DESIGN MANUAL FOR ROADS AND BRIDGES

HD 29/94

Incorporating Amendment No. 3 dated November 1999

THE HIGHWAYS AGENCY

THE SCOTTISH EXECUTIVE DEVELOPMENT DEPARTMENT

THE NATIONAL ASSEMBLY FOR WALES
CYNULLIAD CENEDLAETHOL CYMRU

THE DEPARTMENT OF THE ENVIRONMENT FOR NORTHERN IRELAND

Structural Assessment Methods

Summary: This amendment includes a revised Chapter 5 and Contents list.

Volume 7 home page

VOLUME 7 PAVEMENT DESIGN AND MAINTENANCE

SECTION 3 PAVEMENT MAINTENANCE ASSESSMENT

PART 2

HD 29/94 AMENDMENT NO 3

STRUCTURAL ASSESSMENT METHODS

SUMMARY

This amendment consists of a new revised Chapter 5 on Falling Weight Deflectometer.

INSTRUCTIONS FOR USE

1. Remove existing Contents list and Chapter 5 from HD 29/94 and archive as appropriate.
2. Insert new Contents list and Chapter 5 into HD 29/94.
3. Enter the details of Amendment No 3 on the Registration of Amendments sheet, sign and date to confirm that the amendment has been incorporated.
4. Archive this sheet as appropriate.

Note: A quarterly index with a full set of Volume Contents Pages is available separately from the Stationery Office Ltd.

VOLUME 7 **PAVEMENT DESIGN AND MAINTENANCE**

SECTION 3 **PAVEMENT MAINTENANCE ASSESSMENT**

PART 2

HD 29/94 AMENDMENT NO 2

NON-DESTRUCTIVE ASSESSMENT METHODS

SUMMARY

This amendment includes revised Chapters 1, 4 and 6, a revised Annex 3 and deletes previous Annex 1. These revisions allow for Long Life Pavements and revisions to PANDEF software.

INSTRUCTIONS FOR USE

1. Remove existing Chapters 1, 4 and 6, Annex 3 and Annex 1 of HD 29/94 and archive as appropriate.
2. Insert replacement Chapters 1, 4 and 6 and Annex 3 into Part 2 of Volume 7, Section 3.
3. Insert new contents page and cover sheet.
4. Enter details of Amendment no 2 on the Registration of Amendments sheet, sign and date to confirm that the amendment has been incorporated.
5. Archive this sheet as appropriate.

Note: A quarterly index with a full set of Volume Contents Pages is available separately from the Stationery Office Ltd.

Amendment No 1 (November 1996)

Replacement Pages

Page No	Date
Front sheet	
Chapter 4: 4/1 - 4/10 incl.	November 1996
Chapter 6: 6/1, 6/2	November 1996
Annex 3: 3/1 - 3/6 incl.	November 1996

The replacement sheets supersede those dated January 1994. All superseded pages should be archived as appropriate.

Implementation

The replacement pages should be used forthwith on all schemes for the construction, improvement and maintenance of trunk roads including motorways.

Volume 7 home page

REGISTRATION OF AMENDMENTS

Amend No	Page No	Signature & Date of incorporation of amendments	Amend No	Page No	Signature & Date of incorporation of amendments
One	Front sheet Chapter 4: 4/1 - 4/10 incl. Chapter 6: 6/1, 6/2 Annex 3: 3/1 - 3/6 incl.				

REGISTRATION OF AMENDMENTS

Amend No	Page No	Signature & Date of incorporation of amendments	Amend No	Page No	Signature & Date of incorporation of amendments

Volume 7 home page

VOLUME 7 PAVEMENT DESIGN AND MAINTENANCE

SECTION 3 PAVEMENT MAINTENANCE ASSESSMENT

PART 2

HD 29/94 AMENDMENT NO 3

STRUCTURAL ASSESSMENT METHODS

Contents

1. INTRODUCTION

General

1.1 This Part describes the methods of non-destructive pavement assessment which are available and currently approved by the Overseeing Organisation. 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 given on analysis and interpretation of results, as far as possible, including the means of identifying those flexible pavements which have the potential for long life. The use of each assessment method in the context of the overall pavement monitoring and assessment process is described in HD 30 (DMRB 7.3.3). 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 Organisation's standard assessment procedure are all included.

Implementation

1.2 This Part shall 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 should confirm its application to particular schemes with the Overseeing Organisation.

2. HIGH SPEED ROAD MONITOR

2.1 The High-Speed Road Monitor (HRM) consists of a van and trailer, fitted with laser sensors and other devices, which measures road surface condition at speeds up to 95 km/hr whilst operating in the normal traffic flow (See Figure 2.1). It records, simultaneously, longitudinal profile and macrotexture in the nearside wheelpath, the average rut depth over the traffic lane and the curvature, crossfall and gradient of the road. All data collected is referenced to the highway network.

2.2 HRM surveys offer a new approach to maintenance assessment, by providing an overview of road condition obtained quickly and without any delays to traffic.

2.3 From the results of a single survey, lengths of road with sub-standard surface condition can be identified - texture and rutting being used to evaluate safety aspects and the absolute level of profile to assess ride quality.

2.4 Trends in performance may be determined by repeating surveys by the HRM at regular intervals. The proportional change in longitudinal uneven-ness over a two year period is a particularly useful parameter as it is an indicator of the structural condition of flexible and rigid pavements. Proportional increases greater than certain levels can be used to define increasing levels of structural deterioration.

2.5 HRM surveys are not intended to replace existing slower routine assessment surveys for visual and structural condition, but should enable more effective use to be made of them by targetting them on those lengths of road most in need of maintenance attention.

2.6 Surveys are organised centrally by the Overseeing Department using a survey contractor. The entire trunk road network is surveyed over a 2 year period.

2.7 This Chapter gives detailed guidance on the interpretation of the results of HRM surveys and the development of a maintenance strategy. Surveys are applicable to all schemes for the maintenance of trunk roads, including motorways, as directed by the Overseeing Department.

Figure 2.1 High Speed Road Monitor

MEASUREMENTS RECORDED BY THE HRM

General

2.8 The HRM trailer is 4.5 metres long and carries four laser sensors above the nearside wheelpath. These sensors provide data from which the longitudinal profile and macrotexture of the road surface are derived. A further laser sensor mounted at the mid point of the trailer axle is used in conjunction with the trailer wheels to measure the average rut depth in the nearside and offside wheelpaths. Inclinometers mounted both horizontally along the trailer and perpendicular to the trailer axle, when corrected for acceleration effects, give the crossfall and gradient of the road. A shaft encoder fitted to the nearside trailer wheel provides the distance information relative to which all HRM measurements are referenced. Information from a second encoder on the offside wheel when combined with that from the nearside wheel provides data for the calculation of horizontal radius of curvature.

2.9 The trailer is towed by a large van which houses the electronics to operate the system. Measurement data is stored on magnetic cartridge.

2.10 An essential feature of an HRM is an automatic locational referencing system to ensure that section boundaries are located to the accuracy of ± 1 metre required for trend analysis between successive surveys. Facilities are available to detect markers set in the road at these boundaries and to read bar-code plates with unique reference numbers which are situated at known key points on the network. Manual marking of section nodes is only acceptable if some markers are missing or not detected, but may be used for marking specific features such as bridges and surface changes. A guidance aid to assist the driver to maintain a constant transverse position within the running lane should be used when carrying out surveys.

2.11 Longitudinal profile data is recorded at 0.1m intervals, but measurements of the other five parameters are presented as averages over 10m lengths. All measurements are referenced to the Overseeing Department's network referencing system.

2.12 Surveys are continuous along the left hand lane of a chosen route and consist of a series of runs up to 100km in length. Normally, only those parts of roundabouts and slip roads traversed as part of a run are measured.

2.13 There are no seasonal or temperature constraints on surveys. However, the road surface must be dry during the survey, since the presence of water in the interstices of the surfacing material affects the accuracy of measurements.

Longitudinal Profile

2.14 The measure of profile unevenness used for assessment of riding quality is the variance of individual deviations of the profile relative to a datum derived from a moving average of the profile measurements, see Figure 2.2. This variance value reflects the unevenness associated with profile features which are less than the length of profile used to calculate the moving average datum. For example, the variance of deviations from a 3m moving average datum reflects the uneveness of profile features with a wavelength of less than 3m. Short, medium and long wave features are typically represented by variance from 3m, 10m, and 30m moving averages respectively.

2.15 Uneven roads are not necessarily weak. The proportional change in variance (PCV) with time calculated relative to a 3m moving average has been shown to be an indicator of the structural condition of flexible pavements, RR183 (1989) for jointed rigid pavements, a 10m moving average datum applies, Cooper (1990). PCV is the key parameter which enables lengths of road with possible structural problems to be located, reducing the need for routine visual and machine surveys on the whole road network.

Rutting

2.16 These measurements are not directly comparable with straight-edge and wedge measurements used in visual condition surveys as the HRM records the average rut depth of the nearside and offside wheelpaths. Generally the measurement assumes that the trailer wheels follow a line along the bottom of the ruts in the individual wheelpaths, but there are occasions when this will not be the case. To ensure the required degree of repeatability of profile measurements for calculating PCV, the driver is instructed to maintain a constant distance from the edge

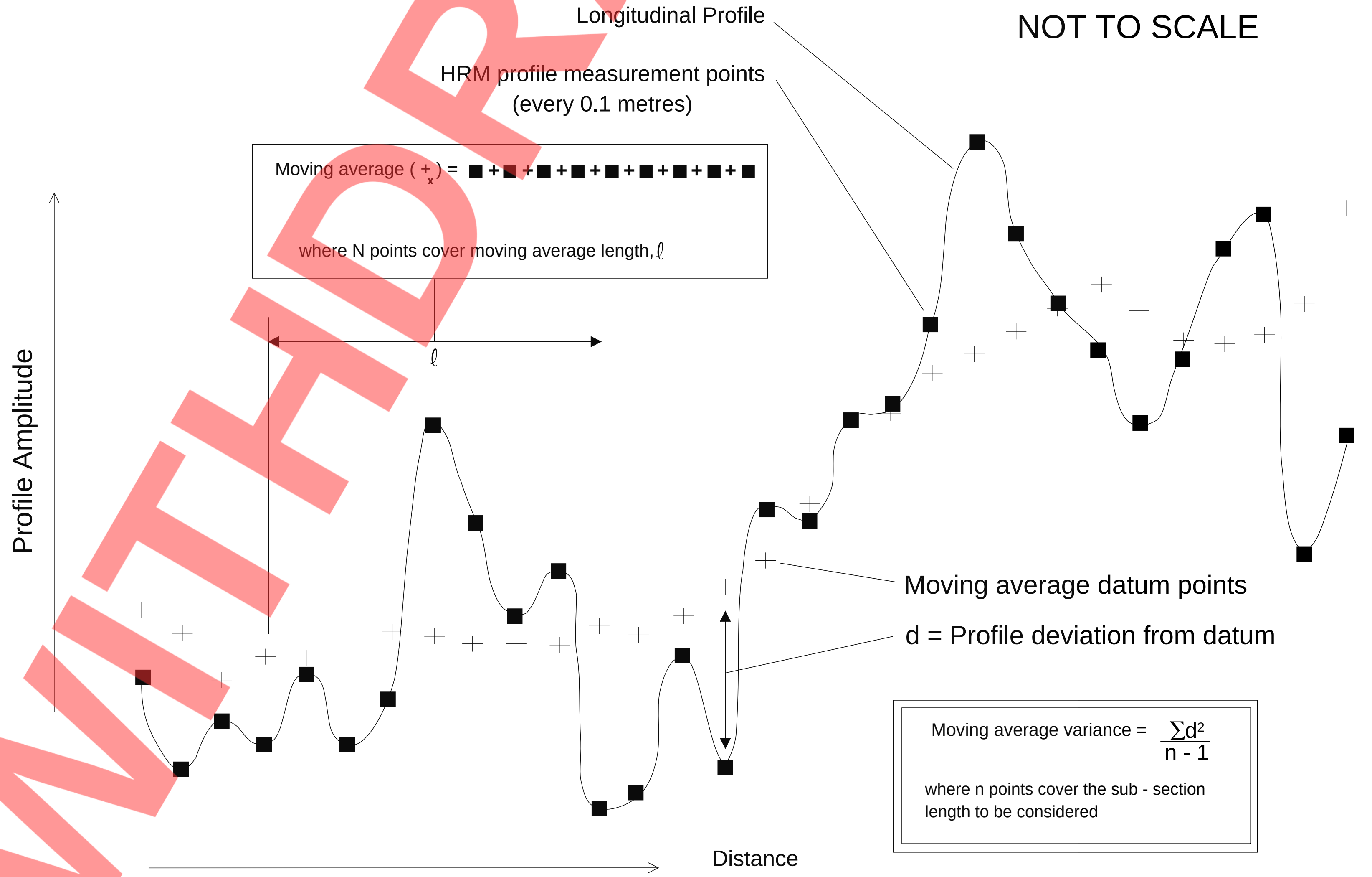


Figure 2.2 Derivation of moving average variance of profile measurements

Volume 7 home page

of the carriageway. On straight sections of road the path followed will coincide with the most used wheel path, but on bends, particularly on motorways this may not occur and inaccurate measurements of ruts may be recorded. Radius of curvature measurements can be used to check whether this is the case. The HRM measurements are best used as an indicator of where the worst areas of rutting may be occurring.

Macrotexture

2.17 The surface texture measured by the HRM is the coarser element or macrotexture formed by aggregate particles in the surfacing, eg the chippings rolled into an asphalt mortar or brushing or grooving on a concrete surface. Macrotexture contributes to skidding resistance, primarily at high speeds, in two ways. It provides drainage paths to allow water to be removed rapidly from the tyre/road interface and the projections which contribute to hysteresis losses in the tyre are an important factor in the braking process.

2.18 Measurements of macrotexture are recorded as Sensor Measured Texture Depth (SMTD). It should be noted that the relationship between SMTD measured by the HRM and that measured by the Mini-Texture-Meter is not unity and is the subject of current research.

Alignment Parameters

2.19 Gradient, crossfall and radius of curvature measurements give an indication of road geometry to an accuracy of ± 10%.

DATA

2.20 Successive HRM surveys on any section of road are normally arranged at intervals of two years (± 3 months) to facilitate the calculation of the PCV indicator of structural condition. Surveys are controlled by a contract specification covering machine calibration, operating conditions and a daily quality audit to ensure the integrity of the data collected.

2.21 All data is processed using the Overseeing Department's HRM software which comprises three groups of programs. Full details are given in the Overseeing Department's HRM Software User's Manual (1990).

2.22 Group 1 and Group 2 programs are used centrally by the survey contractor. Group 1 transfers data from the HRM machine to a computer, where it is validated and standardised to the network by Group 2. Group 3 software provides analysis, reports and graphical displays. Mainframe and PC versions of Group 3 are available on application to the Overseeing Department. All three groups are supported and maintained under contract.

2.23 Subsets of processed data, corresponding to all roads within a particular Maintenance Agency, are distributed in a machine independent format on magnetic medium for further analysis using Group 3 software or an approved equivalent.

2.24 A central store of processed data covering the complete network of roads in a territory is retained by the Overseeing Department. Arrangements can be made for this to be accessed by the Department's staff, using Group 3 software.

ASSESSMENT CRITERIA

General

2.25 HRM surveys on a routine basis are in their infancy, therefore the assessment criteria given in this Advice Note are for general guidance only. The results of the survey analysis may be used as a coarse sift to identify lengths of road in need of further investigation or to supplement existing routinely collected road condition data. The former approach provides the opportunity to reduce the extent of established, but slow and more costly, assessment techniques such as CHART, VCS (Concrete), Deflectograph and FWD. As the criteria are based on experience gained from a research and development programme, Cooper (1991) and DOT Report 4 (1988), carried out on a relatively limited range of sites, the criteria may need to be modified as more experience is gained of their use. Feedback from Maintenance Agents would assist in this process.

2.26 The criteria given in Tables 2.1, 2.2 and 2.3 are for in-service roads. Four categories of condition are defined by threshold values applicable to each parameter:-

Category	Threshold Value		Threshold Value		Threshold Value		Range for MTREN
	0 Sound	↓	1 Lower level	↓	2 Warning level	↓	3 Intervention level
Flexible PCV value		0.6		1.2		2.4	0 - 6.0
Concrete PCV value		0.5		1.0		2.0	0 - 5.0

Table 2.1 : PCV criteria for 20m subsections over a nominal 2 year period

Category	Threshold Value		Threshold Value		Threshold Value		Range for MSIFT/MTREN
	0	↓	1	↓	2	↓	3
Rut depth (mm)		5		10		20	-5.0 - 45.0
Change in rut depth		5		10		20	0 - 25.0
Texture (mm)							
(a) Bituminous		1.0		0.5		--	0 - 2.5
(b) Concrete		0.5		0.25		--	0 - 2.5
Change in texture Bituminous		0.1		0.2		0.5	0 - 1.0

Table 2.2 : Rutting and Texture Depth Criteria

Volume 7 home page

Category	Threshold Value (0 ↓ 1)	Threshold Value (1 ↓ 2)	Threshold Value (2 ↓ 3)	MSIFT entries Acc/Warn/Range
1. MOTORWAYS AND DUAL CARRIAGEWAYS				
Variance				
3m	1.25	3.75	7.5	1.25/ 3.75/ 0 - 12.5
10m	4	16	36	4.0 / 16.0 / 0 - 40.0
30m	55	165	275	55.0 /165.0 / 0 - 550.0
2. PRINCIPAL ROADS AND ROADS WITH 50 MILE/HR SPEED LIMIT				
Variance				
3m	1.5	4.5	10.5	1.5/ 4.5/ 0 - 15.0
10m	7	21	56	7.0/ 21.0/ 0 - 70.0
30m	75	187.5	300	75.0/187.5/ 0 - 375.0
3. MINOR ROADS AND ROADS WITH 40 MILE/HR SPEED LIMIT				
Variance				
3m	2.2	6.6	15.4	2.2/ 6.6/ 0 - 22.0
10m	12	36	72	12.0/ 36.0/ 0 - 120.0
30m	100	200	400	100.0/200.0/ 0 - 500.0
4. ROADS WITH 30 MILE/HR SPEED LIMIT				
Variance				
3m	2.5	7.5	17.5	2.5/ 7.5/ 0 - 25.0
10m	15	45	90	15.0/ 45.0/ 0 - 150.0
30m	120	240	480	120.0/240.0/ 0 - 600.0

Table 2.3(a) : Riding quality criteria for roads of all types of construction (100 subsections)

Category	Threshold Value (0 ↓ 1)	Threshold Value (1 ↓ 2)	Threshold Value (2 ↓ 3)	MSIFT entries
Variance 10m	5	20	50	5.0 / 20.0/ 0 - 50.0

Table 2.3(b) : Additional riding quality criteria for all concrete roads (20m subsections)

Volume 7 home page

Category	Definition
0	Sound, no visible distress.
1	Visible distress, lower level of concern. The distress is not serious and needs no action unless it extends over long lengths or several parameters are at intervention levels.
2	Extensive distress, warning level of concern. The distress is becoming serious and needs to be investigated. Priorities depend on the extent of the distress and the values of all the parameters.
3	Severe distress, intervention level of concern. Immediate action is required. This condition should not occur very often on trunk roads as earlier maintenance work should have prevented this state being reached.

