from Volume 7 and insert new Contents pages for Volume 7 dated May 2008.

2. Remove HD 29/99 from Volume 7, Section 3 which is superseded by this Standard and archive as appropriate.

3. Insert HD 29/08 into Volume 7, Section 3.

4. Please archive this sheet as appropriate.

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1. INTRODUCTION

Mandatory Sections

1.1 Sections of this document which form part of the Standards of the Overseeing Organisations are highlighted by being contained in boxes. These are the sections with which the Design Organisations must comply, or must have agreed a suitable alternative approach through a departure from Standard with the relevant Overseeing Organisation. The remainder of the document contains advice and enlargement which is commended to Design Organisations for their consideration.

Scope

1.2 This Part describes the data required for pavement assessment and the data collection methods that are currently approved by the Overseeing Organisations. These methods cover measurement of the construction and condition of different types of pavements, except skidding resistance which is covered in HD 28 (DMRB 7.3.1). Guidance is also given on the processing of data obtained by the methods (where appropriate). Interpretation of the results is generally covered in HD 30 (DMRB 7.3.3) which also describes the use of each assessment method in the context of the overall pavement monitoring and assessment process. Advice on the interpretation of TRACS data (see Chapter 2) is given in this Part. The list of methods is not exhaustive and is not intended to exclude the use of other machines and methods. However, those which are presently part of the Overseeing Organisations' standard assessment procedure are all included.

Implementation

1.3 This Part must be used forthwith on all schemes for the improvement and maintenance of trunk roads including motorways currently being prepared, provided that, in the opinion of the Overseeing Organisation this would not result in significant additional expense or delay. Design organisations must confirm its application to particular schemes with the Overseeing Organisation.

Use in Northern Ireland

1.4 For use in Northern Ireland, this Standard will apply to those roads designated by the Overseeing Organisation.

Mutual Recognition

1.5 The construction and maintenance of highway pavements will normally be carried out under contracts incorporating the Overseeing Organisations' Specification for Highway Works (SHW) which is contained in the Manual of Contract Documents for Highway Works Volume 1 (MCHW 1). In such cases products conforming to equivalent standards and specification of other Member States (MS) of the European Economic Area (EEA) or a State which is party to a relevant agreement with the European Union and tests undertaken in other MS of the EEA or a State which is party to a relevant agreement with the European Union will be acceptable in accordance with the terms of Clauses 104 and 105 (MCHW 1.100). Any contract not containing these Clauses must contain suitable clauses of mutual recognition having the same effect, regarding which advice must be sought from the Overseeing Organisation.

Health and Safety

1.6 All surveys and data collection on or in the vicinity of highway pavements must be carried out in accordance with:

- Health and Safety at Work Act (1974);
- Management of Health and Safety at Work Regulations (1999);
- Construction (Design and Management) Regulations (2007) (CDM Regulations);

- Traffic Signs Manual Chapter 8 (2006); and
- Safety at Street Works and Road Works – A Code of Practice.

1.7 In Northern Ireland, the relevant Health and Safety documents are:

- Construction (Design and Management) Regulations (Northern Ireland) 2007;
- Health and Safety at Work (Northern Ireland) Order 1978;
- Management of Health and Safety at Work Regulations (2000);
- Traffic Signs Manual Chapter 8 (2006); and
- Safety at Street Works and Road Works – A Code of Practice.

1.8 For the Highways Agency network, further information on Health and Safety is given in Part 1 of the Network Management Manual.

1.9 Where data collection involves excavating or driving probes into the subgrade at locations where there may be buried services, the public utility organisations must be contacted for details of the locations of their equipment. The exact location of buried services should be established prior to carrying out the work using cable locating equipment.

Glossary

1.10 A glossary and list of principal abbeviations is given in HD 23 (DMRB 7.1.1).

1.11 The term "asphalt" replaces "bituminous material" as the generic term for pavement material consising of mineral aggregate combined with a bitumen binder and which is normally laid by a paver. "Asphalt" includes all bitumen bound base, binder course and surface course materials, except surface dressing. There are some exceptions to this as indicated below, where "bituminous material" continues in use:

- Deflectograph processing uses the technical terms "Equivalent Thickness of Sound Bituminous Material (ESBM)", "Total Thickness of Bituminous Material (TTBM)" and PANDEF Base Type Classification "BITS". Use of the term "asphalt" would require changes to these acronyms and to text in the associated software.
- In some instances the term "bituminous materials" may also refer to surface dressings as well as paver laid material.

1.12 The term "Hydraulically Bound Mixture" or "HBM" is used as the generic term for pavement material consisting of mineral aggregate bound with cement, lime, slag or fly ash binder, or a combination thereof. The terms "lean concrete", "cement bound material" or "CBM" are no longer used except in connection with PANDEF Base Type Classification "CEMT".

2. TRAFFIC SPEED CONDITION SURVEYS

Types of Surveys

2.1 On the trunk road network in England, surveys carried out under the Highways Agency (HA) TRAffic-speed Condition Survey (TRACS) contract replaced the previous High-speed Road Monitor (HRM) surveys in the summer of 2000. TRACS data is collected under a central HA contract which includes the loading of data to HAPMS for subsequent use by Agents and others.

2.2 On the National Network in Scotland, designated roads in Northern Ireland and on the Local Authority Road Network in England, traffic-speed surveys are carried out using the Surface Condition Assessment of the National NEtwork of Roads (SCANNER) system. On the National Network in Wales a method similar to SCANNER is used.

2.3 The SCANNER survey details are given in the five-volume User Guide and Specifications published by the UK Roads Board (2007). A summary of the features of SCANNER surveys is given below, following the text relating to TRACS surveys.

Traffic-Speed Condition Survey (TRACS) (Relevant to the HA in England)

2.4 TRACS surveys are carried out using survey vehicles equipped with lasers, video image collection and inertia measurement apparatus to enable surveys of the road surface condition to be carried out whilst travelling at variable speeds, of up to 100 km/h, to match prevailing traffic, and hence cause minimum disruption to other road users.

Figure 2.1: TRACS Vehicle

2.5 TRACS surveys are carried out annually usually over:

a) both lanes of single carriageways;

b) lanes 1 and 2 of the main carriageway on dual carriageways; and

c) lane 1 of slip roads.

Roundabouts are excluded from TRACS surveys. For precise details of the coverage and frequency of these surveys the HA should be consulted.

2.6 TRACS surveys are controlled by an end result specification for the survey equipment and a detailed Quality Audit procedure for the surveys includes regular independent checks to maintain quality assurance.

2.7 The TRACS survey vehicle measures:

- Texture Profile in the nearside wheel-track at approximately 1mm longitudinal intervals;
- Transverse Profile across a 3.2m width at approximately 0.15m longitudinal intervals;

- Longitudinal Profile in the nearside wheel-track at approximately 0.1m longitudinal intervals;
- cracking over a width of 3.2m (continuous monitoring);
- vehicle geographical position (Northing, Easting and altitude) as well as Road Geometry (gradient, crossfall and curvature) at discrete 5m intervals;
- a forward-facing video record of the road being surveyed;
- a downward-facing video record of the road being surveyed.

2.8 All data collected by the TRACS survey vehicle is referenced to the network sections to a longitudinal accuracy of ± 1m. The start and end points of sections are defined by Location Reference Points (LRPs) in Highways Agency Pavement Management System (HAPMS) referencing as described in the Network Management Manual (NMM).

2.9 The TRACS survey data is delivered in raw form as TRACS Raw Condition Data (RCD). The Highways Agency's Machine Survey Pre-processor (MSP) software is used to process the RCD to generate the TRACS Base Condition Data (BCD), which contains:

- Rut Depths in the nearside and offside wheel-tracks calculated from the measured Transverse Profile, over 10m lengths;
- 3m, 10m and 30m Enhanced Longitudinal Profile Variance calculated from the measured Longitudinal Profile, averaged over 10m lengths for the nearside wheel-track only;
- Intensity of Cracking calculated from the crack map, over 10m lengths;
- Intensity of Wheel-track Cracking calculated from the crack map, over 10m lengths;
- Sensor Measured Texture Depth (SMTD), calculated from the measured Texture Profile, averaged over 10m lengths;
- crack map (refer to Annex 2B, clause 2B.17 for an explanation);
- an estimate of the level of Fretting present on the pavement, calculated from the measured Texture Profile, over 10m lengths;
- an estimate of the Surface Type, over 10m lengths;
- the road Geometry (gradient, crossfall and curvature), over 10m lengths;
- an estimate of the retroreflectivity of the road markings, over 100m lengths.

2.10 The TRACS BCD is loaded into HAPMS. HAPMS provides maintenance engineers with access to the condition data collected from their network, and enables them to identify potential maintenance schemes and to monitor network performance. The TRACS BCD can be queried in HAPMS and reported using the database facilities, and can be displayed against a map background. HAPMS also provides reports and information in support of the development of the Road Renewals maintenance programme. The on-line facilities in HAPMS provide a fuller guide to the presentation of project information.

2.11 TRACS survey data is reported within HAPMS in relation to the Sections defined for network referencing, but there may be gaps in the data. These gaps arise for a variety of reasons (e.g. where the survey vehicle drove out of lane due to obstructions or road works, or where the survey data has been identified as Unreliable).

2.12 From an examination of the TRACS condition data in HAPMS, lengths of road with deteriorating surface condition can be identified. Examples of the use of TRACS condition data include:

- Rut Depths can be used to evaluate safety and structural aspects of the pavement surface condition;
- the Longitudinal Profile Variance can be used to assess Ride Quality;
- Texture Depth data can be used to indicate a potential loss of skid resistance, in connection with SCRIM data, or provide warning of some modes of surface failure;
- the Cracking and Fretting data, together with the Surface Type data can be used to evaluate the condition of the surface.

Assessment of Road Condition Using TRACS Data

2.13 An overview of the condition, or the trend in condition, of road pavements is required to give an indication of the scale of possible maintenance

requirements and to identify changes in the general level of service provided over a period of time. At a more detailed level, lengths of road requiring further investigation need to be identified and prioritised.

2.14 The results of an analysis of the TRACS survey data may be used as a coarse sift to identify lengths of road in need of further investigation or to supplement other road condition data to provide a robust road maintenance proposal. To undertake the assessment, the TRACS condition data (with the exception of TRACS Surface Type) must be obtained from HAPMS using the most recent TRACS Combined Length Weighted (LW) Averages data source. The TRACS Surface Type may be obtained using the HAPMS TRACS – Base Surface Type data source.

2.15 For Texture Depth, Rut Depth and Ride Quality, the TRACS survey data can be assessed by means of four Condition Categories, as shown in Table 2.1. These Condition Categories are defined by threshold values applicable to each parameter measured by the TRACS survey vehicle, which are set out in Annex 2A of this Part.

Category	Definition
1	Sound – no visible deterioration.
2	Some deterioration – lower level of concern. The deterioration is not serious and more detailed (project level) investigations are not needed unless extending over long lengths, or several parameters are at this category at isolated positions.
3	Moderate deterioration – warning level of concern. The deterioration is becoming serious and needs to be investigated. Priorities for more detailed (scheme level) investigations depend on the extent and values of the condition parameters.
4	Severe deterioration – intervention level of concern. This condition should not occur very frequently on the motorway and all purpose trunk road network as earlier maintenance must have prevented this state from being reached. At this level of deterioration more detailed (scheme level) investigations should be carried out on the deteriorated lengths at the earliest opportunity and action taken if, and as, appropriate.

Table 2.1: Condition Categories for Texture Depth, Rut Depth and Ride Quality

2.16 For any 100m length in Condition Category 4, a more detailed investigation should be carried out at the earliest opportunity and the need for maintenance assessed. Similarly, where two or more 100m lengths in Condition Category 3 fall within any 1km, the cause of the deterioration should be investigated to determine if maintenance or other actions are necessary. Priority for treatment will depend on the type, extent, distribution and severity of deterioration and the strategic objectives for road maintenance.

2.17 It is not appropriate to apply the classification system defined in Table 2.1 for the assessment of Cracking and Fretting. Annex 2A of this Part gives Guidance Levels which may be used in the interpretation of the values of these parameters reported in HAPMS.

2.18 When carrying out the assessment it is recommended that reference be made to the detailed descriptions and further guidance concerning the TRACS measurement of the Texture Profile, Transverse Profile, Longitudinal Profile, Cracking, Fretting and Noise given in Annex 2B of this Part. In particular, when determining the cause of significant levels of Cracking, it is recommended that the crack map be examined to determine the distribution and type of cracking present.

2.19 The Highways Agency must be contacted if more information is required about the interpretation of data collected under the TRACS contract.

Assessment Criteria for TRACS Data

General

2.20 This Section describes the interpretation of each of the condition parameters measured by the TRACS survey vehicle. The threshold levels or assessment criteria for evaluating the extent of pavement

deterioration are given in Annex 2A of this Part. The levels and criteria are based on experience gained from the HA's ongoing research and development programme, and are currently considered to be the most appropriate criteria for condition assessment. However, they may change in the future as a result of further research.

2.21 All the threshold values and guidance levels are based on characteristic values associated with 100m lengths and are for the assessment of current TRACS data collected from in-service roads, as opposed to newly constructed roads.

TRACS Texture Depth

2.22 Texture Depth values in the TRACS Combined Length Weighted (LW) Averages data source in HAPMS are calculated using the Sensor Measured Texture Depth (SMTD) method. The threshold values for TRACS (LW) Average Texture Depths are given in Table 2A.1 of Annex 2A of this Part.

2.23 Changes in the Texture Depth of the road surface can indicate a potential loss of skid resistance or some other mode of surface failure, e.g. Fretting (resulting in a high Texture Depth) (see also 2.37 to 2.39) or Fatting-up (resulting in a low Texture Depth). Advice on the interpretation of Texture Depth data in connection with skid resistance is given HD 28 (DMRB 7.3.1). HD 28 requires the Investigatory Level for skid resistance to be increased for surfaces (except High Friction Surfacing materials - HFS) with Texture Depth below 0.8mm SMTD (Category 3). Therefore, any location where the Texture Depth (except for HFS) triggers Category 3 or above must be reviewed in the context of HD 28.

2.24 Locations where the Texture Depth (except for HFS) triggers Category 4 will require urgent intervention if the nature of the surface condition means that further loss of texture can reasonably be expected, e.g. Fatting-up of a surface. Conversely, no action may be required if the Texture Depth is stable and a risk assessment undertaken in the context of HD28 does not indicate an elevated level of risk. Therefore, a more detailed investigation will be needed to determine the appropriate response.

2.25 Different thresholds are applied to High Friction Surfaces because of the different ways in which texture is provided by these materials. For these materials, the SMTD value is not an appropriate means of defining Condition Category 2 or higher. In this case, maintenance decisions must also take account of SCRIM results and the results of visual surveys.

TRACS Rut Depth

2.26 HAPMS stores Rut Depth information as the average Rut Depth for each wheel-track over a 10m length. This base data is then used to calculate representative values of rutting for the required reporting lengths. HAPMS uses the stored rut information to calculate the following LW Average values:

- Left Rut (using the left wheel-track values only);
- Right Rut (using the right wheel-track values only);
- Average Rut (using both wheel-track values);
- Maximum Rut (using the maximum wheel-track values from each 10m).

2.27 Table 2A.2 of Annex 2A of this Part shows threshold values for the TRACS LW Average Maximum Rut measurements. Note that concrete surfacings should give negligible Rut Depths. It is recommended that, where any length has been identified for further investigation as a result of high levels of rutting, comparison be made between the Left Rut and Right Rut LW Average values contained within HAPMS as a check on the self-consistency of the rut measurements – see Annex 2B of this Part.

TRACS Ride Quality

2.28 The measure used for the assessment of Ride Quality, or Profile Unevenness, is the Enhanced Longitudinal Profile Variance of individual deviations of the profile relative to a datum obtained by removing (or filtering) longer wavelengths from the measured longitudinal profile. This measure replaces the simpler Longitudinal Profile Variance and removes the effects of pavement geometry (gradient, crossfall and curvature). A fuller description of the differences between the two measures is given in Annex 2B of this Part.

2.29 The assessment of Ride Quality is carried out using three Enhanced Longitudinal Profile Variance values, that indicate the level of profile unevenness within wavelength ranges less than or equal to 3m, 10m and 30m. It has been found that measurements within these wavelength ranges may be broadly related to levels of ride comfort. The Enhanced Longitudinal Profile Variance data is therefore reported within the TRACS Length Weighted Averages data source in HAPMS as LPV 3m, LPV 10m and LPV 30m.

2.30 The threshold values for the assessment of the TRACS LW Average Enhanced LPV measurements within the three wavelength ranges are given in Table 2A.2 of Annex 2A of this Part, and must be applied to all TRACS Enhanced LPV data reported in HAPMS. Note that different threshold values are specified within Table 2A.2 for different road classifications (which can be abstracted from HAPMS), e.g. a Motorway requires a better standard of Ride Quality than an urban single carriageway, where traffic is generally travelling at a lower speed.

TRACS Cracking

2.31 Guidance levels for the TRACS LW Average Whole Carriageway Cracking intensities are given in Table 2A.3 of Annex 2A of this Part. No guidance levels are currently specified for the intensity of Wheel-track Cracking

2.32 As described in Annex 2B of this Part, the TRACS survey vehicle relies on crack identification software to automatically identify cracks in the road surface. The measurement and the interpretation of the types of Cracking made by the crack identification software may differ from that made by an inspector carrying out a visual survey over the same site. As a result of this, the intensities of Cracking measured by the TRACS survey vehicle are generally lower than those recorded by a visual inspection. This behaviour is reflected by the low magnitudes for the guidance levels given in Table 2A.3 of Annex 2A of this Part.

2.33 Monitoring of the behaviour of the TRACS Cracking intensities recorded on the network has shown that they can be affected by variations in the survey conditions, which thereby influence the relative intensities of cracking reported. As a result, the intensities recorded in surveys carried out in consecutive survey years can vary and, when applying analyses based on threshold levels, the categories within which the Cracking measurements fall may change from survey year to survey year. Therefore:

- as the variability in the TRACS cracking intensities can introduce a degree of uncertainty in the cracking measurements, the thresholds defined in Table 2A.3 are provided for guidance only, to aid in identifying lengths in need of further investigation;
- it is not recommended that the intensities of cracking be used in the trending of pavement condition;
- it is essential that, where any length has been identified for further investigation, examination be undertaken of the crack map data contained in HAPMS for the length under investigation before further action is taken;
- further advice regarding the assessment of the cracking data is provided in Annex 2B of this Part.

2.34 No thresholds are specified in Table 2A.3 of Annex 2A for the intensities of Whole Carriageway Cracking measured on concrete surfaces. Although the TRACS survey vehicle provides a measure of the extent of Cracking present on concrete surfaces it has been found that the system may falsely record the presence of joints or grooves in concrete roads as cracks. These false cracks are added to the Cracking area and lead to a higher level of Cracking being reported. Therefore, it is recommended that Cracking intensities derived from the TRACS crack data are not used to directly assess the condition of concrete surfaces within Condition Categories. However, for concrete surfaces the crack map may be utilised to aid in the assessment of the condition of the pavement.

TRACS Fretting

2.35 The Texture Profile data can be used for the estimation of the intensity of Fretting present on HRA surfaces. The guidance levels for the TRACS (LW) Average Fretting data are presented in Table 2A.4 of Annex 2A of this Part. However, the application of such data is relatively new and thresholds are provided for guidance only.

2.36 As the Fretting measure applies only to Hot Rolled Asphalt surfaces, the Surface Type must be known.

2.37 The Fretting measure can be used to assess the presence of minor deterioration and also aid in the assessment of Cracking. Guidance on the use of the Fretting measure is given in Annex 2B.

TRACS Predicted Surface Type

2.38 An estimate of the Surface Type can also be made from the TRACS Texture Profile data, within four categories:

- HRA;
- Thin Surfacing Systems;

- Brushed Concrete;
- Grooved Concrete.

2.39 The TRACS predicted Surface Type information may be obtained from the HAPMS TRACS – Base Surface Type Data data source in HAPMS.

2.40 The TRACS predicted Surface Type may be subject to error. The TRACS predicted Surface Type algorithms will always generate a predicted Surface Type, even when the true Surface Type does not fall within the four categories listed in paragraph 2.39. For example, the TRACS predicted Surface Type often reports High Friction Surfaces (which are not contained within the current list of identifiable surfaces) as brushed concrete.

2.41 The TRACS predicted Surface Type is probably of most use for defining where surface changes occur. Users may consider using HAPMS to plot the surface layer of the construction data alongside the TRACS predicted Surface Type to assist in the assessment of the accuracy of their construction records within HAPMS, which will remain the primary source of surface type information.

TRACS Road Geometry

2.42 The TRACS survey vehicle records the instantaneous gradient, crossfall and radius of curvature of the pavement at intervals of 5m. The data values contained in the TRACS – Base Geometric Data are reported in units of percent (for gradient and crossfall) and metres (for radius of curvature). There are no thresholds specified for the assessment of geometric data.

TRACS Retroreflectivity

2.43 Retroreflectivity data is used to support the description of the condition of road markings. Its use is described in detail in DMRB Volume 8, Section 2, Part 2 (TD 26: Maintenance of road markings and road studs).

TRACS Video Records (Forward and Downward)

2.44 The TRACS survey vehicle is equipped with digital forward- and downward facing video cameras that collects a video record of the road being surveyed. The digital video image data is not accessible from within HAPMS but is transferred to hard disks (separate HA Areas being stored on separate disks), and the disks distributed to each MA/MAC. The TRACS Forward Facing Video system, provided with the video images, is used to view the digitised video record.

2.45 The downward facing video records can be manually assessed to identify cracking and other surface defects which can be used as a preliminary stage to carrying out a full visual condition survey.

Surface Condition Assessment of the National NEtwork of Roads (SCANNER)

2.46 This survey system has been developed by the UK Roads Board to provide a consistent method of measuring the surface condition of Local Authority road carriageways, using automated road condition survey machines, throughout the United Kingdom. Full details of the system are given in the User Guide and Specifications published by the UK Roads Board (2007). The following is only a brief overview of the system.

2.47 For information on any variations from the above Specification, applicable to Scotland or Wales, the relevant Overseeing Organisation should be consulted.

2.48 SCANNER consists of a Specification for the survey machines, a Specification for carrying out the surveys and a method of reporting road surface condition (the SCANNER Road Condition Indicator).

2.49 Before a survey vehicle can be used to carry out a SCANNER survey, it has to pass a very stringent set of accreditation tests each year. It must be operated with a defined Quality Assurance procedure and with an independent Auditor.

2.50 The survey data produced by the survey machines is loaded into a UKPMS-compliant pavement management system where it is processed to produce the SCANNER Road Condition Indicator (RCI) (England and Wales only) and for other highway maintenance and management purposes.

2.51 SCANNER was introduced to provide consistent, reliable survey data on the condition of road carriageways to support four separate requirements to:

- indicate the overall condition of a length of road carriageway, or of an area of a road network, to establish long term trends in road maintenance condition;

- indicate the overall condition of a defined road network, as an outcome measure of local authority management and maintenance of their carriageway asset;
- produce indicative treatments and budget estimation, to plan carriageway maintenance at a network level;
- determine the optimum treatment timing, to prioritise treatment and minimise the whole life cost of maintenance at a scheme or project level.

2.52 SCANNER surveys are machine-based surveys that make a number of different measurements and process the measurements to provide a number of parameters that describe the condition of the road surface the:

- longitudinal profile along the road;
- transverse profile across the road;
- condition of the edge of the road;
- texture depth;
- presence and extent of surface cracking.

2.53 The SCANNER survey equipment makes many thousands of measurements within each 10m subsection along the carriageway. These are analysed and combined into a set of parameters which are reported as SCANNER parameter values for every 10m subsection along the road network. Even after the reduction of data to 10m SCANNER survey parameters, there is still too much data to be analysed by hand and the SCANNER data must be analysed through a pavement management system.

SCANNER Road Condition Indicator

2.54 The SCANNER Road Condition Indicator (RCI) has been developed to characterise the overall condition of the road carriageway. The RCI is calculated from some of the parameters measured by SCANNER, in three stages:

- Each 'measured parameter average value' over a 10m subsection length is scored on a scale of 0 to 100 using an upper and lower threshold.
- The scores of each separate parameter are combined using weightings to obtain a total number of points for each 10m subsection of the road. Each 10m subsection is then assigned to a condition "category" on the basis of the total points.
- The number of 10m subsections in each "category" are then totalled to give an overall figure for the section, the route or the network.

In the second stage, each 10m length is allocated to one of three condition categories – Red (poor overall condition – plan maintenance soon), Amber (some deterioration – needs investigation soon) and Green (in a good state of repair – no need to plan maintenance) – based on the total number of points. The overall condition assessment of a network is based on the proportions of the three condition categories of the total length of the network.

2.55 The thresholds, weightings and factors to be used in the RCI calculations are published on the UKPMS website and may vary over time.

3. VISUAL CONDITION SURVEYS

HA Visual Condition Surveys

3.1 The Highways Agency Network Management Manual (2007) requires that visual surveys of carriageways and adjacent areas are carried out as follows:

Carriageways:	Scheme level only
Off-Carriageway: (Footways, cycleways, kerbs and paved verges)	Network and Scheme levels

This does not include surveys of unpaved verges and earthworks, which are covered in HD 41 (DMRB 7.4.3).

3.2 On the HA network, network level carriageway surveys are carried out with traffic-speed equipment only (TRACS (Chapter 2 of this Part) and SCRIM (HD 28, DMRB 7.3.1)). From these surveys and other information such as routine inspections, candidate maintenance schemes are identified. More detailed investigations are carried out on these, including scheme level visual surveys. The HA has developed a computer based survey system known as Highways Agency Visual Surveys (HVS) for this purpose. The system is applicable to flexible carriageway pavements, all types of Off-Carriageway paved surfaces and to rigid carriageway pavements with asphalt surfacing where the defects are similar to those associated with all-asphalt construction.

3.3 The system requires the use of hand held Data Capture Devices (DCD) together with software provided by the HA to facilitate the input of defect data whilst on the road, and the subsequent downloading of the data into the Highways Agency Pavement Management System (HAPMS).

Pavement Visual Surveys

3.4 For asphalt surfaced carriageways on the HA network, the HVS described in the HAPMS Visual Survey Manual must be used for all scheme level surveys. In cases of asphalt surfaced rigid pavement displaying defects associated with all-rigid pavements, the survey system for Rigid pavements should be used, or a combination of the Rigid and Flexible pavement survey systems, as appropriate.

3.5 HVS must only be carried out by surveyors who have been trained in the relevant survey techniques, and who are able to record defects accurately and consistently, in accordance with the definitions and procedures described in the survey manual. Surveyors are not expected to make decisions about the cause of defects, required treatments or to make other engineering judgements. Objectivity and consistency are paramount considerations in carrying out HVS.

3.6 Visual surveys of all types of highway pavement involves examination of the road surface by surveyors on foot and must always be carried out in accordance with Health and Safety legislation and with appropriate traffic management in accordance with the Traffic Signs Manual Chapter 8.

3.7 For rigid pavements the visual survey procedure detailed later in this chapter is recommended.

3.8 The defects of asphalt surfaced carriageways that are noted during HVS surveys are listed in Table 3.1. Full details of these and the manner in which they are recorded are given in the HAPMS Visual Survey Manual.

