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MINISTRY OF ROADS AND TRANSPORT

RDM 5.1

Road Design Manual

Volume 5: Pavement Maintenance, Rehabilitation and Overlay Design

Part 1: Pavement Condition Surveys

2025

Chief Engineer
Materials Testing & Research Directorate
State Department for Roads
Ministry of Roads and Transport
Machakos Road, Industrial Area
P.O. Box 11873 – 00400
NAIROBI

Principal Secretary
State Department for Roads
Ministry of Roads and Transport
Works Building
Ngong Road
P.O. Box 30260 – 00100
NAIROBI

Foreword

This manual was developed by the Ministry pursuant to The Fourth Schedule of the Constitution which assigns to the National Government the functions and powers of setting standards for the construction and maintenance of all public roads including those under the County Governments.

It is part of a series of manuals that replace the first generation of road manuals developed in the first and second decades after independence. This second generation of the road manuals were developed to cover the entire road project cycle covering planning, appraisal, design, contracts, construction, maintenance, operations and monitoring. The series incorporates best practices, climate change considerations, and recent technologies to enable the provision of road infrastructure that is safe, secure, and efficient.

Under the Kenya Vision 2030 long-term plan, infrastructure expansion and modernisation are some of the foundations for the realisation of economic, social and political transformation of Kenya into a rapidly industrialising middle-income country. The plan envisages an integrated, safe and efficient transport and communication infrastructure network consisting of roads, railways, ports, airports, waterways, and telecommunications infrastructure.

The strategies to be pursued under the Vision 2030 plan to improve infrastructure services and to maximise the economic and social impacts of infrastructure development and management include: Strengthening of the institutional framework for infrastructure development and maintenance; Raising efficiency and quality of infrastructure projects; Enhancing local content of identified infrastructure projects to minimise import content; Benchmarking infrastructure facilities and services provision with globally acceptable performance standards; and, Implementing infrastructure projects that will stimulate demand in hitherto marginalised areas.

The first three 5-year Medium Term Plans (MTP) under the Vision 2030 from 2008 to 2022 targeted construction of 1,950 km, 5,500 km and 10,000 km of new paved roads under MTP I, II and III, respectively, totalling 17,450 km. This was a massive infrastructure development program intended to double the paved road network in 10 years compared to 8,600 km developed from independence in 1963 to 2008.

Implementation of MTP I to III resulted in the construction of 14,000 km of paved roads, which extended the paved road coverage to Arid and Semi-Arid regions, that had been previously neglected. However, some key milestones of the Vision 2030 goals have not been realized. This has been due to internal and external challenges. External challenges included: climate change – prolonged droughts; the emergence of COVID-19 pandemic; global supply chain disruptions; exchange rate volatility; and, rising interest rates in the leading economies.

The internal challenges included: inadequate road maintenance equipment; pavement overloading by heavy goods vehicles; huge maintenance backlog of the road network; low contracting and supervision capacity particularly in the Counties; poor quality control and assurance of works; congestion in urban areas; encroachment on road reserves; high costs and delays in payments of land acquisition; lack of harmonisation of cross-border transport regulation and operational procedures; rapid urbanisation; increased traffic volume with exponential growth of motorcycle traffic; high cost/delays in relocation of utilities and services along and across road reserves; inadequate funding of projects and programs; and, delay or default in payments for goods, services and works.

The implementation of MTP III came to an end on 30th June 2023, ushering in the implementation of the Fourth Medium Term Plan (MTP IV), which has been aligned to the aspirations of the Kenya Vision 2030 and the Kenya Kwanza Government's Bottom-Up Economic Transformation Agenda (BETA) planning approach and its key priorities.

BETA is the Government's transformation agenda geared towards economic turnaround through a value chain approach. BETA has targeted sectors with the highest impact to drive economic recovery and growth. This will be achieved through bringing down the cost of living; eradicating hunger; creating jobs; expanding the tax base; improving foreign exchange balances; and inclusive growth. BETA ensures rational resource allocation by eliminating wastage of resources occasioned by duplication, overlaps, fragmentation and ineffective coordination in the implementation of programmes and projects.

The Fourth Medium Term Plan key priorities are clustered under five key sectors, namely: Finance and Production; Infrastructure; Social; Environment and Natural Resources; and Governance and Public Administration. The infrastructure sector seeks to: enhance transport connectivity by constructing 6,000 km of new roads, maintaining rural and urban roads, rail, air and seaport facilities and services; expand communication and broadcasting systems; and promote the development of energy generation and distribution by increasing investments in green energy (geothermal, wind, solar and hydro). The infrastructure gap is expected to be bridged by promoting economic participation of the private sector through public private partnerships in the financing, construction, development, operation and maintenance of infrastructure

The plan entails a shift of focus to fundamentals in project planning and implementation which include: respect for technical input, regulations and standard practices; adherence to project life cycle i.e., planning, feasibility studies and design before procurement of works; public and stakeholder consultation; procurement within budgetary ceilings; shifting focus during project implementation from the finished product ‘black top’ to the construction of the foundation; building local capacity particularly MSMEs by ensuring prompt payments; and capacity building at all levels to enable internalization of policies and processes.

The first generation of the road manuals were used for 35 to 45 years. It is my sincere hope that the second generation of the road standards which have been developed in alignment with the Government’s strategy will provide guidance in solving most of the above challenges and those expected to emerge in the next 50 years. Implementation of the manuals will enable achievement of the Government aspirations which include: inclusive growth; creation of sustainable employment; building of MSMEs; climate change adaptation and realisation of the UN SDGs; enhanced efficiency in management of infrastructure and transport system; and, laying the foundation for the next national long-term plan at the end of the Vision 2030.

On behalf of the Government of Kenya, I would wish to thank the European Union for financing the development of the first drafts of the manuals in 2009 and the African Development Bank for the financial support in the review and updating of the manuals. I would also like to thank the members of the National Steering Committee and the Technical Task Force for their input. The Technical Administrators, and the Kenya National Highways Authority (KeNHA) for the procurement and able administration of the consultancy Contract. I also thank the Consultant, TRL Limited for their role in providing technical expertise that was essential for the success of the manuals updating exercise. I also wish to express my deepest appreciation to our stakeholders, and all those who have contributed to this process and the staff of the Ministry for their continued input.

Hon. Davis K. Chirchir, E.G.H
Cabinet Secretary, Ministry of Roads and Transport

Preface

Infrastructure development is key for successful economic delivery, therefore all existing infrastructure must be maintained or rehabilitated to enable it to continue servicing the end users safely and efficiently. A road is designed to provide good service for many years and therefore, good maintenance, planning and long-term management are essential. These activities rely on skilled human resources, collecting and maintaining records of historical and performance information and data.

This manual contains methods and procedures that Kenya has adopted to standardise pavement condition surveys for the management of road networks, as well as pavement maintenance, rehabilitation and overlay designs on highways, urban and rural roads .

The manual adopts and encourages context-sensitive and comprehensive conditions assessments, a concept that seeks to inform maintenance and rehabilitation design strategies that combine engineering best practices in harmony with the natural and built environment whilst meeting the required constraints and parameters surrounding each project.

Users of the manual are expected to follow the standards set here-in and seek approval of the Ministry should any departures be warranted.

Eng. Joseph M. Mbugua, CBS
Principal Secretary, State Department for Roads

Document Management

Document Status

This document has the status of a Manual. Users shall apply the contents there-in to fully satisfy the requirements set out. The content of the manual is based on current practice in Kenya and latest practices in the road sector, both regionally and internationally.

Sources of the Document

Copies of the document can be obtained from:
The Principal Secretary, State Department for Roads, Ministry of Roads and Transport, Works Building, Ngong Road, P.O. Box 30260 - 00100, NAIROBI Email: ps@road.go.ke

A secured PDF copy maybe downloaded from: www.roads.go.ke/downloads

Notification of Errors and Requests for Amendments

While all care and consideration has been applied in the compilation of this document, the Ministry accepts no responsibility for failure in any way related to the application of this manual or any reference documents cited in it.

Requests for edits and corrections can be freely sent to the following address:
The Principal Secretary, State Department for Roads, Ministry of Roads and Transport, Works Building, Ngong Road, P.O. Box 30260 - 00100, NAIROBI Email: ps@road.go.ke

Amendments Request Form

Request No.	Name	Organisation	Chapter	Page	Section/ Clause	Ref. to: Figure/ Table/	Type of request	Request

Type of request: General – G; Editorial – E; Technical - T

Amendments to Date

Amendment No.	Description	Amendment Effective Date	Amendment Approved by

Acknowledgements

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A National Steering Committee was set up and chaired by the Permanent Secretary, Ministry of Roads and Transport, with the following membership: Principal Secretary for Devolution, Office of the Deputy President; Chief Executive Officer, Inter-Governmental Relations Technical Committee; Chief Executive Officer, Council of Governors; Managing Director and Council Secretary, Kenya Bureau of Standards; Director, National Transport and Safety Authority; Director General, Kenya Roads Board; Director General, Kenya Wildlife Services; Chief Executive Officer, Engineers Board of Kenya; Director General, Kenya Rural Roads Authority; Director General, Kenya Urban Roads Authority; President, Institution of Engineers Kenya; Director Policy, Strategy and Compliance; Kenya National Highways Authority; Chief Engineer, Roads Division, State Department for Roads; Chief Engineer, Materials Testing and Research Division, State Department for Roads.

The technical work was undertaken under the guidance of a Technical Task Force, chaired by Eng. David Maganda, with the following gazetted members: Francis Gichaga (Prof.) (Eng.), Andrew Gitonga (Eng.), Timothy Nyomboi (Dr.) (Eng.), Rosemary Kungu (Eng.), Charles Obuon (Eng.), Sylvester Abuodha (Prof.) (Eng.), Samuel Kathindai (Eng.), Nicholas Musuni (Eng.), Charles Muriuki (Eng.), Tom Opiyo (Eng.), John Maina (Eng.), Fidelis Sakwa (Eng.), Daniel Cherono (Eng.), Maurice Ndeda (Eng.), Theo Uwamba (Eng.).

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Abbreviations

AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
CIB	Cement Improved Based
CrI	Cracking Index
CSIR	Council for Scientific and Industrial Research
d/D	Deflections
DBM	Dense Bituminous Macadam
DCP	Dynamic Cone Penetrometer
DEM	Dense Emulsion Macadam
DDI	Deformation Index
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
EMPr	Environmental Management Practitioner
ESA	Equivalent Standard Axles
ETB	Emulsion Treated Base
ε_t	Tensile Strain
ε_v	Vertical Strain
FWD	Falling Weight Deflectometer
GDP	Gross Domestic Product
HBM	Hydraulically Bound Materials
HMA	Hot Mixed Asphalt
HVR	High Volume Roads
HWD	Heavy weight Deflectometer
LB	Labour Based
LIB	Lime Improved Base
LIG	Lime Improved Gravel
LVR	Low Volume Road
LWD	Light Weight Deflectometer
MCESA	Million Cumulative Equivalent Standard Axles
NMT	Non-motorised Traffic
OHS	Occupational Health and Safety
PPI	Pothole/Patching Index
RDM	Road Design Manual
SG	Subgrade
Std	Standard
TC	Traffic Loading Class
VEF	Vehicle Equivalence Factor
σ_t	Tensile Stress
σ_v	Vertical Stress

Glossary of Terms

Aggregate	Hard mineral elements of construction material mixtures, for example: sand, gravel (crushed or uncrushed) or crushed rock.
Asphalt	Is commonly used as short hand for asphaltic concrete which is any design of high-quality bitumen / aggregate mixture.
Asphalt Concrete (AC)	A mixture to predetermined proportions of aggregate, filler and bituminous binder material plant mixed and usually placed by means of a paving machine. This term is used for all mixtures of this type including AC and Dense Bitumen Macadam (DBM).
Asphalt Surfacing	The layer or layers of asphalt concrete constructed on top of the road base.
Average Annual Daily Traffic (AADT)	The total yearly traffic volume in both directions divided by the number of days in the year.
Average Daily Traffic (ADT)	The total traffic volume during a given time period in whole days greater than one day and less than one year divided by the number of days in that time period.
Base Course/ Road base	This is the main component of the pavement contributing to the spreading of the traffic loads. In many cases, it will consist of crushed stone or gravel, or of good quality gravelly soils or decomposed rock. Bituminous base courses may also be used (for higher classes of traffic). Materials stabilised with cement or lime may also be contemplated.
Binder Course	The lower course of an asphalt surfacing laid in more than one course.
Bitumen	The most common form of bitumen is the residue from the refining of crude oil after the more volatile material has been distilled off. It is essentially a very viscous liquid comprising many long-chain organic molecules. For use in roads, it is practically solid at ambient temperatures but can be heated sufficiently to be poured and sprayed. Some natural bitumen can be found worldwide that are not distilled from crude oil but the amounts are very small in comparison.
Bound Pavement Materials	Pavement materials held together by an adhesive bond between the materials and another binding material such as bitumen, lime or cement
Carriageway	Portion of the roadway including the various physically contiguous traffic lanes and auxiliary lanes, serving one or both directions of traffic, and not including shoulders.
Channelisation	The use of pavement markings or islands to direct traffic through an intersection.
Chippings	Stones used for surface dressing or sealing
Design Period	The projected period of time that an initially constructed or rehabilitated pavement structure will perform before reaching a level of deterioration requiring more than routine or periodic maintenance.
Design Year	The last year of the design life of the road or any other facility, often taken as twenty years although, for costly structures such as major bridges, a longer period is usually adopted.
Diverted Traffic	Traffic that changes from another route (or mode of transport) to the project road because of the improved pavement, but still travels between the same origin and destination.
Equivalent Standard Axles (ESA)	A measure of the potential damage to a pavement caused by a vehicle axle load expressed as the number of equivalent 80 kN single axle loads that would cause the same amount of damage. The ESA values of all the traffic are combined to determine the total design traffic for the design period.

Glossary of Terms *(continued)*

Fill	Material of which a man-made raised structure or deposit such as an embankment is composed includes soil, soil-aggregate, or rock. Additionally any material imported to replace unsuitable roadbed material is also classified as fill.
Flexible Pavements	Flexible pavements are defined as pavements composed of a base made of deformable material, such as natural gravel, graded crushed stone or cement or lime-improved material with a bituminous surfacing.
Generated Traffic	Additional traffic which occurs in response to the provision or improvement of a road.
Grading Modulus (GM)	Related to the cumulative percentages by mass of material in a representative sample of aggregate, gravel or soil retained on the 2.36 mm, 0.425 mm and 0.075 mm sieves; $GM = 3 - \left(\frac{P_{2.36} + P_{0.425} + P_{0.075}}{100}\right)$ where: $P_{2.36}$ = percentage passing 2.36 mm sieve; $P_{0.425}$ = percentage passing 0.425 mm sieve; $P_{0.075}$ = percentage passing 0.075 mm sieve
Heavy Goods Vehicles (HGV)	Vehicles having an unloaded weight of 3500 kg or more.
Hot Mix Asphalt (HMA)	This is a generic name for all high-quality mixtures of aggregates and bitumen that use the grades of bitumen that must be heated in order to flow sufficiently to coat the aggregates. It includes Asphaltic Concrete, Dense Bitumen Macadam and Hot Rolled Asphalt.
Pavement Maintenance	Routine work performed to keep a pavement as nearly as possible in its as-constructed condition under normal conditions of traffic and forces of nature.
Pavement Layers	The layers of different materials which comprise the pavement structure.
Reconstruction	The process by which a new pavement is constructed, utilizing mostly new materials, to replace an existing pavement.
Recycling	The reuse, usually after some processing, of a material that has already served its first-intended purpose.
Rehabilitation	Work undertaken to significantly extend the service life of an existing pavement. This may include overlays and pre overlay repairs and may include complete removal and reconstruction of the existing pavement, or recycling of part of the existing materials.
Road base	A layer of material of defined thickness and width constructed on top of the sub-base, or in the absence thereof, the subgrade.
Side Slope	Area between the outer edge of shoulder or hinge point and the ditch bottom.
Pedestrian Walkway	The portion of the cross-section reserved for the use of pedestrians
Unbound Pavement Materials	Naturally occurring or processed granular material which is not held together by the addition of a binder such as cement, lime or bitumen.
Unpaved Roads	Natural or graded surfaces without a paved or sealed surfacing layer. Unpaved roads can be categorised into three types, tracks, earth and gravel roads.
Vehicle Equivalency Factors	Cumulative of all Equivalent Vehicle axle load factors (EALF) of all axles of a vehicle.
Wearing Course	The top surface seal or asphalt surfacing or, for gravel roads, the uppermost layer of construction of the roadway made of specified materials.

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1 Introduction

1.1 General

This Manual was prepared by the Ministry for Roads and Transport as part of a series of manuals that cover the entire project cycle for the provision, maintenance, and operation of roads in Kenya.

The Manual is applicable to roads at national, municipal, and county levels. It incorporates best practices, climate change considerations, and modern technologies thereby enabling the provision of road infrastructure that is safe, secure, and efficient.

The road manuals system is composed of documents in Table 1.1.

Table 1.1 Structure of Kenya Road Manuals

Project Cycle Stage	Manual: Volume or Part/Chapter	Code
A. General	**Procedures and Standards Manual**	**PSM**
	1. General	
	2. Policies	
	3. Procedures Guidance	
	4. Codes of Practice	
	5. Guidelines	
	6. Product/Testing Standards	
B. Planning	**Network and Project Planning Manual**	**NPM**
	1. Road Classification	
	2. Route/Corridor Planning	
	3. Route/Corridor Planning	
	4. Highway Capacity	
	5. Project Planning	
C. Appraisal	**Project Appraisal Manual**	**PAM**
	1. Environmental Impact Assessment and Audit	
	2. Social Impact Assessment	
	3. Traffic Impact Assessment	
	4. Road Safety Audits	
	5. Project Appraisal	
	6. Feasibility Studies	
D. Design	**Road Design Manual**	**RDM**
	1. Geometric Design	
	2. Hydrology and Drainage Design	
	3. Materials and Pavement Design for New Roads	
	4. Bridges and Retaining Structures Design	
	5. Pavement Maintenance, Rehabilitation and Overlay Design	
	6. Traffic Control Facilities & Communication Systems Design	
	7. Road Lighting Design	
E. Contracts	**Works and Services Contracts Manual**	**WSCM**
	1. Forms of contracts	
	2. Standard Specification for Road and Bridge Construction	
	3. Bills of Quantities	
	4. Standard/Typical Drawings	
F. Construction	**Road Construction Manual**	**RCM**
	1. Construction Management	
	2. Project Management	
	3. Site Supervision	
	4. Quality Assurance	
	5. Quality Control	

This table continues onto the next page...

Project Cycle Stage	Manual: Volume or Part/Chapter	Code
G. Maintenance	**Road Asset Management Manual**	**RAAM**
	1. Maintenance Management	
	2. General Maintenance	
	3. Pavement Maintenance	
	4. Bridges & Structures Maintenance	
H. Operations	**Road Operation Manual**	**ROM**
	1. Traffic Management	
	2. Vehicle Load Control	
	3. Emergency Services	
	4. Tolling	
I. Monitoring & Evaluation	**Road Design Manual**	**MEM**
	1. Performance Monitoring Manual	
	2. Technical Audits	
	3. Poverty, Gender Equality and Social Inclusion Monitoring	

This Volume 5, Pavement maintenance and rehabilitation Road Design Manual 'Part 1 – Pavement Condition Survey', is part of Road Design Manuals, made up of a series of volumes and shown in Table 1.1:

Table 1.2 Road Design Manual (RDM) Coding Structure

Vol.	Manual Title	Part Name	Code
1	**Road Design Manual: Vol. 1** Geometric Design	**Part 1** - Topographic Survey	RDM 1.1
		Part 2 – Traffic Surveys	RDM 1.2
		Part 3 – Geometric Design of Highways, Rural and Urban Roads	RDM 1.3
2	**Road Design Manual: Vol. 2** Hydrology & Drainage Design	**Part 1** – Hydrological Surveys	RDM 2.1
		Part 2 – Drainage Design	RDM 2.2
3	**Road Design Manual: Vol. 3** Materials & Pavement Design for New Roads	**Part 1** – Ground Investigations and Material Prospecting	RDM 3.1
		Part 2 – Materials Field and Laboratory Testing	RDM 3.2
		Part 3 – Pavement Foundation and Materials Design	RDM 3.3
		Part 4 – Flexible Pavement Design	RDM 3.4
		Part 5 – Rigid Pavement Design	RDM 3.5
4	**Road Design Manual: Vol. 4** Bridges & Retaining Structures Design	**Part 1** – Geotechnical Investigation and Design	RDM 4.1
		Part 2 – Bridge and Culvert Design	RDM 4.2
		Part 3 – Retaining Structures Design	RDM 4.3
		Part 4 – Reinforced Fill Structures Design	RDM 4.4
		Part 5 – Bridges and Structures Condition Survey	RDM 4.5
		Part 6 – Bridge Maintenance Design	RDM 4.6
5	**Road Design Manual: Vol. 5** Pavement Maintenance, Rehabilitation & Overlay Design	**Part 1** – Pavement Condition Survey	RDM 5.1
		Part 2 – Pavement Maintenance, Rehabilitation and Overlay Design	RDM 5.2
6	**Road Design Manual: Vol. 6** Traffic Control Facilities & Communication Systems Design	**Part 1** – Road Marking	RDM 6.1
		Part 2 – Traffic Signs	RDM 6.2
		Part 3 – Traffic Signals and Communication System	RDM 6.3
		Part 4 – Other Traffic Control Devices	RDM 6.4
7	**Road Design Manual: Vol. 7** Road Lighting Design	**Part 1** – Grid-connected Road Lighting	RDM 7.1
		Part 2 – Solar Road Lighting	RDM 7.2

This road design manual must be applied by a qualified designer. Compliance with the guidance in the manual does not relieve designers of the responsibility for establishing that their design is suitable, appropriate, safe, and adequate for the purpose stated in the project requirements.

1.2 Objectives of this Part

The primary objective of the RDM 5.1 is to provide detailed guidelines on conducting pavement condition surveys on existing roads. This part specifically aims to:

1. Provide structured guidance for planning, executing, and reporting on condition surveys critical for assessing pavements.
2. Assist engineers in identifying specific pavement defects and their potential impacts on pavement capacity, road usability and safety.
3. Guide practitioners in collecting and analysing data that is pivotal in making informed decisions for road maintenance and rehabilitation strategies.

1.3 Scope of This Part

Part 1 comprehensively covers the planning, procedures, and methodologies essential for detailed pavement condition assessments covering the following aspects:

1. Condition Surveys: This section discusses standard methods of assessing the following aspects to determine the remaining pavement life.
   i. Traffic survey - such as Traffic counts and Axle load tests
   ii. Function condition assessment:
      a. Visual condition surveys to evaluate defects such as cracking, ravelling, bleeding, polishing, pumping, piping, potholes, patching and deformation.
      b. Surface condition measurements to evaluate roughness, surface irregularity (rut depth measurement), skid resistance and surface texture.
   iii. Structural condition assessment - which includes geotechnical and structural tests such as deflection tests(Benkelman Beam, FWD, LWD, Deflectograph), Dynamic Cone Penetrometer (DCP) tests, Bearing plate test, test/ trial pits, density, Field Moisture tests, Porosity and permeability tests, Carbonation, Coring and coding .
   iv. Sub-surface condition surveys - such as the Ground Penetration radar (GPR) scans.
5. Equipment and Technique Selection - Guidelines for choosing and using suitable survey methods and the relevant equipment for conducting the surveys.
6. Data handling and management - Processes for data collection, recording, collation, analysis, optimisation and reporting to inform maintenance and rehabilitation planning and design.