Structural Condition Indicator

2.27 The 3m PCV for flexible and 10m PCV for jointed rigid pavements should be used as the main indicators of structural condition, but all other parameters should also be considered when deciding upon the need for further more detailed investigations.

2.28 The criteria in Table 2.1 relate to the proportional change occurring in a period of two years (± 3 months) calculated over 20m subsection lengths at 10m intervals.

2.29 No PCV criteria have yet been established for Continuously Reinforced Concrete Pavements (CRCP) or Continuously Reinforced Concrete Roadbase (CRCR) types of construction.

Rutting

2.30 Table 2.2 gives threshold levels for average rut depth measured to an accuracy of ± 2 mm. The criteria for the change in rut depth over a 2 year period are set fairly high to allow for greater measurement error in surveys carried out prior to the 1992 season. Concrete surfacings give negligible rutting.

Macrotexture

2.31 The threshold levels for texture given in Table 2.2 are only provisional and may need to be changed when research on macrotexture is complete. Different levels apply to bituminous and concrete surfaced roads because of the different ways in which texture is provided.

Riding Quality

2.32 Ride criteria are based on profile unevenness with wavelengths less than 3m, 10m and 30m as these have been found to have most effect on vehicle ride. The different threshold levels given in Table 2.3(a) which are for 100m subsections apply to different types of road depending on their usage, eg a motorway requires a better riding quality than a single carriageway in an urban area subject to a speed limit of 30 mph.

2.33 An additional indicator for assessing localised condition of concrete roads, for which most construction is in the form of 6m bays, is given by the variance about a 10m moving average in conjunction with a 20m subsection length. See Table 2.3(b).

ASSESSMENT OF ROAD CONDITION

2.34 An overview of the condition or the trend in condition of roads in a maintenance area is required to give an indication of the scale of possible maintenance requirements and 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.

2.35 The HRM Group 3 software includes facilities for assessment at these two levels of detail. Complete routes, groups of sections or individual sections may be examined against maintenance criteria defined by the user of the software.

2.36 Sections with concrete surfaces should be identified before starting the analysis, because different assessment criteria apply to many parameters. Information on the surface type may be held locally within other systems, but is also held in the network referencing (WAYLEN) file in the HRM software.

Program Usage

2.37 Of the seven Group 3 programs, the ones most likely to be of use are:

MREPB	Reports on the HRM database relating HRM runs to the network reference.
MTREN	Analyses differences in road condition over time
MSIFT	Sifts data against road condition criteria
MDISP	Provides graphical displays on screens.

Detailed instructions on the use of the programs is given in the Overseeing Department's HRM Software Users' Manual (1990).

2.38 The first step is the identification of the HRM run or runs which cover the road or sections of interest. The method of access to the data is through the run number. MREPB, option H, provides this information. Programs MTREN, MSIFT, and MDISP may then be used in turn to provide the results of the analysis at the appropriate level of detail. When the run number requested by the program is entered, all CHART sections covered by that run are displayed. Sections to be included in the assessment and the type of measurement data to be assessed are then selected.

2.39 Reference should be made to Tables 2.1, 2.2, 2.3a and 2.3b for appropriate threshold levels and the range and intervals to be entered for the histogram output, produced by MSIFT and MTREN, since the default criteria in the software may not comply with current recommendations.

2.40 MDISP allows several sets of data of any type, taken from one or more runs on the same stretch of road to be displayed in graphical format.

Overview

2.41 An overview analysis for each separate parameter may be carried out on any number of sections falling within an HRM run. Only roads to which similar assessment criteria apply, eg flexible or concrete, should be included in this type of analysis.

2.42 Each of the HRM measurement types should be sifted separately against the various threshold levels, using program MSIFT. Data on riding quality, wheel track rutting and surface texture will generally prove most useful as indicators of condition.

2.43 Trends in structural and surface condition with time should be assessed using the program MTREN. Any two matching surveys along a route may be compared but the criteria in Tables 2.1 and 2.2 apply only to surveys separated by the interval of 2 years (± 3 months).

2.44 The outputs from programs MSIFT and MTREN are in the form of histograms which show, the cumulative percentage of data exceeding values in bands specified by the user for the sum of all selected sections. The "acceptable" and "warning" level descriptions are advisory only.

2.45 The program MDISP provides an alternative method of checking surface condition by visual means. Long lengths of road can be scanned relatively quickly to identify sections in which one or more parameters exceeds recommended maintenance levels. These can then be examined in more detail later.

Detailed Assessment

2.46 The objective of detailed assessment is to identify for further investigation those sections which have significant lengths of road in condition categories 2 or 3 for one or more parameters.

2.47 The minimum requirement is an assessment of structural condition from HRM data. The following procedure is recommended, using the software to examine successive lengths of about 20km of road:-

a) Flexible pavements

(i) The major indicators are the 3m moving-average PCV over a two year period and the present condition of wheel track rutting. Programs MTREN and MSIFT should be used to analyse data for these parameters respectively.

(ii) The lists of subsections exceeding the "warning" levels, resulting from MTREN and MSIFT should be scanned. Maintenance sections in which 15% or more of the values of each parameter exceed the threshold level for category 2 and/or 4% or more exceed the threshold level for category 3 should be identified and noted.

(iii) An investigation table of the format given in Table 2.4 should be drawn up to combine the results of these separate assessments. The number '2' or '3' corresponding to the higher category found should then be entered against the maintenance section and its length.

(iv) The weighting factors given in Table 2.5 are then applied.

b) Concrete pavements

Deterioration of concrete pavements is generally relatively slow to begin with but then often takes the form of a sharp and rapid increase. Again, PCV alone may not wholly reflect the deterioration occurring so it needs to be used together with the present condition parameter for assessing localised condition (see 2.33). The detailed assessment procedure is generally the same as for flexible pavements except for 2.47, a), (i).

(i) The analysis should be carried out using program MTREN for a 10m moving average PCV and MSIFT for 10m variance over 20m subsections.

(ii) The lists of subsections exceeding the "warning" levels, resulting from MTREN and MSIFT, should be scanned. Maintenance sections in which 15% or more of the values of each parameter exceed the threshold level of category 2 and/or 4% or more exceed the threshold level for category 3 should be identified and noted.

(iii) An investigation table of the format given in Table 2.4 should be drawn up to combine the results of these separate assessments. The number '2' or '3' corresponding to the higher category found should then be entered against the maintenance section and its length.

(iv) The weighting factors given in Table 2.5 are then applied.

2.48 The investigation table may be expanded to give a fuller picture of maintenance needs by supplementing the entries for structural condition with those for surface condition. This time, lists of subsections exceeding the "warning" levels resulting from using MSIFT on the present condition of macrotexture and riding quality should be examined. Maintenance sections in which 15% or more of the values of each parameter exceed the threshold level for category 2 and/or 4% or more exceed the threshold level for category 3 should be noted. The entry in the investigation table for riding quality should be the highest category obtained from analysis of short, medium and long wavelength features.

2.49 The table gives a points total for each section, the higher the total the more advanced the deterioration. An order of priority for further investigation is thus established. An example of a completed investigation table is given in Table 2.6. Recommended action required is summarised in Table 2.7.

SECTION NUMBER	LENGTH (m)	FLEXIBLE		CONCRETE		TOTAL	ALL TYPES		TOTAL
		1. PCV (3m)	2. RUT (mm)	3. PCV (10m)	4. RIDE $10m_{(20)}$	1+2 or 3+4	5. TEXTURE (SMTD)	6. RIDE	5+6

Table 2.4 : Investigation Table

Category	PCV	Rut Depth *	Texture Depth	Ride All Mavge
		Present Condition	Present Condition	
1+				
2	x12	x6	x6	x2
3	x20	x15		x3

* Flexible pavements   + Not used in detailed assessment

Table 2.5 : Measurement weightings

SECTION NUMBER	LENGTH (m)	FLEXIBLE		CONCRETE		TOTAL	ALL TYPES		TOTAL
		1. PCV (3m)	**2. RUT (mm)**	**3. PCV (10m)**	**4. RIDE 10m$_{(20)}$**	**1+2 or 3+4**	**5. TEXTURE (SMTD)**	**6. RIDE**	**5+6**
294SB1	786	2(24)	-			(24)			
213SB1	872	2(24)	-			(24)			
308SB1	923	3(60)	-			(60)			
757SB1	1971	-	2(12)			(12)	2(12)	3(9)	(21)
727SB1	1023	-	2(12)			(12)	2(12)	-	(12)
737SB1	665	2(24)	2(12)			(36)			
144SB1	1676	3(60)	2(12)			(72)			
148SB1	1550			2(24)	2(24)	(48)			
157SB1	1955			2(24)		(24)	2(12)		(12)

Table 2.6 : Example of an Investigation Table

The values in brackets are obtained by multiplying the category by the appropriate weighting for the HRM measurement parameter shown in Table 2.5: the total is the sum of the weighted categories.

Points Total	Action
2 to 10	Observe
11 to 20	Visual inspection
21 to 59	**(1)** Flexible pavements: Commission Deflectograph survey **(2)** Concrete pavements: Commission slab movement tests
> 59	Priority action for full maintenance investigation

Table 2.7 : Action Required

2.50 The software can provide more detail on the sections chosen for further action. The location and magnitude of all values beyond the "warning" limits in the section sifts can be printed out and examined. Also, the interaction of rut and texture data with road geometry can be studied in an on-screen display using program MDISP, which will also show the location of the worst areas within the section to the nearest 10m.

INTERPRETATION OF RESULTS

2.51 The trend in condition of sections of the network can be studied using the HRM software. However, a problem arises if changes to the network occur between surveys. These may be due to renumbering of sections, relocation of section boundaries or the introduction of new sections for road improvements or new bypasses. This problem is not unique to HRM surveys but applies to all network based data. Advice should be obtained from the Overseeing Department.

2.52 Variation in the measurement path followed by the HRM between one survey and the next may affect the change in value of individual 10m or 20m subsections of road. Isolated subsections which exceed the investigation threshold for trends should therefore be treated with caution in the analysis.

2.53 If the machine is forced to divert from the normal track due to obstructions or contra-flow working, the record is marked by the operator. The survey chainage is maintained, but gaps will occur in the recorded data.

Overview Analysis

2.54 This form of analysis is intended to cover relatively long lengths of road, up to 100km. The percentage of values within the various categories of condition, shown in the histogram reports, should be assessed in the context of the length of survey chosen for the analysis.

2.55 A direct comparison of the sift outputs of different parameters over the same length of road can be made. The most significant in terms of possible future maintenance will be those with the highest percentage of values exceeding the "warning" level of condition. In this context riding quality and texture are indicators of surface condition and rut and PCV of structural condition.

2.56 Improvements and deterioration in overall condition are both shown in the trend analysis. These outputs are probably most useful as an indicator of progress in achieving business plan objectives for maintenance.

Detailed Assessment

2.57 Maintenance sections vary in length from under 100m to up to 2km. The percentage of values, given in paragraph 2.47a)(ii), which determine the category of condition for entry into the investigation table have been chosen with this in mind. The extent of deteriorated surface depends on the actual length of the section and priorities and action to be taken will need to be carefully considered using the investigation table as a guide.

2.58 The measurement weightings in Table 2.5 give an indication of the severity of the deterioration. Riding quality is given a weighting that reflects its relative importance and further action will only be required if a bad ride is experienced in combination with a deterioration in other parameters.

2.59 The actions proposed in Table 2.7 on the basis of the points total in the investigation table are based on limited experience of routine use of the HRM. Actual ranges of points for the various actions may need to be modified a experience grows.

2.60 The main indicators for ***flexible*** pavements are those for the commissioning of a Deflectograph survey and a full maintenance investigation. It would be expected that the majority of sites in the latter category would already be known and be awaiting treatment. To be cost effective, Deflectograph surveys should be arranged to cover a group of sites in one locality and not limited to the individual sections identified in the investigation table.

2.61 For ***concrete*** pavements the detailed site investigation should include tests for slab movement.

General

2.62 The PCV calculation in MTREN identifies an 'improvement' resulting from a recently treated length as well as the more usual deterioration. The percentage of the length 'improved' is given in the output summary. Generally a resurfaced road will have increased texture depth and reduced rut depth. However, results on small scale work such as patching may be misinterpreted because a hand laid patch is frequently more uneven than the original machine laid surface, resulting in an increase in the PCV values. Again evidence of increased texture and reduced rutting will help to identify such treatments. In the case of a surface dressing, high PCV values are invariably accompanied by greatly increased texture depth but little reduction in rut depth.

2.63 A large increase in texture between two surveys may be significant as it could occur in areas where remedial work has been carried out or where fretting is present.

2.64 Of the indicators for riding quality, the 3m variance is affected by vehicle induced wear or sharp discontinuities like those caused by reflective cracking and deep texture. The 10m variance may be influenced by bay-length irregularities in concrete roads and longer wavelength deterioration in flexible roads. Subsidence is the main cause of changes in the 30m variance. Riding quality should not be considered in isolation.

2.65 Occasionally the results may show 'positive' rutting. This is a consequence of inaccurate calibration. Rut readings on a concrete surface provide a check on the accuracy, since on this surface they should be within the range of ± 1mm.

2.66 Short lengths of blacktop covering underbridges, within a concrete section, may be identified from operator events CB/BC shown on the screen in MDISP. Also, texture depth is generally lower on concrete surfaces, except where grooving is used, and rutting should be negligible.

2.67 The alignment parameters, which represent the road geometry, should be considered in conjunction with the other condition parameters when deciding on the most appropriate maintenance action. They may also assist in categorising the network (including identifying defined sites) in accordance with the skidding resistance policy.

3. VISUAL CONDITION SURVEYS

3.1 Visual Condition Surveys have four objectives:-

a) to provide factual condition data for establishing suitable structural treatments;

b) to identify homogeneous lengths of road suitable for contracts of remedial treatment;

c) to provide the means of monitoring performance, establishing priorities and planning long-term maintenance programmes;

d) to provide a data bank suitable for calculating priority ratings, whole-life costings and predicting the life expectancy of pavements.

3.2 A visual condition survey forms part of the routine assessment of a pavement, although it will be targeted particularly at sections which the HRM identifies as requiring further investigation. A visual condition survey is applicable to all types of pavement.

CHART SURVEYS

3.3 CHART (Computerised Highway Assessment of Ratings and Treatments) is a management system for assisting maintenance engineers in formulating their annual programme of maintenance. (MARCH is used in Northern Ireland and reference should be made to the Overseeing Department for its application). It warns the engineer that certain lengths of road have deteriorated to a degree where treatment may be required. It is only used on pavements with a bituminous surface.

CHART indicates to an engineer:-

a) lengths of road that are sub-standard;

b) apparent treatments that are needed;

c) relative priorities for treatment.

CHART Sections

3.4 The entire trunk road and motorway network in the UK (except Northern Ireland) has been divided into a system of sections and nodes. Because they have originated from the use of CHART this network is commonly referred to as the CHART network.

3.5 Nodes are located at junctions and at other significant features, such as bridges and changes in pavement construction. They divide the network into sections of not more than 2 kilometres. In England, they are marked on the road itself as a pair of studs. Each node has a unique reference. Further details are available in the Trunk Road Maintenance Manual, Vol. 1, 1992. Slightly different systems are adopted by the Overseeing Departments in Scotland and Wales.

Planning

3.6 Before starting a CHART survey, careful planning and organisation of the work is required including the training of inspection teams, which normally consist of two persons. Full guidance of assessment of defects for classification under the CHART system can be found in CHART 5 (1986). CHART splits the road condition into 14 possible surface defects.

Processing

3.7 The CHART computer system converts defect information into numerical rating values for each defect present over each 100 m sub-section. CHART holds the current standards for each defect with their own rating values. The defects within a sub-section for which treatment is necessary can therefore be easily identified. The relationship between rating value and defect is subjective and can be changed if necessary. This method also allows for different defects to be given their correct relative values. Hence ratings indicate the relative urgency for treatment when set in numerical order. When printing out data, the output can be suppressed for sub-sections where defects are below values preset by the operator. The computer then applies any necessary treatment to those sub-sections printed out i.e. reconstruction, resurfacing or surface-dressing.