	Defect	Definition
1	Major Area Cracking	Single or multiple non-interlocking cracks (>1mm wide) and not classified as Transverse Cracking.
2	Minor Area Cracking	Single or multiple non-interlocking cracks (<=1mm wide) and not classified as Transverse Cracking.
3	Major Crazing	Interlocking pattern of cracks (>1mm wide).
4	Minor Crazing	Interlocking pattern of cracks (<=1mm wide).
5	Major Fatting	Bitumen in the surface course is flush or covering the coarse aggregate.
6	Minor Fatting	Bitumen in the surface course is close to but below the top of the coarse aggregate.
7	Mud Pumping	The visible presence of fines emanating from a crack/hole/joint in the pavement. The occurrence is accompanied by a cracked or depressed area of at least 1 square metre in asphalt pavements.
8	Patching Failure	Patches or reinstatements that have subsided or rutted more than 10mm over any part of the patch/reinstatement or that exhibit more than 20% cracking.
9	Major Surface Defectiveness	Loss of material from the wearing surface to a degree that the original surface is not discernible. Includes Chipping Loss from Surface applied chippings.
10	Minor Surface Defectiveness	Loss of material from the wearing surface to a degree that the original surface is still discernible.
11	Major Transverse Crack	Single or multiple cracks (> 0.1m spaced) cracks, >1mm wide, at right angles to the centre line.
12	Minor Transverse Crack	Single or multiple cracks (> 0.1m spaced) cracks, ≤ 1mm wide, at right angles to the centre line.

Table 3.1: HVS Carriageway Defects

Off-Carriageway Visual Surveys

3.9 Visual Surveys of Off-Carriageway items (footways, cycleways and paved verges) are used at network level to:

- assist in the identification of areas requiring planned maintenance, and to provide information to enable potential maintenance schemes on Off-Carriageway features to be assessed and prioritised;
- allow the overall conditions of the Trunk Road Off- Carriageway network to be monitored for reporting purposes.

3.10 All Off-Carriageway network or scheme level visual surveys on the HA network must be carried out using the HVS described in the HAPMS Visual Survey Manual.

3.11 The Off-Carriageway elements in HVS may be constructed from asphalt, concrete or block paving. Non-paved surfaces are not included. The defects to be recorded depend to some degree on the type of surfacing and include:

- major and minor cracking;
- major and minor local settlement or subsidence;
- major and minor fretting;
- longitudinal trip;

- spot defects;
- damaged, cracked, depressed or missing blocks.

Full details of these defects and the manner in which they are recorded are given in the HAPMS Visual Survey Manual.

Output for HVS

3.12 After loading survey data into HAPMS, it is possible to produce text reports of the defects or coloured strip plans showing the occurrence of all defects. Adjacent lanes can be shown together, provided there is survey data for each. The scale and aspect ratio of the strip plans can be varied to suit the scheme length and complexity of defects. The carriageway visual survey data is not processed to produce any general condition parameters but the data is used by the HAPMS software when carrying out SWEEP Whole Life Costing analyses in support of bids for HA maintenance schemes.

Surveys of Rigid Pavements

3.13 For the visual assessment of rigid pavements at scheme level, the Overseeing Departments have not yet developed a computerised system such as HVS. Instead, a graphical procedure is used to obtain as accurate a record as possible of all observed relevant features, i.e. carriageway condition, edge features, earthworks and drainage problems.

3.14 For rigid pavements on the HA network, faults and defects may be recorded on the field recording form shown in Figure 3.1 and using the symbols given in Table 3.2. Reference may be made to the Concrete Pavement Maintenance Manual (Highways Agency and Britpave, 2001) for detailed descriptions and photographs of each type of fault. The reference chainages used must be based on network sections as described in the Network Maintenance Manual and not on Marker posts or ad hoc systems. Figure 3.2 is an example of a completed survey form.

3.15 The occurrence of alkali-silica reaction must be recorded. This may be inferred from the presence of areas of map cracking containing a white or creamy powdery material which streaks the surface after heavy rainfall.

3.16 A data capture device may be used if it is found to be cost effective and is capable of producing a graphic presentation of the defects similar to Figure 3.1.

3.17 The current method of carrying out visual surveys is laborious, requires traffic management which may cause traffic disruption and exposes highway personnel to some risk of injury. Carrying out visual surveys by manual or automatic processing of traffic speed video images of the pavement would remove or reduce these disadvantages. Research has shown that manual processing of video images is a practical method for carrying out visual surveys of rigid pavements, as an alternative to on-site visual surveys. Advice on which traffic-speed systems are approved for use on the trunk road network will shortly be published. Any requests to use such a system should be referred to the Overseeing Organisation.

3.18 Referencing must be supplemented by numbering the bays on jointed concrete pavements; not only is this a positive referencing system which can be applied on site, but it can be used for contract preparation.

3.19 The size and extent of faults and defects may be estimated but must be plotted accurately at these estimated dimensions. Concrete bay lengths must be checked at the start of the survey and at every tenth bay. Running chainages must be maintained to an accuracy of ± 1 m.

3.20 Surveys of concrete roads should whenever possible be carried out in the cooler months of the year between mid October and mid April when cracks are more noticeable and when the efficiency of joint seals can be better assessed. To assess the significance of cracks, an accurate record of atmospheric temperature is required and weather conditions should always be noted. (Cracks are most readily visible when the pavement surface is drying out after wet conditions; this must be borne in mind when comparing surveys carried out in different weather conditions).

VISUAL CONDITION SURVEYS

WEATHER .....

TEMPERATURE .....

VISUAL CONDITION SURVEY OF .....

SHEET NO..... OF.....

DATE..... BY.....

SECTION IDENTIFIER

START NODE

FINISH NODE

TOTAL LENGTH SURVEYED.....Km

(= from node)

Running Chainage (m)

0 10 20 30 40 50

Offset (m)

0 5 10 15

Figure 3.1: Rigid Pavement Survey Form

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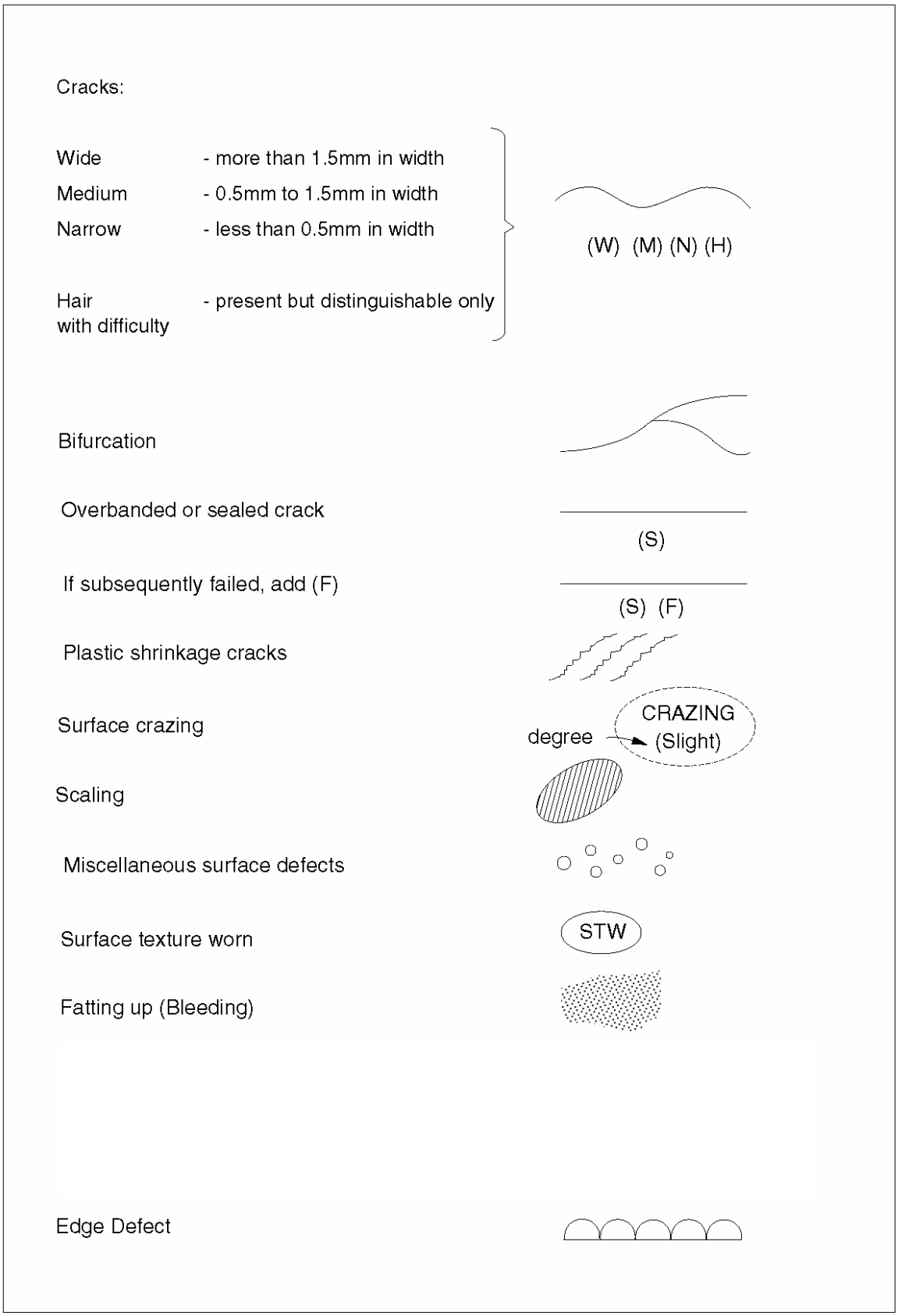
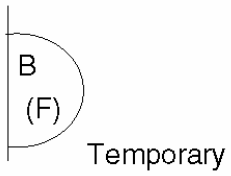


Table 3.2: Standard Symbols for Recording Condition of Rigid Pavements

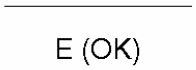
Repairs:

Asphalt - B

Cementitious - C



Epoxy - E
Add (OK) if sound or (F) if failed

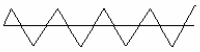


Missing roadstud (+ cracks)

Rust staining

'RUST'

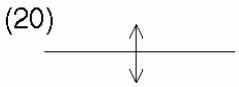
Defective joint seals



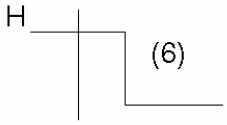
Shallow spalling at joints (or at cracks)

Deep spalling at joints

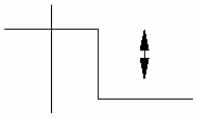
Opening of longitudinal joint (state width in mm)



Faulting (stepping) at joint or crack with difference in level (mm)



Vertical movement at joint or crack under passing of traffic



Evidence of pumping

'PUMPING' or
'STAINING'

Settlement

Table 3.2 (continued): Standard Symbols for Recording Condition of Rigid Pavements

VISUAL CONDITION SURVEYS

WEATHER Sunny

TEMPERATURE 12°C

VISUAL CONDITION SURVEY OF M99 J 5 - 6

1 0 0 5 7

FINISH NODE 1 0 0 6 2

SHEET NO. 21 OF 52

DATE 21/10/91 BY A.N.O.

SECTION IDENTIFIER 1 0 0 0 M 9 9 Δ Δ Δ 6 2

TOTAL LENGTH SURVEYED 2.6 Km

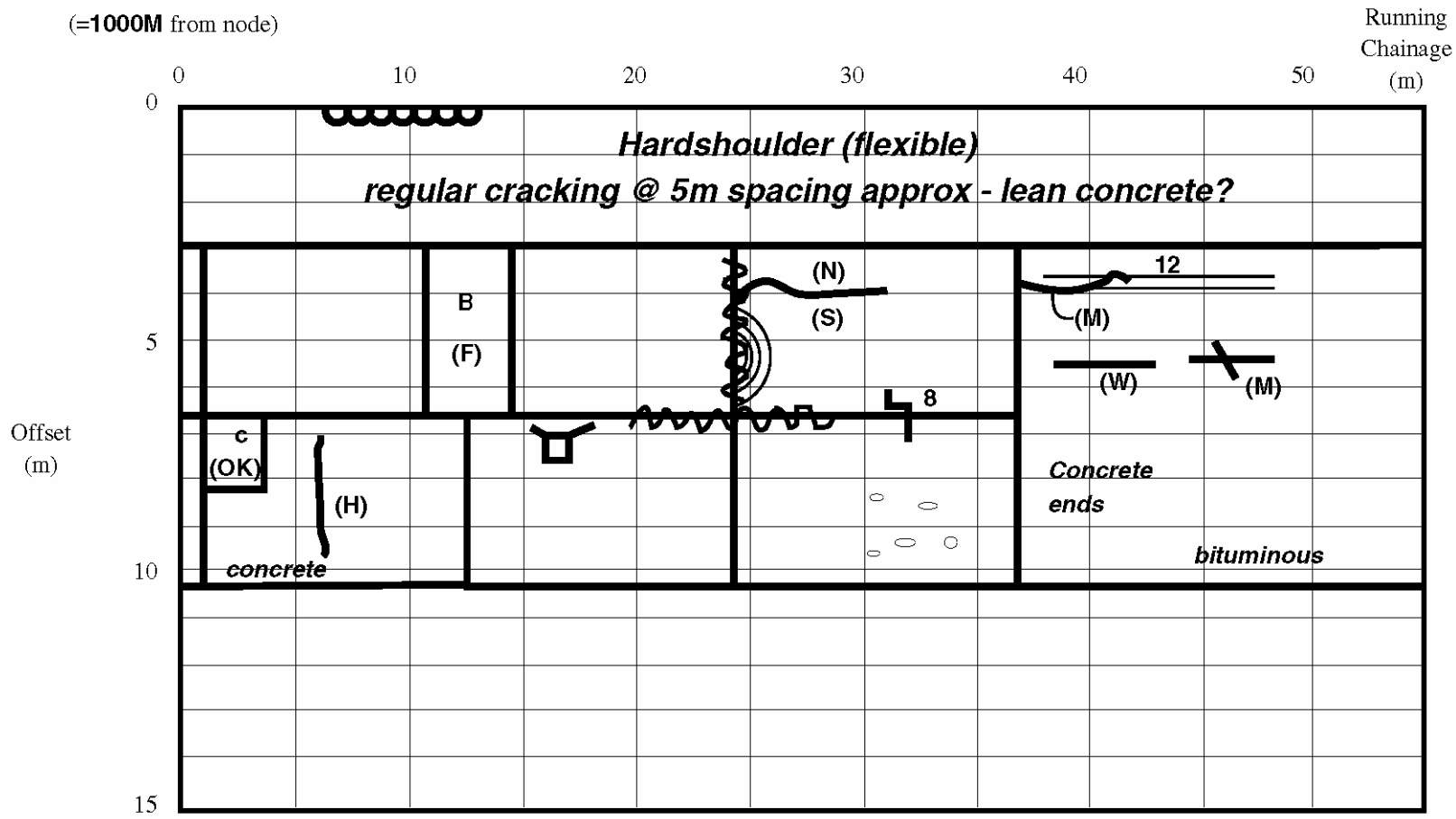


Figure 3.2: Example of Completed Rigid Pavement Survey Form

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Continuously Reinforced Concrete Pavements (CRCP)

3.21 Experience with visual assessment of continuously reinforced concrete pavements to date is limited. The Overseeing Organisations can therefore only give general guidance on visual survey methods.

3.22 CRCP construction has no transverse movement joints to accommodate longitudinal movement, and as a consequence transverse shrinkage cracks spaced between 1m and 4m develop shortly after construction over the total area of the slab. As time passes additional transverse cracks slowly develop between the wider spaced cracks. All these cracks are held closed by a continuous layer of heavy reinforcement, thus maintaining aggregate interlock and ensuring transfer of load across the cracks. Such cracking is considered normal for this type of construction and its presence does not indicate significant failure or weakness.

3.23 These "normal" cracks are defined as follows:

- the cracks are exclusively transverse with no spalling or bifurcations;
- less than 1mm width;
- spaced at least 1m apart.

3.24 Significant defects, indicating a weakened structure or need for maintenance, include:

- transverse cracks at spacings of less than 1m;
- transverse cracks with widths greater than 1mm;
- longitudinal cracks;
- areas of polygonal cracking;
- loose or missing blocks of concrete;
- crack bifurcations;
- failing repairs;
- spalling.

3.25 Similar visual survey methods to those used for jointed pavements should be used for surveying CRCP except that:

- the "normal" cracking is only recorded for the first 10m in every 100m length;
- the significant defects defined in 3.24 are recorded for the entire length;
- at CRCP terminations (involving ground beams), all "normal" cracking, significant defects and slab features must be recorded for the adjacent 100m of the pavement.

3.26 Guidance on the interpretation of visual survey data is given in HD 30 (DMRB 7.3.3).

Presentation

3.27 Field survey sheets, or a fair copy, must be retained. The general condition of the road must be summarised on a plan to a suggested scale of 1:500. A typical form of presentation is shown in Figure 3.3. A record at this scale must also include notes about particular areas where the condition or rate of deterioration needs to be monitored during subsequent inspections.

3.28 The distribution and incidence of faults and defects is likely to be an important pointer to future performance. It may be useful to show the percentage distribution of defects in the following three categories:

a) defects likely to lead to safety hazards or serious surface deterioration within the next year;

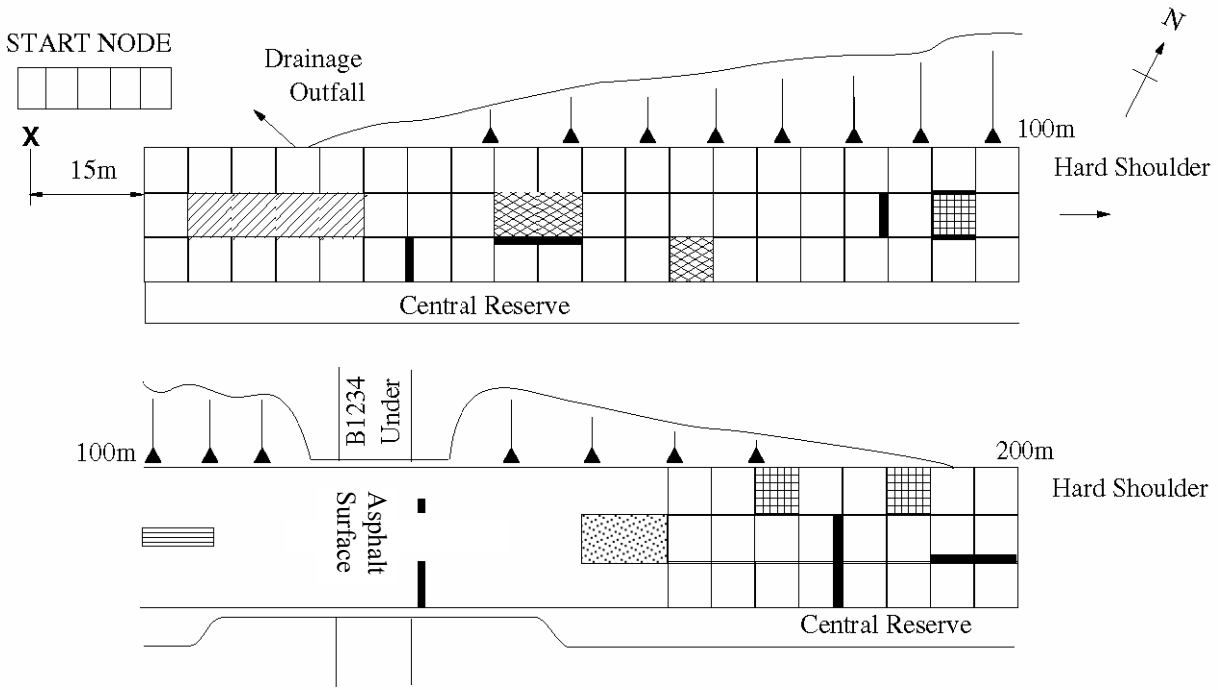
b) defects which immediately affect user comfort or convenience, e.g. faulting or settlement;

c) defects likely to affect structural integrity within the next 3 year period.

3.29 This distribution should be compared with those given in earlier surveys. Summaries must also make clear whether existing repairs fall into the category of temporary or permanent. The material used for the repair must be recorded.

SUMMARY PRESENTATION OF A VISUAL CONDITION SURVEY (CONCRETE PAVEMENT)

SURVEY OF ..... (ROAD), DATE ..... ; SECTION IDENTIFIER



N.B. In practice, the information will be presented on a series of strip plans on an A1 sized drawing covering between 1km and 2km of road.

SCALE 1 : 500

KEY:
- Area of cracking / crazing
- Bays in which there are temp repairs
- Bays likely to cause user inconvenience
- Bays likely to deteriorate structurally in the next 3 years
- Joints / cracks requiring repair
- Ruts over 10mm

Figure 3.3: Typical Presentation Format for Visual Surveys of Concrete

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4. DEFLECTOGRAPH TESTING

GENERAL

4.1 This chapter describes the Deflectograph and the processing of its output. The Deflectograph is used to assess the structural condition of flexible pavements. It works on the principle that as a loaded wheel passes over the pavement, the pavement deflects and the size of the deflection is related to the strength of the pavement layers and subgrade.

4.2 The survey speed is slow (2.5 km/h) and consequently Deflectograph surveys cause considerable disruption, particularly on heavily trafficked roads. On the HA network this type of survey is no longer carried out at network level and is only used in support of individual maintenance schemes. However, other Overseeing Organisations may continue to use the Deflectograph at a network level. Ongoing research of a Traffic Speed Deflectometer (TSD) offers the potential to obtain Deflectograph type data from a survey vehicle traveling at speeds up to 80 km/h.

4.3 The assessment procedure used depends on the type of pavement and its mode of deterioration. Some thick, well constructed flexible pavements with asphalt base have been found not to deteriorate in the conventional way and with timely attention to surface defects can have a long but indeterminate life. These potentially long-life pavements are identified with deflection and thickness criteria. The structural condition of other flexible pavements is assessed in terms of residual life using a long-established Deflection Design Method based on deflection and traffic loading.

DEFLECTOGRAPH

4.4 The Deflectograph (Figure 4.1) is an automated deflection measuring system. It is a fully self-contained lorry-mounted system, whereby measurements of deflection are taken at approximately 4m intervals in both wheel-tracks while the machine is in motion. It is regarded by the Overseeing Organisation as the standard deflection measuring device for use on flexible pavements.

4.5 The transient deflection is measured as the Deflectograph travels slowly along the line of twin measurement beams which are attached to a reference frame. The measurement is not an absolute value of surface deflection since the reference frame sits within the wheelbase of the lorry and is itself influenced by the load. It represents a repeatable measure but since the analysis method is empirical, it is important that the procedures for the use of the Deflectograph are closely followed.

Figure 4.1: Deflectograph

Figure 4.2: Deflectograph Measuring Beams

4.6 It is essential that Deflectograph surveys are carried out as part of an overall assessment of highway condition. Further details of the analysis and interpretation of Deflectograph results in conjunction with other types of pavement condition data are included in HD 30 (DMRB 7.3.3).

Machine Calibration and Approval

4.7 For use on the HA network, all Deflectographs must be tested and approved in an annual Deflectograph correlation trial to check their adequacy for trunk road testing. A copy of the certificate to confirm that the equipment is approved for use must be available to those commissioning Deflectograph surveys.

4.8 Static and dynamic calibration of the machine must be carried out as described in Annex 4A of this part. The records of these calibrations must be available for inspection at the annual correlation trial.

4.9 For use on other road networks, the relevant Overseeing Organisations must be consulted on the equipment approval requirements.

SURVEY CATEGORY

4.10 As the Deflection Design Method is based on empirical data its use requires surveys to be carried out under prescribed conditions defined by survey category.

4.11 The survey category defined by time of year, and temperature limits must be as specified in Table 4.1 and Figure 4.3 respectively. The use of the categories must be as specified in Table 4.2. The reasoning behind these categories is explained in paragraphs 4.12 to 4.15. In certain circumstances it may be necessary to vary these standards, see paragraph 4.24.

MONTHS OF YEAR (Shaded area refers)												Range of Pavement Temperature	Survey Category
J	F	M	A	M	J*	J	A	S*	O	N	D		
												Band 1	1A
												Band 2	1B
												Bands 1 & 2	2
												Bands 1 & 2	3

* Period ends 15th of month, starts 16th of month.

Table 4.1: Time of Year and Survey Categories

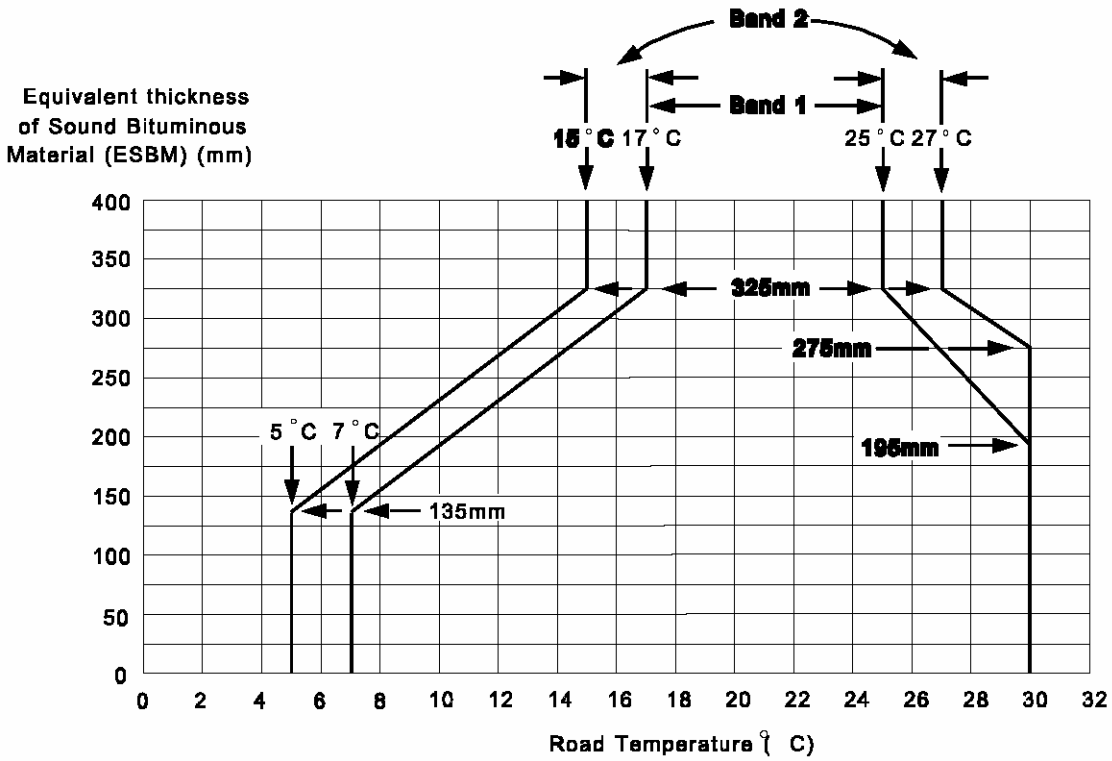

Figure 4.3: Temperature Limits for Survey Categories

Purpose of Survey	Minimum Category Required
To finalise the details of a Maintenance Scheme To identify cause of surface damage already evident or where a change in use is proposed which will result in increased traffic loading	1A with not greater than 10% in 1B
To provide advanced information for maintenance planning (at least one further survey expected before strengthening measures defined)	2
Relative assessment within a site	3

Table 4.2: Survey Specification for Trunk Roads

4.12 CATEGORY 1A defines the preferred conditions for deflection surveys. The highest confidence may be placed on the results of surveys in this category. The identification of potentially long-life pavements must be based on a Category 1A survey.

4.13 CATEGORY 1B extends the upper and lower limits of the temperature range allowed by including Band 2. This category is intended to allow for the situation that may arise when a survey planned for Category 1A does not comply with the specification because of unexpected changes in temperature taking place during the course of a survey.