1.4 Organisation of the Manual

This manual is meticulously structured into nine chapters, ensuring a logical flow and easy navigation of the key aspects of pavement condition surveys:

- Chapter 1: Introduction - Sets the context and purpose of the manual.
- Chapter 2: General Requirements for Condition Surveys - Discusses reference standards, calibration, data and information management, data verification and validation, reporting, project protocols and approvals.
- Chapter 3: Planning Considerations - Focuses on strategic project planning and planning for preliminary and field surveys.
- Chapter 4: Pavement Behaviour and Deterioration - Addresses the identification and evaluation of pavement defects and rating criteria including PCI, PSR, and PSI.

- Chapter 5: Categories of Pavement Condition Surveys - Elaborates on survey criteria for various objectives such as pavement management, maintenance, rehabilitation and overlay design, Compliance with design and Specifications and Criteria for Special Investigations.
- Chapter 6: Preliminary Investigations and Surveys - Covers initial survey steps such as field reconnaissance and desk study, which informs the selection of applicable detailed surveys.
- Chapter 7: Detailed Field Investigations and Surveys -Focuses on the standardisation and execution of detailed field testing methods.
- Chapter 8: Standard Testing Methods - Describes various testing methods for an in-depth analysis of pavement conditions.
- Chapter 9: References - Provides a list of documents referenced in this manual informing the development of methods provided in this manual.
- Appendices: Offer practical tools and forms, enhancing the application of the manual in field settings.

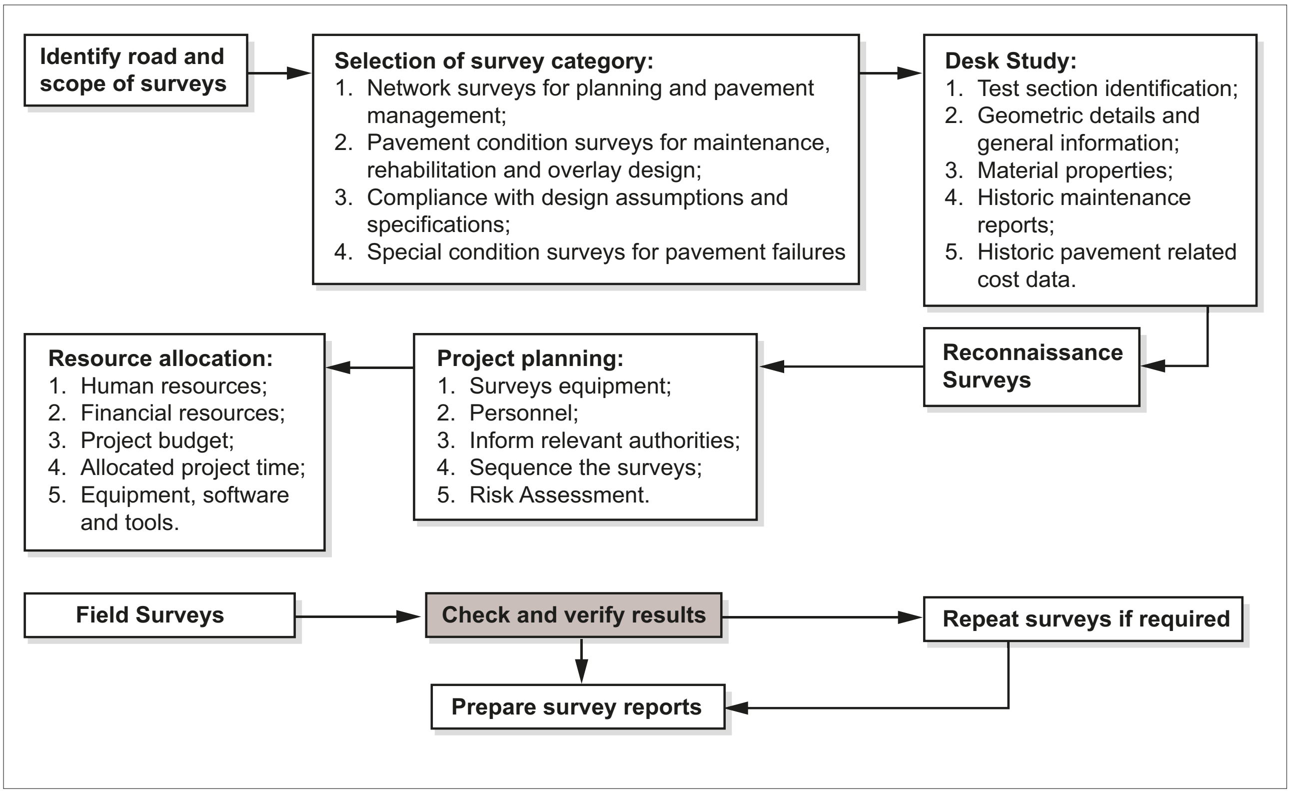
2 General Requirements for Condition Surveys

2.1. General

This chapter establishes a foundation for a systematic and thorough approach to pavement condition surveys, which is essential for developing pavement maintenance and rehabilitation plans. It presents standardised procedures to ensure uniformity in data collection, analysis, and reporting. Emphasising adherence to health, safety, and environmental guidelines, this section highlights the necessity of following established protocols and obtaining necessary approvals. The framework detailed here includes rigorous practices in calibration, data and information management, and data verification and validation, crucial for ensuring survey accuracy and reliability. These practices not only contribute to the precision of current surveys but also inform decision-making in subsequent stages of pavement management, as will be explored in RDM 5.2. The methodologies discussed align with international and regional standards, offering a comprehensive and robust approach to pavement condition surveying.

Figure 2.1 provides an illustrative overview of the pavement condition survey process, setting the stage for the detailed discussions in the subsequent sections of this manual:

Figure 2.1 General Requirements for Conducting Pavement Conditions Surveys



2.2 Protocols and Approvals

The institutional set up may change from time to time, but a minimum set of protocols and approvals is required to make pavement condition surveys reliable for the intended purposes. The following protocols are generic and can be customised when necessary or required, to suit the institutional set up of the relevant authorities.

Minimum technical requirements:

1. A proper and robust testing system should be established as a prerequisite for accreditation of the protocols.
2. Appropriate testing standards should be set and adequately documented to ensure consistency.

3. Minimum test requirements should be set out for each category of field and laboratory testing. The quantities of tests should be determined on the basis of the standard of the road and the size of the project.
4. All tests shall be referred to the Test Methods listed in this manual. The corresponding international standards such as AASHTO, SANS or BS as applicable shall also be referred to.
5. Both field and laboratory equipment should be approved for use in accordance with the project's requirements of the project and with guidance from this manual. The equipment must be in good working order and calibrated by reputable firms or entities.
6. Standard forms shall be used unless specified otherwise.
7. The approval process shall follow agreed protocols and it shall include the following:
   a. Approval of tests as specified in the project specifications.
   b. Approval of testing equipment specified in this manual and/or project specifications and/or by the responsible authority.
   c. Approval of test standards as provided in this manual and/or project documents or other internationally recognised test standards. A formal request shall be made if such tests are not specified in this document or specific internationally recognised standards.
   d. Test results shall be approved using the specified protocols stated in this manual.
   e. Any re-tests shall be documented with reasons.
   f. Approved results shall be copied to relevant persons or parties in the case of a project.
   g. The results shall be archived in electronic databases and physical files for future reference.
8. Regular reviews of testing quality and occasional proficiency testing shall be carried out and recorded. This shall be achieved by involving certified and accredited laboratories or standards experts, both local and regional.
9. Any deviation from the standards must be accompanied by formal requests and approvals. A sample form is provided at the end of this document.

2.3 Standardisation

2.3.1 General

This document guides the standardisation of pavement condition surveys for the tests and investigations involved in road provision, specifically rehabilitation and maintenance. While the test methods are drawn from different standards and some modified to suit the Kenya situation, the standards stated in this manual shall form the standard methods and specifications for Kenya. However, reference may be made to the source documents of the standard where necessary.

The RDM5.1 shall take precedence over all other standards in Kenya regarding pavement condition surveys. Deviation from these standards will require prior approval from the Ministry of Roads and Transport. However, in peculiar cases where further clarity is sought, British Standards (BS) and BS-EN or AASHTO, from which the Kenya condition survey methods are derived, can be referenced.

2.3.2 Departure form Standards

Adherence to established Kenyan standards is crucial for ensuring quality, safety, performance, and consistency. However, there may be situations where deviating from established road rehabilitation and maintenance manuals and standards is warranted due to specific project requirements or unique circumstances. Refer to the Procedures and Standards Manual for the detailed approach and departure from standards approval forms.

The Designer must submit all major and minor Departures from Standards to the respective regional directorate for evaluation. If the proposed Departures from Standards are acceptable, they will be submitted to the Quality Assurance, Road Inspection and Safety Directorate for final approval.

Where the designer departs from a standard, written approval must be obtained from the Chief Engineer Materials. The Designer should submit the following information:

1. The number, name, and description of the road section.
2. The design parameter for which a Departure from Standards is desired.
3. A description of the standard, including normal value, and the value of the Departure from Standards.
4. The reason for the Departure from Standards.
5. Any mitigation to be applied in the interests of safety.
6. Justification for departure.

2.4 Health, Safety and Environment

2.4.1 General on Health, Safety, and Environment

Safety is paramount in pavement condition surveys, especially in active traffic environments. All field investigations must include robust health and safety protocols to protect workers, motorists, and non-motorised traffic (NMT) users. All organisations must have approved health, safety, and environmental management plans and policies and ensure compliance with the prevailing labour and environmental regulations at all times. Surveys, which may occur day or night, should adhere to standardised safety procedures tailored to each field investigation method.

2.4.2 Health, Safety and Environmental Risk Assessment

In addition to the ever-present danger of traffic accidents, conducting risk assessments before each survey is essential to identify and mitigate hazards such as traffic risks, respiratory issues, noise exposure, and adverse weather which can result in injury, loss of life and financial losses. In isolated cases where exposure to certain risks cannot be fully mitigated, the correct personal protective equipment (PPE) and training on safe work practices, traffic regulations, and equipment use must be provided for all people accessing the site.

Important basic tick box measures include:

1. Training and induction to personnel authorised to the construction on safe work procedures and potential risks aligned with the type of work being carried out.
2. Establishing safe sight distances, how to manoeuvre around vehicles and equipment and preparing workers for diverse traffic conditions.
3. Allocating appropriate personal protective equipment (PPE) and tools. This includes other additional precautions for abnormal weather that align with labour law provisions.
4. Follow the detailed plan for signage, safety advice and warnings around the closure areas.
5. Impose and enforce speed limits on all haulage vehicles operating on haul routes.
6. Follow details (provided in OHS guidelines) regarding maximum permissible vehicular speeds within a closure.
7. At the position of the investigation, a flag person and traffic cones placed at 1.0 m apart for at least 20 m must be in place at all times.
8. Enforcing strict policies against alcohol and medication that impair performance.
9. All drivers and operators must be licensed, trained, authorised, and must have relevant experience. Defensive driving training is necessary for heavy vehicle and heavy machinery operators.
10. Ensure regular checks and reporting of equipment condition to the site team leader.
    a. Check for diesel and oil spillages and report them to the environmental agent.
    b. Ensure that all on-site machinery and equipment have valid calibration certificates.

11. The following are the responsibilities of the Investigations Team Leader:

The Investigations Team Lead plays the oversight role, covering all the investigation processes, managing human resources, equipment and plant on site. This person shall complete and distribute all risk assessments on site, or delegate that responsibility to a competent person. In addition, the Team Lead shall be responsible for ensuring that all staff members on site are suitably trained and checking that only trained and competent persons operate or drive vehicles and plant on site. The team leader must ensure the following:

a. All defective items from the plant and vehicles are removed from the site.

b. All vehicles and plant are maintained and serviced regularly and are examined and evaluated following statutory requirements.

c. That drivers and operators shall be competent and operate the plant and equipment according to operating instructions and site rules.

d. The operators and drivers must immediately report all defects and/or malfunctions to their supervisor. Defective vehicles and plant and equipment must not be used under any circumstances.

e. Vehicle and Machine operators must not carry unauthorised passengers or materials at any time. They must ensure, where possible, that personnel are not in an area that may be dangerous to them while the plant is in operation.

f. No person under eighteen should be allowed to operate vehicles, plant, or equipment on site.

g. Ensure that hazardous chemicals and excess materials are disposed of from the site according to the environmental management plan. Any deviations should be discussed with the environmental agent for approval.

2.5 Calibration

To ensure the accuracy of data collected, all survey tools, equipment, and machinery must undergo strict calibration checks and certification. Adhering to rigorous calibration protocols is necessary to maintain the integrity of survey data. The following delineates the general requirements and best practices concerning equipment calibration:

1. **Regular Calibration Schedules**
   Adherence to predetermined calibration schedules for all survey equipment is mandatory, with the frequency determined by the equipment type, usage, and manufacturer guidelines.
2. **On-site and Off-site Calibration**
   a. Distinguish between equipment calibrated on site by trained personnel and equipment that requires off-site calibration by specialist service providers.

   b. Ensure that individuals responsible for calibration are properly trained and competent, with regular updates and assessments to uphold high calibration standards.
3. **Standardised Calibration References and adherence to Manufacture**
   a. Follow manufacturer-prescribed calibration procedures and ensure calibration standards are traceable to national or international benchmarks, assuring measurement consistency and comparability.

   b. For key equipment, engage third-party services for objective calibration, particularly when legal or compliance issues are involved.
4. **Calibration in Varied Environmental Conditions**
   Conduct calibration under diverse environmental conditions that simulate actual field scenarios, thus guaranteeing equipment accuracy in varying settings.
5. **Pre-deployment Calibration Checks**
   Implement calibration checks before field deployment to ensure equipment handling or transportation hasn't affected accuracy.

6. **Fault Identification and Correction**
   Develop a mechanism for swift identification and correction of calibration issues. Equipment exhibiting significant deviations should be temporarily withdrawn from service for adjustments.
7. **Certification and Record-Keeping**
   a. Each calibration must be certified, and comprehensive records should be maintained.
   b. Calibration records should document calibration dates, entities conducting the calibration, any adjustments made, and future calibration due dates.
8. **Calibration Process Audit and Continuous improvement**
   Regularly audit and review calibration procedures for compliance with established protocols and identify potential improvements.

2.6 Data, Information and Document Management

Effective data and information management is integral to the pavement condition survey process. This includes systematic creation, naming, referencing, storage, retrieval, handling and, in some instances, disposal of documents such as contractual information, data collection forms, calibration certificates, test results and survey reports.

The practitioners, relevant authorities responsible for approvals of pavement condition survey outputs, and clients should agree on reporting templates and clearly define the responsibilities for document control, version management, and access control to ensure confidentiality, consistency and security of data recording and reporting. Some commonly used standard forms have been appended at the end of this manual.

1. **Compliance and Standardisation**
   a. Regularly update documentation practices to comply with evolving standards in pavement survey methodologies.
   b. Develop templates for common document types to maintain consistency across different teams and projects.
2. **Document Review and Approval**
   a. Set up designated reviewers for different document types and ensure that only endorsed documents considered final and the rest remain as draft versions.
   b. Incorporate electronic signatures and approval tracking for accountability.
3. **Centralised Digital Repository**
   a. Store all survey-related documents in a centralised digital repository, facilitating easier access, better organisation, and efficient retrieval of data and documents.
   b. Develop and implement a robust document classification system to categorise documents by type, such as field data, analysis reports, calibration records, and health and safety protocols.
4. **Document Control and Version Management**
   a. Implement strict document control practices with version management to track changes over time.
   b. This ensures that all team members are using the correct versions of documents.
5. **Record Keeping and Archiving**
   a. Keep detailed logs of document edits and versions to maintain a clear audit trail. Regularly back up documents on multiple platforms to prevent data loss.
   b. Ensure archived materials are accessible for future reference if needed with clear guidelines on retention periods for different document types and disposal strategies for documents where applicable.

6. **Access and Security**
   a. Implement role-based access control to restrict document access based on user roles;
   b. Use encryption and other security measures to protect data integrity, and confidentiality and ensure that sensitive information is only accessible to authorised personnel.
7. **Training and Awareness**
   a. Conduct regular training sessions for staff on data, information and document management systems and best practices for consistency, nothing should be left to assumptions.
   b. Create and distribute procedures/user manuals on data, information and document management.

2.7 Data Verification and Validation

As part of collecting and analysing data related to condition surveys, data verification and validation processes are key to ensuring the reliability and credibility of survey results. This subsection highlights the key methodologies for cross-checking data, identifying discrepancies, and rectifying inaccuracies as follows:

1. **Cross-referencing and Error Correction**
   a. Compare data sets from different sources to verify accuracy.
   b. Establish a clear protocol for correcting any identified errors or inconsistencies in data in line with established standards
2. **Benchmarking and Control Sites**
   Establish benchmarking and control sites with known conditions for validating the accuracy of survey equipment and methodologies.
3. **Automated Data Checking Software**
   Implement software tools designed to automatically review and flag inconsistencies or unusual patterns in survey data for further manual review.
4. **Expert or Peer Review**
   a. Engage in peer reviews where expert team members review the data to assess its accuracy.
   b. Seek external subject matter expertise to help identify nuances and anomalies in the data that automated systems might miss.
5. **Sequential Data Verification**
   Perform data verification in stages, starting from historic data to field data collection to data entry and analysis. At each stage, implement checks and balances to ensure data integrity.
6. **Sampling and Statistical Analysis**
   a. Use statistical methods to analyse data for outliers or anomalies validate the consistency of data.
   b. Use statistical sampling methods to select a subset of data for intensive verification. This approach is particularly useful when dealing with large datasets.

2.8 Reporting

Reporting is the final, critical stage of the pavement condition survey process. The survey findings must be presented in a clear, concise, and informative manner. The author should customize different reports for diverse stakeholders, making sure that these reports satisfy the informational requirements of those making decisions. The following points summarises the methodology for producing comprehensive reports.

1. **Structured Reporting Formats**
   a. Develop standardised reporting templates, including essential sections such as executive summaries at the beginning of the report, introduction, methodology, findings, interpretations and results, recommendations, conclusion and appendices.
   b. Include a cover page and document control sheet with accurate project and report details, managing report versions, and provision for sign-off by relevant stakeholders.
2. **Visual Aids**
   Include graphs, charts, and maps in reports to provide a visual understanding of the data. Visual aids can make complex data more accessible and easy to comprehend.
3. **Clarity and Conciseness**
   Adopt clear, straightforward language, particularly for sections aimed at non-technical readers, while maintaining technical accuracy.
4. **Appendix**
   To provide complete transparency, include a detailed appendix in the report comprising any key test results or survey reference documents produced by subject matter experts which significantly contributed to developing solutions and recommendations.
5. **Quality Control of Reports**
   Implement a rigorous quality control process where reports undergo a thorough review by a senior experts or qualified peers for accuracy and completeness.
6. **Timely Submission and Distribution**
   Adhere to a strict timeline for report submission and distribution to ensure timely access to information by all relevant stakeholders.
7. **Feedback and Revision Process**
   Facilitate a feedback mechanism allowing stakeholders to review and comment on the draft report, with subsequent incorporation of relevant feedback into the final version.
8. **Report Approval**
   Establish an approval process for the final report, typically involving sign-off by a project leader, department head, or client. This confirms that the report meets all required standards and satisfies the expectation of relevant stakeholders before final distribution.
9. **Report Archiving**
   Systematically archive all finalised reports for future reference, ensuring they are easily accessible for audits, historical comparisons, or further analysis.

3 Planning Considerations

3.1 General

Kenya has a large road network that requires keen management, maintenance and rehabilitation for its sustenance. This section outlines the considerations that should be made when planning for pavement condition surveys. It provides an overview of the planning processes for field investigation and the overall condition survey project planning

There are a few key elements to consider when planning surveys on these networks:

1. The type of surveys required for pavement condition assessment for maintenance and rehabilitation design.
2. The type of equipment that is required.
3. The survey standards to be used and their consistency with the design standards.
4. The capacity of the agencies or industry to carry out the surveys and/or acquire the technologies, especially the modern ones.
5. The accuracy of the data in terms of the requirements of the design and the capacity of the system that is used.
6. The financial resources and logistical complications associated with the surveys.

Surveys should be standardised to ensure that the results are comparable from one project to another and one road or road section to another. This will help in decision-making on the interventions by different entities/authorities. Where different standards are proposed, authorisation shall be sought from the Chief Engineer Materials.

This document complements RDM 5.2 for Maintenance and Rehabilitation Design, which guides test procedures, standards, and material specifications as well as RDM 3 for Materials and Pavement Design for New Roads.

3.2 Guidelines for Road Inventory and Pavement Condition Surveys

3.2.1 Road Inventory Surveys (RIS)

A road inventory system is a database that provides detailed information about the road network's physical characteristics, conditions, and historical data. Establishing criteria for this inventory ensures consistent, detailed, and accurate data collection, allowing for effective pavement management and planning.

The following information must guide all users on the crucial information that should not be omitted.

1. **Road Identification:**
   a. Jurisdiction – The geo-political location and authority responsible for the road.
   b. Road Name/Number – Unique identifier for each pavement section.
   c. Segment/Section ID – Divisions of longer roads for effective management.
   d. GPS Coordinates – Precise location details, including start and end points.
2. **Pavement Condition System (PCS):**
   The main purpose of the pavement condition surveys is to facilitate systematic assessment and decision-making in the management, maintenance, rehabilitation and overlay of pavements, enabling prioritisation of funds, identification of distress patterns, and optimisation of pavement life.

3. **Core Inventory Criteria:**
   a. **Pavement Characteristics:**
      i. Dimensional properties of the pavement: Length, Width, and Area.
      ii. Type: Asphalt, concrete, gravel, or other material specifications.
      iii. Pavement Structure / Layer Composition: Details of each layer (surface, base, subbase, etc.), including material and thickness.
      iv. Year of Construction/Last Rehabilitation: Historical data to determine age and past interventions.
   b. **Functional Classification:**
      i. Traffic Volume: Average Daily Traffic (ADT) or vehicle count data.
      ii. Road Hierarchy: Freeway, arterial, collector, or local.
      iii. Number of Lanes: Including shoulder details.
   c. **Current Condition Assessment:**
      i. Surface Distress: Types (cracking, surface irregularity (rutting), potholes, etc.), severity, and extent.
      ii. Roughness Index: International Roughness Index (IRI) or similar metrics.
      iii. Skid Resistance: Particularly for high-speed or critical areas.
      iv. Structural Distress: Determine Structural Capacity using methods such as Falling Weight Deflectometer (FWD) tests.
4. **Data Collection Techniques:**
   a. **Manual Surveys:** Visual assessments by trained personnel using guidelines to ensure uniformity.
   b. **Automated Surveys:** Using equipment like road profilers, laser scanners, and ground-penetrating radars.
   c. **Mobile Mapping Systems:** Utilising vehicles equipped with cameras, lasers, and other sensors to collect roadway data.
   d. **Geographic Information System (GIS):** Integrating pavement data with spatial information for enhanced visualisation and analysis.
5. **Frequency of Updates:**
   The Responsible Authority should conduct Road Inventory and Condition Surveys (RICs) to collect data for maintenance and management. Traffic and Functional condition surveys should be conducted annually while structural condition surveys should be conducted at 4-year intervals.
6. **Data Management and Storage:**
   The responsible authorities should ensure a secure, accessible, and scalable database. Integrate with other road management systems and allow for easy data retrieval and reporting.
7. **Quality Assurance:**
   The Responsible Authority has set procedures to ensure data reliability and accuracy through:
   a. **Training:** Conducting regular training sessions for data collectors.
   b. **Calibration:** Periodic calibration of automated equipment.
   c. **Audit:** Random checks and independent audits of collected data.
   d. **Integration** with Pavement Management System (PMS): Ensuring the inventory system seamlessly integrates with the PMS, facilitating condition analysis, deterioration modelling, and intervention planning.

Kenya has a well-defined pavement inventory system, built on clear criteria. It is a key tool for proactive pavement management. It provides the baseline data required to monitor pavement health, forecast future conditions, and allocate resources effectively.