3.8 The engineer is provided with lists of road sections requiring treatment with the suggested treatment required and priority order indicated. This will enable him to make a preliminary list of schemes having regard to his available resources. Treatments are allocated to all sub-sections above a `Priority Threshold' and which have defects rated as critical. Where more than one treatment is indicated, the one with higher degree will be recommended in preference.

Types of Output

3.9 MAP CHART: shows the amounts of defects by chainage along the road and across the road.

3.10 SECTION CHART: is a summary including average and maximum ratings, information such as Inspection method and characteristics that might affect the priority for treatment; it can also be used as an index.

3.11 TREATMENT LENGTH CHART: is a list, by Section, containing only those sub-sections for which treatment is recommended. Separate lists are produced for each treatment.

3.12 SUB-SECTION RATING AND TREATMENT CHART: is a list of Sections recommended for treatment, including Section and Inspection characteristics. Main and substitute treatment recommendations are shown for each Sub-section requiring treatment.

3.13 HISTOGRAM CHART: shows in histogram form the combined ratings of all defects present, thereby highlighting severe local defects.

OTHER SURVEYS

3.14 For the visual assessment of rigid pavements, the Overseeing Departments have not yet developed a computerised system such as CHART. The procedure adopted is to obtain as accurate a record as possible of all observed relevant features, i.e. carriageway condition, edge features, earthworks and drainage problems. The information obtained is seen as complementary to the 6- monthly detailed inspections which are already carried out in England for minor repair identification (Trunk Road Maintenance Manual: Volume 2, 1992).

3.15 Table 3.1 provides guidance to survey interpretation, although it should be remembered that surface condition is not always a reliable guide to the condition of the lower layers.

IMPLEMENTATION

3.16 The known details of pavement construction shall be recorded in a form such as that in Figure 3.1. This form is also used as input for the Trunk Road Maintenance Manual: Volume 1 (1992)*. Faults and defects shall be recorded in the form shown in Figure 3.2 and using the symbols given in Table 3.2. For concrete roads, reference may be made to Mildenhall and Northcott (1986) for detailed descriptions and photographs of each type of fault. Figure 3.3 is an example of a completed survey form.

* Currently operating in England only.

3.17 Staff carrying out a visual condition survey shall be supplied with forms such as Figure 3.2, except that a data capture device may be used if it is found to be cost effective and is capable of producing correct output in the form required. Inspectors undertaking visual surveys shall have received adequate training to ensure consistent survey standards.

3.18 The recording form shown in Figure 3.2 is designed to:-

a) provide a clear and complete record of the surface condition of the concrete pavement;

b) permit the addition of concise explanatory notes where necessary;

c) allow correct locational referencing by means of CHART nodes and section identifiers.

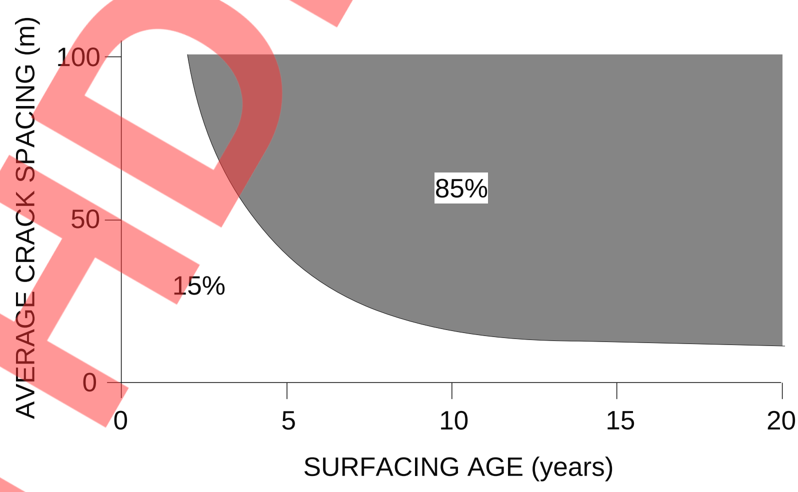
OBSERVATION	INTERPRETATION
Single longitudinal wheelpath cracks in bituminous surface	Indicates the onset of structural failure in a thick (>200mm approx) pavement or one with a cement bound base. If cracks are narrow, then this probably represents the `critical' condition of the pavement. Such cracks do not normally `heal' in any way and deterioration is likely to progress.
Multiple wheelpath cracking and crazing in bituminous surface	If cracks are narrow as defined in Table 3.2 then the structure is likely to be thin, and the condition may not be near failure. Wider cracks mean advanced failure of a thicker structure, particularly if rutting is also present.
Longitudinal cracking outside the wheelpath in bituminous surface	Probably the location of a construction joint in one of the pavement layers.
Short transverse cracks in bituminous surface	Unlikely to be structurally significant. Cracking has probably initiated at the surface, possibly due to faults built in during construction, e.g. roller cracks. Such cracks will develop slowly under thermal and traffic loading, and may allow longitudinal cracks to develop.
Long transverse cracks in bituminous surface	Indicative of a discontinuity in a lower layer. This can be a thermal crack in a cement bound roadbase, a joint in an overlaid concrete carriageway or a construction joint in bituminous material. In the case of cement bound roadbase, the frequency and severity of transverse cracking gives an indication of the state of the material. Widely spaced cracks are typical of a strong or newly laid material. The following is a guide to interpreting crack frequency:- 

TABLE 3.1 Interpretation of Visual Survey Data

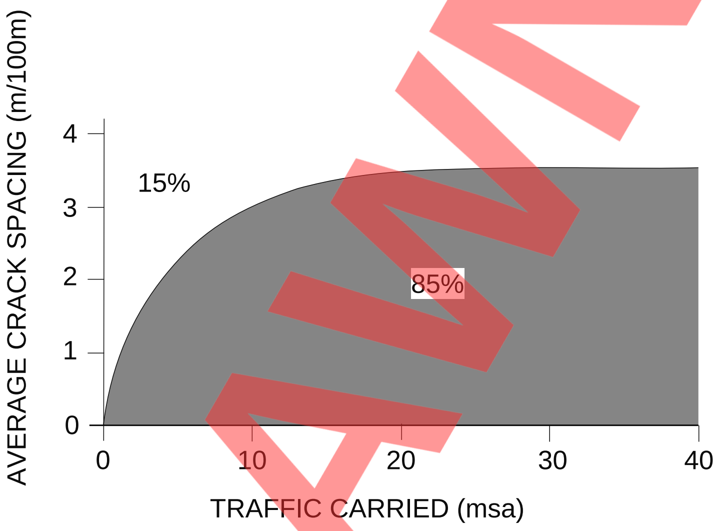
	Similarly, the amount of cracking is indicative of the traffic carried, as follows:- 
Non Structural (narrow) ruts	The upper layers, probably the wearing course, are deforming (rather than simply densifying) under traffic. No effect on lower layers will usually result.
Structural (wide) ruts	Deformation is taking place at depth within the pavement. Significant ruts indicate structural damage, possibly due to excess moisture in unbound materials and/or overstressing of the subgrade.
Longitudinal cracks in concrete pavements	Represents either the onset of structural failure, differential settlement, or compression at joints. Deterioration is likely to be rapid but sealing and stitching of cracks can reduce the crack propogation rate. Such cracking tends to occur in underdesigned (thin) pavements.
Mid bay/third bay cracks in concrete pavements	Thermally induced cracks in URC pavements, a consequence of joint malfunction. They can, if left unsealed, result in more serious distress. If sealed, then little detriment to the pavement may result. In JRC pavements, where cracks are expected and act as warping joints, sealing is only necessary if the cracks are wide.
Joint damage in concrete pavements	Spalling, sealant damage, stepping etc. are all indications that there is excess movement at the joint. Load transfer is probably poor; damage to the foundations and possibly voiding may have occurred.

TABLE 3.1 (continued) Interpretation of Visual Survey Data

Cracks:

Wide	- more than 1.5mm in width	(W) (M) (N) (H)
Medium	- 0.5mm to 1.5mm in width	
Narrow	- less than 0.5mm in width	
Hair with difficulty	- present but distinguishable only	
Bifurcation		
Overbanded or sealed crack		(S)
If subsequently failed, add (F)		(S) (F)
Plastic shrinkage cracks		
Surface crazing		degree → CRAZING (Slight)
Scaling		
Miscellaneous surface defects		
Surface texture worn		STW
Fatting up (Bleeding)		
Rutting with depth (mm)		15
Structural Rutting		St
Edge Defect		

TABLE 3.2 Standard Symbols for Recording Condition of rigid pavements

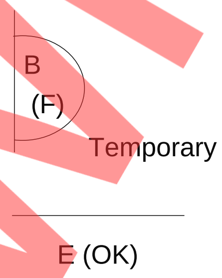
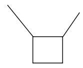
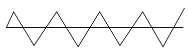
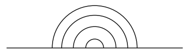
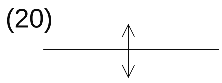
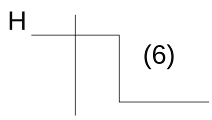
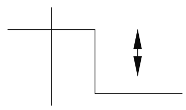
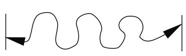
Repairs: Bituminous - B Cementitous - C Epoxy - C Add (OK) if sound or (F) if failed (It may not be appropriate to add a general note about the potential of the repairs to remain in good condition for a further 3 years)	
Missing roadstud (+ cracks)	
Rust staining	'RUST'
Defective joint seals	
Shallow 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

PAVEMENT CONSTRUCTION DETAILS

ALL ROADS

Scheme Region Consultant Contractor Date of Opening

Pavement Type: Flexible/Flexible Composite/URC/JRC/CRCP/CRCR

	Wearing Course	Base-course	Road-base	Sub-base	Capping	Subgrade
Material Type:						
Thickness:						

Surface Texture: HRA + Chipping/Surface Dress/Brushed/Grooved/Other
Drainage Details: (type, gulley frequency, outfall locations)

Cut/Embankment Lengths:
Hardshoulder construction if different from above:

CONCRETE ROADS

Type of Joint	Warping	Construction	Expansion	Longitudinal
Spacing: Wet formed/sawn: Sealant Type: (Hot/cold poured, foam compression, cork) Age:				

Paving details:	Fixed form/Slip form/Auger paver/Razor back screed	
Reinforcement Type:	Deformed/Mesh/Epoxy coated	
Diameter:	Spacing:	Depth:
Transverse reinforcement:	Diagonal/Square	Above/Below Longitudinal
Cats eyes:	Boxed out/Drilled	
Gulleys:	Boxed out/at Roadside	

STRUCTURES
Number of overbridges with minimum headroom:
Number of underbridges with flexible surfacing:
Number of underbridges with concrete surfacing:

FIGURE 3.1 Form for Pavement Construction Details

VISUAL CONDITION SURVEYS

WEATHER ....

TEMPERATURE ....

VISUAL CONDITION SURVEY OF ....

START NODE [| | | |]

FINISH NODE [| | | |]

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

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

SECTION IDENTIFIER [| | | | | | | | | | | |]

TOTAL LENGTH SURVEYED....................Km

(= from node)

Running Chainage (m): 0, 10, 20, 30, 40, 50

Offset (m): 0, 5, 10, 15

FIGURE 3.2 Concrete Pavement Survey Form

Volume 7 home page

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	△	△	△	6	2

TOTAL LENGTH SURVEYED........2.6........Km

(=1000M from node)

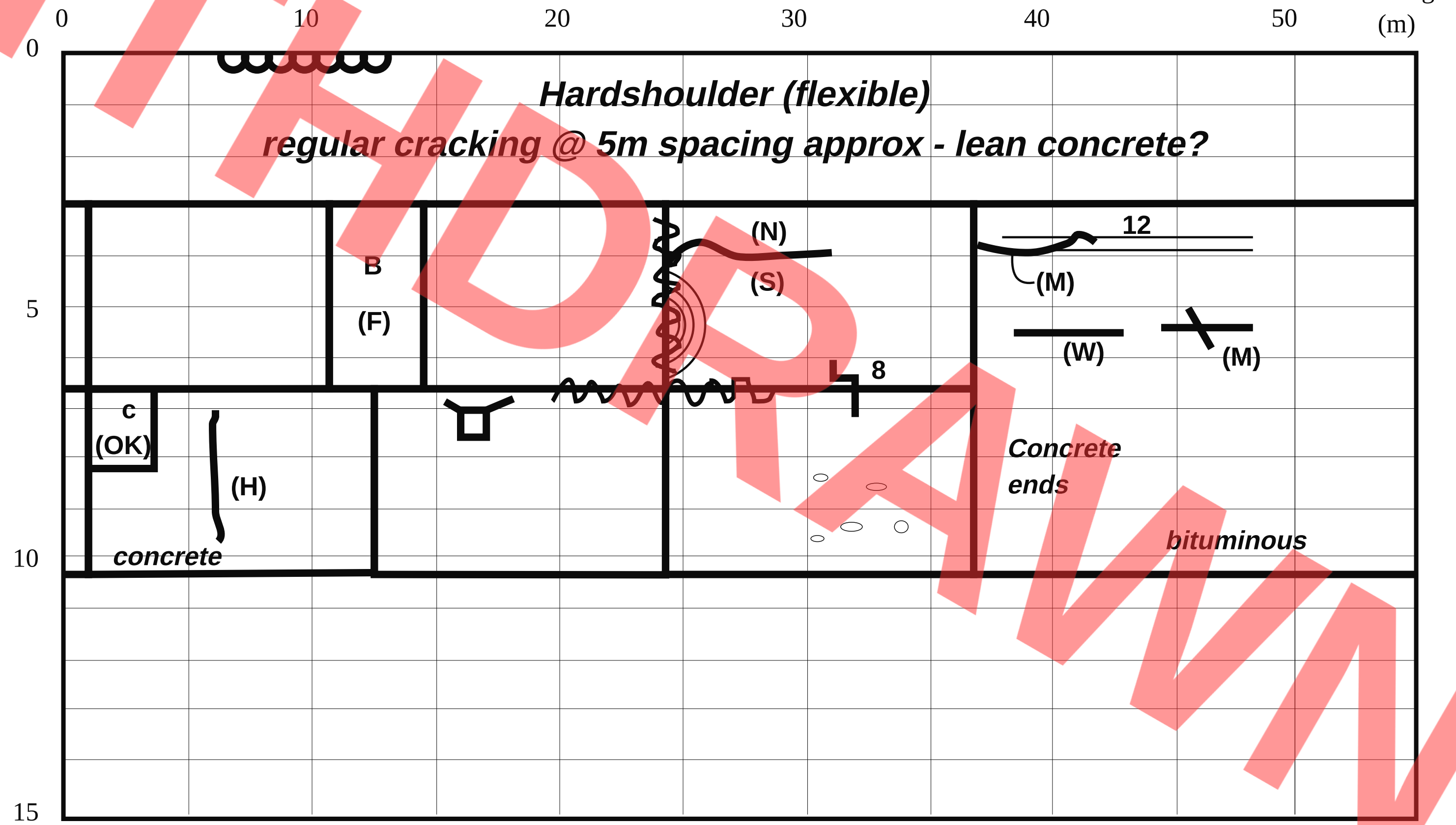


FIGURE 3.3 Example of Completed Pavement Survey Form

Volume 7 home page

3.19 Referencing should 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.

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

3.21 Surveys of concrete roads shall 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 shall always be noted. (Cracks are most readily visible when the pavement surface is drying out after wet conditions; this should be borne in mind when comparing surveys carried out in different weather conditions).

Presentation

3.22 Field survey sheets, or a fair copy, shall be retained. For detailed surveys in connection with the 'test areas' described in HD 30 (DMRB 7.3.3), a fair copy of the field survey sheets shall be presented. Otherwise a plan to a suggested scale of 1:500 shall be used as a basis for summarising the general condition of the road. A typical form of presentation is shown in Figure 3.4.

A record at this scale shall also include notes about particular areas, whose condition or rate of deterioration needs to be monitored during subsequent inspections. For concrete roads in England, a defect listing form, including proposed remedial treatments, is given in the Trunk Road Maintenance Manual: Volume 1 (1992).

3.23 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;

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

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

Continuously Reinforced Rigid Pavements

3.25 Experience with continuously reinforced concrete pavements to date is limited. The Overseeing Departments can therefore only give general guidance on visual survey methods.