4.14 CATEGORY 2. The wider temperature range obtained by adding Band 1 to Band 2 also applies to this category. The first part of September is included in Category 2 because after a hot dry summer, drying out of the subgrade may lead to measured deflections which do not truly reflect the weakest condition of the pavement.

4.15 CATEGORY 3. Surveys must not normally be carried out during the summer months specified for this category because of the difficulty of obtaining reliable, reproducible results.

Equivalent Thickness of Sound Bituminous Material (ESBM)

4.16 Deflection of asphalt pavements varies with temperature. The susceptibility to change in temperature is dependent on the thickness, age and condition of the asphalt layers. The parameter ESBM attempts to embody these factors and is only calculated for the purposes of correction of deflection to a standard temperature. It does not in any way reflect the structural contribution of the asphalt (bituminous) layers.

4.17 ESBM is required for correction of deflection to the standard temperature of 20°C and is calculated automatically during processing following input of construction information. The asphalt type needs to be defined as dense or non-dense and its condition as sound or unsound. Materials such as hot rolled asphalt or dense bituminous macadam are defined as dense whilst materials such as open textured macadam or porous asphalt are non-dense. Unsound materials are those showing cracking, disintegration or evidence of stripping.

4.18 Asphalt pavement layers comprising multiple surface dressings (where the total thickness is less than 25mm), any asphalt layers beneath hydraulically-bound layers and any asphalt layers with their upper surface at greater than a 200mm depth and separated from the higher asphalt layers by granular layer, must be ignored.

Early Life Surveys

4.19 Surveys carried out within two years of a new road being opened or a road having had a major strengthening treatment must not be used to determine residual life or strengthening requirements. This is because the early life deflections can be more variable and are not a reliable indicator of future structural strength of a pavement until the pavement and subgrade have stabilised, which usually takes at least two years.

Permitted Temperature Range

4.20 The road temperature specified in Table 4.2 is that measured at a depth of 40mm below the road surface at a position on or very close to the line of the nearside wheel-track.

4.21 For practical purposes the temperature of the pavement structure, in which considerable temperature gradients can occur, is represented by the measurement at a single depth of 40mm. Equations have been established between deflection and this characteristic temperature for a wide range of ESBM. To ensure that the correction of deflections to the standard temperature of 20°C remains within the validity of these equations, the temperature range within which a survey may take place becomes more restrictive as the ESBM of the pavement increases. The limiting rate of increase of temperature of no more than 2.5°C per hour, as specified in paragraph 4.33, is applied for the same reason.

4.22 Surveys may take place, within the permitted temperature range, at any time of day or night. ESBM values, for the sections of road to be surveyed, must be given to the Deflectograph operator prior to any survey work being undertaken in order that the acceptable temperature range for the survey may be calculated. See paragraph 4.25.

Flexible Pavements with Hydraulically Bound Base

4.23 The deflection behaviour with temperature of pavements with strong hydraulically-bound layers covered by asphalt can be significantly different from that of all asphalt construction. As the pavement temperature of a composite pavement increases the pavement deflection can decrease rather than increase as would be expected from the behaviour of flexible pavements with asphalt base. This effect is due to the hydraulically bound layer expanding with increasing temperature causing the cracks to close and the slabs to start locking together so stiffening the structure. Although the stiffness of any asphalt layers will be reducing, at the same time, the overall effect can be an increase of the total pavement stiffness and hence a reduction in measured deflection to relatively low values.

Time of Year

4.24 It is accepted that weather conditions may vary appreciably in different regions and from year to year. Also, unusual conditions such as prolonged hot, dry weather may occur during periods of the year specified for Category 1. Where it is thought that there is a case for reclassifying a survey, either up or down by one category, the Overseeing Organisation must be given details, including a description of the weather conditions prevailing in the period prior to the survey. Due to the weather conditions generally associated with the more northerly latitudes of Scotland the last two weeks of June are included in survey Category 1 for this Region.

SURVEYS

Frequency and Timing

4.25 A knowledge of the trend of average deflection can be very useful in the assessment of condition particularly when the deflections are predicting low or negative residual lives. If this residual life assessment is valid, deflections measured one year later would be expected to show a deterioration.

4.26 Deflection measurements are inherently variable, reflecting the variability of pavement materials, construction tolerances, the degree of compliance with tolerances and, more problematically, changes in the moisture content of the subgrade. Whereas all factors vary with location, subgrade moisture content varies in relation to seasonal changes of water table, drainage malfunction and ingress of water through the pavement.

Planning Considerations

4.27 Knowledge of the ESBM is required at the planning stage in order to define the temperature range within which a survey may take place. The category requirements of Tables 4.1 and 4.2 and Figure 4.3 will influence the timing of surveys on particular sites within the overall survey plan.

4.28 On single carriageway roads where remedial work is envisaged from visual assessment, or where the traffic split is unequal in terms of numbers of commercial vehicles or known loading pattern, a survey in each direction is normally undertaken. However where OGV traffic is split approximately 50:50 in each direction, a deflection survey in one direction is usually sufficient for maintenance planning purposes.

4.29 On multi-lane roads surveys are required in lane 1 in both directions as a minimum. Surveys of the other lanes may be necessary where:

- visual defects are markedly different;
- there is a significantly different construction;
- the traffic loadings in these lanes are greater than in lane 1.

4.30 The Deflectograph operates at a nominal speed of 2.5km/h. Seasonal and temperature constraints allow a period of about 100 days in a calendar year for surveys in Categories 1 and 2, and in this period a typical Deflectograph output on continuous lengths of road, using an experienced operating team, is unlikely to exceed 1000 lane km.

4.31 The requirements of traffic management, including lane closures, may restrict the working day for survey purposes. Any such limitations on access must be determined at the planning stage.

SURVEY PROCEDURE

Test Procedure

4.32 The following operating procedure must be followed:

a) the Deflectograph must be positioned so that the nearside beam-tip follows the centre of the nearside wheel-track of the lane to be surveyed;

b) the machine must operate at a constant speed not exceeding 2.5 km/h;

c) the operator must reference the deflection record to the network sections. Additionally, the location of easily identifiable features must be marked at intervals of at least 0.5km so that deflection values may be related to their positions on the road;

d) the operator must monitor the recorded output at regular intervals and note any inconsistencies. If these occur, running checks are to be carried out. If faulty records persist, the survey must be terminated.

Road Temperature Measurement

4.33 The road temperature, as defined in paragraph 4.24, and its location and time of measurement must be recorded and entered on the survey record at the start and finish of the survey and at least every 30 minutes during the survey. Temperatures must also be recorded when passing into or out of continuously shaded areas on the carriageway and areas having significantly differing surface characteristics. Surveys must not continue if the temperature at any one point is changing at a rate exceeding 2.5°C per hour, measured over a period of at least 15 minutes.

4.34 It is most important that accurate road temperatures are recorded. Small errors in measured temperature can lead to large errors in corrected deflection especially if the structure includes considerable thicknesses of new asphalt. Before taking a temperature measurement any heat generated in making the necessary hole in the road must be allowed to dissipate. It may be advantageous to pre-drill these holes before the survey starts. Accuracy of measurement will be improved if the hole is filled with glycerol or other suitable liquid to aid heat transfer. Care must be taken to ensure that the temperature value indicated on the gauge has stabilized before a representative value is recorded.

Use on Jointed Concrete Pavements

4.35 A specially-adapted version of the Deflectograph has been developed to assess the condition of joints in concrete pavements. This involves measuring the deflection either side of a joint as the wheel passes. The difference in deflection measurements may then be related to the load transfer properties of the joint and any joints which demonstrate poor behaviour may be readily picked out. Slab temperature will have a substantial effect on load transfer and testing should be carried out at pavement temperatures less than 10°C, when joints may be expected to have opened up. The ratio of deflection each side of the joint appears to be the most useful parameter to indicate the load transfer properties. It is not possible to define a standard value for this above which the joint may be considered satisfactory. This would have to be determined for each site taking into account visual defects such as cracking and pumping of fines from below. This also applies to the slower Falling Weight Deflectometer method of joint assessment, described in Chapter 5 of this Part.

Pavement Condition Inspections

4.36 Results from a recent and representative visual condition survey are required for all sites where a deflection survey is undertaken. It may be advantageous to undertake this visual survey at the time of the deflection survey. In Scotland and Northern Ireland however, the need for such visual surveys must, in all cases, be ascertained by enquiry to the Overseeing Organisation. The type, thickness and condition of the component pavement layers must also be determined by ground-penetrating radar or cores as appropriate. The amount of detailed information to be collected must be determined by the category of survey, the variability of construction in the pavement and its condition. Advice on more detailed investigations is contained in HD 30 (DMRB 7.3.3).

DATA PROCESSING

4.37 For the HA network all Deflectograph survey data must be processed centrally within the HAPMS system. The survey organisation first pre-processes the survey data using the HA's MSP stand-alone software prior to loading into HAPMS, part of the HAPMS. Further details are given in the Network Maintenance Manual and in HAPMS documents.

4.38 The other Overseeing Organisations require Deflectograph survey data to be processed using the PANDEF computer program, or other programs approved by the Overseeing Organisation. Users should be aware that PANDEF is no longer supported by either the HA or the Department for Transport and that different versions of PANDEF may give different results for the same data. Details of PANDEF processing are given in Annex 4B.

Presentation of Results

4.39 For the HA network, summary processed deflection data from the HAPMS processing must be provided in support of bids for maintenance. The details of the parameters to be supplied are given in the annual HA guidance document – Value Management of the Regional Roads Programme. These are required to enable comparisons to be made between the maintenance requirements of different sites and for an order of priority to be established. In either case, a summary of all input parameters affecting the final design solution is to be provided for use as an audit trail.

4.40 For other networks, summary data from PANDEF in support of bids for maintenance must be as specified by the Overseeing Organisation. These are required to enable comparisons to be made between the maintenance requirements of different sites and for an order of priority to be established. They may be in hard copy form or computer files for transfer to a designated Maintenance Management System. In either case a summary of all input parameters affecting the final design solution is to be provided for use as an audit trail.

4.41 When making an assessment of the structural condition of a pavement, deflection measurement is to be considered as only one element of the total information to be assembled, and used in accordance with the advice given in HD 30 (DMRB 7.3.3), in deciding the most appropriate maintenance treatment.

5. FALLING WEIGHT DEFLECTOMETER

GENERAL

5.1 This Chapter gives guidance on the use of the Falling Weight Deflectometer (FWD) for assessing the structural condition of road pavements. It describes the principles of the methods of analysis available and also sets out the requirements for calibration and operation of the FWD. Advice on the interpretation of results is given in HD 30 (DMRB 7.3.3).

5.2 A common approach to the assessment of the structural condition of a road pavement is to measure its deflection under a known load. Application of this load is normally by one of two methods: by the action of a rolling wheel as in the Deflectograph, or by dropping a mass using a device such as the FWD. The deflection measured relates to the combined stiffness of the component layers in the pavement and its ability to distribute traffic loading. The FWD is normally a trailer mounted device, towed behind a vehicle (Figure 5.1). Van-mounted devices are also in use.

Figure 5.1: Falling Weight Deflectometer

5.3 The current policy for strength testing of flexible pavements described in this Part and in HD 30 (DMRB 7.3.3), requires that deflection is measured with a Deflectograph. The associated Deflection Design Method enables the residual life of the pavement to be predicted and strengthening overlays to be designed to extend that life. For rigid pavements, the assessment of structural maintenance requirements currently depends solely on Visual Condition Surveys (VCS). The FWD can provide additional detailed information on the structural condition of flexible and rigid pavements.

5.4 The impact method of load application used by the FWD is fundamentally different from the rolling wheel system employed by the Deflectograph. As yet, no satisfactory relationship has been found to convert FWD deflections to equivalent Deflectograph deflections so they cannot be input to the Overseeing Organisation's design method. Whereas the Deflectograph system normally only uses the maximum deflection recorded at each measurement point, FWD measurements allow the deflected shape of the pavement surface to be derived. Estimates of layer stiffness can be made from knowledge of this deflected shape and the layer thicknesses.

5.5 There are many different methods of analyzing FWD measurements. Although these can produce relatively consistent results for layer stiffness, there is currently no standard approach for estimating residual life or overlay thickness using FWD results. The analytical process is subjective and calculating standard wheel load strains in the pavement and using these in conjunction with strain/fatigue life relationships is unreliable. The high sensitivity of the fatigue relationships used in this process can produce very different residual lives for the same data, when analysed by different engineers.

5.6 For the HA network the FWD must only be used for the following purposes:

a) to assess the stiffness of pavement layers of all pavement types;

b) to determine the load transfer efficiency across joints and cracks in rigid pavements.

These two types of surveys require the FWD to be configured differently and the results to be analysed in a completely different way. FWD data must not be used in isolation to other pavement condition indicators; it is important to characterise the material properties and understand the pavement deterioration mechanisms (see HD 30 DMRB 7.3.3).

SURVEYS

5.7 Surveys may be commissioned for the specific purposes described in paragraph 5.6. They must be carried out on whole lengths, or sample lengths, of the road in need of structural maintenance, as identified by approved assessment methods, and on sample sections in sound condition to enable comparisons to be made. Advice on aspects to be considered when drawing up a survey specification are given below.

Measuring Equipment

5.8 In principle the FWD generates a load pulse by dropping a mass onto a spring system. The mass and drop height can be adjusted to achieve the desired impact loading. Peak vertical deflections are measured at the centre of the loading plate and at several radial positions by a series of geophones. Figure 5.2 shows a typical deflection bowl (with the FWD configured for evaluating layer stiffness). These deflections and the peak impact load are stored electronically.

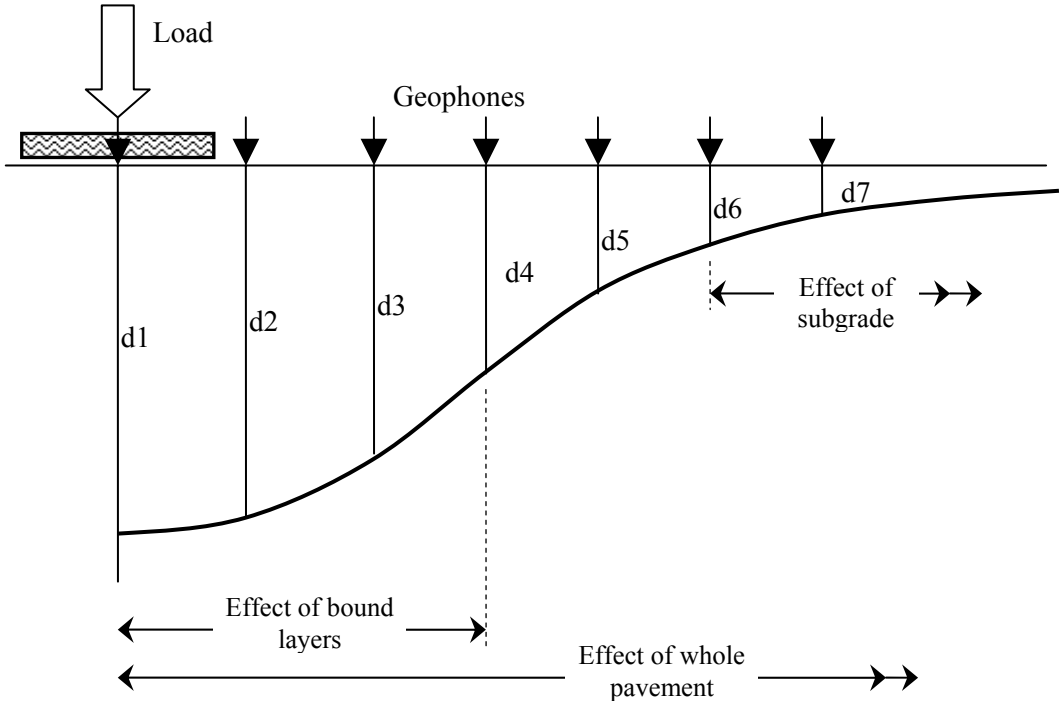

Figure 5.2: FWD Deflection Bowl

Machine Calibration and Approval

5.9 For use on the HA network, all FWDs must be tested and approved in an annual FWD correlation trial to check their adequacy for trunk road testing. A copy of the certificate to confirm that the equipment is approved for use must be available to those commissioning FWD surveys.

5.10 Consistency checks of the dynamic response of the machine as a whole must take place at intervals of between four and six weeks during periods of operation and after any major service involving replacement parts. Details of the requirements are given in Annex 5A of this Part. The records of these checks must be available for inspection at the annual correlation trial.

5.11 For use on other road networks, the relevant Overseeing Organisations must be consulted on the equipment approval requirements.

LAYER STIFFNESS EVALUATION

5.12 It is recommended that the results of FWD layer stiffness surveys are used for the following purposes within the detailed structural investigations, see HD 30 (DMRB 7.3.3):

a) to assess the relative contribution to pavement strength of bound and unbound materials;

b) to provide estimates of layer stiffness of sufficient accuracy to indicate any weak areas that need replacing or require further consideration;

c) to assess the severity of cracks in hydraulically bound mixtures. This is described in HD 30 (DMRB 7.3.3);

d) to assess the Equivalent Surface Foundation Modulus, prior to the design of a concrete overlay. This is described in Annex 5B of this Part;

e) to determine the effective stiffness modulus of cracked and seated and saw-cut, cracked and seated concrete pavements as required in the Specification for Highway Works.

Test Procedure

5.13 On flexible and composite pavements the load level is set at a nominal 50kN + 10%. On concrete pavements, where deflections may be very low, i.e. d1 is less than 100 microns, this may be increased to a nominal 75kN + 10%. The load pulse must be applied through a 300mm diameter plate and have a rise time from start of pulse to peak of between 5 and 15 milliseconds. Most FWDs in the UK have a 60 Hz smoothing filter option. The use of this filter has been shown to improve the agreement between machines and, where available, smoothing must be activated. Deflections must be measured to a resolution of at least 1 micron over the range 0-2mm by a minimum of 7 sensors situated at radii up to a distance of 2.25m from the centre of the loading plate.

5.14 There must be no standing water on the road surface and care must be taken to ensure that the whole area of the plate is in contact with the surface. Recommended sensor positions are set out in Table 5.1. At least 3 drops, plus a small initial drop for settling the load plate, must be made at each test point and checks made for consistency before analysis.

Type of Pavement	Distance (mm) from Centre of Loading Plate						
	Inner			>>>>		Outer	
	Geophone number						
	d1	d2	d3	d4	d5	d6	d7
Flexible and flexible composite	0	300	600	900	1200	1500	2100
Rigid and rigid composite	0	300	600	900	1350	1800	2250

Table 5.1: Recommended Deflection Sensor Positions

5.15 Normally the loading plate is be located in the nearside wheel-track of the left-hand lane to assess the line of greatest deterioration. Additional measurements with the plate set between the wheel-tracks or in the middle of the right-hand lane of dual carriageways, if of the same construction, can provide a valuable indication of the condition of the largely untrafficked area of the pavement that has been subjected to the same environmental conditions as the trafficked wheel-tracks.

5.16 Typically, longitudinal spacing of measurements is between 5 and 20m for sample lengths of flexible pavements with asphalt base. On flexible pavements with hydraulically bound base some close spaced testing at 0.2 to 1.0m intervals may be carried out to assess crack frequency and severity in the underlying cement bound material. Details of this method are given in TRRL Report RR189 (1990) and in HD 30 (DMRB 7.3.3). Measurements on rigid pavements to assess slab and foundation properties must be taken in mid-slab locations and away from cracks.

Pavement Temperature

5.17 The temperature of the bound layer of the pavement is normally taken at a depth of 100mm using an electronic thermometer to an accuracy better than 0.5°C and a resolution of 0.1°C. Holes for temperature measurements must be on the line of the test points and pre-drilled some time before measurement so that the heat energy created by drilling has had time to dissipate. Glycerol, or similar substance, in the bottom of the hole will ensure good thermal contact between the thermometer and the bound material.

5.18 Measurements must be taken at the start and end of each test section and at least every 30 minutes during the survey. Temperatures must also be recorded when passing into or out of continuously shaded areas on the carriageway and areas having significantly different surface characteristics.

5.19 The preferred temperature range for stiffness evaluation testing on flexible pavements with asphalt base is between 5°C and 30°C. At very low temperatures (<5°C), ice may be present in the unbound materials which can significantly affect the results. At high temperatures (>30°C) the response of asphalt becomes increasingly viscous and it is more difficult to distinguish between sound and unsound materials. In addition, since the stiffness of asphalt layers needs to be adjusted to the standard reference temperature of 20°C, additional uncertainty is introduced when testing takes place at temperatures significantly above or below 20°C. On flexible pavements with asphalt bases, greatest confidence can be placed on surveys carried out within the temperature range 10 to 25°C.

5.20 Additional care needs to be taken when assessing flexible pavements with a hydraulically bound base. The effective stiffness of hydraulically bound bases can increase with temperature due to cracks locking together and stiffening the structure. This effect is dependent upon the extent of cracking present and is difficult to predict. However it is not very significant on severely cracked hydraulically bound bases. Where the primary aim of the survey is to assess the condition of the concrete base, it is recommended that testing be carried out below 15°C (but above 5°C). When testing rigid pavements, periods when there are significant temperature gradients must be avoided, as hogging or warping of the slabs can seriously affect the results.

ANALYSIS

Initial Deflection Assessment

5.21 The first stage in the analysis of the data is to prepare simple longitudinal plots of selected deflections. The FWD deflection data "normalised" to a standard load, of 50 or 75kN as appropriate, may be tabulated and plotted to show the variation of pavement response along the road. Certain parts of the deflection bowl are influenced by the different pavement layers. With reference to Figure 5.2, the chosen criteria are usually d1, d6 and (d1-d4). The central deflection d1 gives an indication of overall pavement performance whilst the deflection difference (d1-d4) relates to the condition of the bound pavement layers. Deflection d6 is an indication of subgrade condition. A typical plot of these three deflection indicators is shown in Figure 5.3.

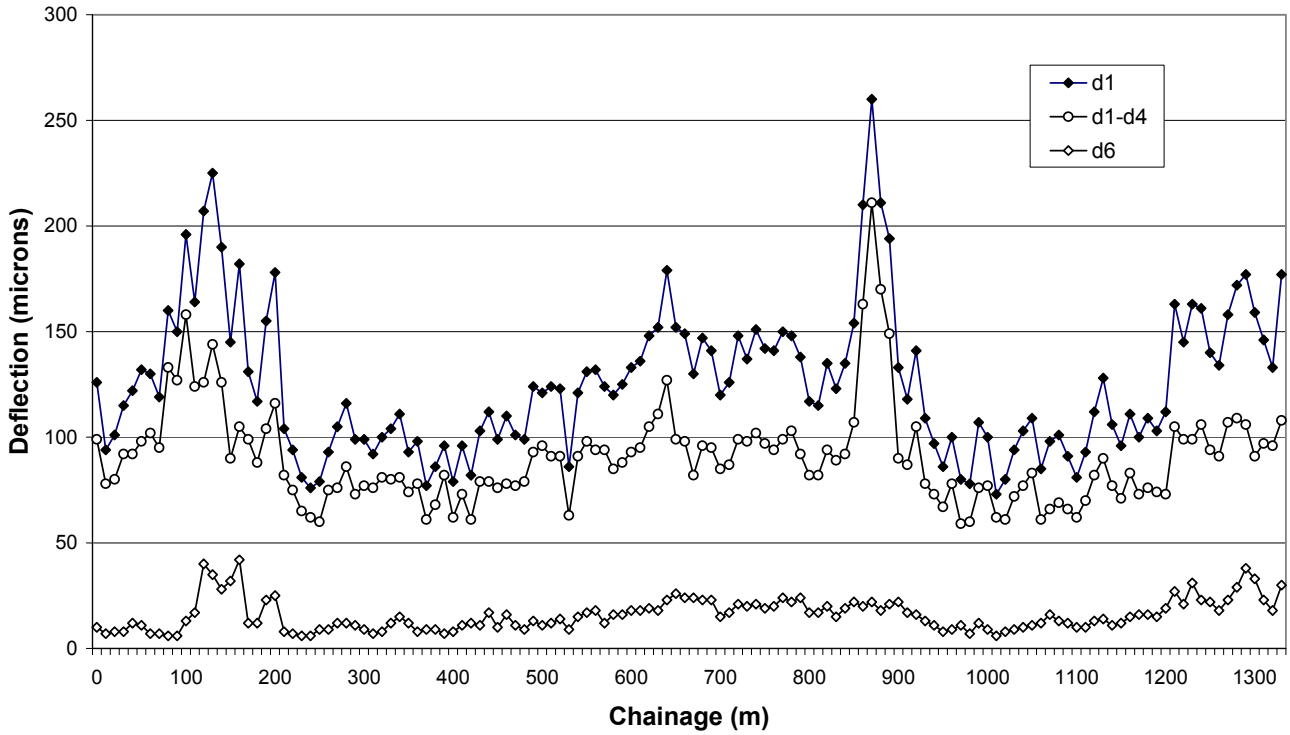

Figure 5.3: FWD Deflection Profiles

5.22 Although actual values of deflection will depend on the type and condition of the material present, such plots will show relative differences in the condition of the layers, enable lengths of road with similar behaviour to be identified and give an indication of where structural weakness may be present.

Cracks in Hydraulically Bound Mixtures

5.23 Results of tests on bases formed from hydraulically bound mixtures showing peaks in the central deflection enable the spacing and severity of primary transverse cracks to be determined even if not visible on the surface. The crack spacing is a function of the age and strength of the cement bound material, a wider spacing indicating a stronger material. Guidance on interpretation of such measurements is given in HD 30 (DMRB 7.3.3).

Calculating Layer Stiffnesses

5.24 The deflected shape of the surface, generated by an FWD impact load, depends upon the type, thickness and condition of the construction layers. Computer programs using linear elastic multi-layered analysis can be used to model the pavement structure. Essentially this analysis is based on a mathematical model of the pavement structure which predicts the surface deflection under a given applied load. An iterative procedure known as "back-analysis" is used to match the computed deflections to the measured values. The layer stiffnesses are adjusted in this process until a reasonable match is obtained.

5.25 There are a number of different programs available for performing back-analysis of FWD data to produce stiffness estimates of pavement layers. The results of the analysis are strongly influenced by the type of program used and the way in which the pavement is modelled (including the number of layers used and the assumed properties of those layers). For this reason, the following back-analysis procedure must be followed whenever performing back-analysis for the HA's network. The use of this procedure is expected to produce reasonably consistent results independent of who is performing the analysis. There will be occasions where alternative back-analysis procedures may be required but their use must be clearly justified and they must be used in addition to the standard procedure.

Back-Analysis Program

5.26 For use on the HA's network, the back-analysis program must comply with the following criteria:

i. it must model the pavement structure as a number of horizontally infinite linear elastic layers;

ii. it must use elastic multi-layer analysis based on Burmister's equations[1] with all layers modelled linearly including an infinite depth subgrade and no slip between layers;

iii. it must be able to model at least three independent layers;

iv. it must be able to handle at least seven deflection sensors;

v. it must be able to report the computed surface deflection values.

Pavement Model

5.27 For the HA's network, the following rules must be applied when determining how to model the pavement:

i. the minimum thickness of any single layer must be 75mm;

ii. the maximum number of independent layers (including the subgrade) must be three;

iii. asphalt layers must be combined and modelled as a single layer;

iv. concrete layers must be combined and modelled as a single layer;

v. where an asphalt layer overlies a concrete layer, these must be modelled as separate layers provided that neither is less than one-third the thickness of the other (subject to constraints i and ii);

[1] The general theory of stresses and displacements in layered soil systems. Burmister. Journal of applied physics, Volume 16, 1945.

vi. Poisson's ratios used must be those shown in Table 5.2.