3.3 Key Considerations for Field Investigations

Field testing and investigations are processes of collecting data in the field, which can be used mainly in road project planning, engineering design and construction, rehabilitation, maintenance, and performance-based road contracts. The RDM1.2 and RDM3.2 provide details on traffic surveys and field investigations respectively. This approach underscores the importance of aligning the survey process with the client's strategic objectives and ensuring compliance with industry standards.

In carrying out field tests and investigations, the following key aspects must be considered.

1. **Purpose and Scope Clarification:**
   The Engineer must clearly define objectives, whether for broad network assessment or focused on specific improvement areas, aligning with the client's needs.

   The extent and limits of the field investigations in the project context need to be considered to avoid inadequacies that may affect the results and intended application.

2. **Planning and Preparation for field investigations:**
   a. **Sampling Strategy:**

      Determine the sampling strategy for selecting roads to survey. Consider factors such as road classification (e.g., highways, urban roads, rural roads), geographical distribution, and diversity of road conditions. Aim for a representative sample that provides a comprehensive overview of road conditions in Kenya.

   b. **Survey Methodologies**

      Select the appropriate survey technique that produces the relevant data for the defined scope of work. The Engineer must use a combination of visual inspection, measuring, and non-destructive and destructive testing techniques.

   c. **Equipment, Tools and Technologies**

      i. Specify the essential tools, equipment and Technologies relevant to the scope of field investigations. The selection of equipment, tools, and technologies must be approved by the responsible engineer.
      ii. Ascertain the need for calibration, licensing and level of expertise required and plan for it.

   d. **The Purpose of the Data**

      Determine the volume and accuracy requirements of the data that should be collected and prepare survey checklists. This can be weighed on the basis of the value of the project and hence the risk associated with any negative impacts on the structure to be rehabilitated or maintained.

   e. **Stakeholder Engagement**

      Identify relevant stakeholders, such as government agencies, transportation authorities, or local communities, who may have an interest in the survey results. Engage with them early in the planning process to gather input, address concerns, and ensure collaboration.

   f. **Communication and Intellectual Property Rights**

      Establish hierarchy and methods of formal communication and frequency of formal meetings needed. Provisions must be made on the control and distribution and access to information and intellectual property.

   g. **Budgetary Considerations:**

      The costs of collecting data are usually small in relation to the value of the infrastructure. However, there are certain specialised tests, which can be costly, and a balance will need to be reached before embarking on such testing exercises.

3. **Data Collection, Validation and Analysis Methods:**
   a. Establish data collection procedures and tools required for surveys such as field measurement devices, cameras, data collection forms, and software for data management. Survey teams should be trained on data collection techniques to ensure consistency in the data collected.
   b. Establish a process to validate the collected data. Conduct independent checks to ensure data accuracy and reliability. Consider conducting field verifications or cross-checking with existing road condition databases for validation purposes.
   c. Plan how you will analyse the collected data. Determine the relevant metrics and indicators for assessing road conditions, such as roughness, cracking, surface irregularity (rut depth measurement), and distress. Consider using appropriate software or statistical methods to process and analyse the data effectively. Apply the standard procedures for collecting data discussed in Chapters 5 and 6.
4. **Statistical Significance:**
   Statistical significance in handling and analysing data is important and should always be considered, however, in some cases the engineering inputs can take precedence.
5. **Health and Safety Considerations:**
   For each project provide a detailed health and safety plan outlining detailed guidelines, measures, emergency procedures and first-aid protocols for field staff. All considerations must comply with the latest version of the construction regulations on occupational health and safety and other reference documents specified in the contract.
6. **Environmental Considerations:**
   Each test must outline measures for minimising environmental impact during field investigations. The measures should include waste management and disposal practices for field teams. All work activities must comply with the latest Environmental guidelines specified in the conditions of the contract.
7. **Quality Control in Field Investigations**
   Establish methods to ensure the accuracy and consistency of data collected in the field, protocols for calibrating equipment and validating data.
8. **Documentation and Reporting:**
   a. Utilise standard forms used for data collection that have been provided in the appendices and develop standardised reporting templates approved by the Engineer, client and or approving authority to consistency and fulfilment of project objectives.
   b. Prepare a comprehensive report that includes an analysis of the current road conditions, identifies areas for improvement, and proposes specific measures or interventions to address the identified issues.

3.4 Laboratory Testing from Pavement Condition Surveys

Laboratory testing protocols should be followed on samples collected during field surveys including reporting of results and data management as well as approval mechanisms and standards.

The quality of the designs, construction and maintenance are dependent on the accuracy of test results. If the results from the laboratories are inaccurate or inadequate, the consequence is a significant loss of value for money and increased risks of failure or poor performance.

The following precautionary measures need to be implemented to ensure improved quality of output information:

1. The testing facilities should be appropriate for the level of testing required.
2. Personnel involved in the testing and approval of results should be trained and suitably qualified to carry out the tests and to make the approvals. Most importantly, they should have the requisite experience. Continuous professional development is necessary for personnel to be conversant with new technologies.

3. The equipment should be appropriate, calibrated and in good working order.
4. Manuals and any documentation, that the laboratories use should be regularly reviewed and updated in order for any advancements or improvements to be incorporated into the testing protocols.
5. Laboratories should be well-resourced financially and facilitated in terms of transport and allowances for personnel.
6. It is advisable for local laboratories to be paired with external, internationally recognised laboratories or organisations for continual technological development and accreditation purposes.
7. For detailed guidance on the applicable laboratory standard test methods for the various tests, refer to RDM 3.2.

3.5 Management of As-built Data.

3.5.1 General on the Management of As-built Data

As built data can be obtained from the ministry responsible for roads and other relevant agencies. As-built data encapsulates the final and exact details, specifications, and locations of all project elements of a project as actually constructed. The effective management of as-built data is not just a best practice, it is a necessity for modern pavement maintenance and rehabilitation efforts. It is considered helpful to achieve the following:

1. **Accurate Representation of Real Conditions:** As-Built Data represents the reality on the ground. While initial plans and designs provide a guideline, the as-built data captures any deviations or changes during construction. This ensures that any future maintenance or rehabilitation work is based on what is actually present, rather than what was originally planned.
2. **A Benchmark for Future Work:** Maintaining an accurate record of as-built data, sets a clear benchmark against which future assessments, maintenance, and rehabilitation efforts can be measured. This allows for a consistent approach to pavement management over its lifecycle.
3. **Enhanced Decision-making:** Helps Pavement Managers to make more informed decisions about maintenance priorities, resource allocation, and long-term pavement strategies. This data-driven approach leads to more efficient and cost-effective pavement management.
4. **Liability and Accountability:** In disputes or issues arising from pavement performance, as-built data is an official record of what was delivered. This can protect firms from undue liabilities and ensure accountability at all levels of the project.
5. **Integration with Modern Technologies:** Today, technologies like Geographic Information Systems (GIS) and Building Information Modelling (BIM) are revolutionising infrastructure management. Properly managed as-built data can be integrated seamlessly with these systems, offering dynamic ways to visualise, analyse, and manage pavement assets.
6. **Facilitating Knowledge Transfer:** Properly documented as-built data ensures that institutional knowledge about the pavement's actual conditions is not lost, ensuring continuity in maintenance and rehabilitation efforts.
7. **Optimising Budget Allocation:** By understanding the exact conditions and specifications of the pavement, responsible authorities can better allocate their budgets, ensuring that funds are directed where they are most needed and will be most effective.

3.5.2 Best Practice for Managing As-built Data

1. Digital documentation, stored in secure cloud databases, ensures easy retrieval, backup, and sharing of data, justifying the need for custodians of information to move away from paper records.
2. As-built data should be updated regularly, especially after significant maintenance or rehabilitation projects.
3. Ensure that personnel are trained on the importance of as-built data, its collection, and its management.
4. Implement regular audits of the as-built data to ensure its accuracy and completeness as a quality control measure.

3.6 Strategic Planning

Most maintenance and rehabilitation projects do not achieve intended objectives due to premature conclusions during investigations or surveys. This normally results in the implementation of quick, cheaper but inadequate solutions as a result of one or a combination of the following:

1. Inadequate historic performance data. Insufficient project planning.
2. Poor selection of survey method.
3. Inappropriate resource allocation.
4. Incompetence or unethical conduct by allocated human resources / Human error.

Strategy for carrying out pavement condition surveys are laid out in Table 3.1.

Table 3.1 Strategy for Pavement Condition Surveys

ID	Description	Challenge	Limitation Risk	Impact	Solution/mitigation
1	**Historic Performance Data** 1.1 Test section identification. 1.2 Geometric details and general information. 1.3 Material properties. 1.4 Historic maintenance reports. 1.5 Historic pavement related cost data.	i. Unavailability of inadequate historical data. ii. Incorrect/inaccurate historical data.	i. Increases the survey scope. ii. Increases project duration. iii. Increases project costs.	Project Implementation will appear to be too costly for funders.	i. Authorities must invest in robust RAMS systems. ii. They must enact paved and unpaved roads inventory policy measures that ensure pavement maintenance procedures are followed and relevant information is documented.
			i. Misinforms the survey planning process regarding scope, time and triggers variation orders during project implementation. ii. If not detected, it can lead to the selection of inapplicable investigation methods	i. Implementation of either inadequate design solutions. ii. Over-design. iii. Results in reduced value for money and wastage of time and financial resources.	i. Survey experts must sample historical data to be reviewed and validated. ii. Clients must provide a budget and allocate time for the verification of historical data.
2	**Project Planning** 2.1 Definition of project objectives. 2.2 Time management. 2.3 Stakeholder involvement. 2.4 Project budgeting. 2.5 Risk assessment.	i. Inadequate or incorrect identification of scope/ misalignment with project objectives. ii. Unclear milestones. iii. Poor identification of required skills and lack of collaboration and coordination. iv. Inadequate financial budget. v. Failure to identify risks affecting project success.	i. Failure to get conclusive results that inform optimal design solutions. ii. Unclear responsibility. iii. Complacency, Failure to meet deadlines. iv. Failure to identify and address route causes. v. Inefficiency during project implementation. vi. Failure to mitigate project-specific risks and challenges.	i. Negatively impact project completion. ii. Oversight, leaving some areas not fully addressed. iii. Poor collaboration between various stakeholders. iv. Failure to get conclusive results that fulfil project objectives. v. Fruitless expenditure. vi. Project delays due to work stoppages.	i. Seek expert advice when drafting Terms of Reference to assist in identifying the required skills and clearly defining the project scope. ii. Project budgeting must be informed by the client's objectives not vice versa. iii. Every stage must be guided by a programme, with consequences for failure to meet deadlines. iv. Encourage collaboration through clearly defined tasks.
3	**Selection of Survey Method** Determining the applicable pavement survey method or technology that provides scientific evidence of current pavement condition.	i. Selecting of incorrect or inadequate pavement survey method.	i. Providing inadequate or over-designed solutions.	i. Value for money is not realised.	i. Review and verify historical data. ii. Conduct site reconnaissance before making conclusions. iii. Conduct a gap analysis to identify all missing information. iv. Select survey methods and technologies that assist in determining the missing information.
		i. Specifying irrelevant / inapplicable test methods.	i. Failure to meet project objectives through implementing inapplicable solutions.	i. Fruitless expenditure.	

Table 3.1 Strategy for Pavement Condition Surveys *(continued...)*

ID	Description	Challenge	Limitation Risk	Impact	Solution/mitigation
4	**Resource allocation** Identification, acquisition, and allocation of **4.1** Human resources.	i. Lack of experience and relevant skills. ii. Incompetence or unethical conduct by allocated human resources / Human error.	i. Poor judgment and diagnosis of pavement failure criteria. ii. Lack of coordination and collaboration.	i. Specifying unsuitable pavement maintenance and rehabilitation solutions which do not provide value for money, either: ii. Inadequate (less durability) and cheap. iii. Over designed and too expensive. iv. May result in poor quality of work. v. Fruitless expenditure vi. Reduced stakeholder confidence and coordination.	i. Invest in policy that guides the Human Resource selection for specific tasks guided by: a. Required skillset. b. Relevant qualification. c. Relevant experience. d. Equal opportunities. ii. High level financial planning and project scheduling for roads projects must be guided by relevant technical experts to minimise variation orders. iii. Road agencies should invest in modern equipment and technologies that helps their internal teams monitor their pavement infrastructure. iv. Contract documents should always carry closes that decisively addresses unethical conduct.
	4.2 Financial resources.	i. Inadequate / Restrictive budget allocation.	i. Reduction in scope. ii. Implementing of inferior cheaper alternative investigation methods		
	4.3 Allocated project time.	i. Inadequate time to conduct research and investigations (Planning). ii. Inadequate time to implement proposed solution.	i. Failure to conclusively identify the root causes of pavement deterioration. ii. Implementation of quicker alternatives inconsistent with best practice.		
	4.4 Equipment, software and tools.	i. Inconsistent or incorrect results ii. Use of outdated, wrong, or uncalibrated equipment iii. Expensive equipment. iv. Environmental, Health and Safety risk.	i. Incorrect design input. ii. Unavailability of new technology and equipment.		

4 Pavement Behaviour and Deterioration

4.1 General

This chapter delves into the nature and causes of pavement defects, equipping surveyors with essential knowledge for accurate evaluation. Different types of pavements exhibit unique deterioration mechanisms therefore, understanding defect evolution over time is critical to prevent misinterpretation during their assessment.

Pavement defects vary widely, from superficial to internal issues that may not be immediately apparent but could manifest as surface anomalies. For instance, surface cracks could stem from either surfacing failure or underlying geotechnical instability, such as issues within the subgrade. Distinguishing between these causes is a key skill for surveyors. Appendix A provides a comprehensive catalogue of defects, including photographic examples of their progression.

This manual offers a general overview of the following pavement types and their respective deterioration processes, aiding surveyors in identifying and understanding the underlying causes of observed defects.

4.1.1 Flexible Pavements

Flexible pavements are composed of multiple layers, with the top layer being flexible, typically made of asphalt or bituminous materials. These layers work together to distribute loads and accommodate deformations. The main deterioration mechanisms include:

1. **Surface Deformation** - Flexible pavements deform and deflect under load, causing surface irregularity (rutting) and depression.
2. **Fatigue and Cracking** - Repeated loading from traffic can lead to fatigue cracking in the flexible surface layer due to cyclic bending and flexing.
3. **Oxidation and Aging** - The asphalt binder in flexible pavements can age and become brittle over time, reducing its ability to resist cracking and deformation.
4. **Moisture Damage** - Moisture infiltration into the pavement layers can weaken the adhesive properties of the asphalt binder and reduce durability.
5. **Base Course Erosion** - Over time, erosion of the base course materials beneath the flexible surface layer can compromise support.

4.1.2 Semi-Rigid Pavements

Semi-rigid pavements are intermediate between flexible and rigid pavements, typically featuring a flexible surface layer (e.g., asphalt) over a semi-rigid base layer i.e., hydraulically bound materials, cement-treated base, lean concrete etc. The main deterioration mechanisms include :

1. **Surface Cracking** - Like flexible pavements, semi-rigid pavements can experience surface cracking due to temperature fluctuations and traffic loads.
2. **Joint and Slab Distress** - Semi-rigid pavements may have joints and slabs, which can experience joint faulting, spalling, and distress, similar to rigid pavements.
3. **Base Course Deformation** - The semi-rigid base layer may undergo deformation under heavy loads, contributing to surface irregularities.
4. **Reflective Cracking** - Existing cracks in the semi-rigid base layer can propagate upward into the surface layer, causing reflective cracking.

4.1.3 Rigid Pavements

Rigid pavements consist of a single, thick layer of rigid material, typically Portland cement concrete (PCC). They rely on the stiffness and strength of the concrete for load distribution. The main deterioration mechanisms:

1. **Transverse Cracking:** Rigid pavements often exhibit transverse cracks perpendicular to the direction of traffic due to temperature changes and shrinkage.
2. **Joint and Panel Distress:** Joints and concrete panels in rigid pavements can experience distress, including joint faulting, spalling, and corner breaks.
3. **Slab Settlement:** Uneven settlement of individual concrete slabs can occur, leading to localised depressions or heaving.
4. **Punchouts:** Localised failures can develop under heavy wheel loads, resulting in circular or semi-circular depressions in the concrete surface.

4.1.4 Unpaved Roads

Unpaved roads are natural or graded surfaces without a paved or sealed surfacing layer, categorised into tracks, earth and gravel roads. The main deterioration mechanisms include:

1. **Surface Erosion:** Unpaved roads are susceptible to erosion by rainfall and flowing water, leading to the loss of surface materials.
2. **Surface irregularity (rutting and Corrugations):** Repeated traffic loads can create rutting and corrugations, causing uneven and rough surfaces.
3. **Dust and Gravel Loss:** Traffic can generate dust and displace gravel, leading to dustiness and loss of surface materials.
4. **Mud and Muddy Conditions**: During wet weather, unpaved roads can become muddy and impassable, requiring maintenance to restore usability.

4.2 Defects and Their Possible Causes

4.2.1 Deterioration Mechanisms

The Pavement Expert must correctly identify the type of distress affecting the pavement. The modes of pavement deterioration can be classified as follows:

1. **Fracture**: general cracking and breakup.
2. **Distortion:** this would be the general deformation or permanent displacement.
3. **Disintegration**: breakup of the pavement, surfacing or both.

The defect type, mode of deterioration and possible mechanism of deterioration are given in Table 4.1.

The actual deterioration in the pavement is often a complex combination of effects in the different layers, e.g.:

1. Deformation originating in one layer will cause deformation or cracking of the overlying layers, such as reflective cracking.
2. Cracking the surfacing will allow water ingress, possibly resulting in the deformation of the underlying layers.

In the absence of remedial measures, deterioration will continue unabated following the 'classical' sequence of pavement degradation, e.g.:

1. Deformation of the flexible pavement, cracking of the surfacing, ingress of water, crazing of the surfacing, potholing, and finally complete disintegration or
2. Cracking allowing moisture ingress, deformation of underlying layers due to reduced strength, potholing/collapse.

Table 4.1 Defects and Their Possible Failure Mechanisms

Deterioration Mode	Surface Defects	Possible Mechanisms of Deterioration	
Fracture	Cracking	1. Traffic Loading, especially overloading 2. Fatigue and ageing 3. Thermal Fluctuations 4. In-adequate joint design in rigid pavements 5. Shrinkage	6. Slippage 7. Geotechnical movements 8. Delamination 9. Reflection cracking (Mirror cracking of underlying layers) 10. Use of ultrahard binders <30 pen
	Spalling	1. Thermal fluctuations 2. Moisture damage 3. Traffic abrasion 4. Ageing 5. Embrittlement of surfacing	6. Surfacing deficient in binder 7. Delamination of surfacing 8. Fatigue 9. Loading/ mostly overloading
Distortion	Permanent deformation	1. Traffic Loading especially overloading 2. Plastic Deformations 3. Inadequate compaction of pavement layers/layer works design 4. Ingress of moisture reducing the strength of pavement layers Excessive secondary compaction by traffic 5. Collapse (e.g., of untreated collapsible soils and sinkholes) 6. Expansion of saline soils	7. Creep 8. Differential settlement/ consolidation 9. Excessive surface irregularity (rutting) 10. Deficient percentage of air voids in asphalt 11. Thermal softening of binder in asphalt 12. Heaving of expansive materials 13. Geotechnical movements
	Faulting	1. Traffic Loading especially overloading 2. Differential compaction 3. Inadequate compaction, 4. Improper joint construction 5. Subgrade settlement / Geotechnical movements 6. Construction-related factors – poor construction practices	7. Ageing and material degradation 8. Block cracking 9. Pumping 10. Swelling 11. Erosion 12. Collapse of road foundation
Disintegration	Disruption	1. Poor-quality materials 2. Chemical reaction 3. Ageing of surfacing 4. Temperature fluctuations 5. Traffic Loading especially overloading	6. Attrition 7. Loss of cohesion 8. Lack of interlock 9. Poor adhesion (of binders) 10. Inadequate binder
	Stripping	1. Moisture infiltration 2. Poor surface preparation - Poor adhesion of aggregate to binder, Inadequate binder 3. Ageing and embrittlement of binder	4. Spillage of solvents (e.g., diesel and oils) 5. Chemical reaction 6. Traffic loading
	Ravelling	1. Abrasion by traffic 2. Degradation of aggregate 3. Poor adhesion of aggregate to binder	4. Insufficient binder/ageing 5. Ageing 6. Moisture infiltration 7. Inadequate mix design
	Scaling	1. Abrasion by traffic 2. Freeze-thaw cycles 3. Ageing	4. Degradation of aggregate 5. Chemical exposure/reaction
	Loss of texture	1. Abrasion by traffic 2. Embedment of aggregate	3. Excess binder 4. Surface erosion

4.2.2 Definitions and Descriptions of Common Defects

Common defects affecting paved roads and their definitions:

Bleeding (or fatting-up)	The upward movement of bitumen resulting in loss of texture and the formation of a film of bitumen on the pavement surface.
Corrugations	A form of plastic movement typified by a series of ripples on the pavement surface across the direction of traffic.
Cracks	Approximately vertical cleavage of a pavement layer /linear openings or fractures in the pavement surface.
Block Cracking	Interconnected cracks forming a series of definite block patterns. Typically distributed over a large area of pavement.
Crazing	Formation of interconnected cracks forming series of small blocks or pattern resembling a spiderweb. Coarse crazing has more than 200mm mesh and fine crazing (or "Crocodile cracking") has less than 200mm mesh.
Crescent Cracks (or Slippage Cracks)	Crescent-shaped cracks that occur along the pavement's edge or at the interface between layers.
Crest-Shaped Cracks	Unconnected irregular parabolic cracks, varying in direction. This usually occurs singly, and they are often found in areas where the pavement has undergone rehabilitation or overlay.
Crocodile Cracks	Interconnected or interlaced cracks that usually form within the wheel path normally signify the end of the pavement design life.
Diagonal Cracks	An unconnected crack running diagonally to the wheel path.
Longitudinal cracks	Cracks that run in a direction approximately parallel to the centreline.
Meandering Cracks	Unconnected irregular crack, varying in line and direction: This usually occurs singly.
Transverse Cracks	Cracks that follow a course approximately perpendicular to the centreline.
Shrinkage cracking	Refers to the formation of interconnected cracks on the surface or within the HMA layer of a flexible pavement. These cracks are often closely spaced and can extend in the longitudinal or transverse direction of the road. In rigid pavements, shrinkage cracks are small, closely spaced cracks that develop during the curing process of newly placed concrete. They result from natural drying and shrinkage of the concrete mix.
Deformation	Deformation refers to the permanent distortion or bending of the pavement surface from its original shape.
Depression	Localised low area of limited size, settled below the surrounding pavement surface, which may or may not be accompanied by cracking.
Disruption	The breaking up of a pavement layer into small, loose fragments. This is severe damage or disintegration of the pavement surface, often leading to the formation of potholes or rough patches.
Edge Defects	Deterioration or damage that occurs along the edges of the road surface. These defects represent the structural integrity and functionality of the pavement.
Edge breaks/ cracking	This is the formation of cracks or breaking off of surfacing material along the edge of the pavement.
Shoulder drop-off	Shoulder drop-off happens when there is a difference in elevation between the pavement and the shoulder. This defect can be hazardous to drivers, especially during lane changes or in emergencies.