3.26 The same approach shall be used as for jointed pavements except that the defects noted will tend to be different. In particular, the possible occurrence of alkali-silica reaction shall be recorded. This may be inferred from the presence of areas of map cracking containing a white or

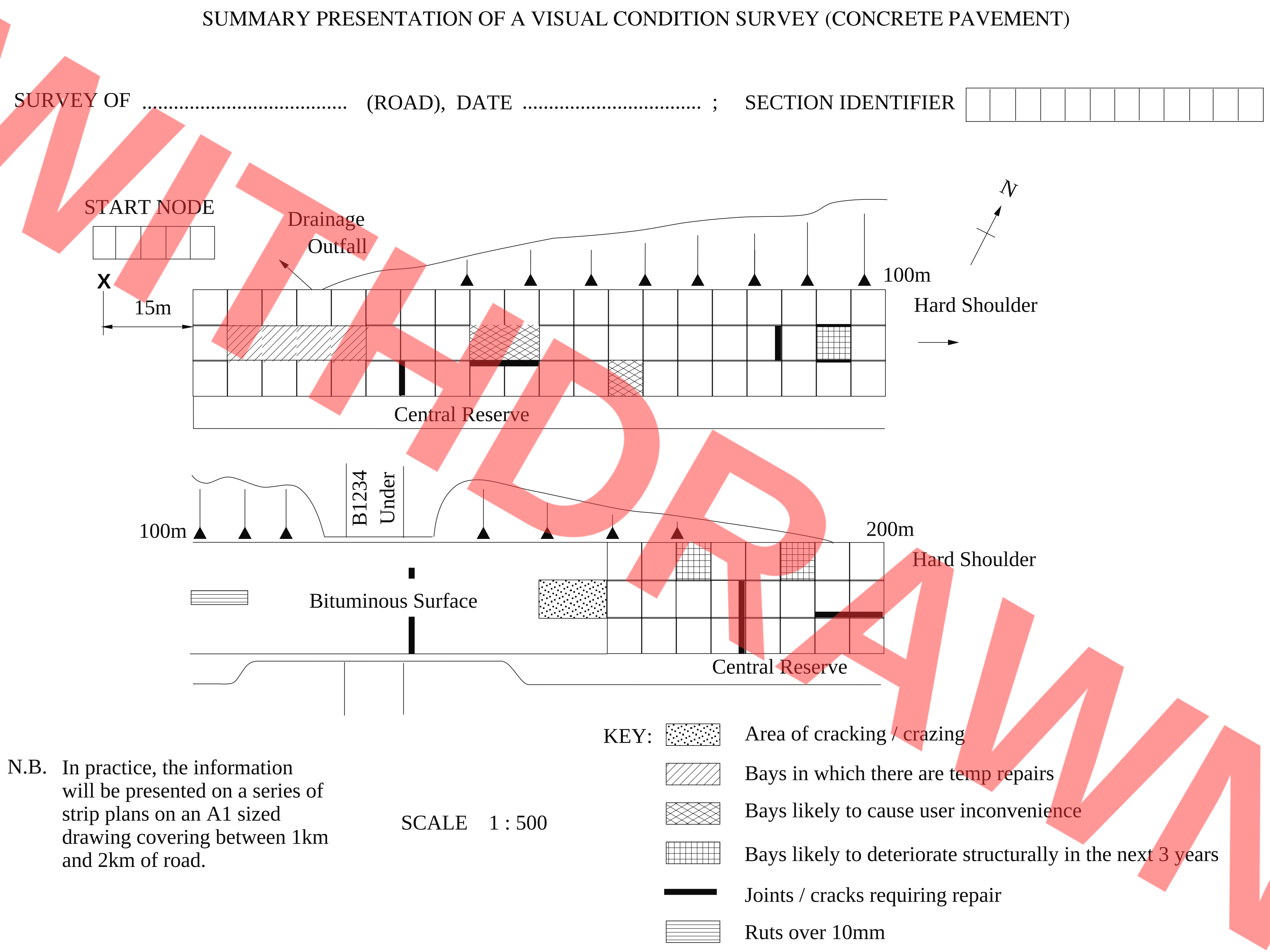


FIGURE 3.4 Typical Presentation Format for Visual Surveys on Concrete Roads

Volume 7 home page

creamy powdery material which streaks the surface after heavy rainfall.

3.27 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. As time passes additional transverse cracks slowly develop between the wider spaced cracks. These cracks are held closed by a continuous layer of heavy reinforcement, thus maintaining aggregate interlock and ensuring transfer of load across the cracks. This behaviour should be regarded as normal for CRCP and does not require noting, except for the first 10m in every 100m length. These 10m lengths should cover the number of wide cracks, other cracks and bifurcations present together with the associated degree of spalling. Transverse construction joints are present and their location should be noted during the survey.

4. DEFLECTION TESTING

GENERAL

4.1 This chapter describes the Deflectograph and the interpretation of its output. The Deflectograph is used to assess the structural condition of flexible and flexible composite 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 assessment procedure used depends on the type of pavement and its mode of deterioration. Some thick, well constructed fully flexible pavements 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 and flexible composite pavements is assessed in terms of residual life using a long established design method based on deflection and traffic loading.

DEFLECTOGRAPH

4.3 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 wheelpaths while the machine is in motion. It is regarded by the Overseeing Organisation as the standard deflection measuring device for use on flexible and flexible composite pavements.

4.4 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. Details are given in Annex 2 to this part.

4.5 The Overseeing Organisation supports the analysis program PANDEF, which uses an updated version of the Deflection Design Method for computerised processing of Deflectograph data.

Figure 4.1 Deflectograph

Details of the procedures required are given in paragraphs 4.41 to 4.64.

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 assessment work is given in Annex 3 to this part and more detailed advice on scheme-level assessment is included in HD 30 (DMRB 7.3.3).

SURVEY CATEGORY

4.7 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.

4.8 The survey category defined by time of year, and temperature limits shall be as specified in Table 4.1 and Figure 4.2 respectively. The appropriate use of the categories shall be as specified in Table 4.2. The reasoning behind these categories is explained in paragraphs 4.9 to 4.12. In certain circumstances it may be necessary to vary these standards, see paragraphs 4.24 to 4.25.

4.9 **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 long-life pavements should ideally be based on a Category 1A survey.

4.10 **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.

4.11 **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 condition of the pavement.

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

4.13 Designs for structural maintenance shall be based on deflection data which complies with Category 1A for at least 90% of the length of each CHART/MARCH section or part section. Category 2 surveys are intended to provide advanced information for maintenance planning. If however the results obtained indicate an unexpected trend, short lengths shall be re-tested under conditions specified for Category 1A. Category 3 surveys may be useful for identifying changes of performance along the length of a particular road without the need for a complete deflection analysis.

Equivalent Thickness of Sound Bituminous Material (ESBM)

4.14 Deflection of bituminous pavements varies with temperature. The susceptibility to change is dependent on the thickness, age and condition of the bituminous layers. The parameter ESBM attempts to embody these factors. It should be noted that ESBM is a temperature/ deflection susceptibility parameter and is not in any way an indicator of the structural equivalence of a pavement or its layers.

4.15 ESBM is required for correction of deflection to the standard temperature of 20°C and is calculated automatically by PANDEF following input of construction information. The bituminous material 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.

4.16 Bituminous pavement layers comprising multiple surface dressings (where the total thickness is less than 25mm), any bituminous layers beneath cement-bound layers and any bituminous layers with their upper surface at greater than a 200mm depth and separated from the higher bituminous layers by granular layer should be ignored and not entered into PANDEF.

Early Life Surveys

4.17 Surveys should not be done within two years of a new road being opened or a road having had a major strengthening treatment. 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

4.18 The road temperature specified in Figure 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 wheelpath.

4.19 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 within the pavement increases. The limiting rate of increase of temperature of no more than 2.5°C per hour, as specified in paragraph 4.36, is applied for the same reason.

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 15 of month, starts 16 of month

Table 4.1 Time of Year and Survey Categories

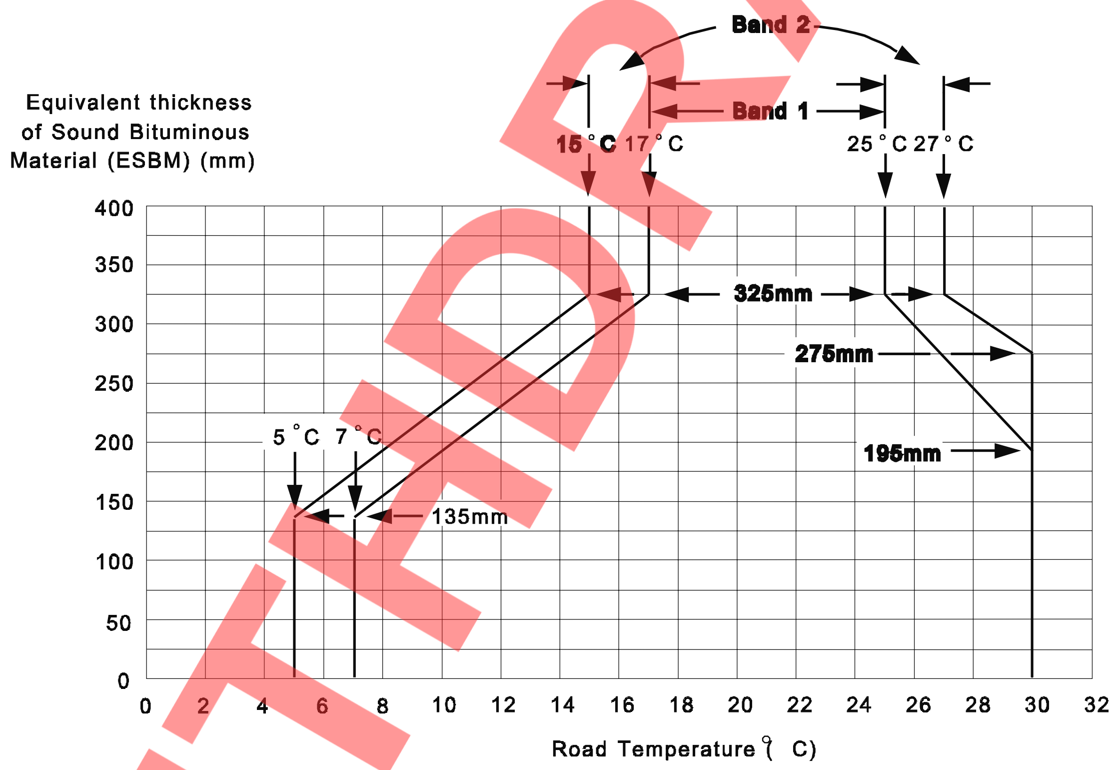


Table 4.2 Temperature Limits for Survey Categories

Purpose of Survey	Minimum Category Required
To finalise the details of a Maintenance Contract 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**
Routine maintenance planning (at least one further survey expected before strengthening measures required)	2
Relative assessment within a site	3

Table 4.2 Survey Specification for Trunk Roads

4.20 Surveys may take place, within the permitted temperature range, at any time of day or night. ESBM values, obtained from PANDEF 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.

Composite Pavements

4.21 The deflection behaviour with temperature of pavements with strong cement-bound layers covered by bituminous material can be significantly different from that of a fully flexible construction. As the pavement temperature of a composite pavement increases then the pavement deflection can decrease rather than increase as would be expected from the behaviour of fully flexible pavements. This effect is due to the cement-bound layer expanding with increasing temperature causing the cracks to start locking together so stiffening the structure. Although the stiffness of any bituminous layers will at the same time be reducing, the actual reduction being related to their thickness, the overall effect can be an increase of the total pavement stiffness and hence a reduction in measured deflection to relatively low values.

4.22 The temperature dependency of seriously cracked composite pavements, characterised by fairly high deflections, is however similar to that of fully flexible pavements. The temperature correction procedure for composite pavements, classified as base type “CEMT” in Table 4.3, is applied only when measured deflections exceed 0.4mm, to take account of this difference in behaviour.

4.23 In addition, many flexible composite pavements have, during their lifetime, received quite substantial bituminous overlays. The temperature and deflection behaviour of such pavements will be more like a fully flexible pavement than a flexible composite pavement. Therefore flexible composite pavements with bituminous bound layers of 300mm or greater are classified as base type “BITS” as shown in Table 4.3.

Permitted Variations

4.24 Circumstances may sometimes occur which make it impossible to work within all the parameters specified for Categories 1 and 2. The PANDEF program will annotate the survey measurements appropriately. In that event, engineering judgement and previous experience should be used when interpreting the deflection results.

Time of Year

4.25 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 should 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.

SURVEYS

Frequency and Timing

4.26 A knowledge of the trend of average deflection is an important factor in the assessment of condition. The preferred approach to monitoring the structural condition of a trunk road network is to establish a record of the deflection history of its various links by carrying out deflection surveys on a routine basis.

4.27 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.

4.28 If conclusions are drawn from individual surveys carried out at discrete points in time, these conclusions carry a high risk of being wrong, whether in relation to high or low readings, unless there is a comprehensive investigation of cause and effect for either condition.

4.29 A more reliable assessment of pavement deterioration may be obtained from an examination of average deflection trends derived from surveys carried out at regular intervals throughout the life of the pavement. At least three surveys are needed to establish a trend. However, the first survey should not take place until the pavement and subgrade have stabilised, which usually takes two or more years after the opening of new roads or major rehabilitations. Deflections on long-life pavements are expected to be constant or decrease with time and therefore a careful inspection of deflection trends can give further confidence about pavement categorisation.

Planning Considerations

4.30 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 4.2 will influence the timing of surveys on particular sites within the overall survey plan.

4.31 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.

4.32 On multi-lane roads surveys are required in both directions but should normally be confined to lane 1 in the first instance. Surveys of the other lanes should normally only be considered where there is a significantly different construction and/or where the traffic loadings in adjacent lanes are greater than in lane 1.

4.33 The Deflectograph operates at a nominal speed of 2.5km/hr. 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.

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

SURVEY PROCEDURE

Test Procedure

4.35 The following operating procedure shall be adopted:

a) the Deflectograph shall be positioned so that the nearside beam-tip follows the centre of the nearside wheelpath of the lane to be surveyed;

b) the machine shall operate at a constant speed not exceeding 2.5km/hr;

c) the operator shall reference the deflection record to the network in accordance with instructions issued by the Overseeing Organisation. Additionally, the location of easily identifiable features shall 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 shall be terminated.

Road Temperature Measurement

4.36 The road temperature, as defined in paragraph 4.18, and its location and time shall 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 shall also be recorded when passing into or out of continuously shaded areas on the carriageway and areas having significantly differing surface characteristics. Surveys shall not continue if the temperature at any one point is changing at a rate exceeding 2.5°C per hour, in any period of at least 15 minutes.

4.37 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 bituminous material. Before taking a temperature measurement any heat generated in making the necessary hole in the road should 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 should be taken to ensure that the temperature value indicated on the gauge has stabilised before a representative value is recorded.

Location referencing

4.38 In addition to location referencing it is also useful to mark cracks and patches that coincide with deflection readings and any areas having an interconnected pattern of cracks. This will assist with identifying possible causes of changes in the deflection profile along the road. A typical format of coded events used by Deflectograph operators is given in Annex 2 to this Part.

Use on Jointed Concrete Pavements

4.39 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. Testing should preferably be carried out at pavement temperatures less than 10oC, when joints may be expected to have opened up. Use of the Deflectograph in this way may prove useful but does not presently form part of the Overseeing Organisation's standard procedure. An approved, but slower, method of carrying out such joint assessments is to use the Falling Weight Deflectometer as described in Chapter 5 of this Part.

Pavement Condition Inspections

4.40 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 should, in all cases, be ascertained by enquiry to the Overseeing Organisation. The type, thickness and condition of the component pavement layers shall also be determined by ground radar, boreholes or trial pits as appropriate. The amount of detailed information to be collected shall 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 (PANDEF)

4.41 The current version of the Overseeing Organisations' PANDEF computer program, or a recognised program approved by the Overseeing Organisation shall be used for processing deflection data.

4.42 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.

4.43 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 should 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

4.44 This category includes strong fully flexible and some flexible composite pavements (as described in paragraph 4.23) with substantial bituminous thickness. They are identified as being potential long-life pavements from their deflection level and total thickness of bituminous material (TTBM). More details on this category of pavement are given in Annex 3 to this Part. 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

4.45 Fully flexible and flexible composite 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 fully flexible pavements 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 Annex 3 to this Part.

4.46 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.

4.47 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

4.48 The construction and traffic data for a site entered into the PANDEF database should 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 present in the pavement.

4.49 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 shall be derived using the method in HD 24 (DMRB 7.2.1).

Classification of Roadbase Type

4.50 The Deflection Design Method includes deflection/performance relationships for the following generalised pavement construction types:

a) unbound ie granular roadbase with no cementing action (GNCA)

b) flexible composite ie cement bound roadbase (CEMT)

c) fully flexible ie bituminous bound roadbase (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 4.3. 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

Table 4.3 Classification of Base Type

a - This does not include naturally cementitious materials.
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 and deflection levels.

4.51 The following functions in PANDEF shall 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

4.52 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

4.53 The traffic module in PANDEF which is used to calculate the annual standard axle flow for each year in each lane is fully compatible with the Structural Assessment and Maintenance Method given in Chapter 3 of HD 24 for calculation of design traffic. It 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.

4.54 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 should be given to the effects of significant planned network changes in determining traffic growth which can either be positive or negative.

4.55 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

4.56 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.

4.57 In England and Wales, factors to convert these flows to 24 hr AADF are available from the Department of the Environment, Transport and the Regions, Directorate of Statistics, Transport Statistics Roads Division, TSR1 Branch, given a description of the road as main urban or inter urban. Highway authorities are likely to have copies of the GTC; otherwise the census information can be obtained from TSR1.

4.58 For the period after 1978, the core or rotating census data held by TSR1 provides 24 hr AADF values for commercial vehicles. The core census consists of some 170 randomly selected sites for which traffic is counted on 3 days in each month of the year. Some 110 of these sites are on motorway, trunk or principal roads. The 6 year rotating census, which was started in 1980, will cover all links (between major intersections) of the motorway, trunk and principal road network with a random sample of about one sixth of the sites, counted once in each year of the cycle.

4.59 Where the sources mentioned in paragraphs 4.56 and 4.57 cannot provide suitable data, it may be necessary to mount a short survey. TSR1 will advise on the design of the survey and would add the data to their national data bank for possible future use (see Traffic Appraisal Manual for further information (DMRB 12.1)).

4.60 In order to obtain the required one direction flow of commercial vehicles, it will be necessary to apply a directional split. Where possible this should be calculated from the census data. A 50/50 split should 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.

4.61 In Scotland and Northern Ireland, all enquiries relating to traffic data should be referred to the Overseeing Organisation.

Presentation of Results

4.62 Summary data from PANDEF in support of bids for maintenance shall 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.

Interpretation and Application of Results

4.63 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.

4.64 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 Annex 3 to this Part and that in HD 30 (DMRB 7.3.3), in reaching a judgement on 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 provides advice on the interpretation of results. It also sets out the requirements for calibration and operation of the FWD.

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 a trailer mounted device, towed behind a vehicle (Figure 5.1).