Material	Poisson's Ratio
Asphalt	0.35
Hydraulically bound mixture	0.35
Pavement quality concrete	0.20
Crushed stone	0.45
Soils (fine-grained)	0.45

Table 5.2: Poisson's Ratios for Use in Back-Analysis

Layer Thicknesses

5.28 Stiffness results from back-analysis are extremely sensitive to the layer thicknesses assumed for the analysis. Underestimating the thickness of bound layers will generally result in an over-estimate of the stiffness of that layer and overestimating bound layer thickness will similarly result in an under-estimate of the stiffness of that layer. For example, a 15 per cent underestimate of the thickness of a bound layer can result in a fifty per cent overestimate of the stiffness of that layer. It is therefore essential that accurate and reliable thickness information be obtained prior to analysis.

5.29 While coring can provide thickness and material-type information of sufficient accuracy, many pavements exhibit significant variations in thickness and material type along their length (and sometimes across the pavement too) and coring of every test point is usually impractical and uneconomic.

5.30 In situations where the construction is expected to be consistent, e.g. where a road section has been constructed all at one time, and coring has shown thicknesses within, say, ±5% of the mean thickness, the core thicknesses alone should be a sufficient basis for back-analysis. In this situation, if the thickness variation is random, then analysis of the section using the overall mean core thickness would be the best option. If there is a progressive increase or decrease of thickness along the section, or there are groups of similar values, it would be preferable to analyse in sub-sections and use the mean thicknesses of these for back-analysis.

5.31 In the more usual situation, where coring shows a range of thicknesses greater than ±5% of the mean thickness and there is no other information to indicate where changes in pavement thickness occur, a Ground Penetrating Radar survey (Chapter 6 of this Part) is suggested. In some instances further coring might also be considered.

5.32 Where the cores and GPR data show significant thickness variation, ideally, each point must be analysed using the corresponding thickness at the test location. However, this will seldom be practicable and therefore it will usually be necessary to split test sites into sections of homogeneous construction for the purposes of back-analysis. The measured bound-layer thickness within a homogeneous section should lie within ±5 per cent of the bound-layer thickness used for that section. The determination of the homogeneous section boundaries may be determined graphically by Cusum analysis or by computation.

5.33 For sections where there is a continuous change in thickness, either a separate thickness must be used for the analysis of each deflection bowl, or a single thickness is used for the section. In this case a sensitivity analysis must be helpful in indicating the dependence of the derived layer stiffnesses on assumed layer thicknesses. In some circumstances e.g. very high or very low values of stiffness, the conclusion on the layer quality will be the same regardless of the value of thickness used in the back-analysis.

Adjustment for Temperature

5.34 The stiffnesses derived from back-analysis represent estimates of the in situ values at the time of testing. The stiffness of asphalt is very dependent on temperature. Therefore, in order to compare the stiffnesses obtained with those expected from standard materials, it is necessary to first adjust them to the standard reference temperature of 20°C.

5.35 The temperature dependency of stiffness can vary quite considerably and is a function of a number of different material properties. Consequently, no single relationship between stiffness and temperature exists that can be applied universally to all asphalt. However, tests on a wide range of materials have indicated that the relationship given below can be used to provide a satisfactory adjustment to asphalt layer stiffnesses provided that testing is carried out in the preferred range of 15 to 25°C. The relationship may also be used where measurements are taken at other temperatures although the absolute values of the adjusted asphalt concrete stiffnesses will need to be treated with caution.

5.36 The temperature dependency of the stiffness of severely cracked asphalt tends to be far less than that of intact materials. Therefore, where a layer is known to be severely cracked throughout its depth, temperature adjustment should not normally be applied.

5.37 For use on the HA's network, the stiffness of asphalt layers, unless severely cracked, must be adjusted to the standard reference temperature of 20°C using the following relationship:

$$E_{20} = E_T \cdot 10^{(0.0003 \times (20-T)^2 - 0.022 \times (20-T))}$$

Where: E_{20} = Stiffness at 20°C;
E_T = Stiffness at temperature T ;

T = Temperature of the asphalt at the time of testing (measured at 100mm depth).

Goodness of Fit

5.38 There are two goodness of fit parameters that are commonly used for indicating how well the program has matched the data. These are the Absolute Mean Deviation (AMD) and the Root Mean Squared Deviation (RMS), defined as:

Absolute Mean Deviation (AMD) $= |\sum(d_{ci} - d_{mi})/n|$

Root Mean Squared Deviation (RMS) $= \sqrt{(\sum(d_{ci} - d_{mi})^2/n)}$

Where: d_{mi} are the measured deflections in microns at positions i =1 to n;

d_{ci} are the calculated deflections in microns at positions i =1 to n;

n is the total number of sensor positions used in the analysis (normally seven).

The AMD indicates whether or not there is an overall bias to the calculated deflection bowl relative to the measured bowl. The RMS indicates how well, on average, the calculated bowl matches the measured bowl. Although a good fit does not in itself indicate that a correct solution has been obtained, a poor fit does indicate that the solution found is suspect.

5.39 Different back-analysis programs vary in their ability to match calculated to measured deflections. Poor fits can also be obtained where cracks or other discontinuities are present in the pavement, where incorrect assumptions about layer thicknesses or material types are made, or where layer de-bonding is present. In addition, increasing the number of layers improves the level of fit. Table 5.3 contains guide values for AMD and RMS for pavements modelled with two or three layers. Bowls for which the AMD or RMS exceed these values must be treated with caution. Isolated results which exceed these limits must be discounted when assessing the overall condition of a section.

Number of layers	Maximum Values (microns)	
	AMD	RMS
2	4	11
3	2	5

Table 5.3: Guide Values for Goodness of Fit

ALTERNATIVE BACK-ANALYSIS APPROACHES

5.40 There will be occasions where the standard back-analysis procedure may not produce the most representative estimates of stiffness and an alternative analysis technique may be more appropriate. Table 5.4 lists some example scenarios where alternative techniques may be appropriate. Where an alternative back-analysis method is used, it needs to be performed in addition to the standard procedure and both analyses need to be reported.

Problem	Possible Alternative Analysis Methods
A non-linear (i.e. stress-dependent) subgrade or the presence of bedrock is indicated by surface modulus plots. (See Annex 5B for information on surface modulus analysis.)	A layered subgrade model or a model using a stiff-layer at depth may be appropriate.
On a flexible-composite (or rigid-composite) pavement modelled using a three-layer model, the stiffness of the asphalt layer is unrealistically high (or low) or the stiffness of the concrete is unrealistically low (or high).	Use a two-layer model combining all the bound materials and use forward-analysis to determine revised guide limits for the quality of the materials (supplementary testing will need to identify which layer is responsible for any low stiffnesses). **Or** Fix the stiffness of the asphalt layer in the analysis. This would need to be determined from a number of ITSM tests undertaken on the main asphalt layers and adjusted to the FWD loading time and temperature at the time of the survey. (See HD 30, DMRB 7.3.3 for further details.)
Presence of poor quality bound materials, i.e. a sub-layer of bound material is known to be in a severely deteriorated condition and to have very low stiffness (e.g. cracked/stripped lower asphalt concrete layers in an evolved pavement).	It may be appropriate to sub-divide the asphalt layers into two (intact and poor) or in extreme cases to combine the poor materials with the foundation layers.

Table 5.4: Example Situations where Alternative (Additional) Back-Analysis Models may be Appropriate

LOAD TRANSFER EFFICIENCY

5.41 The main use of the FWD in relation to Pavement Quality (PQ) concrete pavements is the evaluation of Load Transfer Efficiency (LTE) and underlying slab support at joints and cracks (discontinuities). This is assessed by loading the slab on one side and measuring the deflections on each side of the joint or crack. More details on the assessment of PQ concrete pavements is given in HD 30 (DMRB 7.3.3).

Test Procedure

5.42 The load level must be set at a nominal 50kN + 10%. On pavements with very low deflections, ie d1 less than 100 microns, this may be increased to a nominal 75kN + 10%. The load pulse must be applied through a 300mm diameter plate and have a rise time from start of pulse to peak of between 5 and 15 milliseconds. Deflections must be measured to a resolution of at least 1 micron over the range 0-2mm by a minimum of three sensors.

5.43 There must be no standing water on the road surface and care must be taken to ensure that the whole area of the plate is in contact with the surface. At least 3 drops, excluding a small initial drop for setting the load plate, must be made at each test point and checks made for consistency before analysis.

5.44 The relative degree of load transfer at joints and cracks may be assessed by loading the slab on one side whilst deflections are measured on each side of the joint or crack. Ideally, the LTE of each joint or crack should be assessed by loading each side of the discontinuity. This is because the load transfer efficiency can depend on the support under the edge of the discontinuity. The downstream side ("leave" side) of the discontinuity sometimes is the weaker side. Ideally the joints should be tested in both directions if resources and time permit. However, this will require the FWD testing vehicle to face traffic in adjacent lanes and this recommendation is therefore subject to health and safety considerations and traffic management constraints.

5.45 The preferred arrangement of the equipment is shown schematically in Figure 5.4. Ideally the load plate should be placed 250mm from the discontinuity with the deflection sensors d2 and d3 placed either side, 200 and 300mm from the load centre respectively. Care needs to be taken to ensure that the sensors are positioned to avoid spalled material; spacings may need to be adjusted to allow for this. The test would normally be carried out in the outer (near side) wheel-track.

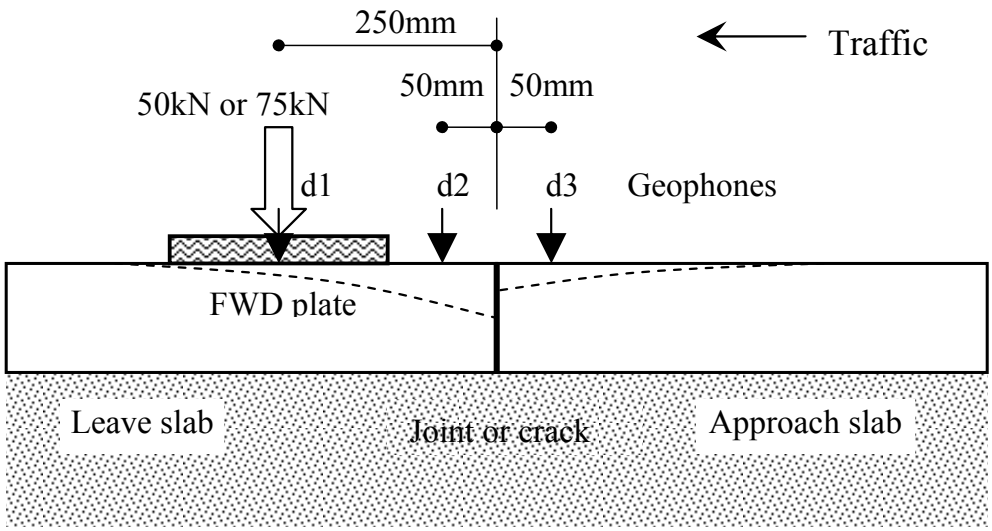

Figure 5.4: Load Transfer Efficiency: FWD Set-up ("Leave" side test)

The load transfer efficiency is defined as:

$$\text{LTE} = \frac{\text{deflection of unloaded slab}}{\text{deflection of loaded slab}} = \frac{d3}{d2} \times 100\%$$

d2 and d3 are as shown in Figure 5.4.

Pavement Temperature

5.46 The temperature condition of the pavement will have a major effect on the measured LTE. Generally, higher values are obtained at high temperatures as the slabs expand and lock together. In order for joints or cracks to be compared they must be tested at a similar, low temperature, without temperature gradients, when the widths of the discontinuities are greater and the relative movement is larger. It is difficult to give a standard test temperature or range below which the locking effect is minimised as this will depend on the roughness and nominal width of the joints or cracks and the coefficient of thermal expansion of the slabs. An upper limit of 15°C has been suggested in the past but this may not apply to all sites. Even at low temperatures there may be some degree of slab locking due to temperature gradients which will produce slab curling.

Reporting of FWD Survey and Back-analysis Results

5.47 For surveys carried out on the HA's network, the following information must be reported:

Survey details

i. The date and time of the survey and the identities of the operator and company.

ii. Location of the survey including road number, lane number, transverse position, geographical location, and precise details of the longitudinal referencing in relation to the network section reference.

iii. Make, model and serial number of the FWD used.

iv. The mass of the falling weight and the diameter of the loading plate.

v. Type, number and positions of the geophones.

vi. Locations, depths (should be 100mm) and times of pavement temperatures recorded during the survey.

vii. Test type, leave or approach for Load Transfer Efficiency (LTE).

viii. "Supplementary" and "F20" files to be provided for loading into the Highways Agency Pavement Management System (HAPMS), for all trunk road surveys.

Survey results

i. Tabulated deflections (normalised to 50kN or 70kN as appropriate).

ii. Graphs of the deflection parameters d1, (d1-d4) and d6 (normalised to 50 or 75kN as appropriate).

iii. Temperature applicable to each test point.

Analysis details

i. Details of the FWD back-analysis program used (name, version, mode of operation).

ii. Details of the model used (thicknesses for each layer, number of layers, type of material assumed, details of the source of the construction information used e.g. cores, GPR, as-built drawings etc.).

Analysis results

i. Tabulated back-analysed stiffnesses (including "as measured" and "adjusted to 20°C" for asphalt layers).

ii. Graphs of the layer stiffness results (asphalt layers adjusted to 20°C).

iii. Tabulated layer thicknesses used for the analysis (i.e. for each test point).

iv. AMD and RMS values for each test point.

5.48 The template given in Annex 5B must be used to record the details. Where an alternative analysis is used, the report must include a clear explanation of the reason for using the additional analysis. Both sets of analyses must be presented in the format specified and it must be made clear which set of results relates to which analysis method.

Lightweight Devices

5.49 Lightweight dynamic plate or falling weight devices are also useful for testing foundation (unbound) layers. Their use is more limited than the FWD and they are not to be used for overall pavement assessment.

6. GROUND-PENETRATING RADAR

INTRODUCTION

General

6.1 Ground-penetrating radar (GPR) is a non-destructive tool that can be used to obtain information about the construction of a pavement and its internal features. This information can be used to enhance pavement condition information obtained from visual condition, deflection surveys, coring and trial pits.

6.2 Typically, GPR can provide information about changes in pavement construction, layer thicknesses and defects/features within the pavement. The quality of the information obtained from ground radar is largely a function of three factors:

- the electrical properties (dielectric constant and the conductivity) of the materials forming the pavement;
- the type of GPR equipment employed;
- the processing software and analysis methodology including calibration procedures employed.

Scope

6.3 This Part gives guidance on the appropriate use of GPR on paved roads only and does not cover the monitoring of services such as subsurface drains, buried pipes and any other non-pavement related features. The advice sets out the requirements for successful operation of a GPR survey, for quality control of the survey, and for the presentation of results.

6.4 Guidance on the use of GPR in connection with the assessment of highway structures is given in BA 86 (DMRB 3.1.7).

Legislation

6.5 Section 1(1) of Wireless Telegraphy Act 1949, makes it an offence for any person to operate any equipment for wireless telegraphy if not used in accordance with the license granted by the Office of Communications (OFCOM). All GPR operators operating in the UK must hold an OFCOM license and operate as required in respect of the EuroGPR Code of Good Practice. Also, the use of GPR on roads near radio astronomy sites requires specific permission from OFCOM.

USE OF GROUND-PENETRATING RADAR

General Principles of Ground-Penetrating Radar

6.6 The general principles of the use of GPR and their antenna types are explained in Annex 6A of this Part.

Location Referencing

6.7 Accurate location referencing is fundamental to the collection of good quality ground-penetrating radar data particularly as thicknesses will have to be calibrated or checked against pavement cores. All GPR surveys carried out on the HA network must be referenced against network sections to an accuracy of better than ± 5m.

If the surveys are carried out at traffic speed then particular care will need to taken to achieve the above requirement, the use of an automatic location referencing system may well be needed such as a sophisticated GPS and inertial guidance system as used with TRACS.

Recommended Uses

6.8 GPR systems available at present are able to identify pavement features to differing degrees of robustness for assessment purposes depending on the feature and the survey speed. The ability of GPR surveys to identify pavement features are therefore classified into four classes A to D, depending on how accurately and reliably they can be identified; as shown in Table 6.1. Surveys with the classification A are considered **Routine** and have sufficient accuracy and reliability to be used regularly for pavement assessment.

Surveys with the classification B are considered to be suitable for **Confirmation** that this pavement condition exists with the assistance of evidence from other techniques. Surveys with the classification C should only be used with **Caution** as a guide and together with other data to indicate the possible construction or condition of the pavement. Surveys with the classification D are **Unproven** and have yet to be demonstrated as suitable for use on the network. Table 6.1 also gives the constraints and other requirements when utilising GPR to ascertain a specific pavement feature. Ongoing developments in GPR systems make it likely that more features will be detected accurately and reliably in future. This advice on the limitations of the technique will be kept under review and any significant developments will be incorporated when they are ready for implementation.

6.9 The sampling rate of a GPR system influences the size of feature that can be detected and the sampling rate depends largely on the survey speed of the equipment amongst other parameters. This is mainly why surveys that detect discrete features in the pavement, such as voids or cracks, have been given different classifications in Table 6.1 depending on the survey speed. The surveys at slower speed, ie less than 30 km/h, will normally require appropriate traffic management. This subject is covered in more detail in Annex 6A in this Part.

6.10 It is recommended that surveys for the HA network be commissioned only if they meet the A and B level classifications as shown in Table 6.1 Further details of how GPR can be used to assess these pavement features are explained from paragraph 6.13 onwards.

6.11 It is also recommended that the GPR surveys should be undertaken prior to any coring to ensure that the core extraction occurs in homogeneous road sections.

Limitations of Use

6.12 GPR cannot penetrate metal, closely spaced reinforcement or highly conducting materials.

6.13 GPR surveys must not be carried out when it is raining or when standing water is present on the surface of the pavement. This is because a thick film of surface water may affect the radar signal making interpretation of the data more difficult. Calibration of the radar may also be less certain as explained in Annex 6B of this Part.

6.14 GPR surveys must not be carried out on salted (de-iced) roads in case there is significant penetration of salt water into the subsurface materials beneath the road. Salt increases the conductivity of the pavement materials and the transmission of ground radar signals is heavily dependent on the pavement's conductivity. High conductivity will lead to an attenuation of the radar signal and therefore reduces considerably the depth of penetration of the radar.

Construction Changes (Class A)

6.15 The following are typical examples of changes of pavement constructions which GPR can detect:

- changes from hydraulically bound to asphalt base and vice versa;
- haunches;
- hidden trenches covered by bituminous surfacing.

However if the construction change is outside the line of the survey, such as haunch construction, or of a short length then the survey may not be able to detect the change.

6.16 Direct evidence of construction changes must be confirmed by coring. Ideally, this must be carried out after the GPR survey has been carried out at locations of homogeneous construction (determined from the GPR) and where the GPR interpretation is unclear.

Pavement features	Classification (see below)		Constraints and requirements
	Slow speed <30km/h	Traffic speed >80km/h	
Construction changes	A	A	If the construction changes are outside the line of the survey or of a short length they may not be detected.
Bound and unbound layer thicknesses and profiles	A	A	Low speed surveys needed for reinforced layers. Caution is required for interpreting disintegrated lean concrete layers. The best depth resolution for concrete is 20mm (2.5GHz antenna).
Deep air-filled voids directly beneath unreinforced concrete slabs	B	C	Void depths need to be at least 80mm for reliable detection. For measurement at traffic speed, the success in detection will depend on the sampling rate and the length of the voids. Depth of the feature and chosen antenna frequency will also affect the accuracy of measurements.
Water-filled voids directly beneath unreinforced concrete slabs	B	C	Water-filled void depths need to be at least 25mm for reliable detection. For measurement at traffic speed, the success in detection will depend on the sampling rate and the length of the voids. Depth of the feature and chosen antenna frequency will also affect the accuracy of measurements.
Depth and gross misalignment of joint dowel bars; detail of steel reinforcement in concrete slabs	B	D	Slow-speed scans are required along the line of the joint to assess dowel and tie bars. With a single antenna, one scan is required just beside the joint, and two further scans each side of the joint on a line just above the ends of the dowel or tie bars. This type of survey will also allow the determination of the depth and spacing of reinforcing steel mesh where present.
Variation of sub-base moisture content (duplicate surveys required)	B	C	Signal velocity changes with material and with moisture content. To eliminate uncertainty of data interpretation, one survey must be carried out in a 'dry' season when the sub base is likely to be in an equilibrium moisture condition and an identical survey carried out when the sub-base is deemed to be wet (i.e. in the 'wet' season). Note that the interface between the sub-base and the subgrade must be visible in the signals for the technique to work.
Depths of surface cracks in fully flexible pavements	C	D	Specialised GPR equipment, a specifically trained operator and a slow survey speed are required. Sample cores are required for calibration of the crack depth measurements. No equipment available for traffic speed survey.
Broad types of pavement materials	C	C	Some idea of material type can be obtained by examining the signal attenuation, amplitude of reflections at material boundaries, continuity of response from within the material, and automatically determined or self-calibrated signal velocity within the material. However, the only certain way to identify materials is to use core data.
Debonding of pavement layers	D	D	This feature might be visible in the bound material at slow speed with high frequency antenna, higher chance to be detected with the presence of water in the debonded area.
Condition of steel in concrete	D	D	Unlikely to indicate directly the condition of any steel but if the steel has corroded and damaged the surrounding concrete the radar may detect the damage.
Voids and wet patches beneath reinforced concrete slabs	D	D	Reflections from voids or wet patches may be masked by reflections from the overlying reinforcement.
Shallow voids directly beneath unreinforced concrete slabs	D	D	Air filled voids less than 80 mm deep are difficult to identify. Water filled voids less than 25mm deep are also difficult to identify.
Debonding of joint sealant	D	D	Might be detected at slow speed with special GPR systems. Not proven to date.

A - Sufficient accuracy and reliability to be used for pavement assessment.
B - Use to confirm assessment of pavement condition based on other data.
C - Use with caution and as a guide, along with other data, to indicate possible construction/condition of pavement.
D - Unproven and candidates for future research.

Table 6.1: Accuracy and Reliability of Identification of Pavement Features by GPR

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Layer Thickness (Class A)

6.17 Correct interpretation of deflection measurements is heavily dependent on having accurate and reliable construction information. When processing Deflectograph measurements, information on layer thicknesses and material types are needed for determining generic base type (see Annex 4B, Paragraph 4B.10) and for classifying flexible pavements as to whether or not they are likely to be long-life pavements (see Annex 4B, Paragraph 4B.4). When analysing Falling Weight Deflectometer measurements accurate layer thicknesses are required to achieve the correct interpretation (see Chapter 5, Paragraphs 5.28 to 5.33) of layer stiffnesses.

6.18 GPR will, in general, detect all adjacent layers constructed of the same basic material as a single layer. For example, asphalt surfacing and base layers will, in general, appear to GPR as a single layer. Therefore, caution should be exercised when a GPR Contractor reports the thicknesses of individual layers within the bound layers. For reinforced layers it will be necessary to survey at a slow speed in order to reliably detect the bottom of the layer through the gaps in the reinforcement.

6.19 Layer thickness determination of lean concrete can be difficult if the concrete has disintegrated. In this situation it will have similar dielectric properties to granular material and the bottom of the disintegrated lean concrete could be misinterpreted as the bottom of the sub-base.

6.20 For use with the PANDEF program layer thicknesses are required to an accuracy of around ±10 per cent or better, but for the accurate interpretation of Falling Weight Deflectometer results accuracies of ±6 per cent or better are required. GPR trials have shown that at slow speed (<25km/h), GPR could determine the combined bound layer thickness with an accuracy of approximately 5 per cent of the real thickness. However, at traffic speed (70km/h) the error could increase to approximately 9 per cent. For underlying layers of hydraulically bound and unbound material, the expected accuracies are approximately ±15 per cent and ±30 per cent, respectively, of the real thickness.

Deep Voids Beneath Concrete Slabs (Class B or C)

6.21 GPR can give good estimates of the depth of deep air filled voids and shallower water filled voids under unreinforced concrete slabs and indicate their position and relative plan size. However, surveys to measure voids should only be undertaken if a visual condition survey has shown that there are problems (e.g. rocking slabs) and it is thought that they are related to poor support under the concrete slab. If a survey is required, it is advised that GPR with distance driven sampling and multiple antennas be used as this will give the greatest coverage and accuracy.

6.22 The reported depths of voids should be treated with caution if the report states that the depth of an air filled void is less than 80 mm and the depth of the wet patch less than 25 mm. A difficulty arises if the slab is reinforced because the reinforcement gives strong radar reflections that can distort or mask the signals reflected from voids.

6.23 A GPR result indicating the presence of voids must not be used, on its own, to justify treatment. Other evidence must be obtained that voids exist and are causing problems, such as deterioration of joints or movement of slabs, before maintenance treatment is considered.

Depth and Gross Misalignment of Joint Dowel Bars and Details of Reinforcement (Class B)

6.24 A GPR survey of dowel bars in concrete pavements should only be undertaken if there is evidence that joints are not working properly and it is thought that the problem is due to the dowel bars.

6.25 GPR will give an indication of the depth of the dowel bars and whether they are grossly misaligned. It is possible to wrongly infer, from radar data, the extent of misalignment of the bars, so any report of misalignment should be treated with care. If a survey is required, it is advised that multiple antennas be used to give greatest accuracy. Surveys aimed at providing details of the reinforcement in the pavement, such as depth and spacing, should be carried out at low speed.

Variation of Sub-base Moisture Content (Class B or C)

6.26 Variations in sub-base moisture appear as variations in sub-base signal velocity and this velocity can be measured providing the interface between the sub-base and subgrade is visible in the radar signals. Any variation in sub-base material will produce a similar variation in velocity so in order to eliminate this effect a second survey on the same section should be undertaken and the results of two surveys compared.

One survey should preferably be carried out in the 'wet' season, when the sub-base moisture content is likely to be at its highest. The other survey should preferably be carried out in the 'dry' season, when the sub-base moisture content is likely to be at its lowest. Areas where there are significant differences between the signal velocities measured during the two surveys are likely to indicate that water may be present. Trial pits or dry coring should be undertaken to confirm the findings of the GPR results.

Crack Depth in Asphalt Pavements (Class C)

6.27 Cracks in fully flexible pavements usually initiate at the surface and propagate downwards. Knowledge of crack depths can aid the maintaining agents to better target any maintenance. A Crack Detection Head (CDH) has been developed for use by GPR contractors to measure surface crack depth in flexible pavements. This equipment is used at slow speed and requires cores for calibration and control purposes.

6.28 When crack depth surveys are carried out, the equipment must be used in accordance with the manufacturer's instructions, and operated by a technician who has attended the equipment manufacturer's training course.

Material Types (Class C)

6.29 Experienced GPR contractors can obtain sufficient information to suggest broad material types from the survey results by considering such information as signal attenuation, the amplitude of the reflection at the material interfaces and signal velocity within the layers. However such interpretations are not 100% reliable and should be confirmed from core samples.

SURVEY PLAN

6.30 The GPR contractor must prepare a Survey Plan and comply with it at all times during the contract. This is to ensure that the information produced by a GPR survey is sufficiently accurate and reliable for use by the highway/pavement engineer.

6.31 The Survey Plan must include the following information in the submission:

- equipment specification;
- serial number of GPR equipment;
- calibration of the radar system;
- quality control procedures for both survey and analysis;
- work programme;
- survey procedure;
- risk assessment of the site work;
- form of presentation of the GPR results (Paragraphs 6.33 to 6.36).