Edge feathering	Refers to the gradual thinning or deterioration of the pavement at the edge, starting as short transverse cracks from the road edge and spreading into the lane.
Vegetation growth	Growth of vegetation along the pavement edge resulting in the roots of plants can penetrating the pavement, enabling to cracking and deterioration.
Faults	Differences in elevation of two slabs at joints or cracks. They manifest as offsets or misalignments in the pavement, where one section of pavement has moved relative to another.
Peeling	The separation of a bituminous wearing course from the underlying layer and its subsequent break-up and loss.
Potholes	Bowl-shaped holes of varying sizes in the pavement, resulting from localised disintegration.
Pumping (or blowing)	Ejection of a mixture of water and fine material forced through joints, cracks and pavement edges under passing traffic loads.
Ravelling	The progressive separation of aggregate particles in a wearing course from the surface downward or from the edges inward.
Roughness/Ride Quality	A term used to describe the relative degree of comfort or discomfort a road user experiences when using a road. The road user's perception of the road condition whilst driving is based on their experience measured by the smoothness of the surface and the riding comfort emanating from irregularities in the pavement surface.
Rutting	Channelised linear depressions which develop in the wheel tracks.
Scaling	The progressive disintegration and loss of a cement concrete wearing surface.
Shoving	A form of horizontal plastic movement often accompanied by de-densification of affected layers resulting in localised bulging of the pavement.
Skid Resistance	The pavement's ability to provide adequate friction for vehicle tyres during braking or cornering. Insufficient skid resistance can lead to unsafe driving conditions, especially in wet or slippery conditions.
Spalling	The breaking or chipping of a pavement layer at joints, cracks or edges.
Stripping	The separation and loss of aggregate particles from the bitumen binder.
Structural Patching	Involves repairing or replacing previously repaired pavement sections to restore load-bearing capacity to address severe structural distress or fatigue cracking.
Surface Patching	Aims at repairing previously patched/repaired localised surface distresses, such as potholes or minor cracks, to restore pavement smoothness and ride quality.
Upheaval	The localised displacement of a pavement due to swelling of the subgrade.
Waves	Transverse undulations at regular intervals (crests 500 mm or more apart).

Common defects affecting unpaved roads and their definitions:

Potholing	Depressions or holes in the gravel surface caused by the erosion or disintegration of the road material.
Corrugations	Wavy or washboard-like ripples that develop along the road surface due to repeated traffic movement.
Surface irregularity (rutting)	Longitudinal depressions or channels formed by the repeated passage of vehicle tyres, often due to weak or poorly compacted road materials.

Loose Material	Loose or unconsolidated gravel that has not bonded effectively, creating a surface susceptible to displacement by traffic or erosion.
Embedded Stoniness	Presence of large or sharp stones within the gravel surface, which can hinder vehicle traction and create a rough ride.
Loose Stoniness	Loose or scattered stones on the road surface that can reduce road quality and lead to vehicle discomfort.
Transverse Erosion	Erosion or wearing away of the road surface perpendicular to the direction of traffic movement.
Diagonal Erosion	Erosion or wearing away of the road surface at an angle to the direction of traffic movement.
Dustiness	Presence of excessive dust on the road surface, which can impair visibility, create discomfort, and lead to environmental issues.
Slipperiness	Reduced traction and increased slipperiness on the road surface, often caused by rain, loose material, or a lack of road maintenance.
Washouts	Sections of the road that have been severely eroded or washed away, often due to heavy rainfall or flooding.
Boulders or Large Obstacles	The presence of large rocks or obstacles on the road that impede traffic flow and pose safety hazards.

4.2.3 Defects and Their Possible Causes

The details of pavement defects and their possible causes are given in Table 4.2 to Table 4.3. The tables provide the distinctions of defects expected of flexible, semi-rigid and rigid pavements. It is important that the information provided in this and subsequent sections is clearly understood before undertaking any surveys. Also, use this information to prepare notes or remarks during the surveys.

Table 4.2 Defects Affecting Flexible Pavements

Type of Defect	Layers Affected	Deterioration Mechanisms	Possible Causes
Longitudinal cracking	Surfacing (AC)	Excessive and repeated loading - fatigue	• Insufficient thickness, and/or excessive rigidity of AC. • Excessive deformation of support • High deflections
	B (Cement treated) + Surfacing (AC)	Excessive and repeated loading - fatigue	• Insufficient thickness and/or strength of the base. • Excessive deformation of subgrade and subbase
Crazing	B (Cement treated) + Surfacing (AC)	Excessive and repeated loading -fatigue	• Insufficient thickness and/or excessive rigidity of AC. • Advanced deformation of support
	Surfacing (AC)	Excessive and repeated loading - fatigue	• Insufficient thickness and/or strength of the base. • Excessive deformation of subgrade and subbase
Crescent Cracking	Surfacing (AC)	Slippage	• Insufficient ACI stability • Poor interface bonding
Surface irregularity (rutting)	B + S SB + B + S SG + SB + B + S	Densification	• Insufficient stability of base • Insufficient stability of subbase and/ or base. • Insufficient base thickness • Insufficient pavement thickness and/or base • Insufficient subgrade compaction
Transverse corrugations	B + S	Densification	• Insufficient base cohesion and compaction • Possible failure of bond between surface and base
Depressions	B + S	• Densification • Disruption	• Lack of stability of base (inadequate material and/or compaction, attrition)
	SB + B + S	• Densification • Disruption	• Lack of stability of subbase (ditto)
	SG + SB + B + S	• Densification • Settlement	• Insufficient compaction of subgrade and/ or pavement • Insufficient fill compaction - slip- groundwater
Reflective Cracking	Asphalt Concrete Surfacing, Overlay	Lack of adhesion, propagation due to underlying layer movement, Freeze-Thaw action	• Movement in underlying layers, poor bond between overlay and existing pavement, freeze-thaw cycles.
Edge deformation	B	• Densification • Lateral movement	• Insufficient edge compaction • Lack of edge restraint (crushed stone)
Upheaval	SB	Soil expansion	• Moisture changes (expansive soils)
Potholes	S + B	Disruption	• Disintegration of surfacing and base (aggravation of some of the above processes)

Note: *AC-Asphalt Concrete, S-Surfacing, B-Base, SB-Subbase, SG-Subgrade*

Table 4.3 Typical Defects Affecting Rigid and Semi-rigid Pavements

Type of Defect	Layers Affected	Deterioration Mechanisms	Possible Causes
Longitudinal cracking	B + S	Excessive and repeated loading - fatigue	• Insufficient thickness, excessive strength of base, or both • Excessive deformation of subgrade and subbase
Tranverse Cracking	B + S	• Thermal changes • Shrinkage	• The rigidity of the base, surfacing or both; excess cement, or moisture • Poor cement-treated base; moisture changes
Reflective Cracking	B + S	• Fatigue Cracking • Temperature • Fluctuations • Stress concentration • Propagation due to cyclic loading	• Age, construction quality and condition of the pavement. • Temperature-induced movements in underlying layers. • Traffic loads and their impact on existing fractures. • Moisture and freeze-thaw effects.
Crazing	B + S	Excessive and repeated loading - fatigue	• Insufficient thickness, strength of the base, or both • Advanced deformation of subgrade and subbase
Crescent Cracking	Asphalt concrete	Slippage	• Insufficient premix stability • Poor interface bond
Surface Irregularity (rutting)	Asphalt concrete	Densification Creep	• Insufficient AC stability
Depression + Cracking	B + S	Densification	• Insufficient compaction or strength of SB • Insufficient fill compaction; slip or Groundwater
	SB + B + S	Settlement	
Faulting	B + S	• Loading, pumping densification • Erosion	• Insufficient strength of subbase and subgrade • Lack of drainage and subgrade swelling
Potholes	B + S	Disruption	• Disintegration of surfacing and base (aggravation of some of the above processes)

Note: *AC-Asphalt Concrete, S-Surfacing, B-Base, SB-Subbase, SG-Subgrade*

Table 4.4 Typical Defects and Their Possible Causes in Various Pavements

Type of Defect	Layers Affected	Deterioration Mechanisms	Possible Causes
Disruption	Asphalt concrete	Loss of cohesion	• Poor adhesion of aggregate • Permeability • Segregation • Insufficient binder • Ageing of bitumen • Chemical reaction
Ravelling	Asphalt concrete	• Abrasion by traffic • Lack of adhesion	• Soft aggregate • Insufficient bitumen • Ageing of bitumen • Chemical reaction • Nature of aggregate • Insufficient compaction
Peeling	Asphalt concrete Surface dressing	Horizontal forces	• The poor bond between base and surfacing • Defective tack coat • Fines on top of the base
Stripping	Surface dressing	Lack of adhesion	• Inadequate binder • Lack of rolling • Fast early traffic • Poor aggregates
Edge spalling	Base	Abrasion Loading	• The poor bond between base and surfacing • Lack of edge restraint • Shoulder erosion
Bleeding	Surfacing	Pumping of binder	• Excess binder • Whipped-off chippings • Too soft binder

Table 4.5 Typical Defects Affecting Unpaved Pavements

Type of Defect	Layers Affected	Deterioration Mechanisms	Possible Causes
Rutting	Wearing Coarse	Shear deformation	• Heavy rainfall • Improper drainage • Traffic loads • Inadequate compaction
Potholes	Wearing Coarse	Erosion and wear	• Frequent heavy rain and flooding • Poor-quality surface material • Lack of maintenance • Heavy traffic
Loose Gravel	Wearing Coarse	Material loss	• Erosion due to rainfall • Inadequate stabilisation • Heavy traffic
Dust and Erosion	Wearing Coarse	Material loss	• Wind erosion • Lack of dust control measures • Heavy traffic
Wash-boarding	Wearing Coarse	Repeated deformation	• Traffic patterns • Improper maintenance • Vehicle overloading
Corrugations	Wearing Coarse	Repeated deformation	• Inadequate compaction • Improper grading • Heavy traffic
Erosion and Sediment	Wearing Coarse/ Subgrade	Material loss	• Poor drainage • Heavy rainfall • Lack of proper erosion control measures
Vegetation Growth	Wearing Coarse	Material intrusion	• Insufficient maintenance • Moisture availability • Seed dispersal from nearby vegetation
Rutting	Wearing Coarse	Shear deformation	• Heavy rainfall • Improper drainage • Traffic loads • Inadequate compaction

4.3 Condition Rating Criteria

Pavement condition rating criteria are essential to quantify and standardise the interpretation of distress. For each type of defect, the severity and extent ratings are given in the range of 1-5, where one is good and five is critical or very severe. These ratings will be used to calculate the overall Pavement Condition Index, which quantifies the overall pavement condition to decided on appropriate levels of interventions subsequently. When recording defects, the following notation should be adopted to describe the location of the defect. Position: Left (L), Centre (C), Right(R), Outer Wheel Path (OWP), Inner Wheel Path(IWP).

4.3.1 Severity Rating

This quantifies the intensity or degree of pavement defects independent of their frequency and provides specific ranges of measurements for each rating level for measurable defects and descriptions for unmeasurable defects. The severity rating and general description that explain the standard measurement ranges assigned to each rating level are outlined in Table 4.6.

Table 4.6 Severity Rating

Severity Rating	Description
1	**Slight:** Noticeable but has no effect on structural integrity or functionality
2	**Mild:** Clearly visible but slightly affects pavement performance.
3	**Moderate/Warning:** Notable distress, starting to negatively affect functionality and structural integrity.
4	**Severe:** Major or significant defects, evidence of major structural issues that require immediate intervention.
5	**Critical/Very Severe:** Extreme level of deterioration that poses safety risks and critical pavement damage.

4.3.2 Extent Rating

The extent of distress quantifies how frequent and widespread a specific defect is over a specific test section (e.g. 50m - 100m sections for rehabilitation). This extent of the distress is expressed as a percentage of the test section. Table 4.7 outlines the extent rating, the aligned percentage ranges assigned and the general description explaining the standard measurement ranges assigned to each rating level.

Table 4.7 Extent Rating

Extent Rating	Percentage of Length Affected	Description
1	0 - 10	Isolated, or sporadic occurrence
2	10 - 20	Scattered, but no regular occurrence
3	20 - 50	Regularly occurring, but moderate concern
4	50 - 80	Widespread and seriously concerning
5	80 - 100	Critical level of deterioration with extensive occurrence.

4.3.3 Surface Condition Rating (SCR)

1. Visual Surface Condition Rating

Guidance for visual condition rating is provided in Table 4.8.

Table 4.8 Pavement Visual Condition Rating

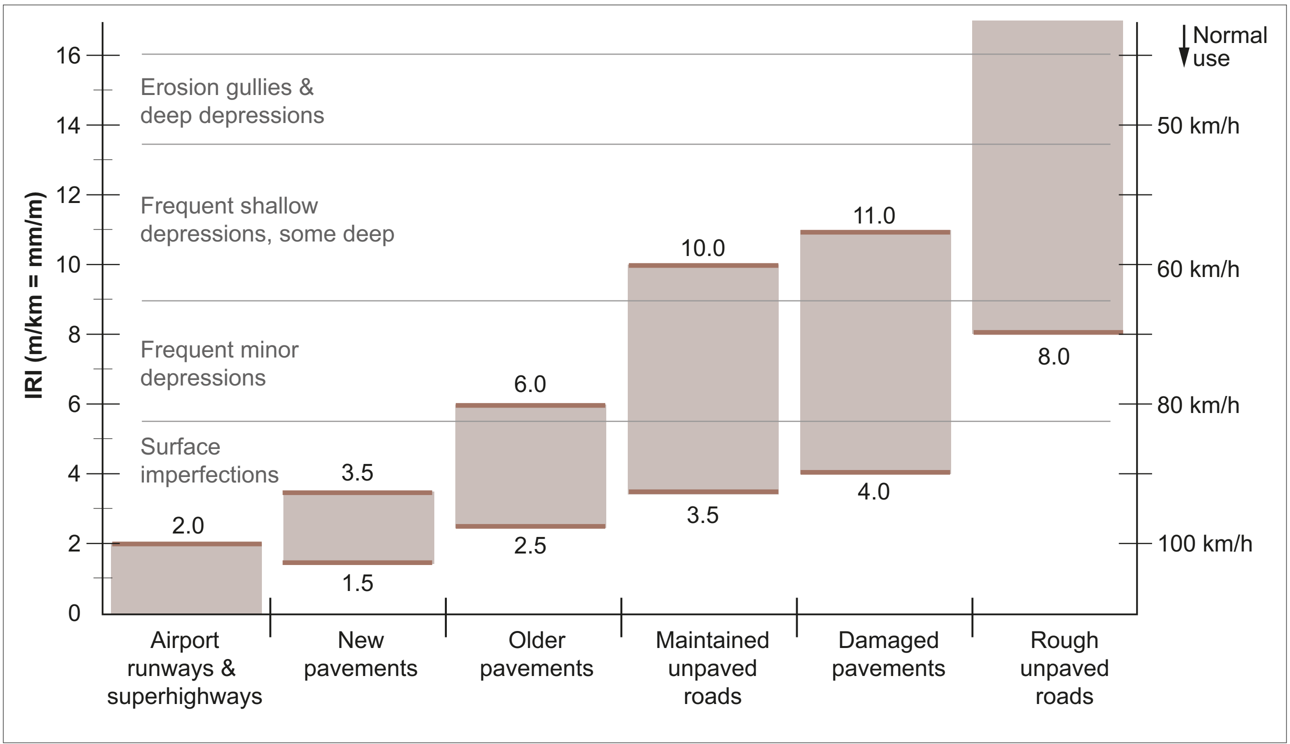
Rating	Reduction in Serviceability, Functionality or Capacity (%)	Condition	Description
1	**0-5**	Excellent	Must be new or like new and fully functional
2	**5-10**	Good	Nearly new with minor defects or damage requiring minor maintenance
3	**10-25**	Fair	These are defects and damage causing a significant reduction in serviceability, functionality and capacity. Substantial additional maintenance or repair is required
4	**25-50**	Poor	Defects causing a significant reduction in serviceability, functionality and capacity. Major maintenance or reconstruction is required
5	**>50**	Very poor	Beyond restoration via routine maintenance. Reconstruction is required

The ratings above are derived from IRI and other defect ratings.

2. IRI Rating for Pavement Condition Surveys

IRI should be applied for a simple and general assessment of the pavement. Guidance be followed in categorising sections of the road pavements using IRI is provided in Figure 4.1.

Figure 4.1 Consideration of Roughness for Road Network Condition Rating



3. Other Pavement Condition Ratings

Other pavement condition defects include:

- **a.** Rut depth.
- **b.** Deformation (geotechnical, shoving, etc.).
- **c.** Polishing and low texture depth.
- **d.** Deflections.

4. Overall Pavement Condition Rating (PCR)

At both network and project levels, the defect indices should be developed for each defect type because threshold values of each defect are used to determine pavement failure criteria and the appropriate interventions, particularly. Cracking and surface irregularity (rut depth measurement) are used more prominently, see Chapters 7 and 8.

The overall pavement rating is given in the form of Deterioration Indices in Equation 4.1 below.

$$\textit{Deterioration Index} = \textit{Extent} \times \textit{Severity}$$

Equation 4.1

Intervention prioritisation decisions are made for each defect or a combination of defects at this stage.

4.3.4 Present Serviceability Rating (PSR)

Present Serviceability Rating (PSR) is a parameter used to evaluate the current pavement serviceability and functional conditions based on user perception. It involves driving a passenger vehicle through a road and recording the onboard passenger's perception of ride quality and surface characteristics on a standard form rated on a scale of 1-5. The PSR rating in Table 4.9 below has been adopted as a standard for this manual's users. It may be used as a first step in evaluating a pavement's adequacy.

Table 4.9 Present Serviceability Rating (PSR)

PSR	Percentage of Length Affected
0-1	Very Poor
1-2	Poor
2-3	Fair
3-4	Good
4-5	Very Good

4.3.5 Pavement Condition Index (PCI)

The pavement condition index is derived from the indices by subtracting the surface condition indices (worst case scenario) expressed as a percentage from 100 % representing a new pavement. Surface condition ratings and the pavement condition index are calculated using Equation 4.2, Equation 4.3 and Equation 4.4.

$$PCI_i = PCI_{max} - \sum_1^k Deduct\ (SCR)$$

Equation 4.2

$$SCR = \left[\sum_1^k \frac{(I_1 + I_2 + I_3 + \ldots + I_k)/k}{25}\right] \text{ x } 100$$

Equation 4.3

$$PCI = PCI_{max} - \left[\sum_1^k \frac{(I_1 + I_2 + I_3 + \ldots + I_k)/k}{25}\right] \text{ x } 100$$

Equation 4.4

Where,

PCI = Pavement Condition Index, %.

PCI_{max} = Maximum PCI = 100% (new pavement).

SCR = Surface condition rating (100 % for fully deteriorated pavement and zero for new pavement).

I = The defect index (RdI, CrI, PPI, etc). The maximum for each defect is 25. (severity 5 x extent 5 = 25).

K = Number of defect types considered.

Table 4.10 Pavement Condition Index

PSR	PCI (%)	Percentage of Length Affected
1	< 25	Very Poor
2	25 - 40	Poor
3	40 – 60	Fair
4	60 – 80	Good
5	80 – 100	Very Good

Note:

1. *The above coefficients depend on the country, types of pavements analysed and the equipment used for measuring longitudinal profile variations or roughness.*
2. *A single PSI value is not a measure of absolute pavement performance, but it is representative of the trend of serviceability that gives indications about the pavement's performance.*

4.3.6 Present Serviceability Index (PSI)

The PSI is mainly dependent upon the roughness of the pavement surface and consequently, a simplified PSI may be determined from the following equation:

$$PSI = 5 - a(IRI) - b(\log IRI)$$

Equation 4.5

Where 'IRI' is the International Roughness Index and 'a' and 'b' are coefficients (see note).

4.4 Evaluation of Defects and Their Possible Causes

This section guides how to identify pavement defects and determine their possible causes. This information must be noted when carrying out the surveys. It should be as accurate as possible because it will be applied in the data analysis in subsequent stages. It will be a good backup to the observations and measurements used by the design engineer for the qualitative analysis of pavement deterioration or performance.

A visual representation of the most common types of defects is given in Figure 4.2, Figure 4.3 and Figure 4.4. Detailed description, possible causes and photographs showing a three-stage deterioration progression of these defects is provided in Appendix A: Catalogue of defects.

Figure 4.2 Typical Surface Distress

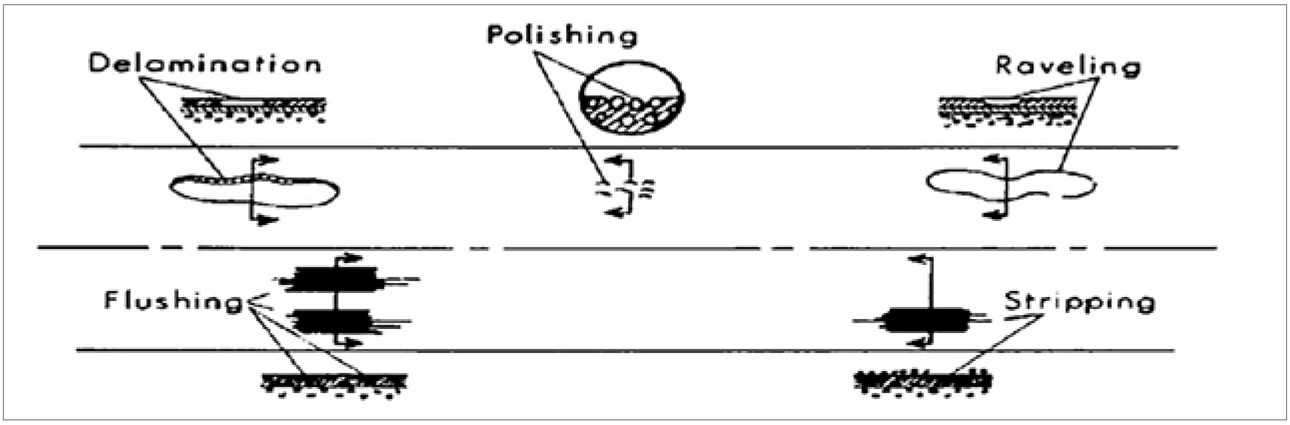


Figure 4.3 Common Types of Cracking

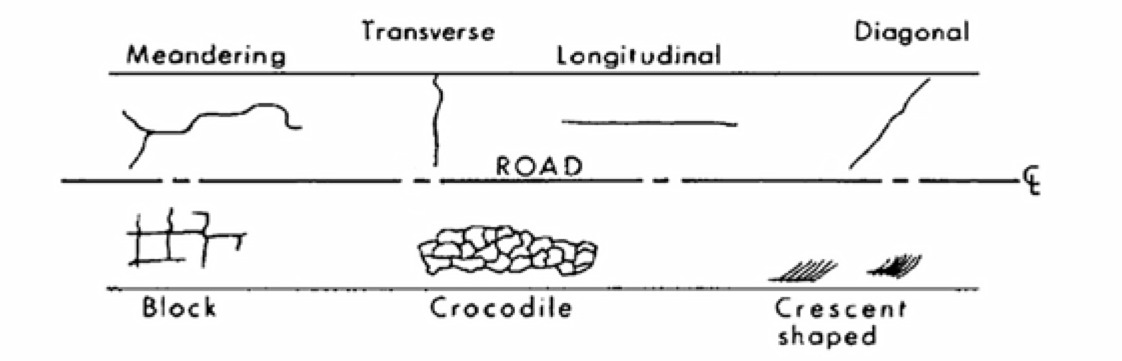
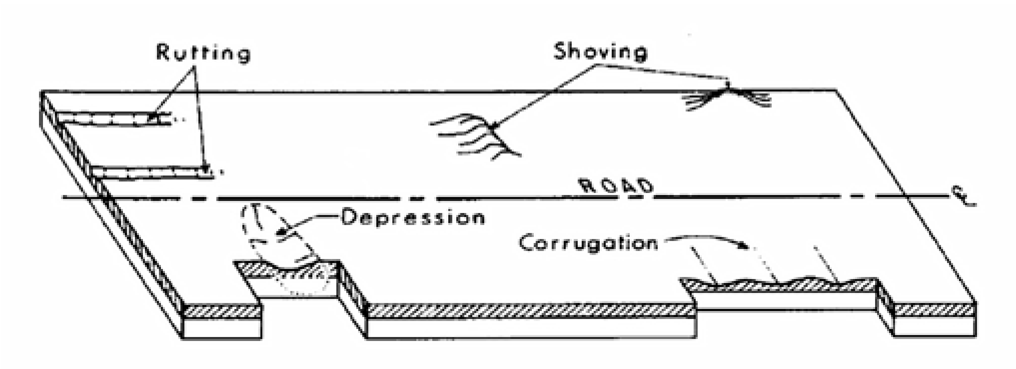


Figure 4.4 Deformation Defects in Flexible Pavement



5 Categories of Pavement Condition Surveys

5.1 General

There are four categories of pavement condition surveys:

1. Network surveys for planning and pavement management.
2. Pavement condition surveys for maintenance and rehabilitation design.
3. Pavement condition surveys for Compliance with design and Specifications.
4. Condition Surveys for Special Investigations.