Figure 5.1 Falling Weight Deflectometer

5.3 The current policy for strength testing of flexible pavements described in this Part and in HD30 (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 and types.

5.5 There are many different methods of analysing 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. Therefore the primary uses of the FWD are as follows:

a) To assess the stiffness of various pavement layers;

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 should not be used in isolation; it is important to characterise material properties and understand pavement deterioration mechanisms (see HD 30 DMRB 7.3.3).

SURVEYS

5.6 Surveys should be commissioned for the specific purposes described in 5.5, following approval by the Overseeing Organisation. They should be carried out on lengths, or sample lengths, of 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

5.7 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.

5.8 FWDs vary in detail depending on manufacturer. Ferne (1990) has reported on comparative trials of FWD systems in use in the UK and found good agreement in machine performance.

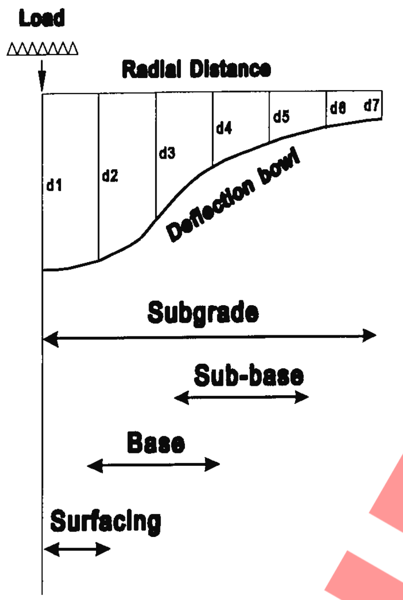


Figure 5.2 FWD Deflection Bowl

Machine Calibration and Approval

5.9 Evidence of a satisfactory absolute calibration by the equipment manufacturer and consistency checks by the operator should be provided. The absolute calibration of the deflection sensors, load cell and system processor should be carried out annually.

5.10 Consistency checks of the dynamic response of the machine as a whole should take place at intervals of six weeks or less during periods of operation and after any major service involving replacement parts. Details of the requirements are given in Annex 4 of this Part. In addition, all FWDs are to be tested and approved by the Overseeing Organisation in an annual FWD correlation trial to check their adequacy for trunk road testing.

LAYER STIFFNESS EVALUATION

5.11 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 CBM. 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 HD 30 (DMRB 7.3.3).

e) To determine the effective stiffness modulus of cracked and seated and saw-cut, cracked and seated concrete pavements. Further information on testing requirements and analysis in England is given in Speclib documents EUSL/1000/14 and EUSL/1000/15.

Test Procedure

5.12 On flexible and composite pavements the load level should be set at a nominal 50kN $\pm$ 10%. On concrete pavements, where deflections may be very low, ie d1 is less than 100 microns, this may be increased to a nominal 75kN $\pm$ 10%. The load pulse should 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 should be activated. Deflections should 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.

5.13 There should be no standing water on the road surface and care should 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 for different types of construction. At least 3 drops, plus a small initial drop for settling the load plate, should be made at each test point and checks made for consistency before analysis.

5.14 Normally the loading plate should be located in the nearside wheelpath of the left-hand lane to assess the line of greatest deterioration. Additional measurements with the plate set between the wheelpaths 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 wheelpaths.

5.15 Typically, longitudinal spacing of measurements should be between 5 and 20m for sample lengths of fully flexible pavements. On flexible composite pavements 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 should ideally be taken in mid-slab locations and away from cracks.

Pavement Temperature

5.16 The temperature of the bound layer of the pavement should normally be 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.

Additional measurements at greater depths may be needed when testing flexible pavements with very thick bituminous layers. Holes for temperature measurements should 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.

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

5.18 The preferred temperature range for stiffness evaluation testing on fully flexible pavements 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 bituminous materials becomes increasingly viscous and it is more difficult to distinguish between sound and unsound materials. In addition, since the stiffness of bituminous 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. Therefore on fully flexible pavements, greatest confidence can be placed on surveys carried out within the temperature range 15 to 25°C.

5.19 Additional care needs to be taken when assessing flexible-composite pavements. The effective stiffness of cement-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 composite 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). Care should also be taken when testing rigid pavements to avoid significant temperature gradients as hogging or warping of the slabs can seriously affect the results.

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

Table 5.1 Recommended deflection sensor positions

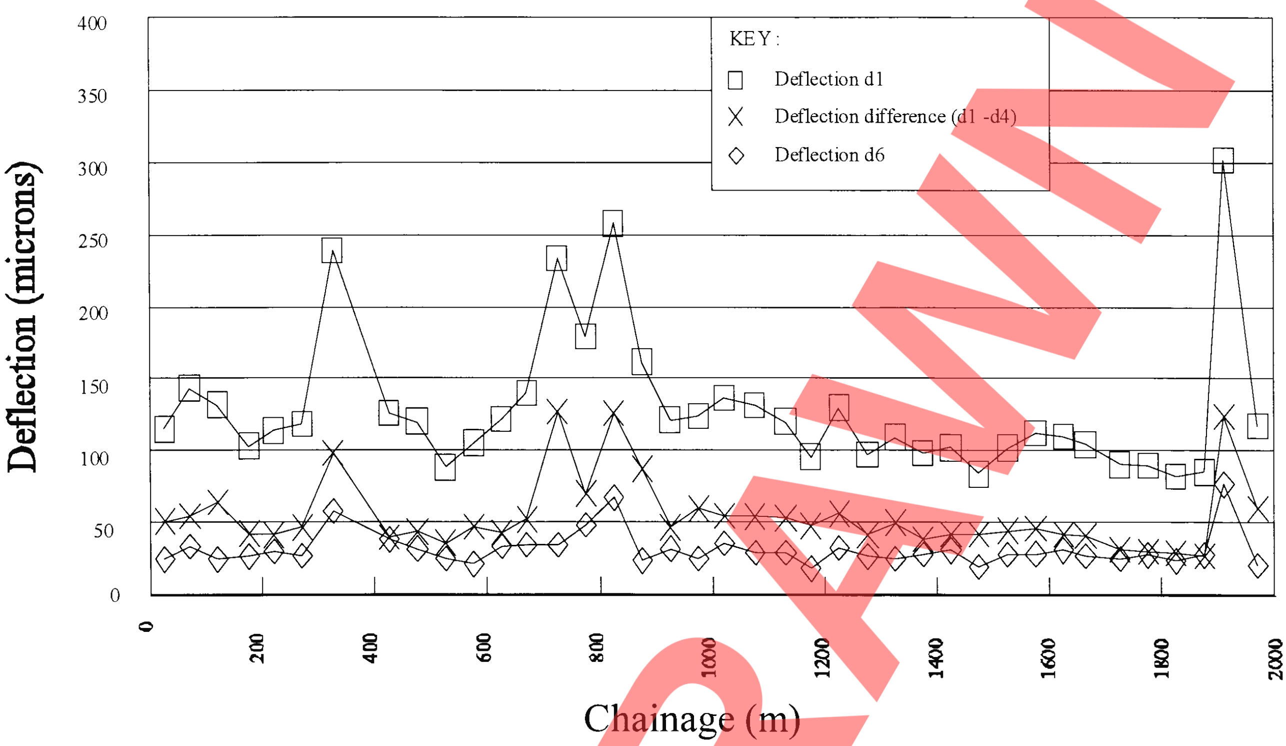


Figure 5.3 FWD Deflection Profiles

ANALYSIS AND INTERPRETATION

Deflection Assessment

5.20 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.

5.21 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 Cement Bound Material

5.22 Results of tests on cement bound bases 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

5.23 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 match is obtained.

Program:

The program used shall model the pavement structure as a number of horizontally infinite linear elastic layers.

Pavement model:

1. No attempt shall be made to model any layer less than 75mm thick as a single layer.

2. The bound layers shall normally be modelled as one layer with a total thickness equal to the combined thickness of the individual layers. However, if there are two layers of distinctly different bound material eg bitumen and cement bound, then these shall be treated as separate layers provided the thickness of each is greater than 75mm and neither is less than one third the thickness of the other.

3. The unbound layers shall be modelled as a single layer of infinite depth. The exception to this is where there is a separate granular layer above the natural subgrade whose thickness is greater than the combined thickness of all the bound layers; in this case this layer shall be modelled separately.

4. Poisson's ratios for each layer shall be those shown in Table 5.3.

5. The stiffness of bituminous-bound layers shall be adjusted to the standard reference temperature of 20°C using the following relationship:

$$\text{Stiffness at } 20^{o}\text{C} = (\text{Stiffness at T}) \times 10^{(0.0003 \times (20-T)^2 - 0.022 \times (20-T))}$$

where T is the temperature of the bituminous material at the time of FWD testing (°C) measured at 100mm depth.

Goodness of fit:

1. The goodness of fit of the calculated to the measured bowl shall be determined for each measurement point. Although a good fit does not in itself indicate that a correct solution has been obtained, a poor fit almost certainly indicates that the solution found is suspect. Further details are contained in paragraph 5.31.

2. The equations used for goodness of fit are as follows:

Absolute mean deviation (AMD) = $\left| \Sigma (d_{ci} - d_{mi})/7 \right|$

Absolute RMS deviation (RMS) = $\sqrt{(\Sigma(d_{ci} - d_{mi})^2/7)}$

where: d_{mi} are the measured and d_{ci} the calculated deflections at positions i=1 to 7, respectively (microns).

3. Guide values of AMD and RMS are contained in Table 5.4.

Table 5.2 Standard back-analysis procedure

5.24 In order to carry out back-analysis of deflection bowl measurements the pavement must first be divided into layers of homogeneous materials. Ideally, the stiffness of adjacent layers should differ significantly if they are to be modelled separately. The simplest model consists of two layers, the results indicating the stiffnesses of the bound and unbound materials present.

5.25 A standard procedure for carrying out FWD back-analysis is described in Table 5.2. This is based on a relatively simple modelling approach with minimum layer-thickness criteria used to limit the number of layers modelled. Although analysis of the pavement and subgrade sub-divided into more layers is possible, the degree of uncertainty in the stiffnesses obtained for the layers increases with the use of these more complex models. The procedure described in Table 5.2 should be followed whenever FWD bowl measurements are back-analysed to provide estimates of layer stiffnesses. Other procedures can be used in addition to the standard procedure but their use shall be clearly justified.

5.26 At present there is no approved standard FWD back-analysis computer program. However, results obtained using the procedure described in Table 5.2 will be relatively consistent provided that a linear elastic multi-layer program is used. Material non-linearity and relative error in deflection measurements are considerations which affect the accuracy of derived stiffness data. Nevertheless, weak layers and strong layers can be identified whichever method is used.

5.27 Accurate measurement of layer thickness is essential to the analysis. An under-estimate of as little as fifteen percent in thickness, which is not uncommon given construction tolerances, can result in an over-estimate of over fifty percent in bound-layer moduli values, enough to give the impression of good integrity of a poor layer. Thickness information may be obtained by coring. Sufficient cores should be taken to provide a reliable record of layer thickness data. An indication of where cores would be most appropriate may be assessed from the deflection profile. Alternatively, ground radar, in conjunction with cores or other supporting data, has shown the potential to provide continuous estimates of layer thickness (see Chapter 6 of this Part).

MATERIAL	POISSON'S RATIO
Bituminous bound	0.35
Cement bound	0.20
Crushed stone	0.40
Soils (fine-grained)	0.45

Table 5.3 Poisson's ratios for use in back-analysis

Adjustment of Bituminous Layer Stiffness for Temperature

5.28 The stiffnesses derived from back-analysis represent estimates of the in-situ values at the time of testing. The stiffness of bituminous materials 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.

5.29 The temperature dependence of the stiffness of bituminous materials 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 bituminous materials. However, tests on a wide range of samples have indicated that the relationship given in Table 5.2 can be used to provide a satisfactory adjustment to bituminous layer stiffnesses provided that testing is carried out within the temperature range 15 to 25°C. The relationship may also be applied to results obtained where the temperature is lower than 15°C or greater than 25°C although the absolute values of the adjusted bituminous stiffnesses should be treated with caution. For severely cracked bituminous materials, temperature adjustment may not be appropriate.

Goodness of Fit

5.30 The closeness with which the back-calculated bowl matches the measured bowl provides an indicator of the goodness of fit of the model. Although a good fit does not in itself indicate that a correct solution has been obtained, a poor fit almost certainly indicates that the solution is suspect. Increasing the number of layers in the model tends to improve the fit.

5.31 Two goodness of fit parameters are defined in Table 5.2: the absolute mean deviation (AMD) and the absolute root mean squared deviation (RMS). It is recommended that values for these parameters are calculated and reported for every bowl analysed. The AMD indicates whether or not there is an overall bias to the calculated bowl with respect to the measured bowl; RMS indicates how closely the calculated and measured bowls match. Table 5.4 contains tentative guide values for AMD and RMS for fully-flexible pavements modelled with both two and three layers and for flexible-composite pavements modelled with three layers (all modelled using the standard analysis method described in Table 5.2). Although different back-analysis programs may vary significantly in their ability to match calculated to measured deflections, there are other reasons why the AMD and RMS values may exceed those shown in Table 5.4. These include the presence of cracks or other discontinuities, incorrect layer thicknesses or material types assumed in the modelling and layer debonding. Back-analysis of rigid pavements is less straightforward and will generally result in significantly greater AMD and RMS values than shown in Table 5.4.

PAVEMENT TYPE AND NUMBER OF LAYERS	PARAMETER VALUES (microns) AMD	RMS
Fully-flexible 2 layers	0.6	6
Fully-flexible 3 layers	0.2	3
Flexible-composite 3 layers	0.5	5

Table 5.4 Tentative guide values for goodness of fit

Reference Stiffness Values

5.32 Some of the factors that influence layer stiffness of various materials are given in Table 5.5. Typical values related to likely condition are given in Table 5.6. In all cases assessments should be checked for correlation with visual condition, evidence from cores and results of laboratory testing.

MATERIAL	STIFFNESS DECREASES	STIFFNESS INCREASES
Bituminous	High voids Cracking Layer debonding Stripping	Low voids Binder-hardening
Concrete	Joint nearby Cracking Debonding Poor compaction	
Granular	High moisture Clay contamination	Low moisture Natural-cementing
Subgrade	High moisture	Low moisture Increased depth

Table 5.5 Factors affecting layer stiffness

5.33 Although FWD back-analysis can provide an indication of the condition of layers, it is not so easy to determine the cause of the deterioration. Comparisons of the layer stiffnesses derived from measurements made where the material is relatively untrafficked, with those from the line of the wheelpath can indicate whether deterioration is due to trafficking.

Bound Layer Stiffness at 20°C Derived from FWD	Condition of bound layer: Poor Integrity Throughout	Some Deterioration	Good Integrity
Bituminous	< 3 GPa	3 - 7 GPa	> 7 GPa
Lean Concrete	< 8 GPa	8 - 15 GPa	> 15 GPa
PQ Concrete	< 20 GPa	20 - 30 GPa	> 30 GPa

Table 5.6 Condition related to bound layer stiffness

5.34 For foundation layers of existing pavements a layer stiffness of 0.1GPa (=100MPa) or greater has been found to be associated with good performance of fully flexible pavements. It is also thought to be a reasonable criterion for the unbound foundation layers of flexible composite and PQ concrete pavements. More than 100MPa would be expected for a lean-concrete sub-base below a PQ concrete pavement. Large variations in the measured foundation support are usually associated with a change in drainage efficiency, sub-base/capping layer or subgrade material or a construction change such as a cut/fill line.

Comparing FWD stiffnesses with ITSM

5.35 Often when carrying out pavement evaluation studies, it is useful to compare results obtained from in-situ measurements with those obtained on samples extracted from the road and tested in the laboratory. The indirect tensile test is a common laboratory test used for determining the indirect tensile stiffness modulus (ITSM) of bituminous materials. This test is currently a British Standard draft for development (DD 213: 1993). Research has shown that there is a strong association between ITSM values and bituminous layer stiffnesses estimated from FWD back-analysis. As the stiffness of bituminous materials is loading-time dependent, the shorter pulse of the FWD results in stiffnesses greater than ITSM values. As an approximate guide, ITSM values at 20°C should be multiplied by 1.5 to allow comparison with FWD-derived bituminous layer stiffnesses at 20°C.

Reporting of Results

5.36 Reports of estimated layer stiffness should include a description of the back-analysis software program used and details of how the pavement was modelled. Where a more complex model has been used in addition to the standard method, this shall be justified. For each test point, the load level, measured deflections, goodness of fit, layer thicknesses and pavement temperature at 100mm depth should be reported.

Maintenance Treatment

5.37 Layer stiffnesses derived from FWD measurements are particularly useful for supplementing data from the assessment method for flexible pavements based on Deflectograph measurements. They provide a qualitative indication of the location of weakness in the structure and assist with decisions on the most appropriate type of strengthening.

5.38 The most straightforward treatment is an overlay on the existing pavement using thicknesses derived from Deflectograph measurements. However, if any of the bound layers have poor integrity they should be replaced, since if they remain they are likely to deteriorate further causing increased stresses in the other layers. If only the upper bound layers are affected the pavement may still be strengthened with an overlay after replacement of the material in poor condition.

5.39 If the lower bound layers need to be replaced, a new pavement should be designed using an approved method, according to the foundation support assessed from the FWD measurements or direct measurements on the exposed foundation.

5.40 Where there is poor foundation support, this may be due to inadequate drainage. If so, remedial works should be carried out before reassessing the site for treatment design. If the drainage is satisfactory, the pavement may be strengthened with an overlay, if this is a practical solution, otherwise full reconstruction will be necessary.

LOAD TRANSFER EFFICIENCY

5.41 The main use of the FWD in relation to PQ concrete pavements is the evaluation of load transfer efficiency 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 should 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 should 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 should be measured to a resolution of at least 1 micron over the range 0-2mm by a minimum of three sensors.