Calibration of GPR for Determination of Depth of Features

6.32 Cores will be required to identify or confirm each type of construction and determine layer thicknesses at specific locations within the survey site in order to calibrate or confirm the calibration of the GPR system that will be used in the survey.

6.33 Cores must be located to an accuracy of ± 1m in the longitudinal direction with respect to the network sections and to ± 0.1m in the transverse direction from the lane edge. Cores must be taken following the initial analysis of the data when changes in construction and layer thicknesses have been identified and located. Coring must be carried out in areas where the material appears to be homogeneous in both quality and thickness.

6.34 The methods of calibrating a GPR system for determination of layer thicknesses are explained in Annex 6B of this Part.

REPORTING RESULTS OF A GROUND-PENETRATING RADAR SURVEY

6.35 The results from a GPR survey must be presented by the GPR contractor in a format which can be readily understood by the highway/pavement engineer and referenced to the network sections to allow easy comparison with other pavement condition data from the same site. In addition, the data must be provided in electronic form such that it can be easily used with the commonly available types of spreadsheet programs.

6.36 The GPR survey report must include:

- a text section summarising the results of the survey, assumptions used to interpret the radar data, measurement accuracy achieved, problems encountered, etc;
- a graphical display of the survey results;
- tabulation of the survey results;
- core logs where appropriate.

6.37 The media (electronic and/or hardcopy) for the display of radar results should be as specified or agreed with the survey customer and may require viewing software to be supplied by the GPS contractor. The format of the tabular data should be suitable for input to a spreadsheet program.

6.38 Graphs and tables should be produced to a standard format, displaying as much information as possible. The following information should appear on the graphs and tables:

- road number;
- network section identifier;
- chainage in metres along road from the start of the network section;
- date of survey;
- direction of survey;
- road type;
- construction;
- lane/s surveyed and track – nearside or offside wheel-track and/or between wheel-tracks;
- survey length;
- sampling of radar system – average sampling interval and sampling method (time driven or distance driven);
- surface moisture condition;
- location of any construction changes and broad identification of materials;
- pavement depth in millimetres and pavement width in metres;
- location and size of subsurface defects;
- location of roadside features where this aids location referencing of the survey data;
- location of cores, core details, and corresponding radar depths.

6.39 An example of reporting is given in Annex 6C of this Part.

7. TESTING AT INVESTIGATION SITES

Location Referencing

7.1 Accurate location referencing of all pavement condition data is essential to allow reliable comparison between each type of data. The locations of all cores, test pits, in situ tests and material samples must be referenced against network sections to an accuracy of ± 1m longitudinally and ± 0.1m transversely from the nearside lane edge.

Coring

7.2 When assessing pavements, coring of the bound layers is normally required for one or more of the following purposes:

a) determination of layer and total pavement thicknesses (usually in conjunction with Ground-Penetrating Radar);

b) determination of the material type and condition of the layers;

c) determination of the depth of cracking;

d) determination of the condition of rigid pavement joints;

e) provision of samples for compositional or physical tests;

f) provision of access for carrying out Dynamic Cone Penetration tests in granular foundation layers.

7.3 Coring on highway pavements must always be carried out in accordance with Health and Safety legislation and with appropriate traffic management in accordance with the Traffic Signs Manual Chapter 8.

7.4 150mm diameter cores are preferable to 100mm diameter as they will normally provide sufficient material for any laboratory testing and, if sited on cracks, are more likely to be successfully extracted. However, if only layer thicknesses are required from sound pavement, 100mm diameter or smaller cores could be satisfactory.

7.5 Cores will sometimes be required on undamaged pavement (for general construction details) and also on defects such as cracks, ruts and joints (in rigid pavements) through which fines are pumping. Coring on cracks is usually slower and more difficult than coring on sound material as the core pieces may jam in the core barrel. If some of the layers are both cracked and de-bonded from each other; it can be very difficult to remove the core from the barrel without further damage. Judgment will be needed to select core locations which are likely to reflect the deepest cracking but are not so disintegrated as to make coring impractical. If there is doubt over the direction of crack propagation (upwards or downwards) cores can be sited near and beyond the end of a crack to establish whether the crack depth has reduced or not. They must penetrate completely through all bound layers, asphalt or hydraulically bound mixtures.

7.6 The asphalt layers responsible for rutting may be identified by extracting a set of three cores sited across a rut at spacings of approximately 0.5m, and comparing the layer thicknesses. The distances of the top surfaces of the cores to a straight edge must also be recorded to assist in matching the layer thinning deduced from the cores to the actual rut depth. Alternatively, a large transverse slab may be sawn from the pavement if the necessary equipment is available.

7.7 For each core, a full record of the core details must be made in the form of a Core Log, an example of which is shown in Figure 7.1. The log must include a good quality colour photograph with a scale strip and the core reference clearly visible. Natural lighting usually produces the best detail in the photographs. Flash photography, particularly when the core surface is wet, should be avoided as it produces strong highlights which obscure the details.

Layers					Aggregate		Comments
No.	Top mm	Btm mm	Thkn mm	Mat'l	Max Size mm	Type	
1	0	40	40	HRA	14	GNT	Full depth crack in layer
2	40	120	80	DBM	28	GNT	Full depth crack in layer. De-bonded from layer 3
3	120	225	105	DBM	28	GNT	Sound. De-bonded from layer 4
4	225	353	128	HRA	28	GNT	Sound
							Asphalt resting on crushed limestone sub-base

Pavement Condition: Transverse crack

Key: HRA=Hot Rolled Asphalt; DBM=Dense Bituminous Macadam; GNT=Granite

CORE LOG	Project: Area 15 Location/Road: A1 Section : 2400A1/357 Section Chainage: 137m Mp: 10/1 Lane: 1 Direction: WB Offset: NSWP	Date: 7th August 2006 Ref: **A1/L1/WB/10/1**

Figure 7.1: Sample Core Log

7.8 The following reference information must be stated on the log sheet for each core:

a) core reference;

b) section reference and chainage;

c) traffic direction;

d) lane and offset;

e) coring date;

f) pavement condition at core location including presence of cracks and their orientation.

7.9 The following details must be stated on the log sheet for each core:

a) thickness of each bound layer;

b) any missing layers;

c) for each layer as appropriate:

- type of material present;
- possible presence of tar bound layers (if smell or staining is present).
- condition of the material, e.g. sound, cracked, friable etc;
- stripping of binder from the aggregate (if present);
- condition of the bonding between layers;
- presence of detritus where there is a lack of bond between layers;
- voiding and segregation (if present);
- crack depth and severity, soft or otherwise deleterious aggregate, bleeding and any other peculiarities.

d) the depth of cracking, providing the cores are suitably located in relation to the pattern of cracking; this may require additional cores in some cases;

e) the nature of the material at the bottom of the core hole, e.g. crushed stone, gravel or further bound material.

7.10 Where pavement material has disintegrated during coring and there is only partial recovery of material, the layer thicknesses must be determined from the core hole if this is possible.

Test Pits

7.11 Excavating test pits is a much slower and more expensive method of obtaining pavement information compared to coring and must therefore be used only when necessary data cannot be obtained by other means. The test pit reinstatement is a significant task and may not be very durable unless hot-mix surfacing material is used. Test pitting is normally required for one or more of the following purposes:

a) obtaining bulk samples of the bound or unbound layers for laboratory testing;

b) detailed examination of the unbound layers or subgrade including density measurement;

c) investigating the causes of rutting;

d) examination of joints in concrete pavements;

e) investigating drainage problems within or beneath the pavement.

Information on bound layer thicknesses and quality is normally best obtained from cores. In test pits, bound layer details can only be reliably observed on the sawn edges of the excavation, which may only extend to 50 to 100mm.

7.12 Excavation of test pits on highway pavements must always be carried out in accordance with the Health and Safety Regulations applicable to the area and with appropriate traffic management in accordance with the Traffic Signs Manual Chapter 8 (2006). The necessary risk assessments must be carried out before work commences. In any locations where there may be buried services the public utility organisations must be contacted for details of the locations of their plant. Cable location devices must be available and be used by a competent operator. In situations of doubt, excavation must proceed with caution, by hand methods.

7.13 The lateral location of the pit will depend on the nature of the distress being investigated but it is common for the pit to include the nearside wheel-track of lane 1 and part of the hard shoulder, where present. The plan dimensions of the pit are to some extent controlled by the excavation method and the required final depth. Usually the test pit boundary is cut to a depth of at least 50mm with a rotary diamond saw, to ensure a neat reinstatement. Excavation is then carried out using a combination of pneumatic tools, hand labour and sometimes a mini-excavator. A typical plan size would be 0.6m wide x 1.0m long for a pit of 0.6m depth. If a greater pit depth is required or the excavator bucket width is greater than 0.5m, larger plan dimensions will be needed.

7.14 If large samples of asphalt are required for compositional analysis or tests on recovered binder, or if hidden cracks in lower layers are being sought, the surfacing and base must be removed layer by layer and a large piece of material from each layer, approximately 300mm square, retained for analysis as required.

7.15 In flexible pavements, where a test pit is being opened to investigate which layers have deformed and caused rutting, a rotary diamond saw of at least 150mm cutting depth, must be used to obtain a clean cut face within the asphalt layers. A steel straight edge across the width of the pit can be used as a datum line.

7.16 The surface of each layer should be closely examined before excavation is continued and particular care taken in removing the lower layer of base, to avoid damaging the surface of the sub-base. The general appearance of each layer must be noted. An air line is useful to clear away detritus and observe any cracking.

7.17 The pavement layer details revealed in the pit sides must be recorded on a test pit log similar to the example shown in Figure 7.2. If the construction variation across the pit is complex, a diagram must also be provided.

TEST PIT LOG

Test Pit: 17 **Date:** 26 July 2006

Location: M1 CH. 113 + 45 Northbound Slow Lane **Rut Depth (mm):** Near Side = 3mm
Off Side = 0mm

Material	Depth From Surface (mm)		Thickness of Layer (mm)		Test Sample No.	Required Tests	Comments
	N/S	O/S	N/S	O/S			
14mm slag HRA Surface course	35	45	35	45	5678	1. Bitumen content 2. Bitumen properties 3. Grading	Surface condition sound
20mm limestone HRA Overlaid Surface course	99	95	64	50	5679	1. Bitumen content 2. Bitumen properties 3. Grading	
28mm limestone HRA Binder course	159	151	60	56	5680	1. Bitumen content 2. Grading	
40mm limestone DBM Base	219	191	60	40	-		
40mm limestone DBM Base	329	306	110	115	-		
Granular sub-base material Type 1 crushed limestone	850	870	521	564	5681	1. Grading	Slight water seepage @ 0.80m at centre of N/S lane. Terram between sub-base and subgrade
Firm mottled grey & olive brown silty CLAY with traces of fine to medium sand and medium gravel	1100	1100	250	230	NS 5682 OS 5683	1. Atterberg limits 2. Field moisture content	
Firm dark grey silty CLAY with traces of sand with some medium gravel size ironstone cobbles	1300	1400	200	300	NS 5684 OS 5685	1. Atterberg limits 2. Field moisture content	Trial hole terminated @ 1.30 - 1.40m with water seepage @ 0.80m as above

Figure 7.2:Sample Test Pit Log

7.18 Photographs of the pit faces are desirable but the confined space within the pit and indistinct material boundaries and characteristics sometimes make it difficult to produce useful images.

7.19 The collection and testing of samples from the granular layers will depend on the purpose for the test pit and the materials discovered during excavation. However, generally it would be prudent to take samples of all distinct foundation layers for possible testing. Samples of sub-base material should be retained for grading, classification and the determination of moisture content, and the final layer again carefully removed to reveal the sub-grade or capping.

7.20 Density testing of foundation layers is only recommended where the stiffness or strength is unexpectedly low and low compaction or high voids are suspected, as it is a laborious and slow process. The sand replacement method is preferred to the nuclear test, as the latter will require calibration against the former unless the results are only to be used on a comparative basis. In order that the density value can be interpreted, it will also be necessary to carry out a Proctor test of the material in the laboratory to determine the Maximum Dry Density (MDD) and hence determine the relative compaction.

7.21 Capping, if present, may also be investigated in the same manner as for sub-base if this is possible

in a safe manner. The record of the distribution of any moisture is particularly important. If the foundation layers in roads containing statutory undertakers equipment are holding water, samples may be taken for analysis, e.g. the presence of chlorine suggests that a water main may be leaking. Note must be made of any contamination between the subgrade and the sub-base or capping layers.

7.22 Samples of subgrade should be taken at 50mm depth and at 300mm depth for classification, including the determination of plastic limit, liquid limit and moisture content.

Test Pits in Rigid Pavements

7.23 The purposes for excavating test pits in rigid pavements are to investigate the following:

a) stepping/differential movement at joints;

b) very poor 'load transfer' at joints;

c) the possibility of suspect material beneath the concrete;

d) evidence of pumping at joints.

7.24 The reinstatement of concrete pavements after pitting is more difficult and disruptive than for asphalt materials. The new concrete will have to be left un-trafficked until a strength of 25N/mm^2 is reached, thus increasing the delay and traffic disruption of the operation. Reinstatement with asphalt material must only be considered a temporary solution. For this reason, it is recommended that test pits should be made in concrete pavements only when it is considered absolutely necessary and no more than two joints are examined on any section. Consideration must be given to using large diameter (≥ 300mm) cores as an alternative to pitting.

7.25 The recommended procedure is to saw cut the outline of the excavation, ensuring that it is taken far enough back from the joint to fully include the dowel bars (if any). Usually, only one side of the joint need be broken out, over a half lane width. Care must be taken when breaking out around dowel bars. The test pits, including any exposed dowels, should be photographed.

7.26 When replacing the concrete, it is essential that the joint is reformed, with intact dowel bars included, and the joint resealed (see HD 32 (DMRB 7.4.2)).

Field Tests on Foundation Materials

7.27 The Dynamic Cone Penetrometer (DCP) is recommended as the most suitable method for use in the bottom of core holes and test pits to indicate the strength and thickness of the foundation layers. The equipment is simple, fast and low cost. The essential features are shown in Figure 7.3.

7.28 The DCP uses an 8 Kg hammer dropping through a height of 575mm and a 60° cone having a maximum diameter of 20mm shown in Figure 1. The strength of the material is assessed on the rate of penetration per drop or "blow". In practice the depth of penetration is recorded at increments of about 10mm, together with the number of blows to achieve this. The number of blows between readings will vary depending on the strength of the layer being penetrated.

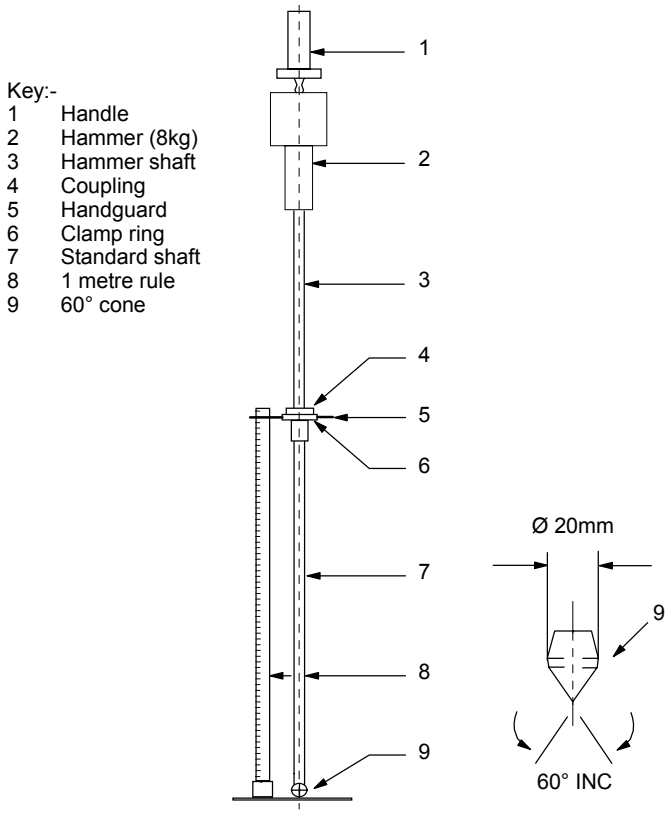

Figure 7.3: Dynamic Cone Penetrometer

7.29 The DCP must always be used in accordance with the Health and Safety Regulations applicable to the area and with appropriate traffic management in accordance with the Traffic Signs Manual Chapter 8 (2006). The necessary risk assessments must be carried out before work commences. In any locations where there may be buried services the public utility organisations must be contacted for details of the locations of their plant. Cable location devices must be available and be used by a competent operator. In situations of doubt, the location of the test must be moved or the test abandoned.

7.30 The DCP will penetrate most types of granular or lightly stabilised materials fairly easily. However, in strongly stabilised layers, very dense, high quality crushed stone and granular materials with large particles progress will be much slower or negligible. If there is no measurable penetration after 20 consecutive blows it can be assumed that the DCP will not penetrate the material. The cone must be replaced when its diameter is reduced by 10 per cent.

7.31 Figure 7.4 gives an example of a field sheet which may be used to record the general reference information for each test together with typical data. The data is normally plotted as the cumulative number of blows (+ve x axis) against depth of penetration (-ve y axis) as shown in Figure 7.5. A change in slope of the plotted data indicates a change of strength and/or material type. The thicknesses of different strength layers are usually determined by inspection and the average penetration rate, in mm per blow, calculated for each. The penetration rate can be converted to a nominal California Bearing Ratio (CBR) value using the following relationship developed by the Transport Research Laboratory:

$$CBR = 10^{(2.48 - 1.057 \times \mathrm{Log}_{10} P)}$$; where P = the penetration rate in mm per blow.

(NB. The accuracy of this relationship reduces for CBR values below 10 per cent.)

DCP FIELD SHEET

Project: *M1 J10/11* Job No: *45678* Operator: *KG*

Date: *4/6/06* Time: *22.30*

Depth from road surface to start of test: *375mm*

Notes: *Drizzle*

Test ID: *C* Lane: *1* Section: *50/8* Chainage: *31m* Direction: *NB* Offset: *0.7m*

No of blows	∑ blows	Penetration (mm)	No of blows	∑ blows	Penetration (mm)	No of blows	∑ blows	Penetration (mm)
0	0	393	2	21	593	2	69	742
1	1	431	2	23	605	2	71	751
1	2	451	2	25	611	2	73	765
1	3	466	2	27	614	1	74	778
1	4	475	4	31	621	1	75	805
1	5	486	4	35	627	1	76	840
1	6	496	4	39	635	1	77	850
1	7	504	4	43	642	1	78	863
1	8	511	4	47	650	1	79	870
1	9	516	4	51	665	1	80	878
2	11	525	4	55	676	1	81	888
2	13	534	4	59	694	1	82	906
2	15	545	4	63	710	1	83	920
2	17	561	2	65	721	1	84	935
2	19	581	2	67	732			

Figure 7.4: Dynamic Cone Penetrometer Field Sheet Example

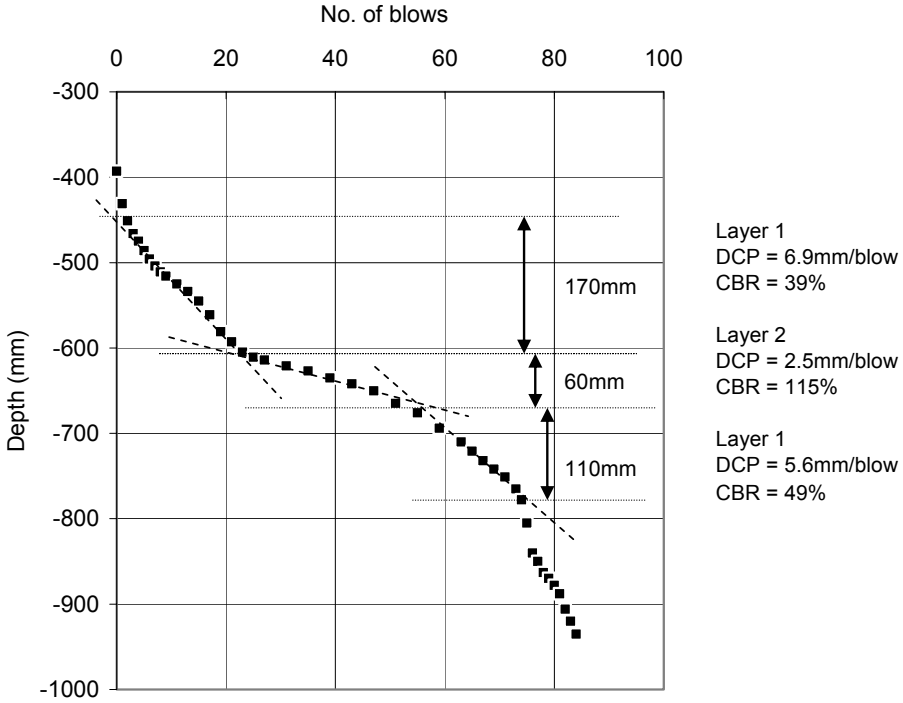

Figure 7.5: Dynamic Cone Penetrometer Plot Example

Laboratory Tests

7.32 Depending upon the nature of the materials found and the type of distress evidenced by the pavement, laboratory testing can provide valuable data for the evaluation process. It must always be remembered that it is often only possible to test material of good integrity and that this may introduce a bias into the results. The following paragraphs give some of the tests available but are not intended to represent a complete list.

7.33 Testing merely to determine whether or not a material complies with past or present standards is not usually very useful as the precise standard applicable to the material is not usually known and even if non-compliant the material may be performing satisfactorily.

Asphalt

7.34 The general condition of the asphalt layers and the depth of any deterioration should be evident from a visual inspection of the cores. The elastic stiffness of the asphalt can be determined using the indirect tension to cylindrical specimens test specified in BS EN 12697-26 (formerly known as the Indirect Tensile Stiffness Modulus test (ITSM)). The stiffness modulus can be used to quantify the load spreading ability of the material as well as to help to confirm or explain measured deflection values or FWD derived layer moduli. Although the deformation resistance of asphalt may be assessed using the Wheel-Tracking test this would be judged more reliably by consideration of the asphalt layer thicknesses across a wheel-track as described in paragraph 7.6.

7.35 Compositional Analysis provides information about the particle size distribution and binder content of asphalt. The information obtained can, for example, be used to assess whether the material is too rich or too lean in binder which may help to explain higher than expected material deformation.

7.36 The recovered binder may also be tested to determine the Penetration and Softening Point. This can be helpful to identify where binder is particularly soft (prone to deformation) or particularly hard which may be associated with cracking or excessive loss of chippings from HRA surfaces. Binder properties will be required if recycling is being considered. If it is suspected that tar may be present, further tests to confirm this may be required.

7.37 The state of compaction of asphalt may also be assessed through density measurements. For historical DBM materials, the Percentage Refusal Density test (PRD) compares the achieved level of compaction with the maximum achievable level. If the Relative Density

of the mixture is measured together with the Bulk Density then volumetric proportions may be calculated including air void content.

Hydraulically Bound Mixtures

7.38 The Cube Strength usually has to be deduced from cylinder tests. It also enables an estimate of flexural strength to be made, since direct testing in flexure is unlikely to be possible. The Density can be used to assess the degree of compaction achieved, particularly if an estimate of the Relative Density of the aggregate is available. As for asphalt, the Stiffness Modulus can be measured on either beam or cylindrical specimens, although it remains a specialist test.

Unbound Materials

7.39 Laboratory testing of the foundation layers, subbase or subgrade, should not normally be necessary as the DCP measurements should indicate the general condition and strength. However, tests may occasionally be necessary to explain the reasons for high or low strength or stiffness or to compare the material properties with specification standards. The most useful of these are:

- Grading;
- Liquid Limit, Plasticity Index and Linear Shrinkage;
- Moisture Content.

7.40 Where pavement failure is believed to be caused primarily by a weak foundation, a laboratory California Bearing Ratio (CBR) test of the material may be carried out, preferably by removing an undisturbed CBR mould-sized sample. (A disturbed CBR sample will also require an in situ density test to be carried out so that that the CBR material can be re-compacted to the in situ density.) An in situ CBR test is generally not very practical as it requires a large-plan test pit and takes considerable time, both of which add considerably to the cost.

8. REFERENCES AND BIBLIOGRAPHY

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9. ENQUIRIES

All technical enquiries or comments on this Standard should be sent in writing as appropriate to:

Chief Highway Engineer
The Highways Agency
123 Buckingham Palace Road
London
SW1W 9HA

G CLARKE
Chief Highway Engineer

Director, Major Transport Infrastructure Projects
Transport Scotland
8th Floor, Buchanan House
58 Port Dundas Road
Glasgow
G4 0HF

A C McLAUGHLIN
Director, Major Transport Infrastructure Projects

Chief Highway Engineer
Transport Wales
Welsh Assembly Government
Cathays Parks
Cardiff
CF10 3NQ

M J A PARKER
Chief Highway Engineer
Transport Wales

Director of Engineering
The Department for Regional Development
Roads Service
Clarence Court
10-18 Adelaide Street
Belfast BT2 8GB

R J M CAIRNS
Director of Engineering

ANNEX 1 NOT CURRENTLY USED

ANNEX 2A TRACS ASSESSMENT CRITERIA AND GUIDANCE LEVELS

Category →	1	Threshold Value ↓	2	Threshold Value ↓	3	Threshold Value ↓	4
Maximum Rut (mm)		6		11		20	
Texture Depth (mm)							
Anti-skid surfacing HFS		0.6		N/A		N/A	
All other surfaces		1.1		0.8		0.4	

Table 2A.1: Rutting and Texture Depth Criteria for TRACS Measurements (100m lengths)

Category →	1	Threshold Value ↓	2	Threshold Value ↓	3	Threshold Value ↓	4
1. MOTORWAYS AND RURAL DUAL CARRIAGEWAYS(†)							
Enhanced Variance (mm^2)							
3m		0.7		2.2		4.4	
10m		1.6		6.5		14.7	
30m		22		66		110	
2. URBAN DUAL CARRIAGEWAYS (†)							
Enhanced Variance (mm^2)							
3m		0.8		2.2		5.5	
10m		2.8		8.6		22.8	
30m		30		75		121	
3. RURAL SINGLE CARRIAGEWAY ROADS (†)							
Enhanced Variance (mm^2)							
3m		0.8		2.2		5.5	
10m		2.8		8.6		22.8	
30m		30		75		121	
4. URBAN SINGLE CARRIAGEWAY ROADS (†)							
Enhanced Variance (mm^2)							
3m		1.4		3.8		9.3	
10m		6.1		18.3		36.6	
30m		48		97		193	

(†)Based on the road classifications in HAPMS

Table 2A.2: Ride Quality Criteria for Roads of all Types of Construction for TRACS Measurements (Enhanced Longitudinal Profile Variance, 100m Lengths)

Category →	Low	Threshold Value (%) ↓	Moderate	Threshold Value (%) ↓	High
Asphalt Surface – Hot Rolled Asphalt	Thresholds for cracking have yet to be decided for the new TRACS contractor. These will be made available once further research has been completed.				
Asphalt Surface – Other					
Concrete Surface					

Table 2A.3: Guidance Levels for TRACS Whole Carriageway Cracking Intensities (100m Lengths) (Refer also to Annex 2B when Assessing the Cracking Data)

Category →	Low	Threshold Value (%) ↓	Moderate	Threshold Value (%) ↓	High	Threshold Value (%) ↓	Severe
Asphalt Surface – Hot Rolled Asphalt		0.20		1.15		1.80	
Bituminous Surface – Other		N/A		N/A		N/A	

Table 2A.4: Guidance Levels for Fretting (100m Lengths)

ANNEX 2B DETAILED DESCRIPTION OF TRACS CONDITION DATA

Texture Depth

2B.1 The surface Texture Depth measured by the TRACS survey vehicle is the coarser element of macrotexture and the finer element of megatexture formed by aggregate particles in the asphalt surfacing or by the brushing or grooving of concrete surfacing. Texture Depth contributes to skidding resistance, primarily at medium and high speeds, in two ways. Firstly, it provides drainage paths to allow water to be removed rapidly from the tyre/road interface. Secondly, the projections, which contribute to hysteresis losses in the tyre, are an important factor in the braking process.