The following pavement condition survey decision-making chart shown in Figure 5.1 summarises the procedures mentioned above. The following considerations are crucial:

1. **The purpose of the survey** – whether the data will be required for:
   a. Network pavement condition assessments – usually these data will be used in pavement management systems. The test points would be more widely spaced.
   b. Pavement maintenance and rehabilitation design – data required for design purposes will depend on the standard of the road to be designed and the size of the job. The data would typically be used to determine:
      i. The condition of the pavement.
      ii. Residual life of the pavement.
      iii. Nature of defects and triggers for maintenance and rehabilitation interventions.
      iv. Staged approach condition remediation.
   c. Compliance – Tests carried out on completed works to check conformity with standards and design specifications during or at the end of the construction period. The tests should predominantly be non-destructive and more spaced out unless serious nonconformities have been identified. These tests include the following:
      i. Deflection tests.
      ii. Skid resistance tests.
      iii. Dynamic Cone Penetrometer tests.
      iv. Roughness tests and level checks.
   d. Special Investigations – to determine causes of premature failures and for research:
      i. Pavement failures investigation for correction of defects: This approach involves lesson learning and determination of solutions to resolve the problems.
      ii. Pavement failures investigation for arbitration or litigation purposes: These processes require a more rigorous forensic approach, where the causes of failure should be proven beyond doubt. This means all scenarios and possible counterarguments should be considered from the outset. Here, the criteria for statistical significance, appropriateness of the method used, data accuracy, and surveyors' and engineers' experience should be satisfied.
      iii. Surveys carried out for research purposes.

2. **Level of accuracy required for the data**

High accuracy is usually required for high-volume roads. However, it should be noted that low-volume roads where non-standard materials are used will also require high accuracy because of the increased sensitivities and vulnerability. This applies to the following:

   a. Determination of design traffic – Failure to predict design traffic loading accurately can lead to overloading and premature failures.

b. Determination of materials characteristics – Materials used for low-volume roads are sometimes marginal, e.g., because of high plasticity, light pumice (cinder gravels), fine sand with rounded aggregate, soils with high mica content, pedogenic materials that degrade significantly during compaction, basaltic soils that degrade significantly in-service, etc.

c. Drainage – Moisture-induced defects are common in low-volume roads. Poor drainage of pavement and the surrounding environment can lead to premature failures due to a significant reduction in pavement strength due to an increase in moisture.

3. **Capacity to conduct the surveys:**

   a. Availability of equipment – the test to be carried out shall be commensurate with the available equipment and class of road or value of the project. Selection, availability and cost of acquiring specialised equipment required for surveys should be considered. For exceptionally low-volume roads, DCP tests could suffice for structural strength assessments. For low-volume road deflection tests, using an LWD or Benkelman Beam in conjunction with DCP would suffice. FWD could be used if available. For high-volume roads, the first choice should be the FWD, but a Benkelman beam or LWD could suffice if the asphalt layer is not thick (≤50 mm).

   b. Availability of technology – Considering the evolving technology and the availability of such technologies, the ministry and agencies, in consultation with their experts, should make decisions on technology to use based on fitness for purpose.

   c. Capacity of field engineers – The capacity of the responsible entities can also be a determinant factor in the method and technology to be used in for the survey, the quality of the data, and interpretation of the results.

5.2 Pavement Condition Surveys for Network Management

Pavement management involves the general assessment of the pavement to monitor the condition, prioritise interventions, and budget allocation. Details of how to carry out condition surveys should be provided in a Road Network Planning and Management Manual. A summary of the procedure is provided in Table 5.1 which guides the condition surveys required, as well as methods, equipment, and technical considerations.

Figure 5.1 Pavement Condition Survey Decision Making Flow-chart

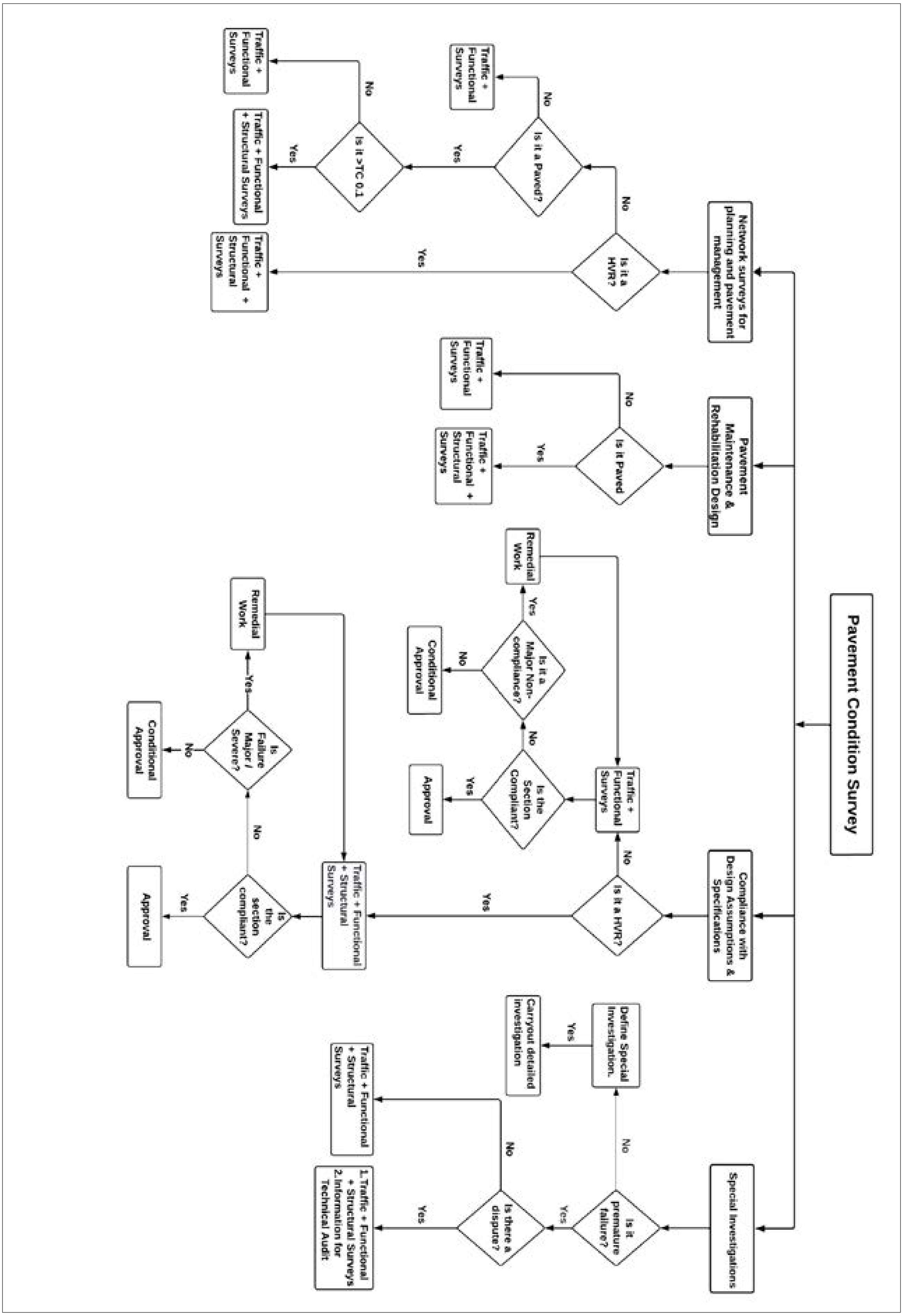


Table 5.1 Condition Survey Criteria for Pavement Management

Item No.	Condition Survey	Summary of the Test Method	Equipment/ Technology	Technical Considerations
1	**Windscreen survey**	Functional condition surveys by visual observation from a moving vehicle.	Vehicle, vehicle mounted camera, GPS.	Suitable for rapidly assessing the overall condition of long road sections, including surface distress and safety issues.
2	**Walk through visual condition surveys (VCS)**	Walk through the road section, conduct a visual condition survey, and record the defects in a standard form.	Vehicle, handheld GPS and camera, measuring tape, measuring wheel, standard form.	It is ideal for evaluating road networks or sections, intersections, or areas with higher pedestrian and traffic activity. Sample 300m section for in every in 3-5km. Also use video footage.
3	**Roughness (IRI)**	Select the section to be surveyed. For Rehabilitation design, carry out 2 or 3 measurements on wheel paths of each lane	Roughness measuring devices like a roughometer, Smart Mobile Phone App, or bump integrator.	Measure roughness on all lanes following the wheel paths.
4	**Ground Penetration Radar (GPR)**	Move the GPR equipment along the road and across	GPR equipment, measuring tape, measuring wheel, standard form.	It is useful in towns and where subsurface service lines must be located before the commencement of work.
5	**Deflection tests**	Conduct deflection tests on the outer wheel path. Apply one sitting drop and three measuring drops at each point. Measure air, surface and pavement temperatures.	Vehicle, camera, GPS, measuring wheel and take FWD for high and low-volume roads. LWD or Benkelman beam for low-volume roads. Benkelman beam for sample sections on high-volume roads.	Evaluate structural capacity. Minimum intervals: Periodic (e.g., every 2-3 years) for major roads; less frequent for lower-traffic roads. Spacing of test points: 500 m for highways; 500 m for medium trafficked roads; and 500 m for low-volume roads.
6	**Coring**	Collect cores of asphalt, rigid pavements, or cement-stabilised bases. Depending on the type of test required by he engineer, use the 100mm or 150mm core bits in the required numbers.	Coring machine with 100mm and 150mm coring bit, generator (power source), water container, callipers, measuring tape (device), core logging forms, camera	Take five cores in each uniform section based on pavement type. The coring positions should coincide with selected deflection points.
7	**DCP tests**	Based on the analysis of deflection data, carry out DCP tests on positions that show weak subgrades and unbound layers. The DCP test positions to coincide with selected coring positions.	DCP equipment, soil sampling containers for moisture content tests, measuring tape, camera and DCP forms.	Frequency: 1 DCP for every 5-10 km. Apply method to evaluate subgrade support on initial construction and periodically thereafter e.g., every 3-5 years for major roads.
8	**Test/ trial pits**	Mark test/ trial pit position to cut across the outer wheel path in the transverse direction, ideally 0.8m x 1.2m. Take photos of the surface of the pavement before excavating the pit. Record the condition. Remove the bituminous where necessary: Carry out field density tests. Measure the deformation of the pavement layers and subgrade under the wheel paths to determine the depth of rutting and the depth of influence of the loading.	Backhoe and/or hand tools (picks, shovels, spades, spatulas, sand replacement density test equipment, weighing balance, measuring tape, cameras, logging forms, sample bags, cable ties, straight edge or spirit level, etc.	Size of test/ trial pits: 1 m x 0.8 m Spacing: 1 test/ trial pit in 10-20 km and only once in a period of 20 years or when work has been carried out on the section, whichever comes first.
9	**Pavement drainage**	Check for water seepage, high water tables, colouration or stains on the side and backslope of drains, cleanliness and drainage grades, and any siltation or scouring. Check crow height. Record all information.	Level machine or line level, measuring tape	Carry out drainage assessment. Stop and carry out a walk-through survey where there is evidence of possible drainage inadequacy or drainage-related pavement deterioration. Drainage inspections must be conducted regularly.

5.3 Pavement Condition Surveys for Pavement Maintenance, Rehabilitation and Overlay Design

Pavement maintenance and rehabilitation design involves determining the strengthening and repairs required on the pavement. It may also include reconstruction or widening. Inadequacies or inaccuracies can lead to under-design or over-design which are failure designs with serious technical, contractual and financial consequences. Table 5.2 shows key condition surveys required.

Table 5.2 Condition Survey Criteria for Maintenance and Rehabilitation Design

Item No.	Condition Survey	Summary of the Test Method	Equipment/ Technology	Technical Considerations
1	**Auto-digital Surface Condition Survey**	Drive through the road and conduct function condition surveys using advanced cameras or visual assessments, collecting data on defects such as cracking, potholes, deformation ravelling, bleeding, surface irregularity (rutting), geotechnical movements, etc.	Vehicle, vehicle mounted camera and laser profilers, GPS, or equivalent system.	Length of sections = 50 m or 100 m.
2	**Windscreen survey**	Drive through the road and conduct visual condition survey through the windscreen of a moving vehicle. Record defects in a standard form, including cracking, potholes, deformation ravelling, bleeding, surface irregularity (rutting), geotechnical movements, etc.	Vehicle, vehicle mounted camera, GPS.	Length of sections = 500 m to 1 km.
3	**Carry out a walk-through pavement surface condition survey (VCS)**	Walk through the road section, conduct a visual condition survey and record the defects in a standard form. Take photos and GPS coordinates.	Vehicle, handheld GPS and camera, measuring tape, measuring wheel, standard form.	Pacing of chainages demarketing sections = 50m or 100m sections. Record video footage and photos to record the defects in each section.
4	**Deflection tests**	Conduct deflection tests on the road network concentrating on the outer wheel path. Conduct one plate sitting drop and three measuring drops at each point. Measure the asphalt's temperature once every hour in sections under the shed of trees or buildings. Check for errors and save the data.	Vehicle, camera, GPS, measuring wheel and measuring tape. FWD for high and low-volume roads. FWD, LWD or Benkelman beam for low-volume roads Benkelman beam for a sample of sections on high-volume roads.	Spacing of test points: 50m or 100 m for highways, 100 m for medium trafficked roads, 100 m for low-volume roads. Carry out the deflections on the outer wheel path in both directions. For multilane roads test the outer wheel path of each lane in both directions.
5	**Coring**	Collect cores of asphalt or rigid pavements or cement-stabilised bases. Use the 100mm or 150mm core bits in the required numbers depending on the type of test required by the engineer.	Coring machine with 100mm and 150mm coring bit, a generator, a 20L water tank for the coring machine, core logging forms, camera. callipers, and measuring tape.	Take a core in each uniform section on a minimum of 5 test positions; 2 on positions with the lowest deflections (strongest) and three on positions with the highest deflections (weakest). The total number of tests should be determined by the Engineer based on the number of tests required and pavement type. The coring positions should coincide with selected deflection test points.

Table 5.2 Condition Survey Criteria for Maintenance and Rehabilitation Design *(continued...)*

Item No.	Condition Survey	Summary of the Test Method	Equipment/ Technology	Technical Considerations
6	**DCP tests**	Carry out DCP tests on positions showing weak subgrades and unbound layers based on the analysis of deflection data. The DCP test positions to coincide with selected coring positions.	DCP equipment, soil sampling containers for moisture content and soil laboratory tests, measuring tape to measure offsets from the edge of the road or centreline, camera and DCP forms.	Frequency: 5 DCP tests; one for each of the five positions earmarked for coring, i.e., two for strongest and three for weakest positions.
7	**Test/ trial pits**	Mark test/ trial pit position to cut across the outer wheel path in the transverse direction, ideally 0.8m x 1.2m. Take photos of the surface of the pavement before excavating the pit. Record the condition. Remove the AC or HBM by cutting blocks off and preserving them for further tests in the laboratory. Carry out field density tests using a nuclear density gauge or sand replacement method on two positions on the pit for each unbound layer. Note that this may not be possible with GCS. Excavate to underlying layers and repeat the process. Collect samples from each layer for lab tests. Measure the deformation of the pavement layers and subgrade under the wheel path to determine the depth of the surface irregularity (rut depth) measured at the surface.	Backhoe and/or hand tools (picks, shovels, spades, spatulas, sand replacement density test equipment, weighing balance, measuring tape, cameras, logging forms, sample bags, cable ties, straight edge or spirit level, etc.	Size of test/ trial pits: 1 m x 0.8 m Spacing: at least 2 test/ trial pits in a uniform section, 1 in the strongest position and another in the weakest position. They should coincide with the position where deflections test, coring and DCP were carried out.
8	**Pavement drainage**	Check for water seepage, high water tables, colouration or stains on the side and backslope of drains, cleanliness and grades of drainage inverts and any siltation or scouring. Check crown height. Record all information.	Level machine or line level, measuring tape	Carry out drainage assessment through windscreen surveys. Stop and carry out a walk-through survey where there is an indication of drainage problems or serious pavement deterioration which could be attributed to poor drainage.

5.4 Pavement Condition Surveys for Compliance with Design and Specifications

Compliance tests are done to determine whether the rehabilitation design standards, assumptions and specifications have been met following construction. The condition surveys required for compliance testing are given in Table 5.3. The detailed condition surveys and test procedures are given in Chapter 7 and Chapter 8 respectively.

Table 5.3 Condition Survey Criteria for Compliance with Design and Specifications

Item No.	Condition survey	Summary of the Test Method	Equipment/ Technology	Technical Considerations
1	**Sample sections for walk-through visual condition surveys (VCS) and image and video recording**	Walk through the road section, conduct a visual condition survey and record the defects in a standard form. Take photos, and videos and record GPS coordinates.	Vehicle, GPS and cameras, measuring tape, measuring wheel, standard forms.	Placing of chainages demarketing sections = 100 m or 200 m. Record video footage and capture photos of the defects in each section. Recording with vehicle-mounted cameras with GPS is recommended.
2	**Roughness (IRI)**	Select the section to be surveyed. For Compliance checks, run twice or 3 times on each lane following the wheel tracks.	Vehicles and GPS-enabled roughness devices such as a roughometer or bump integrator are also included.	Measure roughness at least twice on all lanes following the wheel paths.
3	**Ground Penetration Radar (GPR)**	Move the GPR equipment along and across the road.	Ground penetration data equipment. Measuring tape. Measuring wheel. Data collection forms.	Coring and trenching are performed at pre-selected points for GPR calibration. Useful for concrete pavement structure investigations to detect layer thickness and reinforcement bar positions and properties. It is also used to determine subsurface defects and assess base layer conditions. It also gives information on subsurface service lines, which need to be located and referenced.
4	**Deflection tests**	Conduct deflection tests on completed road sections selected for evaluation, concentrating on the outer wheel path. Conduct two drops for sitting plate and three drops for measuring the deflections at each point. Conduct temperature measurements for the asphalt once every hour.	Vehicle, camera, GPS, measuring wheel. Use FWD for high and low-volume roads LWD or Benkelman beam for low-volume roads.	Spacing of test points: 100 m for highways, 200 m for medium trafficked, and low volume roads. Deflection tests done must not miss the outer wheel path in both directions. For multi-lane roads, test the outer wheel path of each lane in both directions. Record the GPS coordinates of the tests.
5	**Coring**	Collect cores of asphalt or rigid pavements or cement-stabilised bases. Use the 100mm or 150mm core bits in the required numbers depending on the type of test required by the engineer.	Coring machine with 100mm and 150mm coring bit, generator (power source), water container, callipers, measuring tape (device), core logging forms, camera.	Take two cores (100 mm and 150 mm diameter) in every km. Locate the coring positions to coincide with selected deflection test points. Collect more cores if there is a discrepancy in results from quality control tests carried out during construction (as instructed by the Engineer)
6	**DCP tests**	Carry out DCP tests on positions showing weak subgrades and unbound layers based on the analysis of deflection data. It is important to carry out DCP tests on points which would have been cored to remove the bound layers.	DCP equipment, soil sampling containers for moisture content tests, measuring tape to measure offsets from the edge of the road or centreline, camera and DCP forms	Frequency: 1 DCP for every 1-2 km. Apply method to evaluate subgrade support soon after initial construction and the results shall be referenced in future periodic tests thereafter e.g., every 5 years for major roads for pavement management.

Table 5.3 Condition Survey Criteria for Compliance with Design and Specifications *(continued...)*

Item No.	Condition survey	Summary of the Test Method	Equipment/ Technology	Technical Considerations
7	**Pavement drainage**	Check for water seepage, high water tables, colouration or stains on the side and backslope of drains, cleanliness and grades of drainage and any siltation or scouring. Check crow height. Record all information.	Level machine or line level and measuring tape	Carry out drainage assessment through windscreen surveys. Stop and carry out a walk-through survey where there is an indication of drainage problems Use a water cart to spread water on selected road sections exhibiting potential drainage complications, this helps to assess drainage efficiency. Drainage inspections must be conducted to verify that design requirements are met.
8	**Materials sampling**	Materials must be collected from the side of the road for verification tests.	Hand tools, sample bags and measuring tape.	One sample of the materials, and the results should be verified following the specifications. The results do not compare with those obtained from quality control tests carried out during construction, more samples should be taken.

5.5 Pavement Condition Surveys Criteria for Special Investigations

Special investigation cover:

1. **Forensic investigation of pavement failures.**
   Pavement forensic investigation involves providing adequate evidence for the causes of failure to provide solutions, and expert opinion on who is responsible and why. The results may include matters of contractual significance and financial consequences. Hence, the work must be conducted meticulously. The results or the conclusions may be challenged in an arbitration or court of law guided by the criterion shown in Table 5.4.

2. **Investigations for research purposes**.
   The purpose of the research and the intended outputs should be clearly defined.

Table 5.4 Condition Survey Criteria for Special Investigations

Item No.	Condition survey	Summary of test method	Equipment/ Technology	Technical considerations
1	**Auto-digital Surface Condition Survey**	Drive through the road, carry out surface condition surveys using advanced cameras, and collect data on defects such as cracking, potholes, deformation ravelling, bleeding, surface regularity (rut depth measurement), geotechnical movements, etc.	Vehicle, vehicle mounted camera and laser profilers, GPS. Software for interpretation and analysis.	Length of sections = 50 m or 100 m.
2	**Carry out a walk-through pavement surface condition survey (VCS)**	Walk through the section of the road, carry out a visual condition survey and record the defects in a standard form. Take photos and GPS coordinates	Vehicle, handheld GPS and camera, measuring tape, measuring wheel, standard form.	Pacing of chainages demarketing sections = 50m sections. Also, use video footage and photos to record the defects in each section.