5.43 There should be no standing water on the road surface and care should 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, should 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 load transfer efficiency 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 of the discontinuity is generally the weaker side and therefore if resources and time are limited, priority should be given to loading on the downstream side. However, it should be noted that this may mean that the FWD testing vehicle is facing 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.

Pavement Temperature

5.46 The temperature condition of the pavement can have a significant effect on the measured load transfer efficiency. 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 should be tested at a similar temperature, ideally below 15°C, when the widths of the discontinuities are greater and the degree of movement is more severe. It should also be noted that a temperature gradient through the slab may affect the load transfer efficiency.

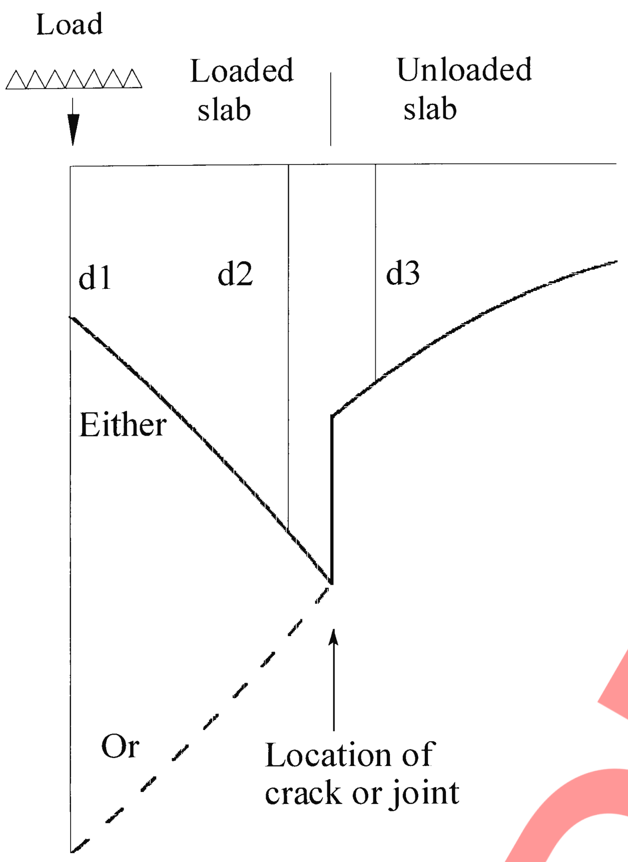


Figure 5.4 **Load Transfer Efficiency: FWD Deflection Profile**

ANALYSIS AND INTERPRETATION

5.47 The load transfer efficiency is defined as the ratio of:

$$\frac{\text{deflection of unloaded slab}}{\text{deflection of loaded slab}}$$

expressed as a percentage. For the arrangement shown in Figure 5.4 this is taken to be equivalent to:

$$\frac{d3}{d2} \quad (\text{x } 100\%)$$

5.48 Joints or cracks with perfect load transfer should give a transfer efficiency, as defined above, of just under 100% but values of 75% or more would be considered acceptable. Poor load transfer at joints is normally caused by non-existent, corroded, broken or loose dowel bars or by a lack of support on the loaded side of the slab. Poor load transfer at cracks can be due to loss of aggregate interlock, lack of support on the loaded side of the slab or, in the case of reinforced concrete, due to the rupture of the reinforcement.

Maintenance Treatment

5.49 Joints where dowel bars need replacing can be identified. Areas with poor support may be rectified by improved drainage, or under-slab grouting techniques provided the subgrade is not weakened by drainage problems. Detailed advice on carrying out structural repairs to concrete is contained in HD 32 (DMRB 7.4.2).

6. REFERENCES AND BIBLIOGRAPHY

References

1978

LR833; Kennedy C K and Lister N W, "Prediction of Pavement Performance and the Design of Overlays", TRRL.

LR834; Kennedy C K, Fevre P and Clarke C S, "Pavement deflection: equipment for measurement in the United Kingdom", TRRL.

1994

HD 28 (DMRB 7.3.1) Skidding Resistance.

HD 31 (DMRB 7.4.1) Maintenance of Bituminous Roads.

PANDEF and POD Easy Guide; Highways Agency.

1996

HD 24 (DMRB 7.2.1) Traffic Assessment.

1997

Traffic Assessment Manual (DMRB 12.1).

1999

HD 30 (DMRB 7.3.3) Maintenance Assessment Procedure.

Bibliography

1986

CHART 5; Illustrated Site Manual for Inspectors, Department of Transport.

1988

High-speed Road Monitor Proving Trial, Report of Assessment and Recommendations for use, Unpublished Report, Department of Transport.

1989

RR183; Jordan P G and Cooper D R C, "Road Profile Deterioration as an Indicator of Structural Condition", TRRL.

1990

Ferne B W, "Comparative trials of Falling Weight Deflectometer systems in use in the United Kingdom". Proceedings 3rd International Conference on Bearing Capacity of Roads and Airfields, Trondheim, Norway.

Young J C and Cooper D R "Assessment of concrete roads: Criteria for use with High-speed Road Monitor surveys, Unpublished Working Paper WP/MC/18, Department of Transport.

HRM Analysis User Manual, Highways Computing Division, Department of Transport.

RR189; Goddard R T N, "Structural investigation of roads for the design of strengthening", TRRL.

1991

Cooper D R "Advice on the interpretation and use of High-speed Road Monitor network survey outputs, Unpublished Working Paper, WP/PE/100, Department of Transport.

1992

Trunk Road Maintenance Manual: Volume 1, Highways Maintenance Code, Department of Transport.

Trunk Road Maintenance Manual: Volume 2, Routine and Winter Maintenance Code, Department of Transport.

1993

PANDEF User Manual. Highways Computing Division. Department of Transport.

1997

Report 250; Nunn M E, Brown A, Weston D and Nicholls J C, "Design of long-life flexible pavements for heavy traffic", TRL, 1997.

1999

Speclib Reference No. EUSL/1000/014, "Cracking and Seating of Existing Jointed Concrete Pavements and Flexible Composite Pavements", Highways Agency.

Speclib Reference No. EUSL/1000/015, "Saw-cut, Crack and Seat of Existing Jointed Reinforced Concrete Pavements", Highways Agency.

7. ENQUIRIES

Approval of this document for publication is given by the undersigned:

Quality Services Director The Highways Agency St Christopher House Southwark Street London SE1 0TE	J KERMAN Quality Services Director

The Chief Road Engineer The Scottish Executive Development Department National Roads Directorate Victoria Quay Edinburgh EH6 6QQ	J HOWISON The Chief Road Engineer

The Director of Highways The National Assembly for Wales Cynulliad Cenedlaethol Cymru Highways Directorate Government Buildings Cathays Park Cardiff CF1 3NQ	K J THOMAS Director of Highways

Director of Engineering Department of the Environment for Northern Ireland Roads Service Clarence Court 10-18 Adelaide Street Belfast BT2 8GB	V CRAWFORD Director of Engineering

All technical enquiries or comments on this document should be sent in writing as appropriate to the above.

1. DEFLECTION BEAM

CALIBRATING AND OPERATING PROCEDURES

1.1 This annex aims to explain briefly the principles of the deflection beam for those unfamiliar with the method and also to give details for calibration and the test procedure.

Description of Apparatus

1.2 The beam shall be made to a design approved by the Overseeing Department. Full details are given in LR834 (1978) and detailed drawinga are available from TRL.

1.3 The main dimensions for the beam are shown in Figure 1.1. It is important that the beam is well maintained with bearings being oiled and bolts tightened. The dial gauge should have a travel of at least 25mm and be calibrated in at least 0.1mm graduations. The dimensions and loading for the test lorry are indicated in Table 1.1. If tyres other than those listed are used, then it may be necessary to modify tyre pressures to maintain the contact area similar to that shown in Figure 1.2 (See LR 834).

Dimensions	Metres	Feet	Dimensions	Metres	Feet
a	2.44	8	d	0.91	3
b	1.22	4	e	0.61	2
c	0.30	1	f	1.30	1.30

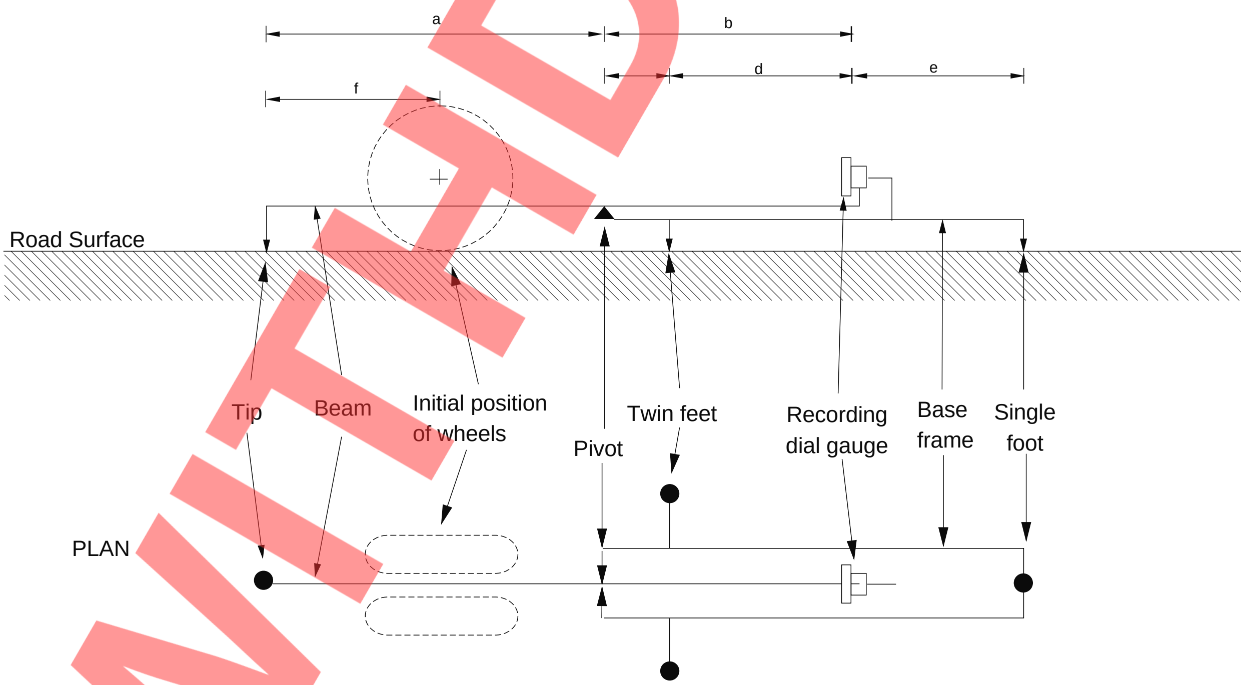
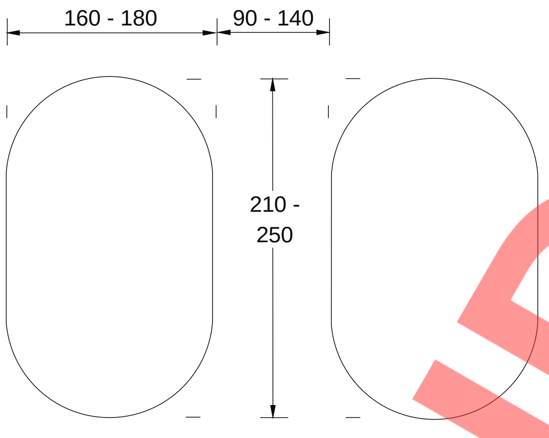


FIGURE 1.1 Diagrammatic Representation of the Deflection Beam

Volume 7 home page

CHARACTERISTIC	VALUE
Rear axle load	6350kg ± 10%
Dual rear wheel load	3175kg ± 10%
Front axle load	Between 2300 and 3300kg
Wheel base	Nominally 3.85m
Tyre size	8.25 x 20 Preferred 7.50 x 20 Preferred 9.00 x 20 Acceptable
Tyre pressure	5.9 bar (85psi)
Minimum gap between walls of twin rear wheels	Not less than 20mm
Gap between contact area of twin rear wheels	90 - 140mm

TABLE 1.1 Details of Vehicles Suitable for Use with the Deflection Beam



(All dimensions in mm)

Calibration

1.4 The Deflection beam shall be calibrated immediately prior to the start of the programme and thereafter at not less than weekly intervals until the programme has been completed.

1.5 Particular attention shall be given to the following requirements:-

a) the calibration rig used shall be that supplied by the manufacturer for the purpose or a similar device approved by the Overseeing Department;

b) the beam vibrator shall be used throughout the calibration process;

c) two levels of input movements at the calibration rig shall be chosen appropriate to the expected range of survey deflections;

d) at least 5 consecutive readings of the beam dial gauge and of the dial gauge on the calibration rig shall be recorded;

e) the beam shall be deemed to be calibrated when the means of the readings taken on each dial gauge shall

not differ by more than 4% where the expected mean is greater than 0.25 mm and by not more than 0.01 mm where the expected mean is equal to or less than 0.25 mm.

1.6 If the calibration procedure indicates errors greater than those allowed, the cause shall be investigated and rectified. Two consecutive sets of calibrations which comply with the required tolerances shall be obtained before proceeding with the survey.

1.7 The Deflection Beam shall be used in accordance with the following requirements and procedures:-

a) measurements shall generally be in the nearside wheel track of the lane tested unless there is evidence that there has been greater deterioration in the other wheel track;

b) the loaded lorry shall be positioned in the wheel tracks of the lane to be surveyed with the centre-line of the rear axle 1.3 m behind the point of measurements;

c) the Deflection Beam, in the locked condition, shall be placed with the beam tip over the point of measurement and the beam centrally located between the twin tyres;

d) the alignment shall be checked to ensure that the tyres will not touch the beam when the lorry is driven forward;

e) the beam shall then be unlocked, the vibrator set running and the dial gauge zeroed;

f) the lorry shall then be driven forward at creep speed, such that the total time required to travel 5 m is 10 ± 1 second, to a position where the rear wheels are at least 3 m beyond the test point;

g) the maximum reading of the dial gauge shall be noted together with the final reading when the rear wheels of the vehicle have reached a point 3 m from the beam tip. (The magnitude of the pavement deflection is obtained by adding the maximum reading to the difference between the maximum and final readings).

Operating Procedures

1.8 Measurements are sensitive to operator technique. Therefore an experienced operator shall always be employed. Differential thermal expansion within the beam can cause significant errors, particularly on stiff pavements. In sunny weather the beam may pass from shade into sunshine as the vehicle moves. The thin metal shield supplied with the beam shall be fitted to reduce this effect. As deflection measurements taken with the Deflection Beam are not absolute, it is most important that the beam is correctly positioned in relation to the load wheels when initial and final readings of the dial gauge are made.

Volume 7 home page

2. DEFLECTOGRAPH

CALIBRATION AND OPERATION PROCEDURE

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

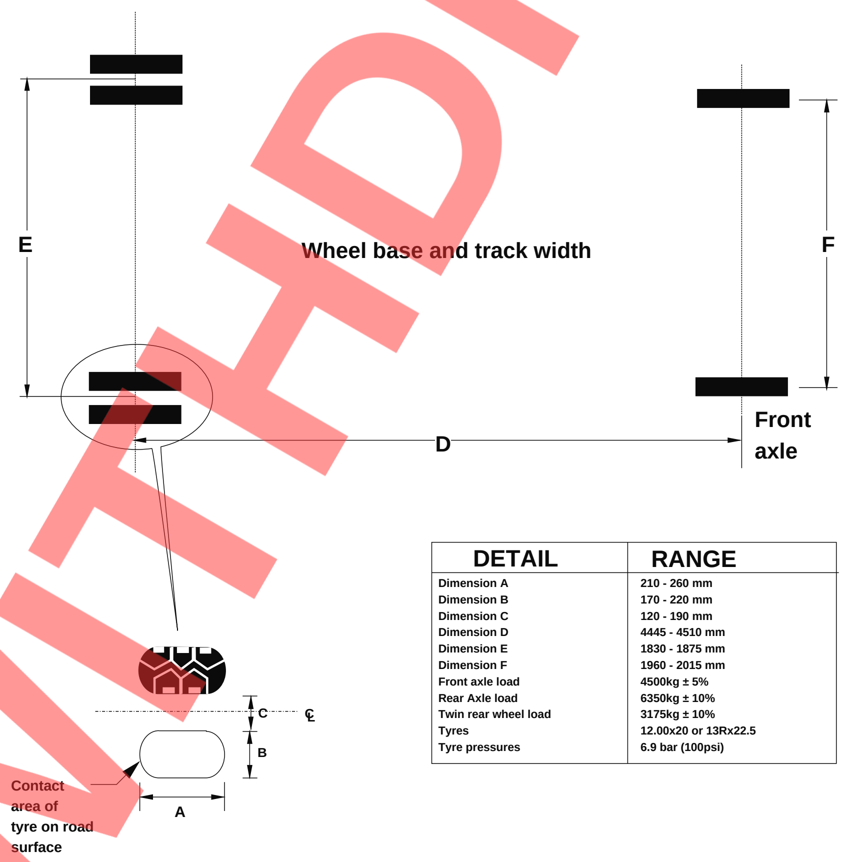
Apparatus

2.2 The details and dimensions for the chassis of the vehicle are given in Figure 2.1 and for the beam assembly in Figure 2.2. The equipment shall be made to a design approved by the Overseeing Department, full details are given in LR 834 (1978).