2B.2 The Machine Survey Pre-processor (MSP) software calculates Sensor Measured Texture Depth (SMTD) from the raw Texture Profile measurements collected by the TRACS survey vehicle for the near side wheel-track and averages them over 10m lengths for storage as Base Data within HAPMS.

Rut Depth

2B.3 To measure Rut Depth, the TRACS survey vehicle records the Transverse Profile of the road surface over a width of 3.2m using 20 laser sensors. The Transverse Profile measurements are processed in MSP, which uses an algorithm to simulate placing a notional 2m straight edge on the recorded Transverse Profile, and measuring the largest deviation from the straight edge to the Transverse Profile. This calculation is carried out for each wheel-track. MSP calculates the average of the individual Rut Depths for each wheel-track over 10m lengths for storage within HAPMS.

2B.4 The Transverse Profile measurement method of Rut Depth determination used by the TRACS vehicle has been shown to be highly comparable with the measurements made using a conventional straight edge and wedge.

2B.5 TRACS Rut Depth measurements can sometimes be affected by variations in driving line. When the survey vehicle drives to the nearside of the traffic lane the lane edge marking may be included in the Transverse Profile measurement, giving rise to nearside Rut Depths that are higher than those actually present on the pavement. Similarly, driving to the offside can result in lower nearside Rut Depths.

2B.6 It is recommended that, where any length has been identified for further investigation as a result of deep Rut Depths, that comparison be made between the Left Rut and Right Rut length weighted average values contained within HAPMS. This is to check that there are no excessive differences which could be caused by the inclusion of the edge line in the Left Rut measurements.

Ride Quality

2B.7 The parameter currently used for the assessment of Ride Quality, or Profile Unevenness, is the Enhanced Longitudinal Profile Variance of individual deviations of the profile relative to a datum obtained by removing (or filtering) longer wavelengths from the measured longitudinal profile. This parameter was introduced in June 2004 and uses sophisticated filtering which removes the effects of the pavement geometry (gradient, crossfall and curvature), which had previously caused high levels of variance at, for example, the approaches to roundabouts. The previous simpler method of filtering produced the parameter Longitudinal Profile Variance.

2B.8 The Enhanced Longitudinal Profile Variance value reflects the unevenness associated with profile features that are equal to or less in wavelength than the length of the filter used to calculate the Enhanced Longitudinal Profile Variance. For example, the variance of deviations from a 3m filter reflects the unevenness of profile features with wavelengths equal to or less than approximately 3m.

2B.9 The measurement of Profile Unevenness can be used to investigate the Ride Quality of the pavement. The short, medium and long wavelength features are found to relate with the perceived effect on vehicle ride are represented by variance from 3m, 10m and 30m filters respectively. The 3m, 10m and 30m Enhanced Longitudinal Profile Variance values are calculated from the TRACS longitudinal profile measurements by MSP and averaged over 10m lengths for storage within HAPMS.

2B.10 Extremes of 10m Enhanced Longitudinal Profile Variance may arise from poor reinstatements along the wheel-track, the presence of high and/or variable levels of rutting, and bay length irregularities (in concrete roads). High levels of 30m Enhanced Longitudinal Profile Variance may be associated with subsidence. Changes of crossfall along the length of a road may also result in slightly higher 30m ELPV being reported.

2B.11 High levels of Profile Unevenness do not only affect Ride Quality. High levels of Profile Unevenness, particularly in the 3m and 10m wavelength ranges, have been shown to contribute to increased dynamic loading of the pavement, hence accelerating the deterioration of the road pavement. Extremes of Profile Unevenness can also lead to increased stopping distances, and can have an adverse effect on vehicle manoeuvrability and safety.

2B.12 The values of Enhanced Longitudinal Profile Variance calculated from TRACS Longitudinal Profile measurements must not be compared directly with either values of Moving Average Longitudinal Profile Variance (produced by TRACS surveys prior to 1st June 2004) or, the values of Moving Average Longitudinal Profile Variance provided by earlier HRM surveys. This is because there are significant differences in the scaling of the data and the Enhanced Longitudinal Profile Variance measure generally reports lower values than the other two systems. However, the Moving Average Longitudinal Profile Variance and Enhanced Longitudinal Profile Variance methods are well correlated. On lengths where there is little variation in the geometry they will, in general, agree with regard to the locations at which higher values are reported. On lengths containing variations in the geometry the Enhanced Longitudinal Profile Variance is likely to report lower values.

2B.13 Further research carried out on TRACS measurements has shown that the TRACS survey vehicle may provide Longitudinal Profile data having lower levels of accuracy when surveying at slow speed, or under conditions of significant acceleration or (more commonly) deceleration. To reduce the occurrence of low accuracy data, limits have been specified for the TRACS surveys for speed and acceleration/deceleration beyond which the data is considered invalid. Where these limits have been exceeded the data is marked as Unreliable in the TRACS Base LPV Data. The presence of a significant proportion of Unreliable values within any 100m length will result in missing values when the data is expressed as 100m Length Weighted Averages in HAPMS.

2B.14 Ride Quality measurements provided by TRACS surveys prior to 1st June 2004 were reported as Moving Average Longitudinal Profile Variance. As the TRACS Length Weighted Averages data source in HAPMS reports the most recent TRACS data, the data source may contain data collected prior to 1st June 2004.

2B.15 To distinguish between Moving Average LPV and Enhanced LPV, the TRACS Length Weighted Averages data source in HAPMS provides an additional label for the LPV data called “Enhanced”. Where the label is not present this indicates that the value reported in the HAPMS TRACS Length Weighted Averages data source is the old Moving Average Longitudinal Profile Variance.

2B.16 Where it is required that an assessment be made of TRACS measurements of Moving Average Longitudinal Profile Variance (for TRACS surveys carried out before 1 June 2004) it will be necessary to apply the thresholds given in Table 2B.1.

Category →	1	Threshold Value ↓	2	Threshold Value ↓	3	Threshold Value ↓	4
1. MOTORWAYS AND RURAL DUAL CARRIAGEWAYS(†)							
Variance (mm^2)							
3m		1.3		4		8	
10m		4		16		36	
30m		55		165		275	
2. URBAN DUAL CARRIAGEWAYS (†)							
Variance (mm^2)							
3m		1.5		4		10	
10m		7		21		56	
30m		75		187		300	
3. RURAL SINGLE CARRIAGEWAY ROADS (†)							
Variance (mm^2)							
3m		1.5		4		10	
10m		7		21		56	
30m		75		187		300	
4. URBAN SINGLE CARRIAGEWAY ROADS (†)							
Variance (mm^2)							
3m		2.5		7		17	
10m		15		45		90	
30m		120		240		480	

(†)Based on the road classifications in HAPMS

Table 2B.1: Ride Quality Criteria for Roads of all Types of Construction for TRACS Measurements Obtained Before 1 June 2004 (Moving Average Longitudinal Profile Variance, 100m Lengths)

The TRACS Crack Identification System

2B.17 The measurement of Cracking by the TRACS survey vehicle is made using four downward facing video cameras that continuously collect images of the road surface over a transverse width of 3.2m. The video images from each camera are passed to a data processing system onboard the TRACS survey vehicle that automatically interprets the images to detect Cracking.

2B.18 The TRACS image collection system has a transverse and longitudinal resolution of approximately 2.5mm (the "pixel size"). The system is therefore unlikely to detect cracks in the road surface having widths less than 2.5mm.

2B.19 Cracking is reported as a "crack map" which describes the transverse and longitudinal position of each crack (reported as a straight line), the length of each crack and the angle of each crack relative to the direction of travel of the survey vehicle. The crack map can be viewed using facilities in HAPMS.

2B.20 Crack maps are processed by MSP to obtain the intensity of Cracking over each 10m length, for storage within HAPMS. To obtain the intensity of Cracking, MSP simulates the placing of a grid, made up of 0.2m squares, over the crack map. The percentage of grid squares containing at least part of one or more cracks is then evaluated over 10m lengths to give a value of Cracking as a %.

2B.21 Crack maps are also processed by MSP to obtain a measure of the intensity of Wheel-track Cracking over 10m lengths in both the left and right wheel-tracks. To calculate the intensity of left Wheel-track Cracking, MSP simulates the placing of a grid 0.8m wide over the left wheel-track, made up of 0.2m by 0.8m grid rectangles. The percentage of grid

rectangles containing at least part of one or more cracks along the 10m length is evaluated to give a value of Wheel-track Cracking intensity (in %). The procedure is repeated for the right wheel-track.

2B.22 Due to way that the road surface images are processed to identify cracking and the need to suppress spurious reports of cracking, the total intensity of Cracking recorded by the TRACS survey vehicle will be lower than that recorded by an inspector in a manual crack survey.

2B.23 Furthermore, where a manual inspection will estimate the extent of the cracking by placing a theoretical frame around the cracking and recording the area within the frame, the MSP software will only record the total area of grid squares that contain cracks in the crack map. Since the grid squares are relatively small, the TRACS measurement will not tend to "fill-in" between cracks, as is the case when an inspector estimates an area of cracking. It has been found that this contributes to an additional reduction in the area of cracking recorded by the TRACS survey vehicle, in comparison with the results of a manual survey, regardless of the surface type.

2B.24 The TRACS contractor changed in 2006 and this resulted in a change in performance of the crack detection system, thus new thresholds were required. Where it is required that an assessment be made of TRACS measurements of cracking, for TRACS surveys carried out before 1st April 2006, it will be necessary to apply the thresholds in Table 2B.2. The sensitivity of the previous contractor's TRACS crack detection system was lower on finer textured surfaces, such as thin surfacing systems and surface dressing. It was found that the intensity of Cracking on these Surface Types was reported at a level that is proportionately lower than on Hot Rolled Asphalt (HRA) surfaces, and in particular fretted HRA surfaces. Therefore separate guidance levels for the assessment of Cracking data are specified for HRA and other asphalt surfaces in Table 2B.2.

Category →	**Low**	**Threshold Value (%) ↓**	**Moderate**	**Threshold Value (%) ↓**	**High**
Asphalt Surface – Hot Rolled Asphalt		0.45		1.5	
Asphalt Surface – Other		0.15		0.5	
Concrete Surface		N/A		N/A	

Table 2B.2: Guidance Levels for TRACS Whole Carriageway Cracking Intensities (100m Lengths) for TRACS Measurements Obtained Before 1 April 2006

Initial Assessment of TRACS Crack Data

2B.25 The TRACS measurement of cracking is subject to a degree of variability that can result in changes in the intensities of cracking reported over individual 100m lengths from survey year to survey year, even when the actual surface condition (cracking) has not changed significantly. Reasons for these changes in intensity include:

- Variations in driving line can result in the identification of road edge features that contribute to the cracking intensity recorded in one survey year, but not the next.
- Changes in surface appearance (e.g. darkness, detritus etc) may affect the sensitivity of the crack identification system to different types of cracks.

2B.26 Although variability has been identified in the TRACS crack measurements, research has shown that the system reports, with a reasonable level of reliability, locations on the network that are cracked.

2B.27 However, because of this variability, it is essential that a careful approach be taken when assessing the TRACS Cracking data. Specifically, it must be noted that the use of the Cracking Intensities to trend the changes in cracking from year to year is not considered a reliable method to assess the crack data.

2B.28 Therefore, it is advised that detailed investigations are targeted at locations where consistently high Cracking intensities are observed in TRACS data from successive survey years. The average Cracking intensities over two or more years should be compared in terms of the guidance levels provided in Table 2A.3 of Annex 2A. Note that this method is only

applicable for lengths where no maintenance has been carried out during the averaging period.

2B.29 This approach must enable more reliable identification of lengths with high levels of cracking present. Further investigation of these lengths must begin with the examination of the crack map data contained in HAPMS. This must be carried out using the most recent survey year and, where available, at least two preceding survey years.

Fretting

2B.30 On pavements having coarse textures with large chip size, such as Hot Rolled Asphalt (HRA), the presence of severe Fretting (loss of stone from the surface) may be reported as Cracking by the TRACS survey vehicle. This can lead to lengths reported as containing high levels of Cracking that, in a visual survey, may have been reported as containing high levels of minor deterioration. TRACS surveys only measure fretting in the near side wheel-track.

2B.31 An estimate of the extent of Fretting can be derived from the Texture Profile by identifying characteristic shapes resulting from missing surface aggregate. Algorithms have been developed on this basis and incorporated into the MSP software to provide an indication of the presence of Fretting.

2B.32 The Fretting algorithms are currently optimised for the identification of Fretting of HRA. On other Surface Types the algorithms will generally report levels close to zero. Therefore, the Fretting data reported in HAPMS must only be used in the assessment of HRA surfaces.

2B.33 The Fretting algorithm reports the intensity of Fretting as a percentage value. The guidance levels for the assessment of Fretting have been obtained by undertaking manual surveys of fretted HRA pavements and comparing the reported levels of Fretting with those reported by the Fretting algorithm. It can be seen that the threshold levels have reasonably low absolute values. This is a result of the Fretting calculation process and its relationship to the identification of missing aggregate particles. The values must not be compared directly with measures obtained from manual visual condition surveys.

2B.34 The Fretting data is, in particular, intended for use when assessing the condition of HRA pavements that have been reported to contain high levels of Cracking. Where both the Fretting and Cracking report high levels it is probable that the crack measurements are actually reporting the presence of Fretting.

2B.35 The crack map may be also used to show the presence of Fretting in the crack data.

ANNEX 3 CURRENTLY NOT USED

ANNEX 4A DEFLECTOGRAPH CALIBRATION

4A.1 This annex aims to explain briefly the principles of the Deflectograph for those unfamiliar with the apparatus. It includes details of the calibration procedure.

Apparatus

4A.2 The details and dimensions for the chassis of the vehicle are given in Figure 4A.1 and for the beam assembly in Figure 4A.2. The equipment must be made to a design approved by the Overseeing Department, full details are given in LR 834 (1978).

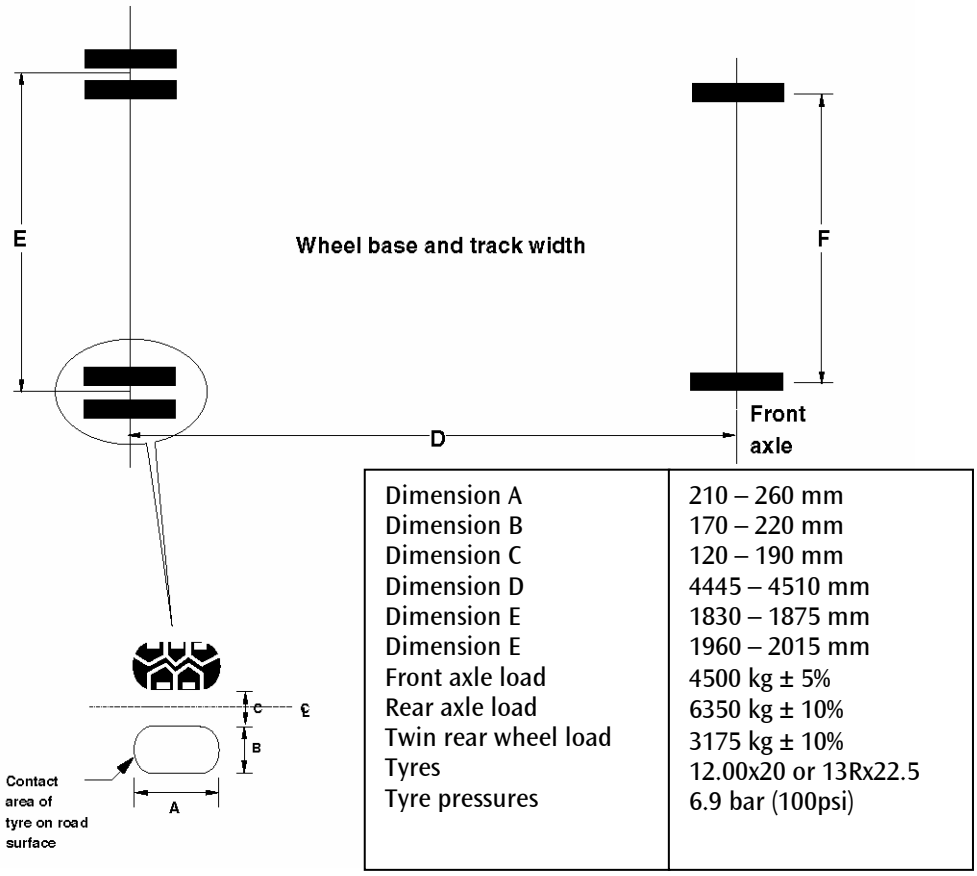
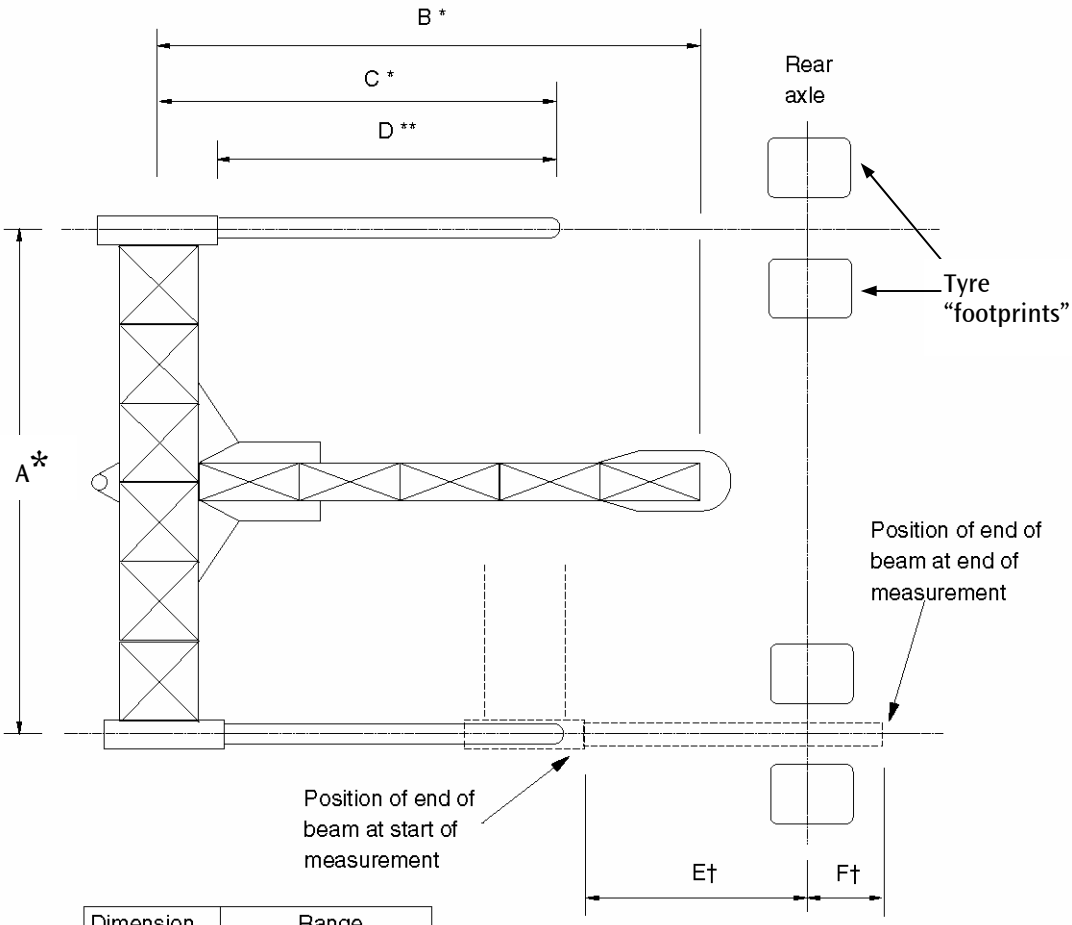


Figure 4A.1: Chassis Details for Deflectograph Vehicles



Dimension	Range
A	1830 - 1875 mm
B	2125 ± 50 mm
C	1520 ± 10 mm
D	1395 ± 10 mm
E	950 mm minumum
F	200 mm minimum

* Centre of skid to centre of skid

** Centre of pivot to centre of skid

† Measured with vehicle stationary

Figure 4A.2: Deflectograph – Beam Assembly

Calibration

4A.3 Particular attention must be paid to calibration as deflection measurements are small, typically in the range 0 to 0.5mm.

4A.4 Static and dynamic calibrations are required. Deflectographs must be tested and approved annually in a group calibration trial by the Overseeing Organisation.

4A.5 Static calibration must be carried out before each day's work, or every twelve hours, and must comply with the specification in Table 4A.1. A written record of all calibrations must be kept for reference, see Table 4A.2.

Beam Tip Input Level (mm x 10^{-2})	Digital Output (mm x 10^{-2})	
	Tolerance*	Max Range**
10	+1 - 2	2 2
20	±1	2
30	±1	2
40	±1	2
50	±1	2
60	±2	3
80	±2	3
100	+4 - 2	3

Three separate movements at beam tip are required for each input value making up a calibration set.

* for each reading
** for each set of readings

Table 4A.1: Calibration of Deflectograph

4A.6 The static calibration must be carried out in the following manner:

a) the calibration rig used for transmitting movements to the beam tip must be the type approved by the Overseeing Organisation;

b) the dial gauge must be mounted on a separate baseplate and must be positioned vertically with the measuring point placed on the beam over the point of contact of the beam tip with the road.

c) three separate movements at the beam tip of offside and nearside beams must be made for each input value between zero and 1mm.

d) the dial gauge and the recording system must be returned to zero between each input movement.

4A.7 Static calibration is influenced by the state of maintenance of the machine and calibration equipment and the accuracy with which the operator achieves input movements at the beam tip. The conditions under which calibration is carried out can also affect the result achieved. In particular, the roadside is sometimes not a suitable place to achieve the calibration specified. It may be preferable to do the required daily calibration at the overnight base. The recording equipment may need a warming-up period prior to calibration (see makers instructions).

Non-Compliance

4A.8 The results of the calibration set must be compared with the appropriate limits specified in Table 4A.1. If the results are within the limits, the survey may proceed. If the results at only one input level are out of specification, calibration at that input level must be repeated but 5 input movements are then required. The tolerance and range of 4 out of 5 of these are to be in the specification before the survey may proceed. Otherwise the calibration rig must be removed and repositioned under the beam tip and a second calibration set obtained – see the flow chart given in Figure 4A.3. If the second calibration set is out of specification reference must be made to the Deflectograph manufacturers' Operators Instruction Manual to determine the likely cause and recommended course of action. A minimum of two calibration sets which comply with the specification must then be achieved before the machine may be considered fit for surveys. If this is not achieved it should be reported to the Overseeing Organisation who will decide on whether to proceed with the survey or require a new Deflectograph to be used.

Consistency

4A.9 The written records of daily static calibration must be examined by the operators for consistency at least every two weeks during periods of operation. If any serious trends or substantial variations are found in the calibration, reference must be made to the Deflectograph manufacturer's Operators Instruction Manual.

DEFLECTOGRAPH STATIC CALIBRATION					Date:	
Purpose: SURVEY/MACHINE CHECK*					Number:	
Location: BASE/ROADSIDE*					(of calibration)	
Beam Tip Input	Digital Output		Compliance with Specificaiton		Mean Calibration ◊	
(mm x 10^{-2})	Nearside	Offside	N/S	O/S	N/S	O/S
10						
20						
30						
40						
50						
60						
80						
100						

* Delete as necessary
◊ Values for calibration correction program should be to one decimal place

Table 4A.2: Deflectograph Static Calibration Record

Calibration Correction by Computer Program

4A.10 The calibrations to be entered must be the mean of the results of all calibration sets taken on the day of the survey that comply with the Specification.

Servicing of Calibration Equipment

4A.11 The calibration rig must be kept in good condition. The dial gauge must be serviced and checked against a standard gauge at least annually.

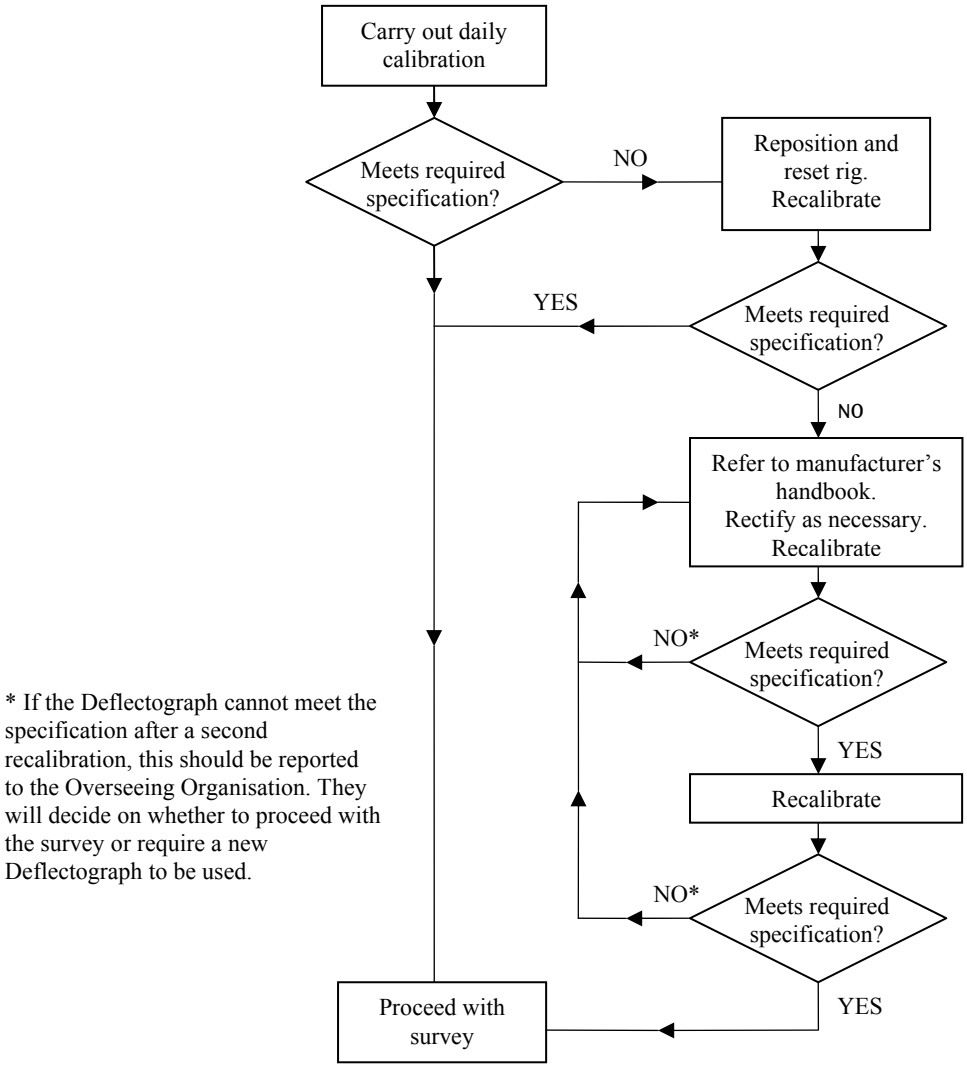


Figure 4A.3: Flowchart for Checking the Calibration of the Deflectograph

Dynamic Calibration

4A.12 The dynamic response of the machine must be checked on a calibration site by comparing the pattern and general level of deflection obtained from a minimum of 3 runs with that previously established for the site. This check must be carried out at intervals of not more than 6 weeks during periods of operation and whenever any major service involving replacement parts has taken place.