Table 5.4 Condition Survey Criteria for Special Investigations *(continued...)*

Item No.	Condition survey	Summary of test method	Equipment/ Technology	Technical considerations
3	**Deflection tests**	Carry out deflection tests on the project road(s) concentrating on the outer wheel path. Carry out 1 plate sitting drop and 3 measuring drops at each point. Carry out temperature measurements for the asphalt once every hour and in sections under the shed of trees or buildings. Check for errors and save the data .	Vehicle, camera, GPS, measuring wheel and measuring tape. FWD for high and low-volume roads. Benkelman Beam for low-volume roads	Spacing of test points: 50m for highways. 50 m for medium trafficked roads. 50 m for low-volume roads. Carry out the deflections on the outer wheel path in both directions.For multilane roads test the outer wheel path of each lane in both directions.
4	**Coring**	Collect cores of asphalt or rigid pavements or cement-stabilised bases. Use the 100mm or 150mm core bits in the required numbers depending on the type of test required by the engineer.	Coring machine with 100mm and 150mm coring bit, a generator, a 20L water tank for the coring machine, core logging forms, camera, callipers, and measuring tape.	Take cores in each uniform section on a minimum of 5 test positions. More tests should be done on positions with the highest deflections. The total number of tests should be determined by the Engineer based on the number of tests required and pavement type. The coring positions should coincide with selected deflection test points.
5	**DCP tests**	Carry out DCP tests on uniform subgrades and unbound layers based on the analysis of deflection data. It is important the carry out DCP tests on points which would have been cored to remove the bound layers.	DCP equipment, soil sampling containers for moisture content and soils laboratory tests, measuring tape to measure offsets from the edge of the road or centreline, camera and DCP forms.	Frequency: 5 DCP tests; 1 for each of the 5 positions earmarked for coring, i.e., 2 for strongest positions and 3 for weakest positions.
6	**Test/ trial pits**	Mark test/ trial pit position to cut across the outer wheel path in the transverse direction, ideally 0.8m x 1.2m. Take photos to record the surface condition of the pavement before excavating the pit. Remove the surfacing material while preserving it for laboratory tests. Carry out field density tests using a nuclear density gauge or sand replacement method on two positions on the pit for each unbound layer. Excavate to underlying layers and repeat the process. Collect samples from each layer for lab tests. Measure the deformation of the pavement layers and subgrade under the wheel path to determine the depth of the rutting and affected layers.	Backhoe and/or hand tools (picks, shovels, spades, spatulas, sand replacement density test equipment, weighing balance, measuring tape, cameras, logging forms, sample bags, cable ties, straight edge or spirit level, etc.	Size of test/ trial pits: Very low volume = 1m x 0.8m Spacing: at least three (3) test/ trial pits in each uniform section. They should coincide with the position where deflections test, coring and DCP were carried out. Select one in the strongest position and another in the weakest position
7	**Pavement drainage**	Check for water seepage, high water tables, colouration or stains on the side and back slopes of drains, cleanliness and grades of drainage inverts and any siltation or scouring. Check crown height. Record all information.	Level machine or line level, measuring tape.	Carry out drainage assessment through windscreen surveys. Stop and carryout a walk-through survey where there is indication of drainage problems or serious pavement deterioration which could be attributed to poor drainage.

6 Preliminary Investigations and Surveys

6.1 General

The preliminary investigation serves as an initial assessment to identify potential problem areas and prioritise which road segments require more detailed analysis. It focuses on gathering essential information and identifying possible areas of concern without delving into extensive data collection or analysis.

6.2 Desk Study

Desk study involves a comprehensive analysis of existing data and information related to the pavement for the road under consideration. This section outlines the purpose, objectives, and key steps in conducting a desk study for pavement rehabilitation and maintenance.

1. **Purpose:**
   The desk study aims to gather and analyse relevant data and information to inform the decision-making process for pavement rehabilitation and maintenance. It provides a foundation of knowledge about the pavement network, its as-built details, and its history of its condition and performance. This helps in developing effective and efficient strategies for maintenance and rehabilitation activities.
2. **Objectives:**
   The main objectives of the desktop study are:
   - **a.** Evaluate the historical performance and maintenance records.
   - **b.** Assess the current condition of the pavement network.
   - **c.** Identify the underlying causes of distress or deterioration.
   - **d.** Analyse traffic patterns and loadings on the pavement.
   - **e.** Identify any environmental or geological factors affecting the pavement.
   - **f.** Review and select relevant design standards, guidelines, and specifications.
   - **g.** Assess the availability of resources, including budget and equipment.
   - **h.** Identify any legal or regulatory requirements.
3. **Key Steps:**
   The following steps should be followed when conducting a desktop study for pavement rehabilitation and maintenance:
   - **a.** Data Collection:

     Gather all available data related to the pavement network. This may include:
     - **i.** Pavement condition surveys and reports.
     - **ii.** Maintenance and repair records.
     - **iii.** Traffic volume and loading data.
     - **iv.** Geological and environmental data.
     - **v.** Design standards and specifications.
     - **vi.** Budget and resource allocation information.
     - **vii.** Social Impact assessment reports.
     - **viii.** Environmental Impact Assessment reports.

b. Data Analysis:
Analyse the collected data to gain insights into the pavement's condition, performance, and potential causes of distress or deterioration. This analysis may involve:

i. Selection of the appropriate software and data processing techniques.

ii. Statistical analysis of condition data.

iii. Trend analysis to identify patterns of deterioration.

iv. Identification of pavement distress types and severity.

v. Correlation analysis between pavement performance and traffic data.

6.2.1 Collection and Repository of Historical Data and Information

1. **Road Inventory and Condition Surveys (RICS)**
The road assets' inventory and condition are surveyed periodically to determine the condition of the road network and the information is kept in a central repository for future reference. This information is essential for the evaluation of pavement performance and the prioritisation of interventions on the network. This is essential for identifying uniform sections and developing the appropriate intervention.

This information is critical in defining the purpose of the intervention. It assists in determining the level of investment required and the consequences of decisions on the remediation options selected.

2. **Collection of Inventory Data, Review of Historical information and Performance Data:**
a. Historical Information required - Historical information is essential to producing a comprehensive desk study. The information required for the desk study is given in Table 6.1.

Table 6.1 Historical Information Required

Item No.	Data & Information Required	Purpose
1	Road Network Inventory. Refer to Table 6.2 for a detailed road network inventory.	The list, location and nature of components of the road network and related features, including pavements. The information should be detailed enough for engineers and planners to make decisions on interventions that may be required.
2	Information on the designs and as-built data	To determine parameters and assumptions considered during design and as-built pavement structure and changes in pavement condition. The data and information should be archived using systems such as Road Asset Management Systems (RAMS) and Pavement Management Systems (PMS), which are computer-based for easy reference or retrieval.
3	Maintenance data and information, including associated costs	To determine the maintenance demand and life-cycle costs of different parts of the road network. This will feed into the prioritisation of interventions and budget allocations. Maintenance history is required in the assessment and evaluation of defects as well as past performance of the pavement.
4	Traffic counts	To determine traffic volumes, peak flow or level of service demand and traffic categories, and traffic growth rates. These data are used to estimate the historical traffic loading required for pavement evaluation and rehabilitation.
5	Axle load surveys	To determine traffic loading on different parts of the network. Overloading is critical in evaluating the pavements' past and future performance. These data are essential for pavement maintenance and rehabilitation design.
6	Roughness	To determine serviceability ratings and indices used as criteria for maintenance and rehabilitation interventions.

Table 6.1 Historical Information Required *(continued...)*

Item No.	Data & Information Required	Purpose
7	Pavement Surface condition surveys	To determine modes of deterioration, which are used for scheduling maintenance and rehabilitation. This information is also valuable for determining the most cost-effective interventions.
8	Condition surveys for structures	To determine the structural integrity and capacity of structures on the road. This information indirectly influences the determination of the pavements future performance, particularly in the vicinity of the structures concerned.
9	Unit Costs	Road provision is a costly undertaking, and the economics of road provision is a key component of the design process regarding affordability. Data on unit costs are essential in determining the most cost-effective intervention, rehabilitation or maintenance design options.
10	Climate	Climate impacts performance significantly. On low-volume roads, climate-induced deterioration dominates deterioration caused by traffic. Cracking on bituminous surfacing and pavements are caused by oxidation bitumen and loss of volatiles from the binders, causing embrittlement and cracking of the bituminous surfacing and pavements under traffic loading.
11	Earthquakes	Seismicity causes movement in the pavement structure and foundations. It is crucial to distinguish defects caused by seismic waves from other causes of cracking and deformation of pavements.

b. Pavement Inventory Data: For pavements, the types of surfacing should be recorded. Table 6.2 shows the inventory information for pavements.

Table 6.2 Pavement Inventory Data

Surfacing Type	Description	Implication for Baseline Values
Asphalt	Hot mix asphalt, cold mix asphalt.	The baseline condition is low roughness (IRI < 3).
Surface dressing	Single, double or triple surface dressing.	Coarse texture with initial IRI of values between 2 and 3.
Gravel	Coarse or fine, and natural or processed.	Initial surface conditions can be fine for sandy gravel (GM<1.5) and coarse (GM>1.5). Initial IRI between 3 and 5
Earth	Coarse or fine and natural. Made by forming natural ground.	Engineered earth: Initial IRI can be between 4 and 7.
Sand	Sand can be cohesive with clay or very firm due to high content of iron oxides or calcareous material content.	Usually very smooth: Initial IRI between 2-4.
Shoulder	The pavement between the side slope and the carriageway.	Exist or not, shoulder width, shoulder materials.
Drains	Include side drains, mitre drains and catchwater drains.	Exist or not, one side or both sides, condition.

3. Typical Methods of Data Collection

a. Most Common Methods for Data Collection During Pavement Evaluation.

Pavement evaluation is a multi-faceted process, with each method offering unique insights into the pavement's condition and performance. By understanding the nuances of each method, practitioners can ensure comprehensive evaluations that inform maintenance and rehabilitation decisions effectively. Table 6.3 below provides insight which will help in the selection of the relevant methods to each project.

Table 6.3 Typical Data Collection Methods

Item	Method	Description	Benefit	Limitation	Precautions
1	**Falling Weight Deflectometer (FWD)**	FWD is a non-destructive testing tool that uses an impulse or vibratory load onto the pavement surface to measure the pavement's deflection.	**1.** Provides rapid and continuous measurements. **2.** Efficient Non-destructive method for maintenance Planning. **3.** Provides insight into the load-bearing capacity of different pavement layers. **4.** Quick and reduces road closures.	**1.** Requires skilled operators. **2.** High capital cost.	**1.** Ensure the testing area is free from debris. **2.** Calibrate the equipment regularly. **3.** Assign trained experts to interpret the results. **4.** Suitable for flexible and rigid pavements.
2	**Ground Penetrating Radar (GPR)**	GPR uses radar pulses to image the subsurface of the pavement, identifying layers, thicknesses, and anomalies.	**1.** Provides continuous data. **2.** Non-destructive method. **3.** Detects subsurface defects and moisture presence. **4.** Detect underground service lines. **5.** Rapid data collection.	**1.** Requires trained experts **2.** Performance can be affected by high-conductivity materials.	**1.** Ensure the surface is relatively clean. **2.** Avoid interference from other electronic equipment. **3.** Calibration is crucial for accurate results. **4.** Depth penetration varies based on equipment and pavement type.
3	**Surface Distress Surveys**	Manual or automated surveys are used to identify, classify, and quantify visible pavement distresses like cracks, potholes and surface irregularity (rutting).	**1.** Simple and direct method for observing pavement conditions for primary indicators. **2.** Can be combined with other survey methods.	**1.** Manual surveys can be subjective. **2.** Might not capture subsurface defects. **3.** Labour-intensive	**1.** Ensure safety during surveys. **2.** Use standardised classification and rating systems. **3.** Frequency of surveys should be based on pavement age and traffic volume. **4.** Using automated systems can offer consistency.
4	**Skid Resistance Testing**	Measures the frictional resistance of the pavement surface, often using a locked-wheel skid trailer.	**1.** Results are directly related to road safety. **2.** Quantitative measure of surface texture and friction.	**1.** Weather conditions can affect results. **2.** Requires periodic calibration.	**1.** Testing should be done at consistent speeds. **2.** Ensure the water supply system (for wet testing) is functional. **3.** Use calibrated equipment. **4.** Conduct tests in various weather conditions, (wet and dry conditions).
5	**Core Sampling**	Extraction of cylindrical samples from the pavement for detailed laboratory analysis.	**1.** Provides in-depth material analysis and direct and accurate assessment of material properties and layer thickness. **2.** Validates non-destructive test results.	**1.** The evidence is limited to sample spots. **2.** Destructive test method.	**1.** Carefully select test sections. **2.** Ensure restoration of all sampled test positions. **3.** Adhere to strict safe work procedures and environmental protection measures.

Table continues on the next page...

Table 6.3 Typical Data Collection Methods *(continued...)*

Item	Method	Description	Benefit	Limitation	Precautions
6	**Test/ trial pits**	Excavation of a small section of the pavement to expose its layers for direct observation and assessment. This method involves excavating a pit to a specified depth or until the subgrade is reached.	**1.** Provides an unobstructed view of all pavement layers, allowing for a comprehensive assessment. **2.** Allows for extraction of material samples from specific layers for laboratory testing. **3.** Can be used on all types of pavements and is not restricted by surface material or construction type. **4.** Enables direct observation of signs of moisture ingress or trapped water within the pavement layers. **5.** Cost-effective, particularly for smaller projects or isolated problem areas.	**1.** The pavement is disturbed. **2.** Labor-Intensive if done manually. **3.** It can be time-consuming. **4.** Provides information only about the specific location where the pit is dug, which may not be representative of the entire pavement. **5.** Open pits can pose safety hazards to workers, motorists and the public.	**1.** Implement Safety measures such as use of barriers, cones, and warning signs around the excavation site to ensure safety. **2.** Ensure good equipment care practices for example, if using mechanical excavators, ensure they are in good condition to avoid accidental over-excavation. **3.** Avoid excavation during adverse weather conditions, especially heavy rainfall, to prevent the pit from caving in or getting flooded. **4.** Document site evidence such as photographs taken at various stages of excavation to maintain a record. **5.** Select test/ trial pit locations that are representative of the uniform sections identified in the area under investigation. **6.** Before excavation, decide on the depth based on the information required and the expected layer thickness guided by as-built data. **7.** Plan for the necessary materials and methods to restore the pavement layers after the evaluation. **8.** Depending on the project's scale and objectives, determine the number and spacing of test/ trial pits to ensure a comprehensive evaluation. **9.** If extracting samples, ensure that the laboratory is equipped and prepared to conduct the required tests promptly.

b. Simple Data Collection Methods Applicable During Pavement Evaluation

In Some instances where the abundance of information is not a priority, it is essential to apply cost-effective methods for pavement evaluation without compromising the quality and accuracy of the data collected. By understanding each method's strengths and limitations, agencies can make informed decisions that best suit their needs and resources, especially during high-level planning stages. Table 6.4 below identifies some of the most common types of simple data collection methods. It should be noted that under each category or type of test there are various methods that cannot be exhausted from this manual. Reference should be made to other methods in other standards published and approved by the Ministry responsible for roads after the production of this manual.

Table 6.4 Simple Data Collection Methods

Item	Method	Description	Benefit	Limitation	Precautions
1	**Visual Surveys**	Manual inspections where trained personnel visually assess and document pavement conditions, noting distresses, deformations, and other visible defects.	**1.** No special equipment is required. **2.** Immediate feedback and firsthand information. **3.** Flexibility in scheduling and area coverage.	**1.** Subjectivity can lead to inconsistent results. **2.** Limited to surface-level observations.	**1.** Ensure Pavement Experts are trained and use standardised criteria. **2.** Perform during optimal lighting conditions. **3.** Regularly calibrate Pavement Experts for consistency. **4.** Use a standardised checklist or rating system.
2	**Digital Photography and Video Logging**	Using digital cameras or smartphones can be used to capture images and videos of pavement conditions, allowing for post-inspection analysis.	**1.** Provides a permanent visual record. **2.** Can cover large areas quickly. **3.** Widely available technology.	**1.** May not capture subsurface defects. **2.**Requires storage and post-processing.	**1.** Use consistent camera settings for clarity. **2.** Ensure systematic coverage of the area. **3.** Organise and label files systematically. **4.** Ensure backup storage solutions.
3	**Public Feedback and Crowdsourcing**	Engaging the community to report pavement issues using mobile apps, online platforms, or simple feedback forms.	**1.** Wide area coverage. **2.** Real-time feedback. **3.** Engages the community, increasing public awareness.	**1.** Varying data quality. **2.** Potential for duplicated or non-relevant reports.	**1.** Varying data quality. **2.** Potential for duplicated or non-relevant reports. **3.** Varying data quality. **4.** Potential for duplicated or non-relevant reports.
4	**Simple Measurement Tools**	Using basic tools like straightedges or simple apps that utilise a smartphone's accelerometer to measure pavement roughness.	**1.** Low-cost and easy to use. **2.** Provides a quantitative measure of surface evenness.	**1.** Less accurate than specialised equipment. **2.** Limited to the tool's length or phone's capabilities.	**1.** Ensure tools are in good condition and apps are calibrated. **2.** Take multiple measurements for better accuracy. **3.** Choose tools or apps based on the specific pavement type and expected distresses. **4.** Regularly cross-check with other methods for consistency.
5	**Use of Free or Open-Source GIS Software**	Geographic Information System (GIS) software allows for spatial mapping and analysis of pavement conditions.	**1.** Visual representation of data. **2.** Integration with other datasets. **3.** Several open-source options are available (e.g., QGIS).	**1.** Requires basic training to use. **2.** Data input might be time-consuming.	**1.** Ensure regular backups of GIS datasets. **2.** Use standardised data formats. **3.** Integrate GIS data with other data sources for a comprehensive view. **4.** Regularly update software for new features and security patches.

4. **Structures Inventory**
   The inventory of other features of the road such as structures like culverts, bridges and side drains should be noted because their condition adequacy or lack of it can impact on the performance of the adjacent pavements.

6.2.2 As-Built Data

As-built data refers to the collection and documentation of information regarding the actual, existing construction of the pavement infrastructure. It data provides valuable insights into the construction history and characteristics of the pavement network. This section highlights the purpose, objectives, and key considerations for as-built data relevant to a pavement maintenance and rehabilitation manual.

1. **Purpose:**
   The purpose of as-built data collection is to create an accurate record of the constructed pavement network. It is a valuable reference for future maintenance and rehabilitation activities, providing insights into the original design, materials used, and construction details. As-built data

enables effective decision-making, and quality control, and facilitates the efficient execution of maintenance and rehabilitation projects.

2. **Objectives:**

The main objectives of collecting as-built data for pavement maintenance and rehabilitation are as follows:

a. Document the design specifications and standards followed during the pavement construction.

b. Record the actual materials used, layer thicknesses, and pavement composition.

c. Capture any modifications or changes made during the construction process.

d. Establish a baseline for future assessments and comparisons.

e. Support quality control and verification of the construction work.

f. Aid in the identification of potential issues or deficiencies that may affect future maintenance or rehabilitation efforts.

3. **Key Considerations**:

When collecting as-built data for pavement rehabilitation and maintenance, the following key pieces of information should be put together:

a. **Construction Drawings and Specifications:**
Obtain and review the construction drawings, plans, and specifications related to the pavement project. These documents provide valuable information about the intended design and construction details.

b. **Field Verification:**
Conduct field verification to confirm that the constructed pavement aligns with the design specifications. This may involve measurements of pavement layer thicknesses, cross-sections, and other relevant features.

c. **Material Documentation:**
Collect information on the materials used in the construction of the pavement, including the type and source of aggregates, asphalt mixtures, binders, and additives. This information aids in assessing the performance and durability of the pavement.

d. **Construction Modifications:**
Identify any modifications or changes made during the construction process compared to the original design. Document these modifications and assess their potential impact on the pavement's performance and future maintenance requirements.

e. **Geometric Data:**
Record key geometric features of the pavement network, such as alignment, cross slope, super-elevation, and curb profiles. These details are essential for accurate pavement evaluation and analysis.

f. **Testing and Quality Control**:
Compile test results and quality control records conducted during construction, such as compaction tests, asphalt core samples, density tests, and any other relevant inspections. These records help ensure that the pavement was constructed in compliance with the specified standards and specifications.

4. **Documentation:**

The as-built data should be documented comprehensively to ensure its accessibility and usability in future maintenance and rehabilitation efforts. The documentation should include the following information:

a. Construction drawings, plans, and specifications.

b. Measurements and field verification records.

c. Material specifications and sources.

d. Records of modifications or deviations from the original design.

e. Geometric data and profiles.

f. Test results and quality control records.

5. **Integration with Asset Management Systems:**
To enhance the effectiveness of as-built data, it should be integrated into an asset management system or database. This integration enables easy retrieval and analysis of the information, facilitates future decision-making, and supports long-term pavement management strategies.

6.2.3 Review of Past Events

It is beneficial to review past events related to the road or pavement being assessed. This historical review can provide valuable insights and context for understanding the current condition of the pavement. Below are some key events to consider:

1. **Construction and Design History:**
Review the construction records and design specifications of the pavement to understand its original design, materials used, and construction techniques. This information can help assess the expected performance and identify any potential design or construction-related issues.

2. **Maintenance and Rehabilitation History:**
Examine the maintenance and rehabilitation records of the pavement to identify past repair and maintenance activities. This includes details about the type of maintenance performed, the frequency of repairs, and the materials used. It can help identify recurring issues, evaluate the effectiveness of previous maintenance strategies, and plan future interventions.

3. **Assessment and Analysis of Traffic and Load History:**
Analyse the historical traffic data, including traffic volume and composition, as well as any specific load restrictions or abnormal load events that may have impacted the pavement. This information can assist in assessing the level of stress the pavement has experienced over time and understanding its durability and performance.

a. **Traffic Assessment**
The assessment of traffic involves carrying out traffic counts, determining the growth rates and, ultimately, future traffic loading required for rehabilitation design. It should be noted that RDM 1.2 should be referenced for more details on traffic study. Key areas for consideration by the design engineer include:

i. Historical traffic counts.

ii. Project-specific traffic counts.

iii. Growth rates.

iv. Axle load surveys and analysis.

v. Traffic loading classes.

b. **Historical traffic**
Details of traffic counts and categorisation are given in Vol. 1 Part 2. Regular traffic counts are important in determining:

i. Traffic categories.

ii. Historical traffic growth rates by traffic category. This would be the basic traffic without diverted or generated traffic.

iii. Seasonal changes for the developing seasonal factors are required to calculate annual average daily traffic (AADT) from average daily traffic (ADT).

c. **Project Specific Traffic Counts**
For specific traffic counts, details on the different vehicle classes should be followed. Refer to RDM 1.2 and RDM 3.3.

d. **Traffic volumes:**

i. Initial traffic – traffic obtained from traffic counts that are conducted at the data collection stages of the project. These may consist of 7-day counts of which 5 would be day counts (6 am to 6 pm) and 2 would be full 24-hour counts. The 24 hrs counts are used to extrapolate the 12 hr counts to 24 hr counts. The traffic counts are categorised by type of vehicles, as per the vehicle classes table in RDM 1.2. For pavement rehabilitation design, vehicles less than 1 tonne are not considered.

$$C_{24} = \frac{C_{24F}}{C_{12F}} \times C_{12P}$$

Equation 6.1

Where,

C_{24F} = full 24-hour count.

C_{12F} = daytime 12-hour count of the full 24-hour count.

C_{12P} = 12 hour count of the daytime partial counts only.

a. Generated traffic – this is traffic that is generated due to normal growth.

b. Diverted traffic – this is traffic diverted from other alternative routes to the road under design for various reasons.

ii. Origin destination surveys – Origin destination surveys are conducted on commercial vehicles carried out to determine the goods they are carrying and the destinations for the goods. The information is important in subsequent stages to determine diverted traffic.

iii. Axle load surveys – Axle load surveys are required to determine the vehicle equivalent (VEF) factors for each vehicle class.

4. **Environmental Events:**
Consider any significant environmental events that may have affected the pavement condition. This includes extreme weather events such as heavy rainfall, flooding, notable freeze-thaw cycles, or prolonged periods of high temperatures. These events can contribute to pavement distress, deterioration, or accelerated ageing if they were not catered for in the original designs, and understanding their occurrence can help interpret the current condition. This helps with special investigations that are useful for producing climate-resilient pavement solutions.

5. **Accidents or Incidents:**
Evaluate any accidents or incidents on the pavement, such as vehicle collisions, chemical spills, or other incidents that may have caused damage to the pavement. This information can provide insights into localised pavement distress and help in determining the appropriate remedial actions.

6. **Utility Installations and Repairs:**
Identify any utility installations or repairs conducted on or near the pavement. Utility work can impact the structural integrity and condition of the pavement due to excavation, backfilling, or compaction issues. Understanding the history of utility work can help identify potential underlying problems.

7. **Complaints and Feedback**:
Consider any documented complaints, feedback, or concerns from road users, local communities, or relevant stakeholders regarding the pavement condition. This feedback can provide insights into specific areas of concern and help prioritise maintenance or rehabilitation efforts.