Calibration

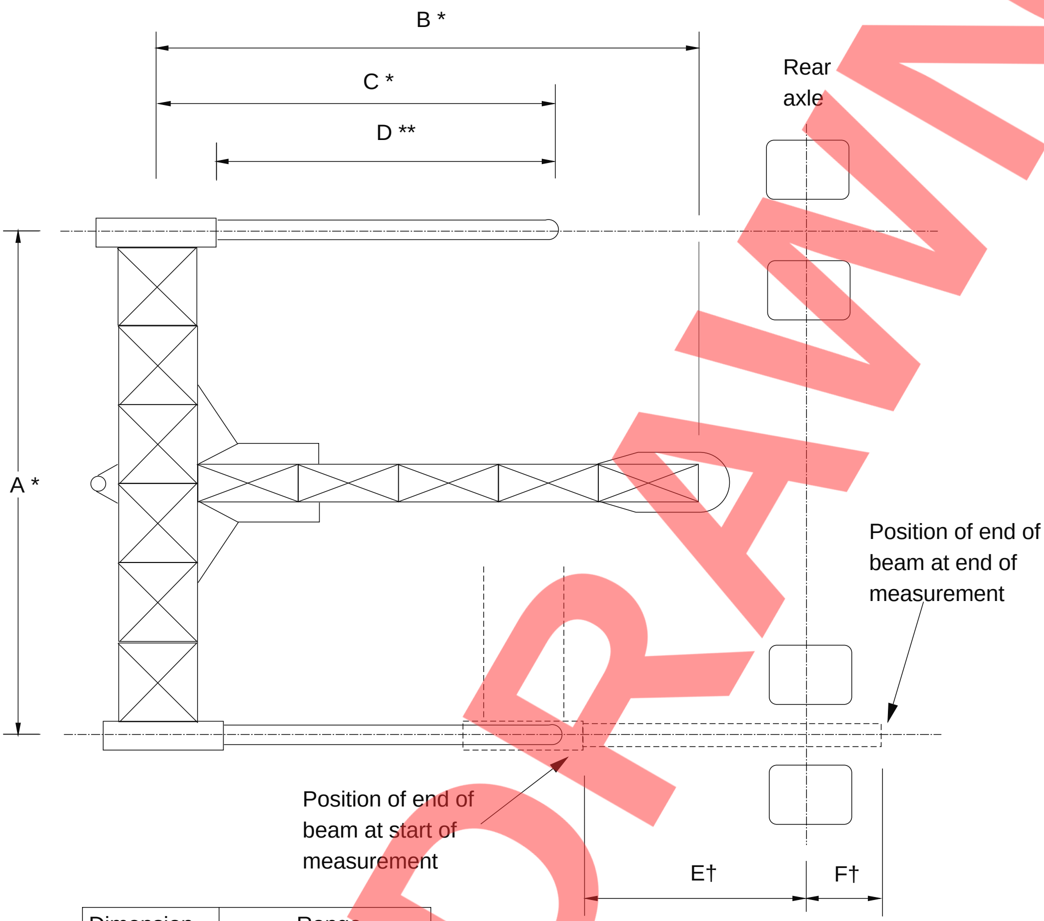
2.3 Particular attention shall be paid to calibration as deflection measurements are small, typically in the range 0 to 0.5mm.

2.4 Static and dynamic calibrations are required. Deflectographs shall be tested and approved annually in a group calibration trial by the Overseeing Department.



DETAIL	RANGE
Dimension A	210 - 260 mm
Dimension B	170 - 220 mm
Dimension C	120 - 190 mm
Dimension D	4445 - 4510 mm
Dimension E	1830 - 1875 mm
Dimension F	1960 - 2015 mm
Front axle load	4500kg ± 5%
Rear Axle load	6350kg ± 10%
Twin rear wheel load	3175kg ± 10%
Tyres	12.00x20 or 13Rx22.5
Tyre pressures	6.9 bar (100psi)

Figure 2.1 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 2.2 Deflectograph - Beam Assembly

2.5 Static calibration shall be carried out before each day's work, or every twelve hours, and shall comply with the specification in Table 2.1. A written record of all calibrations shall be kept for reference.

Static Calibration Procedure

Beam Tip Input Level (mm x 10^{-2})	Digital Output	
	Tolerance*	Max Range**
10	+1 - 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 2.1 Calibration of Deflectograph

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

b) the dial gauge shall be mounted on a separate baseplate and shall 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 shall be made for each input value between zero and 1mm.

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

Procedure

2.7 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).

TABLE 2.2 Deflectograph Static Calibration Record

DEFLECTOGRAPH STATIC CALIBRATION — Date :

Purpose : SURVEY / MACHINE CHECK * — Number :

Location : BASE / ROADSIDE * — (of calibration)

Beam Tip Input (mm x 10^{-2})	Digital Output		Compliance with Specification		Mean Calibration ◊	
	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

Volume 7 home page

Non-Compliance :

2.8 The results of the calibration set shall be compared with the appropriate limits specified in Table 2.1. 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 shall 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 shall be removed and repositioned under the beam tip and a second calibration set obtained. If the second calibration set is out of specification reference shall 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. A flow chart is given in Figure 2.3.

Consistency

2.9 The written records of daily static calibration should be examined for consistency at least every two weeks during periods of operation. If any serious trends or substantial variations are found in the calibration, reference should be made to the Deflectograph manufacturers' Operators Instruction Manual.

Calibration Correction by Computer Program

2.10 The calibrations to be entered should 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

2.11 The calibration rig should be kept in good condition. The dial gauge should be serviced and checked against a standard gauge at least annually.

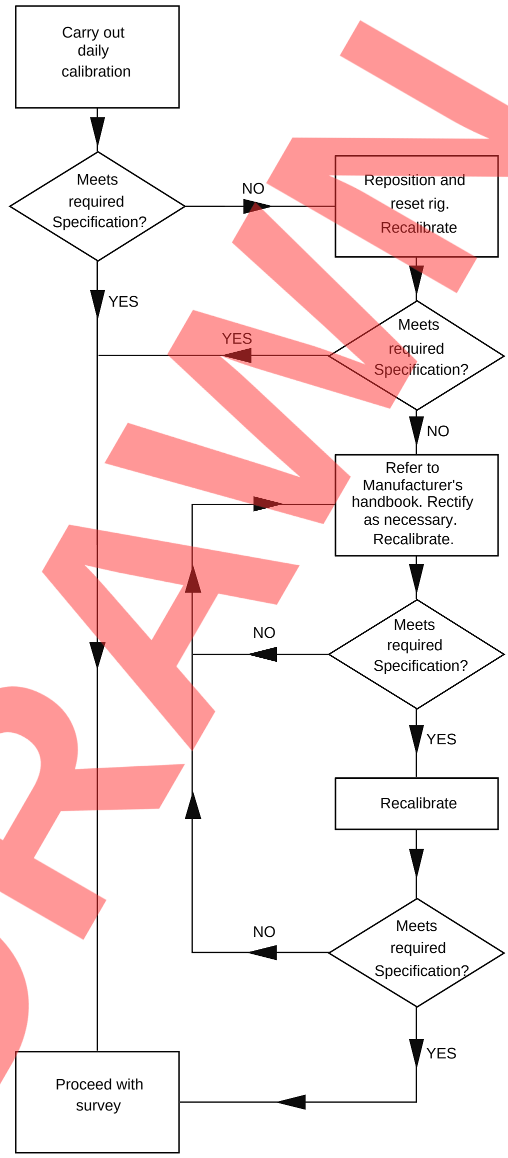


FIGURE 2.3 Flowchart for Checking the Calibration of the Deflectograph

Dynamic Calibration

2.12 The dynamic response of the machine shall 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 shall be carried out at intervals of not more than 6 weeks during periods of operation and

Volume 7 home page

whenever any major service involving replacement parts has taken place.

The Site

2.13 The choice of dynamic calibration site should be influenced by factors such as convenience of access and safety of operation.

2.14 Three sections should be chosen in order to check the machine on stiff, medium and weak pavements, each section having a reasonably uniform deflection with average deflections preferably within the range of 15-20, 25-35 and 40-50 x 10^{-2}mm respectively. The sections should be in one length of road, but if this is not possible separate sites should be located.

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

2.16 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.

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

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

2.19 If the pavement contains cement bound material it should be largely uncracked otherwise the deflection profile is liable to be excessively variable.

2.20 The wearing course should be in sound uncracked condition, except as described in paragraph 2.19, 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 up to 10 mm deep should be considered the absolute maximum.

2.21 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 wheelpaths in different directions.

2.22 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 path the overall mean deflection of each section and the variability should be calculated for each temperature at which measurements are taken.

Procedure

2.23 At least one calibration set should precede and follow the dynamic calibration, which comprises a minimum of 3 runs over the test sections of the calibration site.

Assessment of Results

2.24 Results of the calibration runs should 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 should 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 should be made. (This may be achieved by testing the site in the reverse direction).

Factors Affecting Dynamic Response of Machine

2.25 The permitted weights given in Figure 2.1 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 should 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.

2.26 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.

2.27 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.

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

Annual Group Calibration Trial

2.29 The specifications for static and dynamic calibration are intended to ensure that any one machine gives a consistent output. Variations in performance which occur should be evident from the calibration records. The object of the 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

2.30 A typical format of coded events used on the Overseeing Department's Deflectographs 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

2.31 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 should be made on all possible external causes.

3. DEFLECTOGRAPH: ANALYSIS AND INTERPRETATION OF RESULTS

3.1 Deflection measured under a rolling wheel load provides an indication of the strength of a flexible pavement structure. The requirements for routine deflection measurement with a Deflectograph are set out in Chapter 4 of this Part. Careful interpretation of deflection measurements in relation to many other factors is required when making an assessment of pavement condition and considering the options for strengthening. This Annex provides information and guidance on some of these interpretation processes. It is intended to be read in conjunction with other Chapters of HD 29 (DMRB 7.3.2) and also HD 30 (DMRB 7.3.3).

The Method of Assessment

3.2 The Deflection Design Method (1978), on which the PANDEF computer program (1993) is broadly based, depends on the conventional theory of pavement deterioration, manifested by fatigue at the underside of the roadbase or structural deformation, and assumes that deflection increases with time and traffic as the pavement deteriorates from traffic induced stresses. However, more recent research has shown that thick well-constructed fully flexible pavements on strong foundations do not deteriorate in this way and can have very long lives in structural terms, albeit with the need to maintain the surface in a serviceable condition.

3.3 The deflections of these “long-life” pavements (LLP) do not increase over time but stay steady or even decrease and show no other evidence to suggest deterioration of the structure. Clearly, deflections measured on such pavements need a different type of interpretation from that traditionally provided by PANDEF, otherwise ever shorter residual lives will be predicted with the passage of traffic even if deflections show no sign of increasing.

3.4 Criteria have now been derived so that some potentially long-life pavements on the network can be identified by PANDEF from deflection measurements and the total thickness of bituminous material (TTBM) present in the pavement. The criteria, which have been derived from linear-elastic modelling, are cautious and apply only to fully flexible pavements and flexible composite pavements with thick bituminous layers.

Total Thickness of Bituminous Material (TTBM)

3.5 TTBM is the combined thickness of all the contiguous intact bituminous layers present in the pavement. Most flexible pavements contain layers of bituminous material overlaying either granular or cement bound layers. However, some pavements which have been subjected to various maintenance treatments throughout their life, may contain layers of deteriorated or non-standard materials sandwiched between intact bituminous layers. Therefore, to take account of this, in addition to the criteria for pavement layers given in paragraph 4.16 of this Part, the definition of TTBM is subject to the following:

a) Bituminous surfacing layers (ie those within the top 100mm of the existing pavement) are included in TTBM regardless of their condition.

b) Bituminous layers which are known to be severely deteriorated and whose upper surface is at greater than a 100mm depth are not included in TTBM.

c) Any intact bituminous material (or deteriorated surfacing material) that is separated from other intact bituminous materials by either a severely deteriorated bituminous layer or any granular layer (either of which must be greater than 25mm thick and have their upper surface at greater than a 100mm depth) is not to be included in TTBM.

PANDEF uses the information stored in its construction database to automatically calculate TTBM. Using the definitions employed in PANDEF’s construction database, intact bituminous material includes sound dense and non-dense bituminous material. All other bituminous material is considered severely deteriorated (ie bituminous material which is either partially cracked, cracked or unsound).

Pavement Life Categories

3.6 The three pavement life categories identified in PANDEF are defined according to the TTBM, standard deflection and roadbase type. The category limits are described below and are shown in Figure 3.1:

a) The Long-Life Pavement (LLP) category is bounded by a minimum TTBM of 300mm and by an upper deflection limit, the value of which decreases with increasing TTBM.

b) The Upgradeable to Long-Life Pavement (ULLP) category is bounded by a minimum TTBM of 200mm, a maximum TTBM of 299mm and by an upper deflection limit, the value of which decreases with increasing TTBM. This categorisation applies only to pavements with roadbase type BITS (see HD 29, Chapter 4, Table 4.3).

c) The Determinate Life Pavement (DLP) category constitutes all those pavements whose deflection/ TTBM and base type combinations lie outside of the LLP and ULLP limits.

PANDEF uses deflection and construction information to determine which category is appropriate. Although this categorisation can be applied to individual deflections, the classification of a length of pavement as long-life should normally be based on the 85th percentile deflection within each 100m length. Further details on identifying site lengths are contained in paragraphs 3.25 to 3.29.

Determinate pavements - phases of behaviour

3.7 There are four main phases of structural behaviour in the life of determinate-life pavements. First, during the first and possibly second year after construction, when the new or strengthened pavement is stabilising, there is a period during which deflection is variable but generally decreasing. Second a period when there is a slow increase in both average deflection and deformation with traffic. Third a period which may be as long as the second when there are increasingly unpredictable changes, deflections may continue gradually increasing as before, or rapidly increase. Finally when the third stage ends, the pavement deteriorates to a failed condition from which it can be restored only by total reconstruction.

3.8 During the second phase the rate of deterioration can be predicted but in the third phase the rate of deterioration to structural failure is difficult to forecast with any certainty. This does not mean that the pavement is necessarily in immediate danger of failure; there may be many years of useful life left.

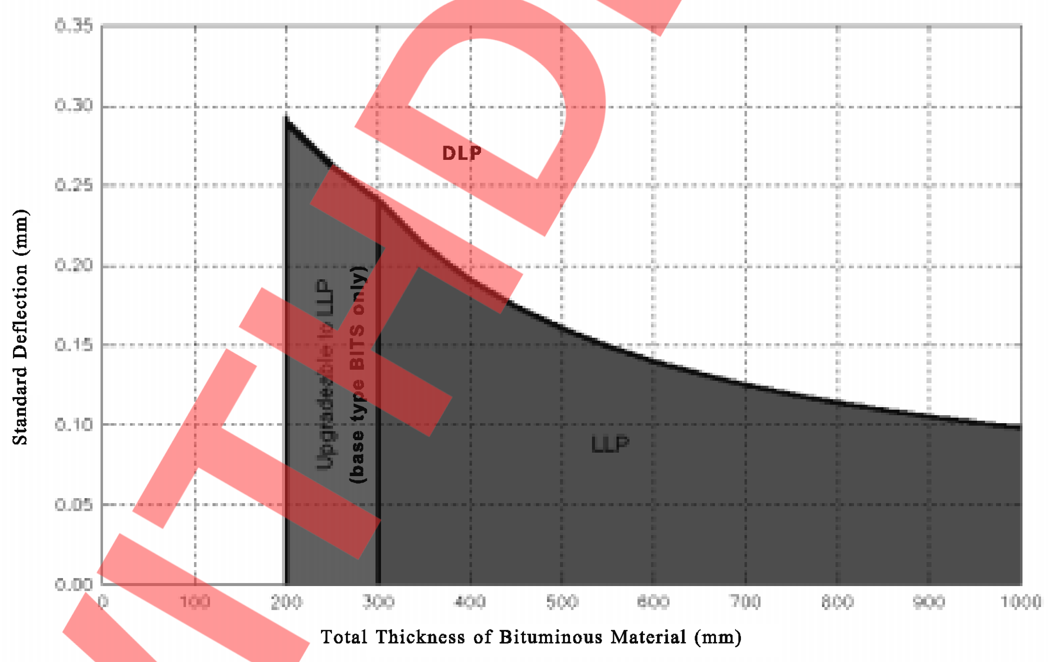


Figure 3.1 Pavement Categories used in PANDEF

Deflection analysis - DLP category

3.9 For pavements in the DLP category, PANDEF uses the Deflection Design Method to predict the residual life to the start of stage three or the onset of investigatory conditions, ie the latest time for assessing the need for structural maintenance and setting in motion further investigatory procedures. PANDEF also uses the Deflection Design Method to calculate the overlay thickness required to extend the life of the pavement for a specified number of years (or standard axles) - further details of this are given in paragraphs 3.28 to 3.31.

Deflection analysis - LLP category

3.10 For pavements in the LLP category, PANDEF reports a residual life equivalent to 20 years and recommends zero overlay (regardless of the future design life requested). In practice, these pavements can be expected to last for an indefinite period provided that deterioration at the surface is not allowed to compromise the pavement structure. Further assessment of condition and possible maintenance treatments for long-life pavements are covered in HD 30 (DMRB 7.3.3).

Deflection analysis - ULLP category

3.11 For pavements categorised as ULLP, PANDEF uses the Deflection Design Method to predict the residual life to the onset of investigatory conditions, as for pavements categorised as DLP. It can also use the Deflection Design Method to calculate the overlay thickness required to extend the life of the pavement for a specified number of years (or standard axles). However, some (but not all) pavements in this category will be sufficiently strong to enable them to be upgraded to LLP status by overlay. Therefore, PANDEF also offers the facility to calculate the overlay thickness required to upgrade these pavements to LLP status. The application of this facility is subject to confirmation that the pavement is not suffering from fatigue cracking or other forms of structural deterioration.