Calibration Site

4A.13 The choice of dynamic calibration site should be guided by factors such as convenience of access and safety of operation.

4A.14 Three sections on stiff, medium and weak pavements must be chosen in order to check the machine. Each section should have a reasonably uniform deflection with average deflections preferably within the range of 15-20, 25-35 and 40-50 x 10 mm respectively. Ideally, the sections should be in one length of road, but if this is not possible separate sites should be located.

4A.15 On each section there should be sufficient reference points to ensure accurate location of deflections.

4A.16 The sections should not be too heavily trafficked, thus giving a long useful life as calibration lengths and obviating the need for frequent updating of the deflections to allow for traffic carried. A recently by-passed section of road would appear appropriate.

4A.17 The drainage should be satisfactory so as to keep the seasonal variation of results to a minimum.

4A.18 Each section should have a uniform road surface and not be subject to sun/shadow effect making it difficult to determine pavement temperatures accurately.

4A.19 If the pavement contains hydraulically bound material it should be uncracked otherwise the deflection profile is liable to be excessively variable.

4A.20 The surface course of any type of pavement should be in sound, uncracked condition, preferably with wheel-track rutting less than 5 mm deep. This requirement may be difficult to attain where a pavement in the highest deflection range is required and a lesser standard may have to be accepted. However, rut depths of 10 mm should be considered the absolute maximum.

4A.21 The gradient of the road should not exceed 4 per cent. A steeper gradient could have an adverse effect when checking the machine by measuring the same wheel-tracks in different directions.

4A.22 The deflection profile of the test sections at the calibration site should be established for a range of temperatures using a Deflectograph of known satisfactory performance. This will involve making at least five runs with the machine on each of several occasions during the year when suitable temperatures occur. For each wheel-track the overall mean deflection of each section and the variability should be calculated for each temperature at which measurements are taken.

Procedure

4A.23 At least one calibration set must precede and follow the dynamic calibration, which comprises a minimum of 3 runs over the test sections of the calibration site.

Assessment of Results

4A.24 Results of the calibration runs must be compared with those already established for the site at the temperature of the test. It should be remembered that measurements with a Deflectograph may be taken at slightly different locations on each run, therefore the mean deflection values for different runs are not from identical samples. However, if there are any major discrepancies between the results these must be investigated by checking that there have not been any changes in conditions at the calibration site or in factors affecting the dynamic response of the machine. If an imbalance between nearside and offside results is suspected, further runs in which the nearside beam follows the track previously measured by the offside beam must be made. (This may be achieved by testing the site in the reverse direction).

Factors Affecting Dynamic Response of Machine

4A.25 The permitted weights given in Figure 4A.1 are for the vehicle plus crew with the beam assembly in the carrying position. The load on the front wheels influences the magnitude of the measured deflection. As it is not possible to use a simple scaling factor to apply a correction, it is most important that the front axle load is as close as possible to the value specified. If the rear wheel loading is different from the recommended value of 3175 kg, but within the tolerance allowed, measured deflections must be multiplied by a correction factor of 3175/(actual wheel loading). This correction is made to all measured deflections by the PANDEF computer program when actual rear wheel weights are entered. The intention is that typical average values should be entered, as weights will vary depending on fuel carried and the number of crew on board.

4A.26 The position of the T frame relative to the vehicle axles is important because the front skids can be within the deflection bowl generated by the front wheels of the machine. The shape of this bowl varies depending on the type of pavement material used and the magnitude of the deflection.

4A.27 Although recent developments have made it possible for the Deflectograph to operate at higher speeds, measured deflection decreases with increasing vehicle speed. The limiting speed of 2.5 km/h must therefore not be exceeded during testing.

4A.28 Components which operate during the recording cycle, i.e. pivot bearings, transducers and amplification circuits should be particularly well maintained. The winch cable must be slack when the beam frame is stationary.

HA Annual Group Calibration Trial

4A.29 The specifications for static and dynamic calibration are intended to ensure that any one machine gives a consistent output. Variations in performance which occur must be evident from the calibration records. The object of the HA Annual Group Calibration Trial is to establish, at least annually, a bench mark of the performance of every machine operating on Trunk Roads and to ensure that there is a common base from which to assess the results from different machines. Tests include machine inspection, static calibration and measurements on a dynamic calibration site. Owners/operators are advised of the results and a certificate of acceptability given.

Coded Events

4A.30 A typical format of coded events used on the Deflectographs operated for the Overseeing Organisations is as follows:

1. = left junction
2. = right junction
3. = Traffic lights
4. = Start/End slip roads
5. = Surface change
6. = Small patch
7. = Crack
8. = Telephone
9. = post box
10. = Field gate
11. = Bridge over
12. = Bridge under
13. = Marker post
14. = Start of patch
15. = End of patch
16. = Road sign
17. = Advance Direction Sign
18. = Gantry
19. = Start of area cracking
20. = End of area cracking

Monitoring of the Equipment

4A.31 The correct functioning of the equipment can be monitored by reference to the recorder output in terms of the display of incremental change in deflection occurring in each recording cycle. Before attributing faults to the machine a check must be made on all possible external causes.

ANNEX 4B DATA PROCESSING USING PANDEF

4B.1 PANDEF is no longer used on the HA network to process Deflectograph data but is still used on the networks of other Overseeing Organisations.

4B.2 PANDEF is a modular program with four main elements:

a) a database of road network definition, construction and traffic data and verified Deflectograph surveys referenced to the network;

b) deflection processing: validation of measured deflection, correction to standard deflection, matching of surveys to the network, categorisation of pavement type and derivation of residual life and overlay thickness, where appropriate, by reference to the database information;

c) deflection analysis: selection of maintenance sites based on homogeneity of residual life values and ranking of sites;

d) pavement overlay design: interactive design facility.

4B.3 PANDEF identifies two broad categories of pavement, those with the potential for a long life and those with a finite, or determinate life, which deteriorate in the conventional way. This categorisation must be considered as a first sift in the assessment process. Research is ongoing to refine the criteria and extend them to a wider range of construction types.

Long-Life Pavements

4B.4 This category includes strong flexible pavements with asphalt base and some flexible pavements with hydraulically bound base with substantial asphalt thickness. They are identified as being potential long-life pavements from their deflection level and total thickness of bituminous material (asphalt) (TTBM). More details on this category of pavement are given in HD 30 (DMRB 7.3.3). Assessment of these pavements and their maintenance treatment is not considered further in this Chapter – see HD 30 (DMRB 7.3.3).

Determinate Life Pavements

4B.5 Flexible pavements which do not fall into the long-life category and pavements with granular roadbases are categorised as having determinate life. For these pavements, PANDEF uses the Overseeing Organisation's Deflection Design Method to predict residual life to the onset of investigatory conditions and provide a facility for designing strengthening overlays if all the condition parameters show this to be necessary. Some flexible pavements with asphalt base can potentially be upgraded to long-life pavement status by overlay. PANDEF will identify these pavements and calculate the overlay thickness required. More details are given in HD 30 (DMRB 7.3.3).

4B.6 The Deflection Design Method relates standard deflection to traffic loading for three different types of construction. The date of the construction of the road or its most recent strengthening and the type of material in each layer of the roadbase and surfacing together with its age, condition and thickness must be known. Details of traffic are also required.

4B.7 Outputs from PANDEF in terms of residual life and overlay thickness for a specified future design life, are automatically updated from the time of the selected survey to the enquiry report date entered. Past and future traffic loadings are calculated from this date.

Data Required

4B.8 The construction and traffic data for a site entered into the PANDEF database must be kept up to date so that the data is applicable to the survey being processed. Reliable construction information is particularly important because the categorisation of pavements as long-life or determinate-life is dependent on the thickness of bituminous material (asphalt) present in the pavement.

4B.9 The standard deflection value used by PANDEF is that measured at a pavement temperature of 20°C at 40mm below the surface. Traffic is expressed in terms of equivalent standard axles and must be derived using the method in HD 24 (DMRB 7.2.1).

Classification of Roadbase Type

4B.10 The Deflection Design Method includes deflection/performance relationships for the following generalised pavement construction types:

a) unbound ie granular base with no cementing action (GNCA);

b) flexible with hydraulically bound base (CEMT);

c) flexible with asphalt base (BITS).

Pavements do not always fit neatly into one of these construction types. PANDEF draws on details of the type, thickness and condition of the pavement layers in the construction database to determine the appropriate base type classification using the criteria given in Table 4B.1. Some pavements with base type BITS may be identified by PANDEF as being potentially long-life.

Generalised Pavement Construction Type	Thickness of Material in the Pavement Construction (mm)			PANDEF Base Type Classification
	Cement-bound[a]	Bituminous bound[b]	Granular without cementing action	
Flexible composite	> 100	< 275	ANY	CEMT
	> 100[c]	275 – 299	ANY	CEMT
	> 100[d]	275 – 299	ANY	BITS
	> 100	> 300	ANY	BITS[e]
Fully flexible	< 100	> 150	ANY	BITS[e]
	< 100	< 150	< 150	BITS
	< 100	< 150	UNKNOWN	BITS
Granular Roadbase	< 100	< 150	> 150	GNCA

a - This does not include naturally cementitious materials, e.g. some crushed limestones.
b - Deduct thickness of stripped material and surface dressing layers less than or equal to 25mm thick. Sum total of remaining layers.
c - If cement-bound layer is not extensively cracked.
d - If cement-bound layer is extensively cracked.
e - May be identified as potential long-life pavements depending on actual thickness of bituminous bound material (asphalt) and deflection levels.

Table 4B.1: Classification of Base Type

The following functions in PANDEF must be used when processing data for the Overseeing Organisation:

a) validation of surveys and referencing to the highway network;

b) correction of Deflectograph measurements to standard conditions using temperature values entered on the survey record and machine calibration data, construction type and ESBM appropriate to the survey from the database;

c) calculation of traffic loading from the time of construction or the last major maintenance to the end of the chosen future design life, from traffic flows in AADF, preferably in disaggregated form;

d) classification into potentially long-life or determinate life pavement;

e) for determinate-life pavements, estimation of residual life and calculation of overlay thickness for a twenty year future design period or to upgrade the pavement to long-life status, as appropriate, for each deflection record;

f) division of the deflection record into maintenance sites of a minimum length to be specified by the Overseeing Department, based on the homogeneity of the residual life values using the automatic splitting algorithm.

Calculation of Traffic Loading

4B.11 The Deflection Design Method requires, at a minimum, a value of cumulative traffic loading from the year of construction or last major strengthening to the date of the deflection survey. If future design lives are to be estimated in years, then the annual traffic loading, in standard axles, is also required for each year from the date of the survey to at least twenty years into the future.

Traffic Module

4B.12 The traffic module in PANDEF which is used to calculate the annual standard axle flow for each year in each lane is based on two basic look-up tables. The first table provides default wear factors for each year from 1955 to 2040 for the following seven vehicle classes: buses and coaches, 2 axle rigid, 3 axle rigid, 3 axle articulated, 4 axle rigid, 4 axle articulated and 5 axle articulated. The second includes default relative flow rates for each of the years given in the first table and the corresponding vehicle classes.

4B.13 The minimum input required is a daily total commercial vehicle flow in one direction for a base year, normally at, or close to, a survey year between 1980 and 2010. The program uses default proportions by which flows are disaggregated into the seven vehicle classes. If a growth rate is not entered, a value from the default flow rates is assumed. When flows are entered for more than one year, even growth rates are applied between the available data. Consideration must be given to the effects of significant planned network changes in determining traffic growth which can either be positive or negative.

4B.14 Facilities are also provided for the user to enter fully disaggregated flow data and overall growth rates for total traffic flow.

Available Sources of Information

4B.15 For the period up to 1978, the General Traffic Census (GTC) provides information on 16 hr flows of commercial vehicles for 6,300 (non-random) sites on motorway, trunk and principal roads. This information is in the form of flows on an average August day and in some cases an average April/May day.

4B.16 In England and Wales, factors to convert these flows to 24 hr AADF are available from the Department for Transport, Directorate of Statistics, Transport Statistics Roads 2 Division, Zone 2/14.

4B.17 In order to obtain the required one direction flow of commercial vehicles, it will be necessary to apply a directional split. Where possible this must be calculated from the census data. A 50/50 split must only be adopted in the absence of more specific information. The growth rate applying to commercial traffic will not necessarily be the same as that applying to all traffic.

4B.18 In Scotland and Northern Ireland, all enquiries relating to traffic data must be referred to the Overseeing Organisation.

Interpretation and Application of Results

4B.19 The precision of estimates of residual life and thickness of strengthening overlays given in PANDEF are limited by the accuracy of the input data. Machine calibration and operation are closely controlled by the Overseeing Organisation, but errors in construction and traffic data entered will have a significant effect on program outputs.

ANNEX 5A FWD REQUIREMENTS FOR CONSISTENCY CHECK

Long-Term Repeatability Verification

5A.1 As well as the requirement to take part in the annual FWD correlation trial, referred to in Section 5.9, it is recommended that reassurance of the continuing consistent operation of the equipment is obtained by carrying out regular deflection and temperature measurements on a well-characterised test pavement at intervals of between four and six weeks whilst the survey equipment is in routine operation. Well-characterised means that similar tests have been carried out on the site over at least a continuous twelve month period. Ideally the test site should encompass a wide range of deflections on the three main pavement types but in reality this may not always be possible.

5A.2 Comparison of the consistency of the measured deflections, corrected for load, from each of the geophones, taking account of the measured pavement temperature and previous deflection temperature history of the site, will give an early indication of any significant faults developing that need further investigation.

ANNEX 5B FALLING WEIGHT DEFLECTOGRAPH SURFACE MODULUS ANALYSIS

5B.1. Deflection measurements can be used to produce surface modulus plots. The surface modulus at a point, distance r from the centre of the loaded area, is roughly equal to the "weighted mean elastic stiffness" below a depth R on the load centre line. Note that the depth R is based on the "equivalent pavement thickness", where the thickness of the pavement layers is converted to an equivalent thickness of a material with an elastic stiffness equal to the subgrade stiffness. At a point sufficiently far from the loaded area, the deflection is not influenced by the upper pavement layers. Therefore the surface modulus calculated at the outer points on the deflection bowl is approximately equal to the subgrade modulus. Such plots give an indication of the stiffness of the pavement at different equivalent depths and can be used as guidance for the selection of further investigation and analysis methods. Further details of this method are given elsewhere (FEHRL, 1996)[2].

The surface modulus at the top of the pavement (equivalent depth = 0mm) is calculated as:

$$E_o = 2(1-\nu^2)\,\sigma_o\, a/\delta_o$$

The surface modulus at the equivalent depth R (valid for r>2a) can be calculated from:

$$E_o\,(r) = (1-\nu^2)\,\sigma_o\, a^2/(r.\delta_r)$$

Where: E_o = the surface modulus at the centre of the loading plate (MPa)
E_o (r) = the surface modulus at a distance r (MPa)
ν = Poisson's ratio
σ_o = contact pressure under the loading plate (kPa)
a = radius of the loading plate (mm)
r = distance from sensor to loading centre (mm)
δ_r = deflection at a distance r (microns)

5B.2 For surface modulus analysis, it is normal to assume a value of 0.35 for Poisson's ratio. Five common examples of surface modulus plots are shown in Figure 1.1:

i. A continuously decreasing value of surface modulus with increasing distance. This indicates that the outermost deflection measurement points were not far enough away from the load.

ii. A decreasing value which becomes constant. This indicates a normal pavement structure overlying a linear elastic subgrade.

iii. A decreasing value which starts to gradually increase for the outer deflection measurement points. This indicates a normal pavement structure on a non-linear elastic subgrade, or a layered subgrade which increases in stiffness with depth.

iv. A decreasing value with a sudden large increase for the outermost measurement points. This indicates that a very stiff subgrade layer underlies the pavement (e.g. bedrock).

v. A minimum value close to the surface. This indicates a weak interlayer somewhere in the upper bound layers.

[2] FEHRL. Harmonisation of the Use of the Falling Weight Deflectometer on Pavements Part 1 – Harmonisation of FWD Measurements and Data Processing for Flexible Road Pavement Evaluation. FEHRL Report No. 1996/1.TRL, Crowthorne, 1996.

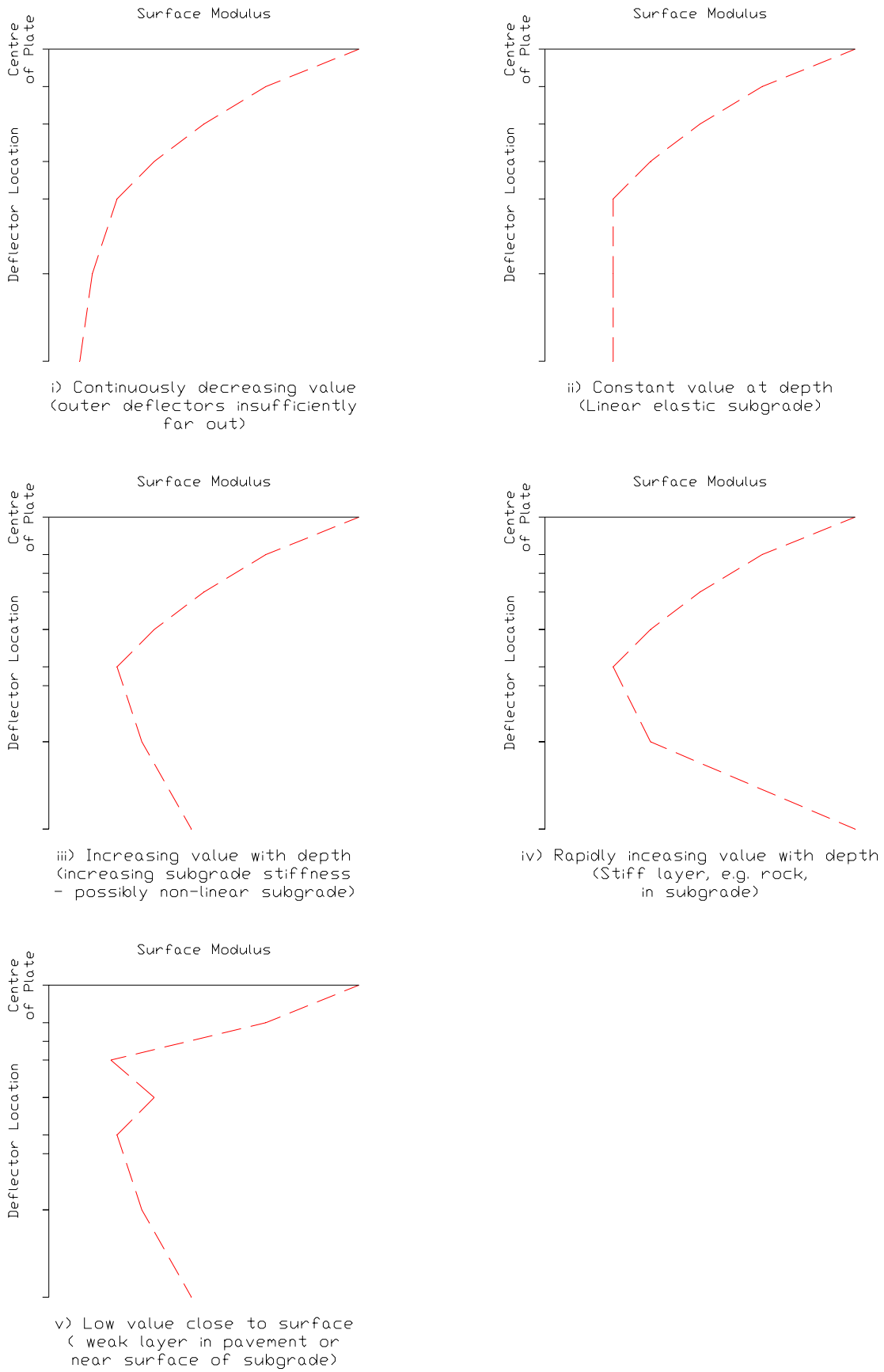


Figure 5B.1: Typical Surface Modulus Plots

TEMPLATE FOR REPORTING FWD SURVEYS AND BACK-ANALYSIS

Survey - General

Start date: . . . . . .

Finish time: . . . . . .

Survey Company: . . . . . .

Finish date: . . . . . .

Operator: . . . . . .

Start time: . . . . . .

Location

Road No: . . . . . Lane No: . . . . .

Start Section: . . . . . Ch: . . . . . .

Location: . . . . . .

End Section: . . . . . Ch: . . . . . .

Pavement type: FF / FC / Rigid

Total length: . . . . . m

FWD

Make: . . . . . Model: . . . . . .
Serial number: . . . . . .

Load : . . . . . kN Plate size: . . . . . .mm

Test type: Standard / LTE

Geophones

Type: . . . . . .

Number: . . . . . .

Positions: . . . . . .

Temperatures

Locations: . . . . . .

Maximum temperature: . . . . . .°C

Depths (if not 100mm): . . . . . .mm

Minimum temperature: . . . . . .°C

Times of measurement: . . . . . .

HAPMS Files

"Supplementary" and "F20" files attached: Yes / No

Survey Results

1. Normalised tabulated deflection data attached: Yes / No
2. Normalised d1, [d1-d4] and d6 plots attached: Yes / No
3. Temperature data attached: Yes / No

Analysis Details

Name of Program: . . . . Version: . . . . . Mode: . . . . . .

No. of layers: . . . . . Asphalt thicknesses - Max: . . . . . mm Min: . . . . . mm
Hydraulically bound mixture thicknesses - Max: . . . . . mm Min: . . . . . mm

Sources of thickness information: Cores (No. . . . .) / GPR / As built Drgs / Other (Please specify)

Type of analysis: Standard / Non-standard (give reasons and details)

Analysis Results

1. Tabulated back-analysed stiffnesses (at field temperature) attached: Yes / No
2. Tabulated back-analysed stiffnesses (adjusted to 20oC for asphalt layers) attached: Yes / No
3. Tabulated layer thicknesses used for each test point for analysis attached: Yes / No
4. AMD and RMS values for each test point attached: Yes / No
5. Layer stiffness (adjusted to 20oC for asphalt layers) plots attached: Yes / No

If any data not attached please provide explanation:

ANNEX 6A INTRODUCTION TO GROUND-PENETRATING RADAR

General Principles

6A.1 Ground-penetrating radar (GPR) operates by transmitting a pulse of electromagnetic radiation from an antenna into a pavement. The electromagnetic radiation penetrates down into the pavement as an energy wave, with an envelope in the shape of a cone.

6A.2 As the wave travels through the various pavement layers, its velocity is changed and its strength is attenuated. Part of the signal will be reflected back at buried discontinuities or interfaces between different materials such as different pavement layers. These reflected signals and the two-way travel time contain the information about the interior of the pavement. The strength of the reflected wave depends mainly on the difference in the dielectric constant of the adjacent materials in the pavement, the greater the difference the stronger the reflection. In addition, polarisation of the wave and its angle of incidence will affect the strength of the reflected signal.

6A.3 The pulse of electromagnetic radiation can be visualised as a single cycle of a sinusoidal wave travelling into the pavement in a straight line and being partly reflected at each layer interface. The path of the wave and its reflection at layer interfaces is shown in the left hand part of Figure 5.1. As the signal penetrates the pavement, in addition to some of the wave being reflected, part of the energy is absorbed and the wave is attenuated. The attenuation depends on frequency and on the type and condition of the pavement material. Eventually the wave will be too weak for any reflections to be picked up by the radar receiver. For these reasons the depth to which GPR can penetrate into the pavement is limited, although at the frequencies used for road surveying the penetration is usually adequate to determine the thickness of most pavements.

6A.4 The radar receives, via its antenna, the reflected wave, recording its amplitude (strength), phase, frequency and arrival time relative to when the signal pulse was transmitted from the antenna. The reflected signal may be displayed as a radar waveform as shown in the right hand part of Figure 5.1. The waveform shows the reflected signal amplitude against time. The amplitude wavelets on the waveform are caused by the interface between the pavement layers and represent the reflections of the sinusoidal radar signal. The attenuation of the signal, with depth, is shown by the decrease in the amplitude of the wavelets as time increases.

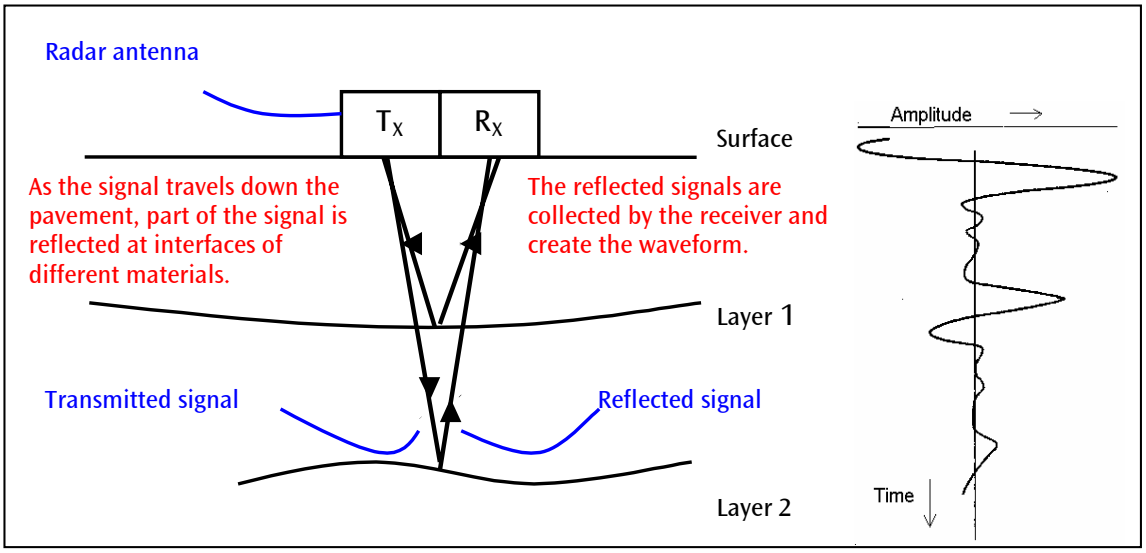


Figure 6A.1: Reflection of Radar Signal at Pavement Interfaces and Signal Waveform

6A.5 By moving the radar along or across the pavement, transmitting (firing) pulses at fixed time or distance intervals, and recording and storing digitally the reflected waveforms, a waveform graph representing the pavement structure is built up. Figure 5.2 is an example of a sequence of reflected waveforms recorded as a GPR system is moved along a pavement.