This brings a clearer understanding of the pavement's performance, deterioration patterns, and potential contributing factors. This historical context can enhance the accuracy and effectiveness of the pavement condition survey, as well as inform decision-making regarding appropriate maintenance and rehabilitation strategies.

6.2.4 Review of Performance Data

Reviewing performance data is an essential step in assessing the condition of the pavement and making informed decisions. The following are some key aspects to consider when reviewing performance data:

1. **Pavement Performance Metrics:**

   Review performance metrics such as roughness, distresses (e.g., cracks, potholes, surface irregularity (rutting), ride quality, surface texture, and structural integrity give an understanding of the overall condition and functional performance of the pavement. Compare current data with historical data to identify trends and changes over time.

2. **Data Collection Methods**:

   Assess the reliability and accuracy of the data collection methods used to gather the performance data. Consider the survey methodology, equipment calibration, data collection protocols, and quality control procedures. Understanding the data collection process helps ensure the integrity of the performance data.

3. **Data Consistency and Reliability:**

   Evaluate the consistency and reliability of the performance data across the survey sections or sample points. Look for any anomalies or inconsistencies that could affect the interpretation of the pavement condition. Address any data quality issues or discrepancies during the review process.

4. **Longitudinal Analysis:**

   Conduct a longitudinal analysis of the performance data to identify trends and patterns over time. Examine the historical performance data to understand the progression of pavement deterioration, the effectiveness of past maintenance actions, and the overall performance of the pavement throughout its lifespan.

5. **Comparison to Standards and Criteria:**

   Compare the performance data against established standards, criteria, or thresholds. This may include national or regional pavement performance guidelines, agency-specific standards, or predetermined performance targets. Assessing the data against these benchmarks helps determine whether the pavement meets the required performance levels or if intervention is necessary.

6. **Correlation with Other Factors:**

   Analyse the performance data concerning other influential factors such as traffic volume, climate conditions, soil characteristics, and maintenance history. Identifying correlations or relationships between these factors and pavement performance can provide insights into the underlying causes of distress and guide future maintenance or rehabilitation strategies.

7. **Statistical Analysis:**

   Apply appropriate statistical analysis techniques to the performance data to extract meaningful insights. Statistical methods can help identify statistically significant trends, patterns, or relationships within the data and support evidence-based decision-making.

8. **Data Visualisation:**

   Utilise data visualisation techniques such as charts, graphs, maps, or GIS (Geographic Information System) tools to effectively present and interpret the performance data. Visualising the data can facilitate a clearer understanding of the pavement condition and aid in communicating the findings to stakeholders.

9. **Reporting and Documentation:**

   Document the findings of the performance data review comprehensively. Prepare a clear and concise report that summarises the current condition, highlights important observations, and provides recommendations for future actions. Include supporting data, analysis methodologies, and relevant visualisations in the report.

By reviewing performance data, you can gain valuable insights into the current condition and performance of the pavement. This information forms the basis for making informed decisions regarding maintenance, rehabilitation, and pavement management strategies to ensure the longevity and functionality of the road network.

6.2.5 Review of Previous Maintenance Interventions

Reviewing past interventions is an essential step in any pavement maintenance and rehabilitation project. It provides valuable insights into the effectiveness of previous strategies, helps optimise costs, identifies patterns and trends, and facilitates performance evaluation. By learning from past experiences, we can make informed decisions, ensure long-lasting solutions, and enhance the overall efficiency of pavement management.

This section includes relevant information about the maintenance or repair interventions performed, the reasons behind them, and their outcomes. Here is a suggested structure that can be followed when gathering such information:

1. **Introduction:**
   a. Provide a brief introduction to the importance of previous maintenance interventions in prolonging the lifespan and ensuring the functionality of the pavement.
   b. Emphasise the significance of documenting past interventions for future reference and decision-making.
2. **Overview of Previous Maintenance Interventions:**
   a. Provide a chronological list or timeline of previous maintenance interventions, starting from the initial construction of the pavement.
   b. Include a brief description of each intervention, such as crack sealing, patching, resurfacing, or other relevant activities.
   c. Mention the dates or periods when these interventions were conducted.
3. **Reasons for Interventions:**
   a. Explain the reasons or triggers that led to each maintenance intervention.
   b. Discuss common issues or distresses observed in the pavement that necessitated intervention, such as cracking, surface irregularity (rutting), potholes, or structural deficiencies.
   c. Highlight any external factors or events, such as heavy traffic, extreme weather conditions, or construction activities, which influenced the need for maintenance.
4. **Techniques and Materials Used:**
   Any innovative or specialised approaches used, if applicable.
5. **Outcomes and Performance Evaluatio**n:
   a. Discuss the effectiveness and performance of each intervention.
   b. Present data, if available, on the post-intervention condition of the pavement, such as improved ride quality, reduced distress, or extended service life.
   c. Include any monitoring or evaluation reports that assess the long-term performance of the interventions.
6. **Lessons Learned:**
   a. Summarise the key lessons learned from the previous maintenance interventions.
   b. Highlight any successful strategies, best practices, or innovative solutions from the interventions.
   c. Discuss any limitations or challenges encountered during the maintenance interventions and how they were addressed.

7. **Future Considerations:**
   a. Provide recommendations or suggestions based on the lessons learned and outcomes of the previous interventions.
   b. Discuss how the knowledge gained from past interventions can inform future decision-making processes for pavement rehabilitation and maintenance.
   c. Encourage continuous monitoring, evaluation, and adaptation of maintenance strategies to improve the effectiveness and efficiency of future interventions.

8. **References:**
   Include a list of references, sources, or documents consulted during the preparation of this section, such as reports, studies, or technical literature.

6.2.6 Consolidation and Analysis of Desk Study Information

At the end of the Desk study, all the data collected needs to be synthesised into useful data for decision-making. The following steps should be followed, and considerations be made:

1. **Consolidation of collected information.**
   The following steps are to be taken when reviewing past interventions:
   a. Documentation Retrieval - Gather all documentation related to past pavement maintenance and rehabilitation projects. This includes construction reports, inspection records, maintenance logs, and other relevant documentation.
   b. Data Compilation - Compile relevant data from the retrieved documentation, such as project specifications, materials used, work methodologies, costs, and performance data. Systematically organise this information to facilitate analysis.
   c. Performance Analysis - Evaluate the historical performance of the pavement network by examining maintenance records, repair history, and rehabilitation activities undertaken in the past. Identify key lessons learned from the review process. Determine which interventions were successful and why and identify any shortcomings or failures. Document these lessons to ensure they inform future decision-making.
   d. Environmental and Geological Factors - Consider any environmental or geological factors that may influence the pavement's performance. This includes climate, soil conditions, water table, and vegetation that can impact the deterioration process.
   e. Regulatory and Legal Requirements - Identify and review any legal or regulatory requirements that govern pavement maintenance and rehabilitation activities. Ensure compliance with relevant standards, guidelines, and specifications.
   f. Social Considerations - When conducting work in rural areas, it is important to acknowledge and identify responsible traditional leadership through social facilitators and gather any relevant information, historic or recent about the areas that you shall be working in.
   g. Technology and Innovation Assessment - Consider any advancements in pavement maintenance and rehabilitation technologies since the previous interventions. Assess the feasibility and potential benefits of implementing new techniques or materials based on the latest industry practices.
   h. Resource Assessment - Evaluate the availability of resources, including budget, manpower, and equipment, to support the proposed maintenance and rehabilitation activities. This assessment helps determine the feasibility of different strategies and prioritise projects.

2. **Outputs:**

   The desktop study should result in the following outputs:

   a. Comprehensive data analysis report.
   b. Summary of pavement condition and performance outlining the distress types and severity levels.
   c. Summary of environmental and geological factors.
   d. Review of historical performance and maintenance records.
   e. Evaluation of resource availability and constraints.
   f. Recommendations for further investigation and prioritisation of projects.

6.3 Reconnaissance Surveys

Field reconnaissance involves on-site inspections and assessments of the pavement network by all relevant stakeholders. The field reconnaissance provides critical on-site information that complements the findings of the desktop study. Guidance on the standards testing methods to be followed in conducting the surveys is provided in Chapter 8 of this manual. The essential technical specifications and guidelines for collecting data, along with appropriate techniques for determining and prioritising pavement conditions are given below.

This section outlines the purpose, objectives, and key steps in conducting a field reconnaissance for pavement rehabilitation and maintenance.

1. **Purpose:**

   The purpose of field reconnaissance is to gather first-hand information about the condition, distress, and site-specific factors affecting the pavement. It allows for a detailed visual inspection of the pavement network and identifies additional data not captured during the desktop study. Field reconnaissance helps validate and supplement the findings of the desktop study, leading to a more accurate assessment and informed decision-making.

2. **Objectives:**

   The main objectives of field reconnaissance are as follows:

   a. Verify and supplement the information gathered during the desktop study.
   b. Conduct a visual inspection of the pavement condition and distresses.
   c. Identify localised issues and factors impacting the pavement's performance.
   d. Assess the need for additional testing or investigations.
   e. Determine the feasibility and practicality of planned maintenance and rehabilitation strategies considering site conditions.
   f. Evaluate safety considerations and traffic management requirements.

3. **Key Steps:**

   The following steps should be followed when conducting field reconnaissance for pavement rehabilitation and maintenance:

   a. Site Selection:

      Identify representative sections of the pavement network for inspection, considering factors such as traffic volume, pavement condition variations, and critical areas that require immediate attention.

b. Available Equipment:

i. Appropriateness of equipment – Equipment should be sourced from reputable equipment suppliers to ensure that correct and accurate data are collected.

- Data collected using recent technologies such as pavement laser profilers, imagery including video footage of the surface condition of the road and accurate GPS location is necessary, especially for the classified road network.
- For unclassified roads, simpler equipment should be used such as hand-held GPS, Roughness measurement applications on smartphone applications, straight edge for rut depth tests, handheld cameras for images and videos, measuring tapes for dimensions, etc.

ii. Condition of the equipment – The calibration of equipment should be carried out as specified by the manufacturer, and calibration certificates should be readily available. The condition of the equipment should be regularly checked at designated and purpose-made calibration sites.

c. Visual Inspection:

Conduct a detailed visual examination of the pavement condition, distresses, and surrounding factors. This inspection should include the following:

i. Identify and characterise pavement distress (e.g., cracks, potholes, surface irregularity (rut depth measurement), etc.).

ii. Measurement of distress severity, extent, and progression.

iii. Evaluation of the pavement surface texture and roughness.

iv. Assessment of the drainage system and its effectiveness.

v. Identification of pavement markings, signs, and other safety features.

d. Field Measurements:

Take relevant measurements to supplement the desktop study data and aid in the analysis. This may include:

i. Collect sample measurements of defects and road profiles.

ii. Determine roughness measurements using appropriate devices (e.g., mobile phone app.).

iii. Visual assessment of skid resistance.

iv. Visual assessment of the extent and severity of defects.

e. Safety Considerations:

Evaluate safety conditions at the site, including traffic flow, work zone requirements, and any potential hazards. This assessment ensures the safety of field personnel and road users during the maintenance and rehabilitation activities.

4. **Outputs:**

The field reconnaissance should result in the following outputs:

a. Detailed field inspection report documenting the pavement condition, distresses, and site-specific factors.

b. Visual records (photographs, videos) of the observed pavement conditions and distresses.

c. Additional data and measurements collected during the on-site assessments to determine relevant detailed follow-up investigations and tests to be conducted.

d. Safety assessment report outlining safety considerations and traffic management requirements.

The data collected during field reconnaissance serves as a foundation for detailed investigations to develop a comprehensive pavement maintenance and rehabilitation plan, ensuring effective and targeted interventions to extend the lifespan and performance of the pavement network.

7 Detailed Pavement Condition Surveys

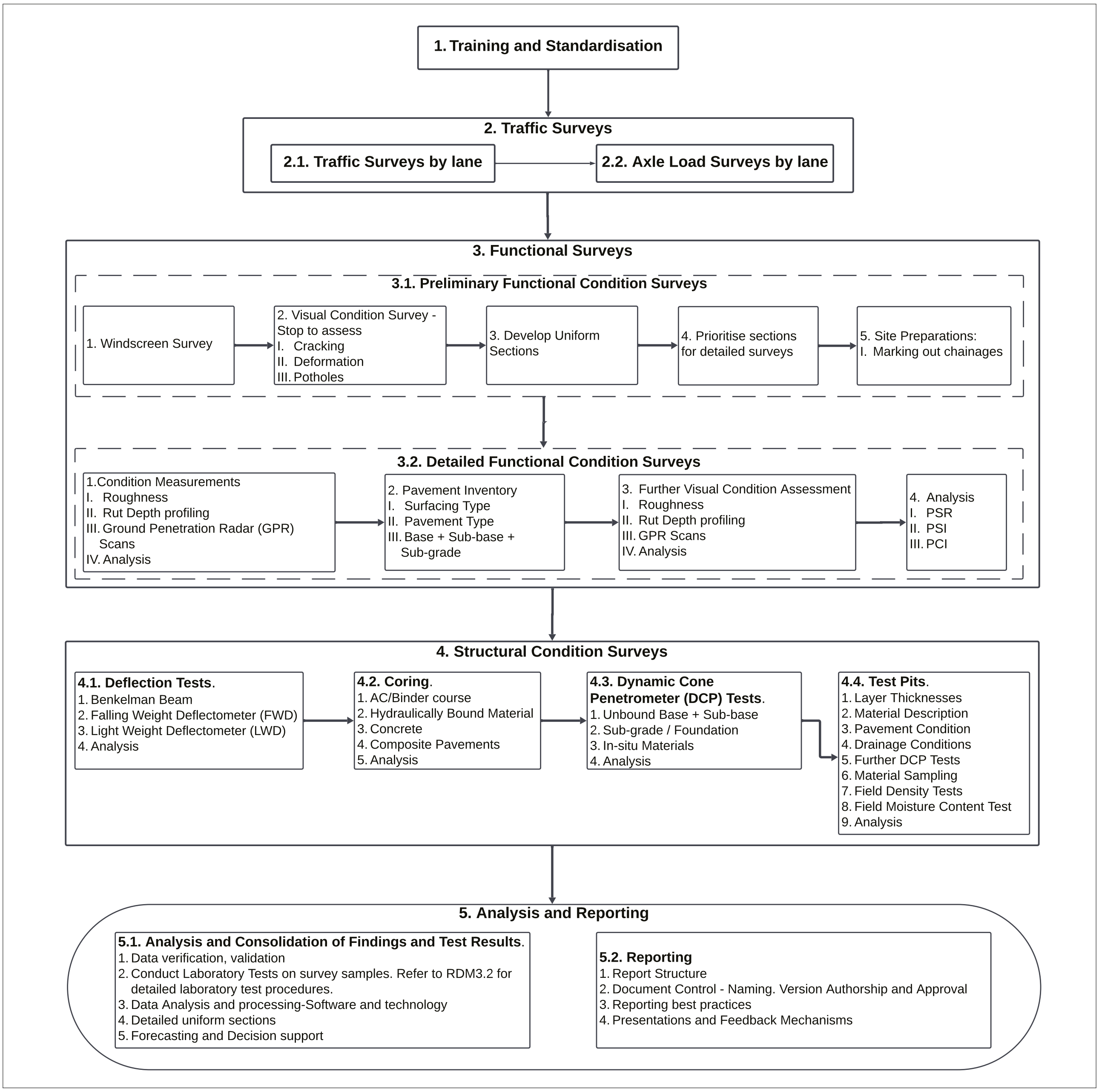
7.1 General

This Chapter provides guidance on detailed pavement condition surveys, providing a critical integration of traffic, functional, and structural surveys. This composite survey is engineered to meticulously assess the pavement's condition, surface performance, traffic-induced deterioration, and underlying structural integrity using advanced methodologies for data collection and analysis. The survey results guide the development of effective maintenance strategies, rehabilitation plans, and resource allocation, ensuring the pavement's longevity and optimal performance.

Comprehensive survey forms, including a Compaction Judgment Form for post-excavation reinstatement, are provided in Appendices B through I. The detailed pavement condition survey procedures, i.e. the Standard Testing Methods are provided in Chapter 8. Guidance on the minimum essential information required for conducting a detailed pavement condition survey is outlined in Table 7.1.

Figure 7.1 below is a visual representation of the overview of the detailed pavement condition survey process:

Figure 7.1 Detailed Pavement Condition Survey Process



7.2 Capacity Development and Standardisation for Pavement Condition Surveys.

7.2.1 Training of Engineering Field Technicians

The Lead Pavement Expert must be a qualified engineer approved for the assignment and take responsibility for training the survey assistants and first-time field technicians. The first-time field technicians must have at least 2 years of relevant experience or qualification, which is required for a civil engineer or technician. The assessment training programme should at least cover the following:

1. A detailed understanding of the objective's pavement conditions survey manual RDM5.1 with special emphasis on the objectives of visual condition assessment.
2. A detailed understanding of the distress types, their progression and rating criteria.
3. A detailed understanding of standard information and assessment sheets is required.
4. Practical training on correctly using measuring tools and testing equipment and technologies. The practical training must include the application of visual assessment procedures and guidelines provided herein. It is key for the Trainer to also assess the application of the rating criteria provided in sections 4.3 of this manual.
5. Safe work procedures and environmental protection strategies.

The emphasis of this training is to harmonise perceptions of the condition of defects, correct use of testing equipment, standardise measuring techniques and use of standard units and tolerance levels.

7.2.2 Standardisation of Field Testing Data

This section describes the collection and recording of generic information about the road or road section under investigation or monitoring. This information is critical to ensure that the relevant authority receives comprehensive and clear information comparable across different projects conformity with the standards, any departure from standards must be approved by the Chief Engineer Materials. Referencing to the Overseas Road Note 18 (ORN 18). The information to be collected is given in Table 7.1.

Table 7.1 Information to be Collected During Field Tests

Item	Category	Key Information	
1	**Summary information on the road**	• Road Name • Road Number • Road class • Jurisdiction • Section of road – chainages	• Road width • Number of lanes • Functionality • Sealed or unsealed.
2	**Supplementary information**	• Climate • Terrain • Drainage • Gradient	• Type of surfacing • Traffic volume • Traffic Loading • General condition
3	**Standardisation of Technical Information**	• Standard forms for field surveys for new construction • Standard forms for field investigations for rehabilitation • Standard forms for condition monitoring	
4	**Standard test procedures**	• Standard equipment and apparatus for tests • Standard procedures to be followed. • Standard reporting mostly in standard forms or software platforms	
5	**Standardisation training**	• Harmonising perceptions e.g., of defects • Standard measurements • Standard units • Accuracies • Use of testing equipment.	

7.3 Traffic Surveys

Important surveys for quantifying the vehicular demands on pavement, measure traffic volumes, types, and axle loads, providing critical data on the stresses exerting wear and dictating the pavement life. They are essential for estimating the pavement's load-bearing capacity and identifying specific stress points that may accelerate deterioration.

7.3.1 Traffic Counts

The methodology for traffic counts is discussed in detail in RDM 1.2. However, in the context of pavement rehabilitation and maintenance:

1. **Historical traffic counts**
   Review and analyse historical traffic data to understand long-term trends and past traffic patterns, crucial for baseline assessments. This data can be sourced from road authorities and agencies, previous surveys, or a central repository.
2. **Detailed traffic counts**
   Conduct detailed, real-time traffic counts using automated and manual methods to capture current traffic volumes, vehicle classification, and temporal variations. This data is essential for understanding current stress on the pavement. Other more advanced methods are traffic speed deflection (TSD) and laser-based traffic speed deflection measurements.

7.3.2 Forecasting

Forecasting future traffic trends is essential for planning long-term maintenance and rehabilitation strategies. Refer to RDM 1.2 for detailed insight into traffic forecasting.

The engineer must, therefore, determine traffic growth rates based on parameters such as historical data, regional development plans, and economic trends and utilise growth models to forecast future traffic. This helps determine the anticipated future pavement loading, which informs maintenance planning strategies.

7.3.3 Axle Load Surveys

The methodology for traffic counts is discussed in detail in RDM 1.2 and RDM 3.3. Axle load survey data provides information on specific sections under high stress. This helps determine the type and urgency of remedial measures. The Engineer should therefore:

1. Conduct surveys to measure the weight per axle of vehicles using the road. This data is vital for understanding the impact of heavy loads on pavement deterioration.
2. Focus on key factors like percentage overloading (vehicles exceeding legal load limits) and tyre pressure impacts on pavement wear.
3. Measure and record tyre size and pressure.

7.3.4 Verification Traffic Surveys

This detailed traffic survey must indicate a directional split of the traffic to ensure that the design is adequate for lanes with the highest traffic.

1. **Pre-Design Verification:** Conduct these surveys before finalising the pavement design to ensure that traffic inputs are current and accurate.
2. **Rehabilitation Projects:** For rehabilitation projects, focus on verifying whether traffic patterns have changed significantly since the last recorded data.
3. **Verification Traffic Surveys:** Can be conducted in scenarios where there has been a gap or sufficiently long lead time between the planning, design and construction stages. A 3-7 day survey should be conducted to confirm the adequacy of the design in relation to new traffic patterns before implementation of works.

7.4 Function Surveys

These surveys are focused on the operational characteristics of the pavement; they are pivotal in assessing user safety and comfort. They involve a thorough evaluation of surface conditions like roughness, skid resistance, and visible distress such as extent surface irregularity (rutting) and cracking. They highlight immediate maintenance needs and serviceability issues. The level of data collection depends on the road category.

7.4.1 Visual Condition Surveys (VCS)

This is a fundamental and commonly used approach that involves trained field technicians visually examining the pavement surface, and documenting distresses like cracks, potholes, surface irregularity (rutting), and surface wear. It's often the first step in assessing pavement condition because it is relatively quick and cost-effective. It is often used in conjunction with other survey methods for a comprehensive understanding of pavement conditions. VCS incorporate photographic or video recording evidence taken during visual inspections done by experts providing a record for future comparison.

Below are the key visual condition survey types which should be implemented when carrying out detailed condition surveys:

7.4.1.1 Windscreen Surveys

This involves Field Technicians driving along the pavement and visually assessing the condition from within a vehicle. Reference distances from the origin can be measured using the car odometer. A portable GPS can be used to record coordinates of positions of interest. The vehicle should have a video camera to record video evidence and the field technician should have another camera to take images. This method is cost-effective and covers large areas quickly, but it might miss finer details that slower, more thorough methods would catch. The Field Technician carrying out windscreen surveys should occasionally stop to have a closer look at the defects. Areas of interest shall include:

1. Good sections – it is difficult to see finer cracks through the windscreen in a moving vehicle. It is important to confirm whether the section is free of cracks, pumping and piping, and minor ravelling. This is important because premature crack initiation is problematic and is symptomatic of a non-performing pavement or the start of premature failures.
2. Severe sections – this is more crucial than 1(a) above. A closer look at the defects is necessary and should be viewed together with the pavement environment, materials, and drainage in order to hypothesise the root causes of the failures and the levels of severity.
3. Boundaries between severely deteriorated sections and the good to fair sections. A closer look will help in demarcating the various sections to be prioritised for more detailed surveys especially when the project involves long stretches of road e.g. 10 km or more.