Limitations of deflection analysis

3.12 The precision of estimates of residual life is limited by the accuracy of the input data such as measured deflection, construction and traffic details, and experimental error within the empirical relationships used. Estimates of residual life have been found to be within a range of ±2 years when the pavement structure is approaching the investigatory condition. Deflection analysis should never be considered in isolation, but as one stage in the process of assessment of the structural maintenance requirements of a site, which also includes evidence from visual inspection surveys, cores and trial pits.

3.13 It should be noted in particular, that pavements with lean concrete bases behave differently from the other types of road base and some minor treatment may postpone considerably the need for strengthening without undue risk of sudden failure, provided the development of cracking is carefully monitored.

3.14 The sub-grade strength, as measured by the CBR test, must be established because if its value is outside the range of 2.5 to 15 per cent, PANDEF may not be fully applicable and therefore the results should be viewed with caution.

3.15 The recommended method of carrying out a detailed structural examination of pavement condition with cores and trial pits is described in HD 30 (DMRB 7.3.3).

Interpretation of the Deflection Profile

3.16 The combined maximum deflection profile of the two wheel paths should be used in all deflection analyses unless the profiles of individual wheelpaths differ noticeably in shape and magnitude, when they should be used separately. Marked differences between wheelpaths are more likely on old roads with pavements that have been widened, re-aligned and overlaid in the past and do not conform to current standards.

3.17 If variations in the type of road base are suspected, a ground radar survey should be undertaken or further cores taken for confirmation. Re-processing of the deflection data may then be necessary using the type of base appropriate to the materials found. This may result in the re-categorisation of a section of pavement, for example, into or out of the long-life category.

3.18 The first step in the diagnosis of pavement condition is to make a comparison between the deflection profile and the surface and structural condition surveys in relation to location of features like cut, fill or at grade construction, presence of structures, streams and ditches. Possible reasons for groups of higher and lower than average deflections in the deflection profile may emerge when this information is set out on a map of suitably large scale. The cause of localised damage in a pavement of apparently uniform construction should always be investigated, see paragraph 3.15.

Volume 7 home page

3.19 The information on rut depth and extent of cracking should be used in conjunction with Table 3.1 to classify the road surface condition. If the proportion of a section length found to be in investigatory or failed condition according to surface condition correlates with deflection analysis then this provides additional confidence that the analysis is broadly correct.

3.20 However, there is sometimes no such simple correlation, and reasons for this need to be found by carrying out the more detailed structural examination as described in HD 30 (DMRB 7.3.3). It is also appropriate to consider whether the discrepancy could have been caused by any error in the measurement of road temperature and/or estimation of traffic flows. Examples of circumstances where there is a lack of correlation between visual condition and deflection are as follows:

a) Extensive deterioration of the road surface is sometimes observed on pavements which have been categorised as determinate-life but which have relatively low deflections and/or long residual lives. This may indicate deterioration solely of the surfacing or may occur if the pavement is constructed on a strong subgrade which may be outside the range of applicability (see paragraph 3.14).

b) Lower-than-normal deflections, measured towards the end of a prolonged period of hot weather sufficient to reduce moisture contents in the subgrade soil, can also give the impression of a pavement of greater strength than its surface condition suggests.

c) Where relatively high deflections are associated with a pavement whose surface condition is good, the cause may be a deterioration in subgrade strength brought about by a recent increase in the moisture content. The increase may be the result of thawing at the end of a prolonged period of cold weather during which frost has penetrated deep into the pavement, and possibly also the subgrade.

d) Relatively recent adverse changes in the drainage conditions of the area immediately around the road may also be the cause of high deflections. Timely measures to correct drainage faults before the pavement is permanently damaged may obviate the need for strengthening or reduce the thickness of overlay required. Irrespective of the condition of the road surface, the engineer should always look for any correlation between high deflections and signs of adverse drainage conditions. Overlaying a pavement weakened by poor drainage will normally be more expensive than improving the drainage itself and can be less effective.

Composite bases

3.21 The assessment of pavements which include cement bound material requires special consideration because it is more than usually dependent on the findings of the visual and structural condition surveys. The primary transverse shrinkage cracks, which form in a layer of medium to high strength lean concrete at the time of construction, often cause corresponding cracks in the road surface. The timing of the appearance of such cracks in the surface is partly influenced by the age and thickness of the overlying bituminous layers and partly by other factors such as strength of mix, sub-grade strength, weather conditions during and immediately after construction and traffic loading.

3.22 With lean concrete bases investigatory conditions first develop in the vicinity of cracks, the pavement structure on either side retaining high structural stiffness. Deflection measurements on composite pavements tend to be very low (less than 15 mm x 10^{-2}) unless they happen to coincide with cracks. In these circumstances two consecutive deflection surveys are recommended to increase the chance of recording high deflections associated with the presence of cracking and thus give an indication of this type of deterioration.

3.23 Some caution must apply to the forecasts of long residual lives which are derived for cement bound bases in combination with low deflections and moderate traffic loadings, because these forecasts are dependent on the pavement remaining substantially uncracked. It is necessary, therefore, to arrange for regular visual condition surveys to check that cracking is not developing.

3.24 When cement bound materials are used for more than one layer of the pavement structure, shorter lives may be achieved for a given deflection than would be indicated by deflection analysis. Much depends on the condition of the lower cemented layer. Deflections may be kept low by the undamaged lower layer concealing progressive deterioration of the upper layers and the onset of investigatory conditions can be marked by a sudden occurrence of transition from low to high deflections. Ground radar may assist in identifying the presence of two layers. In which case cores should be taken to confirm the presence of a lower cemented layer and to determine the condition of both layers.

Wheel-track cracking	Wheel-track rutting under 2 metre straight edge			
	less than 5mm	from 5mm to < 10mm	from 10mm to < 20mm	20mm or greater
None	SOUND Code 1	SOUND Code 2	INVESTIGATORY Code 3	FAILED Code 6
less than half width or single crack	INVESTIGATORY Code 4	INVESTIGATORY Code 4	INVESTIGATORY Code 4	FAILED Code 7
more than half width*	FAILED Code 5	FAILED Code 5	FAILED Code 5	FAILED Code 8

Table 3.1 Condition of the road surface broadly comparable to definition of condition of the whole pavement (for Determinate Life Pavements only)

* Take the wheel-track width as the width of rutting as shown by the 2m straight edge when making rut depth measurement. Half width is likely to be in the range 0.5 to 1.0 metre. If there is no rutting to define the wheel-tracks use 0.5m as half the wheel-track width.

For further information on the definition of these descriptions see CHART 5; illustrated Site Manual for Inspectors (1986).

Choice of maintenance site

3.25 Since all Deflectograph surveys processed by PANDEF are matched to the network, it is possible to select a maintenance site in which parts of the length are covered by different surveys. If this is the case the surveys are merged within the software and brought to a common base, the report date.

3.26 The identification of sites having a potentially long-life and sites where structural maintenance may be required on a selected length of road within the network is assisted by the application of an automatic site definition routine. This divides the road into sites according to the homogeneity of the residual life profile, but modifications to suit practical restraints may be applied manually.

3.27 Sites earmarked for structural maintenance, and those on other roads of the same class defined in a similar way, may then be ranked in order of the proportion of the site which is below a predefined life (eg 5 years) to give a suggested order of priority for treatment.

Role of deflection in treatment design

3.28 A site may then be selected from the ranked table for more detailed study. Although it is desirable to achieve as uniform a future life as possible after maintenance, it is not practicable to match the normal variations in individual deflections along a length of road with corresponding strengthening measures. The recommended approach, offered by PANDEF, divides the site into 100m lengths, calculates the 85th percentile deflection for each length and uses this deflection, in the case of determinate-life pavements, to determine a corresponding theoretical overlay thickness for the required future life. The site is then split into suitable lengths of similar treatment, be it overlay or reconstruction, for consideration in the design of the final surface profile.

3.29 In a more sophisticated approach, PANDEF selects optimum lengths for uniform treatment on the basis of the homogeneity of the theoretical overlay thickness profile after over-riding break points, which take into account any constraints, have been defined. Full details are given in the PANDEF and POD Easy Guide.

3.30 The cause of any atypical deterioration, as initially indicated by deflection analysis, on a given length of road must be established from a detailed structural examination using techniques described in HD 30 (DMRB 7.3.3) before work can proceed on the practical design of strengthening measures.

3.31 The life of a determinate-life road can be extended by overlaying or by reconstruction. This is discussed in more detail in HD 30 (DMRB 7.3.3). Strengthening by overlaying takes into account any residual life in the existing pavement. It may be possible for the overlay to provide the thickness of material required to change the pavement categorisation to LLP. For pavements in the ULLP category, PANDEF calculates the additional thickness of material required to upgrade to LLP status (see paragraph 3.11). In all cases, cracked and other seriously deteriorated material should be removed prior to overlay.

Timing of maintenance treatment

3.32 The ideal timing of strengthening treatment is difficult to determine. The onset of investigatory conditions is not necessarily the optimum time since many years of good service can be obtained subsequently, albeit with increased risk of failure. Deflection levels usually vary considerably along a length of road. Consequently, when investigatory conditions appear, they do not occur at the same time at all parts, so the extent to which investigatory conditions are present at the time of assessment is an important consideration.

3.33 The rate at which a road is deteriorating is another important indicator and a good reason for observing deflection trends over time in the period leading up to the onset of investigatory conditions and until a decision to strengthen is taken. Deflection trends also provide further confirmation as to the category/ behaviour of a pavement (see paragraphs 3.2 and 3.3).

3.34 Where a road includes cement bound materials the timing of the treatment is more problematical and should be determined as much in relation to the extent and nature of the cracking as by deflection measurements.

4. FWD REQUIREMENTS FOR CONSISTENCY CHECK

FREQUENCY OF CHECK

4.1 In addition to the requirement for a valid annual calibration certificate issued by the manufacturers the FWD shall be regularly checked during its operational periods for measurement consistency. This check should take place every six weeks.

BASIC REQUIREMENTS OF TEST POINTS AND SECTIONS

4.2 This consistency check requires measurement at a minimum of fifteen test points in total, five points of similar deflection level on each of three different sections of road. Two of the sections should be of fully flexible bituminous construction, the first giving peak central deflections in the range 10 to 30 microns and the second in the range 30 to 50 microns. The third section should be of sound pavement quality (PQ) concrete construction giving deflections in the range 5 to 20 microns. This latter site provides deflection measurements that should be relatively independent of variations in the pavement temperature and foundation support. To help ensure this the test points should be located on sound pavement well clear of any joints or cracks. Further recommendations on the selection of suitable consistency sections are given in paragraph 4.6.

MEASUREMENTS REQUIRED

4.3 At each measurement point six loading cycles should be carried out with the equipment adjusted to give a peak load of 50kN ± 10% over a 300mm diameter loading plate. Measurements of the pavement temperature should be recorded for each section during the testing. These measurements should be made at 100mm depth and at the mid-depth of the bound layers.

PROCESSING AND PRESENTATION OF MEASUREMENTS

4.4 At each test point the mean central deflection of the last five drops should be calculated after first linearly correcting each deflection to a standard load of 50kN. The mean result of all five test points from a particular section should then be plotted against the measured pavement temperature as should the mean load for the section. Examination of the variations of these parameters with time will then provide an indication of any anomalies in the consistency of the measuring equipment which need to be further investigated. An example of such a plot for the central deflection value of a typical section is given in Figure 4.1. Records of consistency checks should be retained for a period of 2 years.

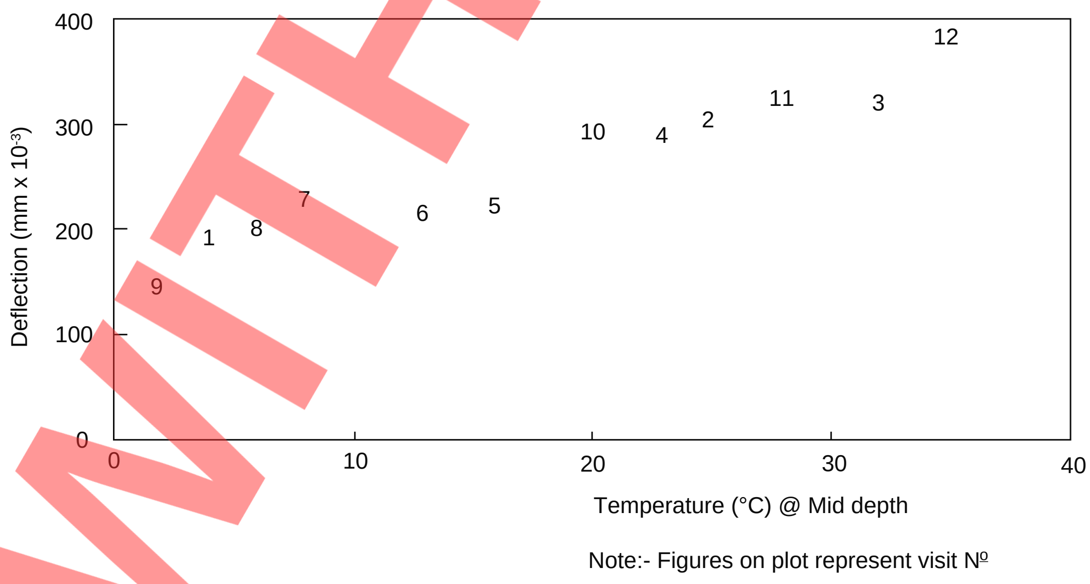


FIGURE 4.1 Example of Calibration Site Results

Volume 7 home page

RELATIVE CONSISTENCY CHECKS

4.5 The above procedure would normally be only used to check the consistency of the central geophone and load cell measurements. Checks on the deflection measurements by the other geophones should be provided by means of a relative consistency check. This is achieved using a calibration tower available from the FWD manufacturer as shown in Figure 4.2. The relative calibration or consistency check procedure is fully described in the manufacturer's literature.

4.6 The following are additional recommendations on the selection of consistency sections:-

a) The choice of site should be influenced by factors such as convenience of access and safety of operation.

b) The sections should be lightly trafficked, giving a long useful life as a consistency length. A recently by-passed section of road would appear appropriate.

c) The drainage design should be particularly efficient so as to keep the seasonal variation of results to a minimum.

d) All sections should be on level ground and have a uniform road surface and construction. They should not be subject to shading in bright sunshine thus making it difficult to determine pavement temperature accurately.

e) The road surface should be in sound uncracked condition, preferably with wheel track rutting less than 5mm deep. This requirement may be difficult to attain especially where the highest deflection range is required and lesser standards may have to be accepted.

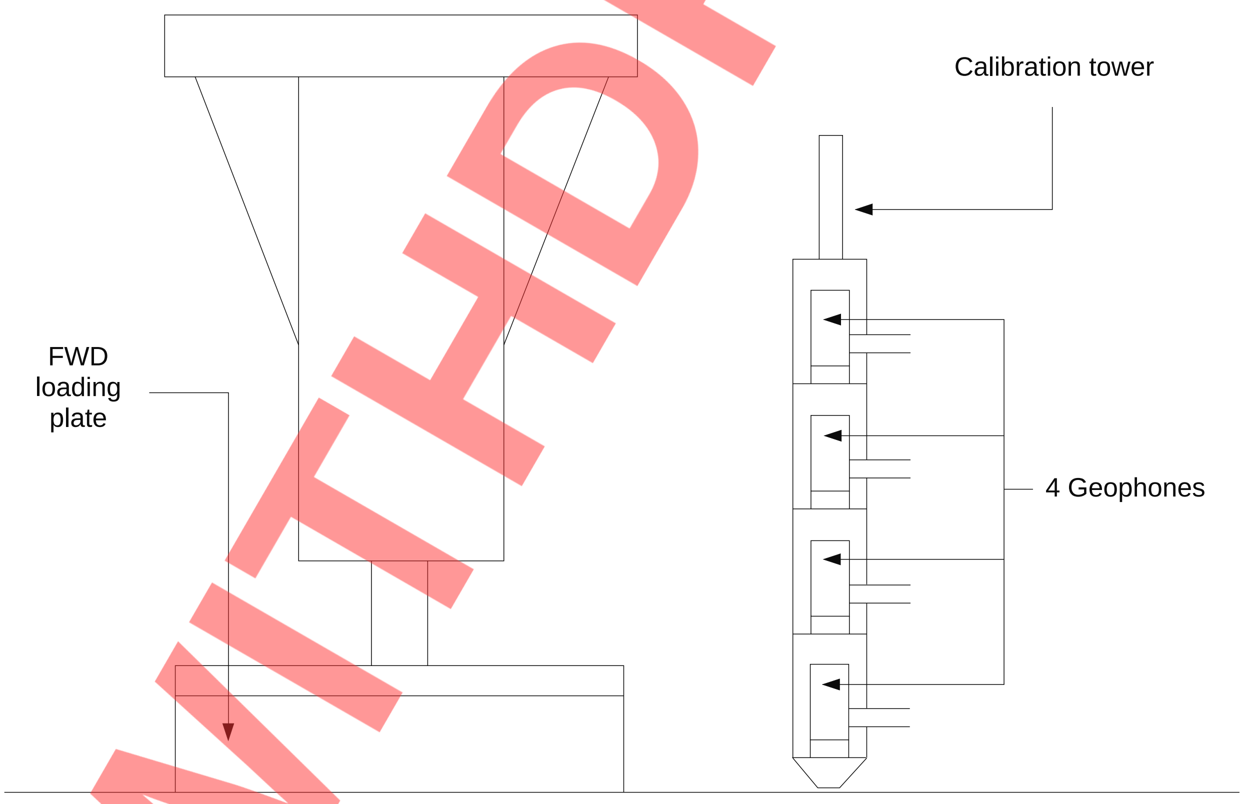


FIGURE 4.2 Relative Calibration of Geophones

Volume 7 home page