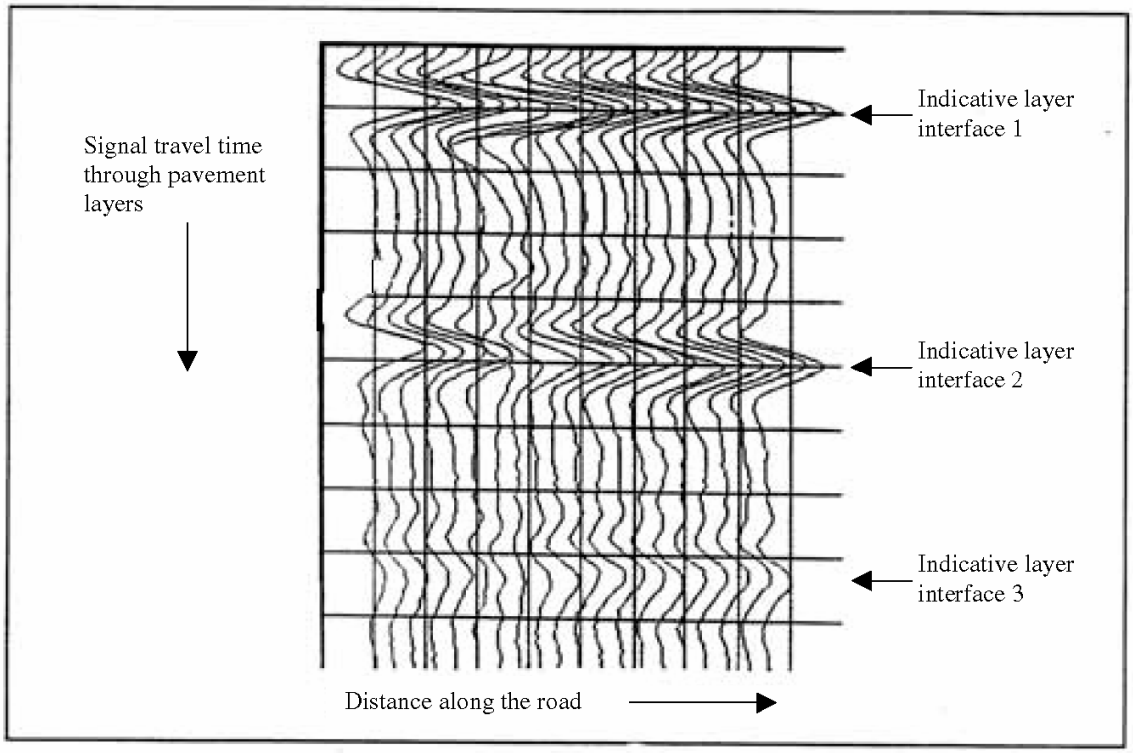


Figure 6A.2: Waveform Graph of Longitudinal Section of Road

6A.6 Electronic distance measuring devices should be used to make GPR systems fire at fixed distance intervals rather than time intervals. This is important in situations where the speed of the survey is likely to be affected by traffic. It also should improve the accuracy of measurement of the alignment of dowel bars in concrete roads.

6A.7 The waveform is made up of a number of measured amplitude points equally spaced down the time axis; the more points that make up the waveform, the better the data quality. Conversely, however, as the number of measured points per waveform is increased, the sampling rate the radar system can achieve in the direction of travel decreases.

6A.8 Interpretation of the pavement structure and features from a waveform graph requires:

- the wavelets to be correctly related to changes in material or other features; and
- the signal travel time interval between the wavelets to be converted to thickness using signal velocity.

Note that signal velocity will depend on the material the wavelets are passing through.

6A.9 The general procedure used by GPR Contractors to identify layer interfaces and the equation to convert the time data to depth data is given in Annex 6B of this Part. The conversion process, commonly known as calibration, requires a value for the velocity of the signal in each detected layer.

6A.10 There are four methods of obtaining the signal velocities in the layers and these are described in more detail in Annex 6B of this Part:

- Use of published velocity data – This is the least accurate method because, for a given material, the range of possible velocities is relatively wide, as indicated in Table 6B.1 of this Part, and it is difficult to estimate where within the range the material will be. In addition any moisture present in the material will greatly affect the velocity.

- The 'core' method – This method can give an accurate estimate of velocities and material types providing that the whole of the layers are recovered. The limitations are that the estimate relates to the core's position and applies over the area of the core which is different to the area of the antenna footprint. The method cannot take into account material variations between core points.

- The 'common depth point' method – This method takes into account material variations along the pavement but relies on averaging over many measurements to reduce errors and therefore cannot deal with very localised variability in materials. Also, when surveying at high speed very shallow layer boundaries can present difficulties when wider separations of the antennas are used.

- The 'reflection coefficient method' – This method also takes into account material variations along the pavement, but determines the velocity at the upper surface of a material layer and this velocity may not always represent the velocity in the whole of the layer. As layers lower and lower in the structure are measured the accuracy decreases because the method assumes no energy loss by scatter and absorption in the pavement material.

6A.11 The interpretation of the raw data should either be carried out by the GPR Contractor undertaking the GPR survey or by another Contractor specialising in the interpretation of GPR surveys of pavements.

6A.12 Highway Engineers should not undertake, without training, interpretation of raw radar data, such as waveform graphs.

6A.13 A measure of the accuracy of the results of a survey can be obtained by comparing layer thicknesses obtained from cores, not used to calibrate the radar system, with the radar reported thicknesses at the same points. It should be noted however that the core data will not always correlate perfectly with the radar results. This can be due to errors in location, material loss from the core, radar measurements giving the average depth over the antenna footprint rather than the area of the core, and internal bound layer boundaries in the core being incorrectly identified as the base of the bound layer.

Types of Radar and Their Operation

6A.14 GPR measuring systems are generally defined by the:

- method of data storage (analogue or digital);
- single or multi-channel system;
- measured points per waveform;
- sampling rate;
- method of sampling (per fixed interval of time or per fixed interval of distance);
- antenna operating frequency;
- antenna signal coupling;
- antenna type.

6A.15 Analogue radar systems record data on rolls of paper while the digital systems allow storage of data direct to DAT tape or hard disk as well as to roll printers. Analogue recording has some disadvantages in that the data cannot be filtered to increase quality, settings such as signal gains cannot be varied at the analysis stage to take account of variations in the road, and the process of digitising the data from the paper printouts can introduce additional errors.

6A.16 The surface area, or footprint, that a radar signal examines depends mainly on the antenna design. The area will typically be about 300 mm diameter for a dipole antenna and about 100 mm diameter for a horn antenna. Multi-channel systems allow a wide range of data collection options ranging from, one measuring line being scanned with antennas operating at different frequencies in one run, to a number of parallel measuring lines being scanned with antennas operating at the same frequency in one run. The first option is useful for network level surveys where data is only gathered from one line (generally the nearside wheel-track) and the second option is useful where large areas need to be surveyed in detail.

6A.17 Each waveform is made up of a number of measured amplitude points equally spaced down the time axis; the more points that make up the waveform,

the better the data quality. Conversely however, as the number of measured points per waveform is increased the sampling rate that the radar system can achieve in the direction of travel decreases.

6A.18 The sampling rate in the direction of travel depends on the speed of travel, the firing rate of the radar pulses, the number of points per waveform, and the number of channels available. The sampling rate controls the size of pavement features that the radar can detect. For example with a single channel radar that has a typical firing rate of 90 pulses per second, 512 points on the waveform, and a typical speed of travel of 80 km/h, a measurement is made every 250 mm of travel and at this sampling rate features, such as voids, smaller than 250 mm in length may be missed. It is therefore necessary to select an appropriate sampling rate for the size of features that need to be detected.

6A.19 Some radar systems take samples of the road at fixed time intervals. This will cause some location errors when the speed of travel of the system changes, The problem can be reduced by recording survey events at frequent intervals and avoided altogether by using electronic distance measuring systems that control the radar system to take samples at fixed distance intervals.

6A.20 The operating frequency will affect the depth of penetration and the resolution of the radar as shown in Table 6A.1.

6A.21 The positioning of the radar antenna in relation to the pavement surface determines how the signal is coupled. If the antenna is in contact with the surface, the radar signal is ground coupled, if not then it is air coupled. The method of coupling affects both sensitivity and depth of penetration into the pavement. Ground coupling introduces more signal into the pavement, enhancing sensitivity and increasing penetration depth, but it makes traffic speed operation more difficult.

	450MHz			900MHz			1GHz		
Dielectric constant	Wavelength (mm)	Depth of resolution (mm)	Min. depth of penetration (mm)	Wavelength (mm)	Depth of resolution (mm)	Min. depth of penetration (mm)	Wavelength (mm)	Depth of resolution (mm)	Min. depth of penetration (mm)
5	298	75	894	149	37	447	134	34	402
6	272	68	816	136	34	408	122	31	366
7	252	63	756	126	31	378	113	28	339
8	235	59	705	118	29	353	106	27	318
9	222	56	666	111	28	333	100	25	300
10	211	53	632	105	26	316	95	24	284
11	201	50	603	101	25	302	90	23	271
12	192	48	577	96	24	289	87	22	260
	1.5GHz			2GHz			4GHz		
Dielectric constant	Wavelength (mm)	Depth of resolution (mm)	Min. depth of penetration (mm)	Wavelength (mm)	Depth of resolution (mm)	Min. depth of penetration (mm)	Wavelength (mm)	Depth of resolution (mm)	Min. depth of penetration (mm)
5	89	22	267	67	17	201	34	8	101
6	82	20	245	61	15	184	31	8	92
7	76	19	227	57	14	170	28	7	85
8	71	18	212	53	13	159	27	7	80
9	67	17	200	50	13	150	25	6	75
10	63	16	189	47	12	141	24	6	71
11	60	15	181	45	11	136	23	6	68
12	58	14	173	43	11	130	22	5	65

Table 6A.1: Typical Values of Penetration and Resolution for Various Types of Radar

6A.22 There are two types of antenna design, dipoles and horns. Dipoles operate most effectively when they are ground coupled, however, they can be air coupled but the gap between the antenna and pavement surface has to be small, ideally one-tenth of the transmitted wavelength to give satisfactory results. This means that the antenna mounting has to be carefully designed to enable surveys to be done at traffic speed. Horn antennas are air coupled and operate with a large air gap and so are more easily adapted to surveys at traffic speed.

6A.23 Radar can be used to detect other features such as buried services and drains but this is outside the scope of this Annex.

6A.24 Depending on the coupling and design of the radar system, a survey can either be carried out at low speed, typically between 0.5 and 20 km/h, or at traffic speed, typically between 50 and 80 km/h. Figure 6A.3 illustrates radar systems operating over this range of survey speeds. The sampling rate, in the direction of travel, achieved with high speed surveys will be lower so only larger features will be detected.

Radar with Ground Coupled Dipole Sntenna – Surveying at 0.5 km/h

Crack Depth Investigation at 0.5 km/h

Radar with Horn Antenna – Surveying at 80 km/h

Radar with a Pair of Air-Coupled Dipole Antennas – Surveying at 80 km/h

Figure 6A.3 Ground-Penetrating Radar Systems

ANNEX 6B CALIBRATION OF GPR FOR DETERMINATION OF LAYER THICKNESS

General

6B.1 This annex gives details of the methods used by the GPR Contractors to determine the thickness of the pavement layers from the radar data. The information is presented to illustrate the strengths and weakness of the different approaches.

6B.2 The process of determining the layer thicknesses from a GPR waveform is carried out in two stages:

- identifying layer interface wavelets on the waveform;
- using the times between the wavelets to calculate the layer thicknesses.

Stage 1 – Identifying Layer Interface Wavelets

6B.3 The layer interfaces appear on the waveform as wavelets and the following processes are carried out to identify and characterise all the layer interface wavelets:

- relate wavelets to material boundaries (it may be necessary to filter the data to clearly resolve the wavelets);
- track along pavement, wavelets relating to material boundary;
- record time to wavelet at each sample point along the pavement;
- repeat the above processes for all material boundaries forming the pavement.

While it is theoretically possible to carry out the above processes manually it is very impractical to do this due to the excessive time required and associated high cost incurred. The processes are much more accurately and rapidly carried out with a computer system that can automatically track clear boundaries but can be manually overridden, e.g. with a mouse pointer, where the signals are difficult to track automatically.

Stage 2 – Calculating Layer Thickness

6B.4 The thickness of a layer is related to the signal travel time in the layer by the equation:

$$D = T\left(\frac{T}{2}\right) \quad \text{.....(1)}$$

where:

D = layer thickness (mm);
V = velocity of radar signal in layer (mm/ns);
T = two way travel time of the signal in layer (ns).

Two way travel time of the signal in the layer is the time interval between the wavelets occurring at the layer's lower and upper interfaces at the same location along the pavement.

Signal Velocity in Layer

6B.5 The velocity of the radar signal within a layer is related to the layer material's dielectric constant ε by the equation:

$$V = \frac{299}{\sqrt{\varepsilon}} \quad \text{.....(2)}$$

where:

V = velocity of radar signal in layer (mm/ns).

There are four basic methods of calculating velocities:

(a) use published data of mean velocities of pavement materials;

(b) use cores to establish layer thicknesses and then calculate velocities by rearranging equation (1) above;

(c) calculate velocity from recorded radar signal using 'common depth point' method;

(d) calculate velocity from recorded radar signal using 'reflection coefficient' method.

6B.6 Method (a) uses published data and typical velocities for different pavement materials which are given in Table 6B.1. These have been calculated from the material's dielectric constant using equation (2). Any moisture in the material will alter the dielectric constant and hence affect the signal velocity greatly.

Pavement material	Velocity (mm/ns)	Dielectric constant
Air	299	1
Asphalt	90 – 160	4 - 10
Concrete	100 – 130	5 - 9
Hydraulically bound mixture	100 – 120	6 - 9
Granular	70 – 120	6 - 18
Capping	70 – 110	7 - 18
Water	33	81

Table 6B.1: Range of Velocities and Dielectric Constants for Various Pavement Materials

6B.7 Method (b), often called the 'core method', enables velocities to be accurately calculated if done with care. Aspects requiring particular attention are:

- ensuring that the core position is accurately located within the GPR data;
- correctly estimating the layer thicknesses from a core;
- ensuring that the complete core is extracted from the pavement.

6B.8 It is known that layer thicknesses can change significantly over longitudinal distances of as little as a metre. If a core is not located on the radar data to an accuracy better than a metre it is possible that the wrong layer thickness will be used to calculate the signal velocities.

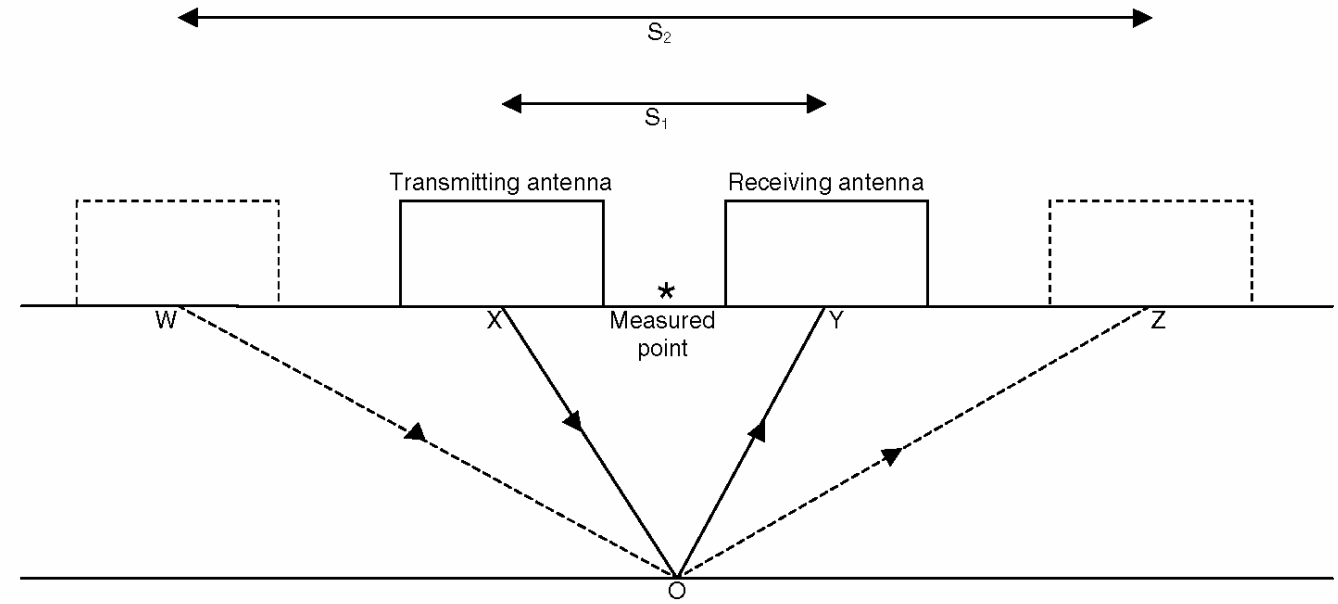
6B.9 Often the interface between pavement layers is quite rough. This means that it can be quite difficult to measure, on a core, the layer thickness. Typically, the accuracy with which the actual thicknesses may be measured from a core is ± 5 mm if the core is fully extracted and not damaged.

6B.10 Care must be taken when coring to extract the full depth of the bound layer because if the core is incomplete there is a risk of underestimating the thickness of the bound layer by incorrectly identifying an internal layer interface as the bottom of the layer.

6B.11 Method (c) is based on calculating the velocity using a common depth point and requires a multi-dipole antenna system. With this system, the various return signals for the different antennas, which have different travel times through a layer, are analysed to obtain values for the velocities in each layer. The method is illustrated in Figure 6B.1 for the surface layer of the pavement. It can be seen that, for a fixed antenna spacing, as the thickness of the layer increases and also as the layer being measured moves lower in the pavement structure, T1 approaches T2 thus decreasing the accuracy of the method. This can be compensated for by increasing the antenna separation but accepting that shallow layer boundaries will then be difficult to resolve. Care must also be taken when moving down the pavement to ensure that each dipole pair samples the same spot.

6B.12 Method (d) is based on calculating the velocity using the reflection coefficient and requires a horn antenna. Before making measurements a metal plate is placed on the pavement surface to determine the amplitude of the signal returned from a perfect reflector. This amplitude is compared with the amplitude of the signal returned from the pavement surface and the other layer interfaces in the construction to obtain the velocity at the top of each layer. The method, illustrated in Figure 6B.2 for the surface layer, assumes that the receiving antenna collects all the transmitted energy. This assumption becomes less valid with increasing depth due to the combination of the horn's

narrower receiving aperture and the increasing scatter and absorption of the radar signal by the pavement materials. For this method it is particularly important that conditions where there is standing water on the pavement surface be avoided as the water layer may affect the calibration.



$$V = \sqrt{\frac{S_2^2 - S_1^2}{T_2^2 - T_1^2}}$$

where:

V = Signal velocity in surface layer of pavement (mm/ns)

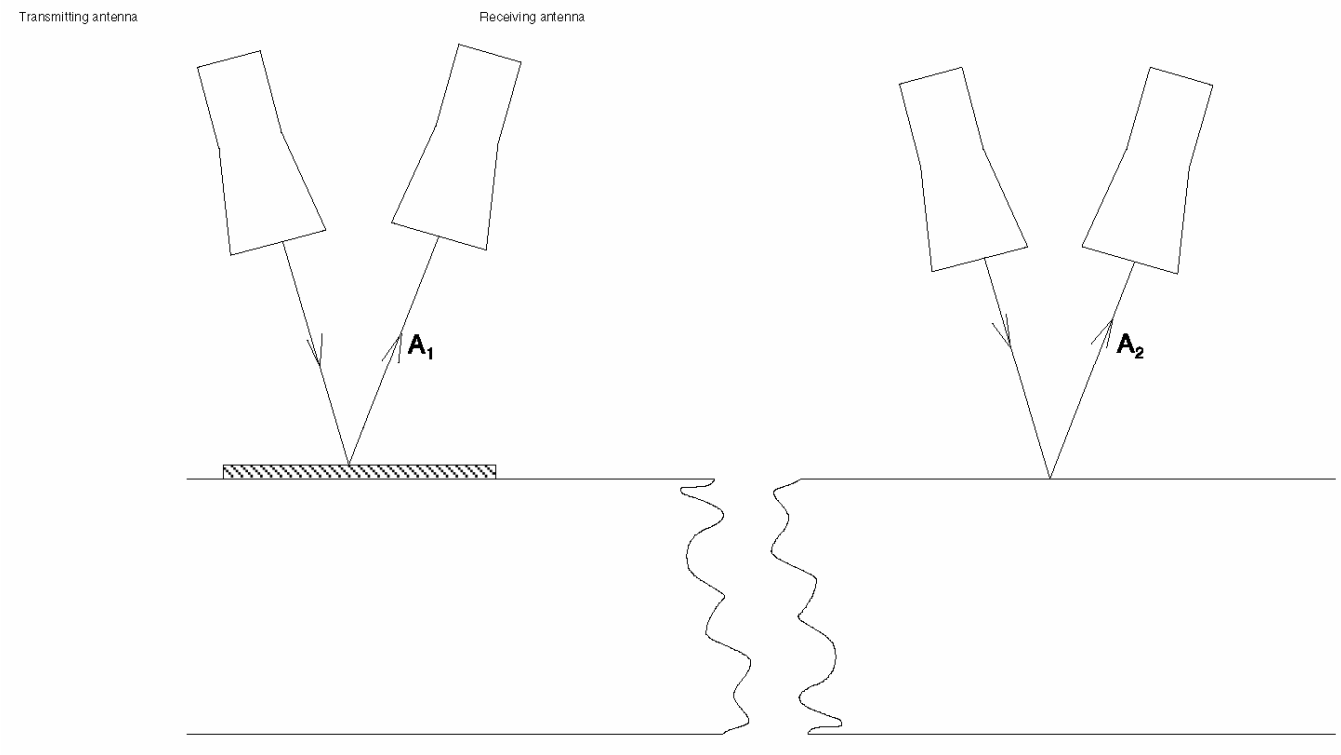
T_1 = Signal travel time along path XOY (nsec)

T_2 = Signal travel time along path WOZ (nsec)

S_1 = Antenna spacing XY (mm)

S_2 = Antenna spacing WZ (mm)

Figure 6B.1: Common Depth Point Method for Signal Velocity in Surface Layer of Pavement



$$V = \frac{299}{\left(\frac{A_1 + A_2}{A_1 - A_2}\right)}$$

where:

V = Signal velocity in surface layer of pavement (mm/ns)

A_1 = Signal amplitude reflected from metal plate

A_2 = Signal amplitude reflected from pavement surface

299 = Signal velocity in air (mm/ns)

Figure 6B.2: Reflection Coefficient Method for Signal Velocity in Surface Layer of Pavement

ANNEX 6C REPORTING THE RESULTS OF A GROUND-PENETRATING RADAR SURVEY

6C.1 Examples of how the data may be presented in graphical form and tabular form are shown in Figure 6C.1 and Tables 6C.1 and 6C.2.

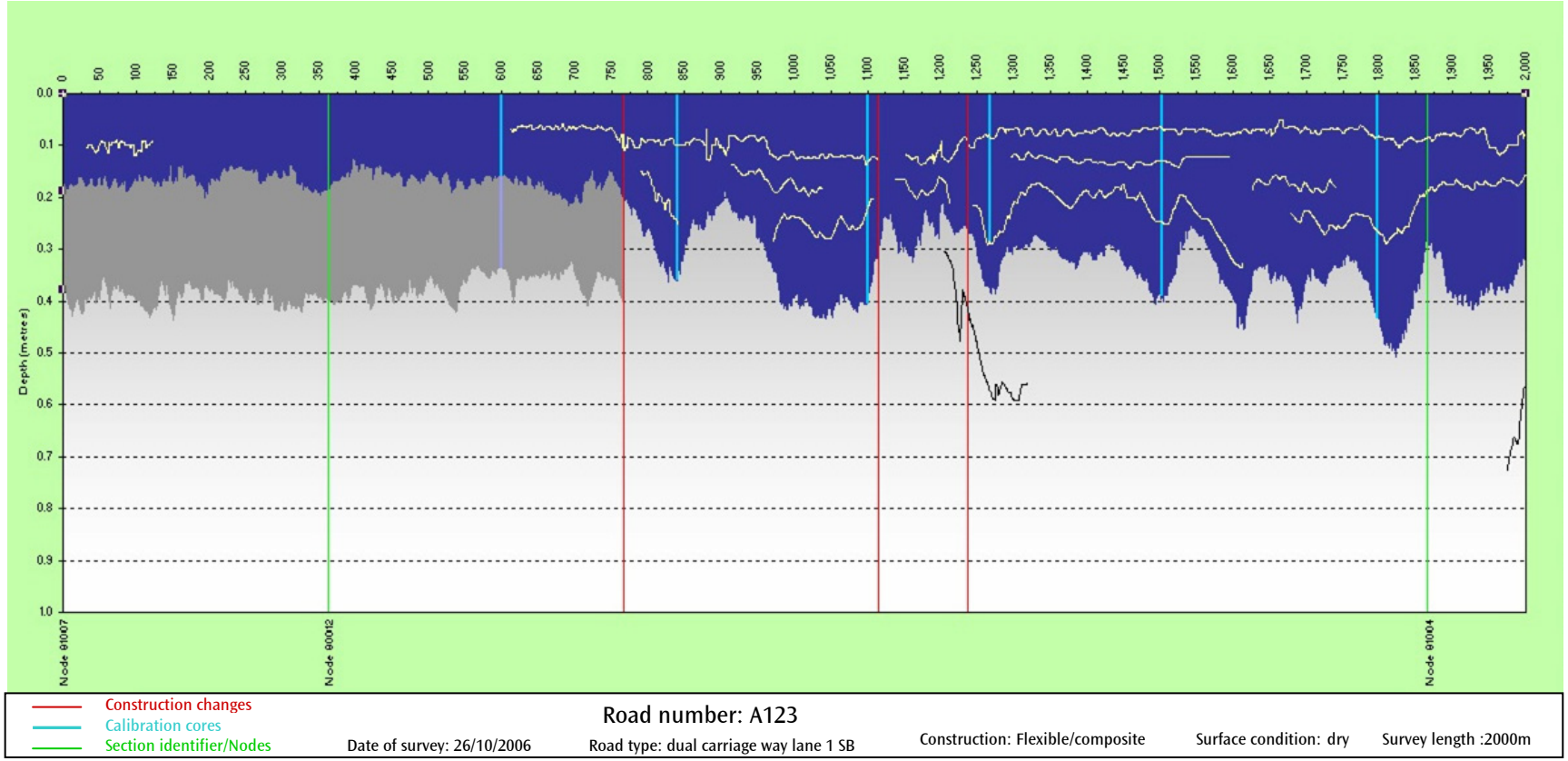


Figure 6C.1: An Example of a Graph Showing the Longitudinal Depth Profile of the Bound and Granular Layers of a Pavement

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Network section identifier: 600A123 12 **Road number:** A123 **Date of survey:** 19-6-2006 **Direction of survey:** South **Road type:** Dual 2 lane APTR **Construction:** Flexible with asphalt base			**Lane/s surveyed and track:** Nearside lane, nearside wheel-track **Length surveyed:** 900 m **Surface moisture condition:** Dry
Chainage from start of network section (m)	**Bound layer depth (mm)**	**Granular layer depth (mm)**	**Comments (defect features, construction changes and core information)**
100	245	225	
200	245	220	
300	250	215	Calibration core taken from nearside wheel-track at chainage 320m
400	255	215	
500	255	210	
600	250	210	

Table 6C.1: An Example of How Layer Thickness Data from a GPR Survey Should be Presented

Network section identifier: 1900M21 10 **Road number:** M21 **Date of survey:** 19-6-2006 **Direction of survey:** South **Road type:** Dual 2 lane motorway **Construction:** Concrete			**Lane/s surveyed and track:** Nearside lane, nearside wheel-track **Length surveyed:** 1200 m **Surface moisture condition:** Damp no standing water
Chainage from start of network section (m)	**Bound layer depth (mm)**	**Granular layer depth (mm)**	**Comments (defect features, construction changes and core information)**
120	260	180	Indications that some dowel bars are misaligned
130	260	175	
140	260	180	
150	270	180	Possible void starting about 2 m from nearside edge of lane, approximate area 2 x 1.5 m. Indications that some dowel bars within area of void are too close to the surface
160	270	180	
170	270	180	
180	280	175	
190	280	175	

Table 6C.2: An Example of How the GPR Survey Data for a Concrete Pavement Should be Presented