Table 7.2 gives guidance on key considerations to be made by the surveyors

Table 7.2 Key Considerations for Windscreen Surveys

Item	Defects	Considerations	Preliminary Interpretation
1	**Longitudinal Cracks**	**1.** Usually, construction or foundation or traffic-induced. **2.** Note the position of the cracks. **3.** Is traffic heavy? **4.** Is there a cut and fill? **5.** Is there the potential for geotechnical movement under the pavement?	More detailed investigations required if cracks are long and wide and or associated with surface irregularity (rutting).
2	**Transverse cracks**	**1.** Usually, material induced. **2.** Note the position of the cracks. **3.** Are they equally spaced? **4.** Are they wide? **5.** Are there stabilised layers in the pavement?	More detailed surveys required focussing on pavement materials plasticity and stabilisation
3	**Both transverse and longitudinal cracks appear in regular patterns or intervals**	**1.** Usually, materials induced especially expansive heaving significantly. **2.** Is there clay or clayey subgrade? **3.** Is the section prone to flooding?	Detailed investigation is required on the SG materials and both surface and subsurface drainage
4	**Ravelling, bleeding, delamination and stripping**	Induced by heavy traffic, binder deficiency or excess, low binder affinity of aggregate, extreme flood events, etc.	Detailed investigation is not necessary if defects are minor and not severe.
5	**Deformation**	**1.** Surface irregularity (rutting) is traffic-induced and exacerbated by weak pavement layers. **2.** Corrugations are induced by materials and weak layer interface bonding is induced. **3.** Shoving by layers or material weakness, which could be due to poor compaction.	Detail structural condition surveys are required if severe but may not be necessary if defects are localised.

7.4.1.2 Walk Through Surveys

Following the windscreen surveys and carrying out an initial subdivision of the road into uniform sections of reasonable lengths suitable for detailed investigation, a priority list of sections shall be prepared and targeted for detailed investigations. The following shall be considered in defining uniform sections:

1. Type of defects
2. Severity and extent of defects.
3. Pavement types
4. Subgrade materials
5. Drainage Conditions

Once the prioritisation has been completed, the selected sections shall be further subdivided into short sections e.g. 50 or 100 m or as specified by the engineer. Guidance on these criteria is provided in Chapter 5. The chainages shall be painted along the centreline of the road.

The Field Technician will walk the pavement and visually inspect its condition, often recording details manually or with handheld devices. This method allows for a more detailed and thorough inspection than windscreen surveys but is more time-consuming and covers less ground. For visual condition surveys, the type, position, extent and severity of each defect shall be measured and recorded in field forms for each segment of subsection (50 m or 100 m lengths). At this stage it is important to be able to identify the defects appropriately and to determine their possible causes. Guidance is given in Chapter 4 and Appendix A, Catalogue of defects.

7.4.2 Automated Pavement Condition Profiling

1. **Specialised Survey Vehicles**
   Specialised vehicles equipped with cameras, lasers, and other sensors are used to collect data on pavement distresses. This method can be more accurate and faster than manual inspections but is also more expensive. These include:
   a. Rapid response roughness measuring devices.
   b. Ultrasonic profilers.
   c. Laser mounted vehicles for measurement of cracks, surface irregularity (rut depth measurement) and other profiles, texture depth, etc.
   d. Video recording, which sometimes comes with machine learning capabilities.
   e. Vehicle-mounted Ground Penetration Radar for internal profiling of pavements including the detection of underground service lines, height of the water table and thickness of the different pavement layers.
2. **Drone Surveys**
   These are increasingly being integrated into automated pavement condition assessment processes. Drones can be equipped with high-resolution cameras and other sensors to capture detailed images or videos and data on the pavement surface. Their ability to capture aerial imagery means a wider extent of the pavement and its surroundings can be assessed, which can unearth other causes of pavement deterioration that could be missed when using traditional methods. The data captured by drones can then be processed using automated software to identify and quantify pavement distresses such as cracking, potholing, and surface irregularity (rut depth measurement). This process significantly reduces the need for manual data collection and analysis, aligning it with automated survey methods. Stakeholder engagement, and legal and ethical compliance with local and international legal standards governing the licencing of drone operations, data collection, and privacy should be upheld.

7.4.3 Roughness Measurements

Measure the pavement's surface roughness to assess ride quality and identify sections with affected ride quality impacting comfort and safety. Roughness measurements are done using the MERLIN, Roughness measuring beam or Vehicle mounted response type road roughness measuring system (RTRRMS).

1. Calibrate equipment as per manufacturer's guidelines.
2. Perform multiple runs along the pavement at standard traffic speed.
3. Record the vertical displacement of the pavement surface.
4. Compute the International Roughness Index (IRI) or other relevant indices.
5. Analyse data to identify sections with poor ride quality.
6. Record location, severity, and extent of roughness for maintenance planning.

7.4.4 Skid Resistance Measurements (SRM).

Test the pavement's skid resistance to measure the frictional properties of the pavement surface especially under wet conditions. Employ methods like the Circular Friction Meter Equipment (CFME) and Portable Skid-Resistance Tester.

1. Conduct tests at multiple locations and in various conditions (wet, dry).
2. For skid resistance, maintain a constant speed and braking force.
3. Identify areas with insufficient skid resistance.
4. Log test locations, values, and any deviations from Standards.

7.4.5 Texture Depth Measurements (TDM)

1. Use sand patch tests or laser profilometers for texture depth measurement, which is essential for wet weather skid resistance.
2. Conduct tests at multiple locations and in various conditions (wet, dry).
3. For texture depth, apply and measure the spread of a known volume of sand/material.
4. Identify areas with insufficient pavement texture depth (PTD).
5. Log test locations, values, and any deviations from Standards.

7.4.6 Surface Regularity (Rut Depth Measurement)

Measure the depth and severity of surface irregularity (rut depth measurements) to assess structural and functional conditions using a Pavement Surface Profilometer or HB Wedge rut depth measuring device or a straight edge to measure rut depth.

1. Place equipment perpendicular to the direction of travel in multiple locations.
2. Measure the depth of the rut compared to the adjacent undistorted surface.
3. Determine the severity of surface irregularity (rut depth measurement) against predefined thresholds.
4. Note areas where surface irregularity (rut depth measurement) exceeds acceptable limits.
5. Record the location and severity of the surface irregularity (rut depth measurements).

7.4.7 Cracking (Crack Width Measurement)

Systematically document cracking patterns, types, and severity to identify potential structural failures.

1. Visually inspect the pavement surface in a systematic manner.
2. Measure crack width, length, and depth where applicable.
3. Categorse cracks by type and severity.
4. Analyse crack patterns to determine underlying pavement issues.
5. Prioritise areas based on crack severity and potential for progression.
6. Provide detailed records of crack locations, dimensions, and types.

7.5 Structural Surveys

Focused on evaluating the underlying strength and longevity of the pavement structure, these surveys employ techniques such as deflection testing, core sampling, and Dynamic Cone Penetrometer (DCP) tests, they unveil the condition of different pavement layers and the subgrade. This information is critical for guiding decisions on structural rehabilitation or comprehensive reconstruction.

It is important to identify and mark the test sections and ensure that the coring, DCP and test/ trial pits are sampled from the same positions for comparable results. The test position is determined by the magnitude of the deflection.

7.5.1 Pavement Deflections Measurements (PDM)

Use equipment such as the Falling Weight Deflectometer (FWD) or Benkelman beam and Light Weight Deflectometer (LWD) to assess the structural capacity of the pavement by measuring surface deflection response to a known applied load. It helps in identifying weak spots that might not be evident from surface inspections. Deflection testing is relevant to both flexible and rigid pavement.

The Falling/weight deflectometer (FWD) can be used for both flexible and rigid pavements by measuring the pavement's response to a load similar to that of a single heavy vehicle wheel. FWD tests are typically done along the wheel track since this is where deflections are more prevalent compared to the alignment centre line.

Benkelman Beam is more suitable for flexible pavements by measuring the deflection of a pavement surface to static load, however, it can be used to assess rigid pavements as well.

The Light Weight Deflectometer (LWD) is more suitable for flexible pavement.

The spacing requirements for the tests are in Chapter 5. More frequent testing is recommended near areas showing visible signs of distress.

Analyse output data to estimate the pavement's structural capacity and identify sections weakened by traffic loading. Higher deflections indicate weaker pavement sections.

A summary of the deflection test characteristics are given in Table 7.3. The detailed procedure for the deflection test using FWD is given Chapter 8. The requirements given below are applicable to the LWD method except that the LWD has three sensors, and the applicable load is up to 25vkN.

Table 7.3 Characteristics of Deflection Tests Using FWD.

Item	Defects	Considerations
1	**Impulse load**	The load can be adjusted by changing increasing or decreasing weights or the drop height of the load. It is important during evaluation to note the load applied for the tests. The results of the analysisanalysis results will need to be normalised to 40 kN (load on a dual wheel 80 kN axle) or as advised by the materials engineer. The pulse of the load is given in milliseconds (usually 15-35ms) and will be displayed for each load. The result should be rejected if the impulse is outside the specified range by a significant amount.
2	**Loading plate**	The diameter of the plate is used to determine the pressure that is applied to the surface of the pavement (pressure = load/area). This can be 300 mm in diameter.
3	**Sensors**	The FWD generally has 7 to 18 sensors that measure deflections of the surface of the pavement when the impulse load is applied. The values of the deflections reduce progressively from the highest at the centre of the load to the lowest at the one with the furthest radial distance (r) from the central load. This consistency is necessary for the results to be valid for analysis. The test should be discarded if this criterion of consistency is not satisfied. Also, check that all sensors are recorded consistently. It is possible that one or more sensors could be faulty or may fail during testing.
4	**Drops**	At least 1 drop are is for seating the loading plate properly on the surface of the pavement and at least two (2) collected drops are applied, and an average is taken as representative of the deflections for the test points. Check that the difference in the deflection for the 3 drops is not insignificant. This may signify some changes that may have occurred to the pavement during testing, such as fracturing of the surfacing.
5	**Condition of the pavement at the test point**	It is critical to have a good idea of the surface condition of the pavement at the test point. Results can be greatly affected when the surfacing/pavement at the test point is badly cracked. Discontinuities greatly affect the results because the test method is based on the principle of continuum and homogeneity of the layers.
6	**Software**	The software must be updated and compatible with the analytical packages to be used to analyse the data.
7	**Temperatures**	It is important to check that the air, surface and internal pavement temperatures are measured. The internal pavement temperatures are obtained by drilling a 13 mm hole in the Asphalt and measuring the temperature using an asphalt thermometer. The air and pavement surface temperatures are measured automatically for each test point and should be provided in the report.

7.5.2 Pavement Assessment using Ground Penetrating Radar (GPR) Tests

Ground Penetrating Radar (GPR) scans are Non-Destructive Testing techniques used to evaluate both the surface and subsurface pavement conditions gaining insights into the structural integrity and thickness of pavement layers, moisture content, and other subsurface features and service lines that cannot be identified through visual inspection alone without causing damage. The method is applicable to both functional and structural surveys.

1. Select GPR equipment with appropriate frequency (1-2 GHz for pavement).
2. Plan survey lines based on objectives (e.g., detecting layer thickness).
3. Results should be interpreted by trained and experienced personnel.

7.5.3 Coring

This method is applicable to all types of pavements such as flexible, rigid, and composite pavements. Extract core samples for visual assessment and laboratory testing to evaluate material properties, layer thickness, and subsurface conditions. Essential for validating design assumptions and identifying hidden distresses.

Typically, a diamond-tipped cylindrical core drill of diameter 100 -150 mm is used to extract core samples by drilling vertically into the pavement without damaging the surrounding areas. The depth of each core is recorded and the sampled position is clearly labelled for future reference.

Core samples should be taken from the same locations as selected deflection measurements, marked for future reference. Choose locations that represent different conditions such as stages of visible distress, traffic loading or joints in rigid pavements. Sampling for coring is less frequent than deflection measurements, with areas showing higher deflections requiring more core samples.

Analyse core samples by visual inspection and laboratory testing:

1. Visual inspection of the core sample gives evidence of the condition of the following:
    a. Layer thicknesses of the different layers in the pavement structure and their material types.
    b. Cracking within Layers
    c. Asphalt binder condition - Indications of ageing, oxidation or hardening of the binder.
    d. Void Content – Distribution of voids indicating compaction or binder quality.
    e. Aggregate Structure - Condition and aggregate distribution within the asphalt or concrete.
    f. Moisture Presence - Signs of moisture retention or water damage within the pavement layers.
    g. Discoloration or Oxidation - colour changes that may indicate ageing, oxidation, or material degradation.
    h. Stratification or Delamination - Layers separating or showing signs of weakness.
2. Laboratory testing of core samples includes tests to identify the following parameters:
    a. Compressive Strength (for Rigid Pavements) - For concrete cores, to determine the load-bearing capacity.
    b. Tensile Strength (For Flexible Pavements) - Assessing the resistance of the material to tension, is important for crack analysis.
    c. Flexural Strength (For Rigid Pavements) - Evaluating the bending strength of concrete.
    d. Asphalt Binder Content and Aggregate Gradation - Determining the exact composition of asphalt mixtures.

e. Density and Void Analysis - Measuring compaction density and void spaces is critical for evaluating pavement durability.
f. Moisture Content - Evaluating the moisture content present within the pavement materials.
g. Particle Size and Gradation - Analysis of the aggregate particle size and distribution.
h. Chemical Composition - Identifying the presence of harmful chemicals or materials.
i. Permeability - Measuring the rate of water infiltration through pavement materials.
j. Durability Tests - Assessing how well the pavement materials can withstand environmental and load-related stresses over time.

7.5.4 Dynamic Cone Penetrometer (DCP) Test

The DCP tests are primarily used for unbound materials in the base/subbase and subgrade layers under neath flexible and rigid pavements to evaluate the strength, density and compaction quality of the pavement layers. It is useful for assessing unbound base/subbase and subgrade materials; however, the method should be avoided when assessing Graded Crushed Stone (GCS) bases.

The DCP device consists of a weight dropped onto a cone that penetrates the pavement layers. Measurements are taken of the penetration depth per blow. The device can be fitted with different types of cones depending on the type of layer materials being tested. The 30-degree cone provides less penetration resistance, suitable for more granular layers, whereas the 60-degree cone penetrates more easily, making it suitable for softer materials.

The selection of test points must be guided by preliminary tests such as deflection tests and coring samples taken. The DCP test should also be taken within the same locality for comparable results. Fewer DCP tests (spaced approximately 500m apart) will be required compared to coring frequency within a test section. Frequency should be increased in areas exhibiting distress or where subgrade conditions vary.

From the recorded penetration measurements calculate the penetration rate which is presented in mm/blow. Higher penetration rates indicate potentially weak subgrade while lower penetration rate indicates good stiffness and compaction of the subgrade material.

Compute the Structural Number (SN) values using the DCP test results and layer thickness information. SN values should be integrated with other pavement condition data, such as surface distresses and traffic loads, for a complete understanding of pavement condition. SN gives an indication of current conditions, however, pavement structures change over time due to traffic and environmental impacts, so periodic reassessment is necessary.

The purpose of determining Structural Number is to:

1. Determine the pavement structural capacity,
2. Compare and analyse different pavement sections or for assessing the same section over time, helping in understanding the deterioration pattern and the effectiveness of maintenance strategies.
3. Guide maintenance and rehabilitation decisions - Higher SN values generally indicate a stronger pavement, capable of supporting heavier traffic loads or withstanding additional traffic before requiring significant rehabilitation.

7.5.5 Test Pits

Following visual and functional surveys, deflection tests, coring, and DCP tests, it's crucial to assess areas representing different pavement conditions such as areas with notable distress and those with little or no deterioration. The evidence from earlier tests allows for fewer trial pit test positions, which should align with the marked locations from initial tests. Typical dimensions of test pits are 1 to 2 meters deep, and 1 to 1.5 meters square, but size may vary based on objectives and pavement structure.

The main purpose of assessing test pits is to visually assess the pavement layer properties such as layer thickness, material properties and moisture conditions to identify subsurface problems like poor drainage, material contaminations or layer separation.

Due care must be taken to carefully excavate and avoid disturbing the natural state of the layers, sequentially exposing each layer, documenting the conditions and collecting samples for laboratory testing to determine material properties such as gradation, density and strength.

Conduct further DCP tests inside the test pit for the following benefits:

1. **Direct Layer Access** - targeted testing of specific layers without interference from the layers above for Layer-Specific Analysis.
2. **Enhanced Layer Accuracy** - it provides more accurate results by accurately assessing the strength and compaction of the specific layer of interest, such as the subgrade or base material.
3. **Identifying Subsurface Problems** - in areas with complex soil conditions such as heterogeneous soil conditions or where the subgrade has variable characteristics or material inconsistencies that require detailed assessment.

Key considerations when carrying out test pit assessments:

4. **Safety and Traffic Management**
   a. Implement safety measures during excavation, especially in trafficked areas.
   b. Use appropriate signage and barriers to ensure safety.
5. **Environmental Factors:**
   a. Consider the environmental impact of excavation and disposal of materials.
   b. Take precautions to minimise disturbance to the surrounding area.
6. **Restoration of Test Pit**
   a. After inspection, backfill the pit properly to restore the structural integrity of the pavement.
   b. Use appropriate materials for backfilling and ensure adequate compaction.
7. **Documentation**
   a. Maintain detailed records of the location, size, and findings from each test pit.
   b. Photographs and sketches can be valuable for documentation.

7.5.6 Integration of Field Density and Field Moisture Density Tests with Test Pits

This section delineates the procedures for integrating Field Density Tests and Field Moisture Density Tests with Test Pit Tests to ensure a comprehensive assessment of in-situ pavement conditions.

1. **Field Density Tests**
   The Field Density Test is a critical procedure that confirms the actual in-situ density of the pavement's compacted layers. It is an essential quality control measure for verifying compliance with density specifications, a determinant of pavement durability and performance. Refer to the sand replacement and nuclear density gauge Standard Testing Methods in Chapter 8 for detailed procedures of conducting the test.
   a. Perform Field Density Tests on each exposed layer during test pit excavations.
   b. Pay particular attention to layers beneath visible distress areas to identify potential compaction anomalies.
2. **Field Moisture Content Tests**
   The Field Moisture Content Test measures the water content in the compacted pavement layers. Correct moisture levels are essential for optimum compaction and stability; deviations can compromise the structural integrity of the pavement.

7.6 Pavement Detailed Analysis and Reporting

Detailed analysis involves systematically interpreting data collected from detailed condition survey methodologies discussed in earlier sections of this Chapter. This phase transforms raw data into actionable insights, guiding maintenance and rehabilitation decisions and finally synthesising the findings and recommendations from the detailed analysis into a formal document and communicating to relevant stakeholders. The report produced herein is key to processes discussed in RDM 5.2 such as pavement evaluation and Pavement design.

The following guides this final process to ensure all information is accurately analysed and reported:

7.6.1 Pavement Detailed Analysis

1. **4.3 Use of Technology**
   a. Software Tools employ specialised pavement management software for data analysis and visualisation.
   b. GIS Integration-Incorporate Geographic Information Systems (GIS) for spatial analysis of pavement conditions.
2. **Data Integration and Processing**
   a. Quality Assurance through verifying data accuracy and consistency.
   b. Combine data from traffic, functional, and structural condition surveys to form a comprehensive view of the pavement's state.
   c. Trend Identification – Analyse patterns and correlations, such as the relationship between traffic loads and pavement deterioration using trend analysis, statistical evaluations, and forecasting predictive modelling techniques.
   d. Modelling and Simulation – Utilise advanced modelling tools to simulate pavement behaviour and predict future performance or conditions under various scenarios.
3. **Identification of Issues and Prioritisation**
   a. Identify uniform sections based on the type and severity of specific pavement distresses, such as cracking, surface irregularity (rutting), or structural failures.
   b. Use the analysis to identify areas needing urgent intervention based on severity, impact and available resources, considering factors like safety implications, traffic volumes, and future deterioration rates.
4. **Decision Support**
   a. Develop recommendations for maintenance and rehabilitation activities, tailored to address the identified issues effectively.
   b. The information will assist in budget planning by indicating high-level estimated costs associated with recommended actions.
5. **Long-Term Planning**
   a. Use data analysis to forecast the Pavement Life Cycle or predict future pavement conditions of the current pavements.
   b. Strategic Planning-Provide long-term planning by forecasting the need for future rehabilitation and maintenance activities.

7.6.2 Pavement Condition Reporting

The final stage in the detailed pavement condition survey process is reporting. This phase involves the preparation of comprehensive documentation that summarizes findings, analysis, and recommendations.

1. Structure of the Report
   a. **Document control** – To ensure integrity and traceability of reports, every report should include:
      i. **Naming** – Correctly name the project and include the address and contact details of the organisation producing the report and the organisation receiving the report.
      ii. **Version Numbering** - Each report should have a unique version number, typically starting from 1.0 for the initial release and incrementing with subsequent revisions.
      iii. **Revision Dates** - Record the date of each revision. This helps in tracking the development and updates of the report over time.
      iv. **Authorship and Approvals** - Clearly indicate the author(s) of the report and any approvals required or received. This includes names and titles of the responsible personnel or departments.
   b. **Executive Summary** - Provide a high-level overview for quick understanding by decision-makers high the key findings and recommendations.
   c. **Methodology** - Detail the survey and analysis methods used.
   d. **Findings and Results Presentation** - Summarize the data from each survey type and utilise visual aids like graphs, charts, and GIS maps for simplification and clarity.
   e. **Analysis and:** Discuss the results of the detailed analysis, highlighting critical issues and trends.
   f. **Recommendations** - Offer evidence-based recommendations for maintenance and rehabilitation, including prioritization and estimated resource allocation.
   g. **Future Considerations** - Suggest areas for future surveys or continuous monitoring.
   h. **Data Transparency** - Include raw data or appendices for those seeking deeper analysis.
2. Reporting Best Practices
   a. **Clarity and Accessibility** - Ensure the report is clear and understandable, even to non-specialists.
   b. **Digital and Interactive Elements** – Provide digital versions of the report with interactive elements for enhanced engagement with the relevant stakeholders.
   c. **Distribution** - Distribute the report to all relevant stakeholders, including decision-makers, maintenance teams, and funding bodies.
3. Follow-Up
   a. Arrange presentations and meetings to discuss findings and next steps for stakeholders.
   b. Develop a concrete action plan based on the report's recommendations.
   c. Establish a feedback mechanism to assess the efficacy of posed strategies and inform future surveys.

8 Standard Testing Methods

8.1 Standard Testing Methods for Traffic Surveys

8.1.1 Traffic Surveys – Traffic Counts, and Origin-Destination Surveys

This method describes the standard procedure for traffic data including classified traffic counts and origin and destination surveys.

The procedure involves developing traffic categories and counting traffic in each direction usually for 24 hrs. for a minimum of 7 days. Where required longer periods of collection of traffic data can be achieved using automatic counters.

The results are used to determine the traffic volumes for geometric design, estimation of cumulative traffic loading, origin and destination among other purposes.

1. **Apparatus:**
   a. Apparatus for manual counts:
      i. Handheld counters – click type, essential for counting high traffic volumes.
      ii. Clipboards.
      iii. Traffic count forms – for classified counts to record traffic in both directions separately. Refer to Appendix B: Traffic Counts Survey Form and Appendix C: Origin Destination Survey Form
      iv. Chairs – for personnel to sit on
   b. Automated counters, Figure 8.1:
      i. Counting device - electric induction loops,
      ii. Pneumatic tube sensors,
      iii. Piezo sensors, etc.

      Cheaper automatic counters are usually used to count the number of axles passing over them.

      Expensive automatic counters are used to develop axle configurations and therefore can give a general categorisation of the traffic.
   c. Data recorder – for capturing and storing traffic data from the automatic counters.
   d. Installation tools – equipment required to install the automatic counters.

Figure 8.1 Automatic Traffic Counters (ref: TST data, Kenya)

2. **Procedure:**
   a. Manual traffic counts:
      i. Scope the traffic counting required in order to meet the purpose or objective of the exercise i.e., whether the data is required for traffic forecasting for design or maintenance or network management.
      ii. Acquire the requisite forms.
      iii. Locate the most appropriate position for the count to be carried out i.e., a position with good visibility, which is also safe and secure. The position may be predetermined at the beginning of a test section or junction or the middle of a section under design.
      iv. Engage the field staff – Training and standardisation of counting is required.
      v. Position the traffic counters as necessary and start the counts depending on survey hours.
      vi. Carry out the full 24 hours of counting where it is safe to do so. If not provide security during surveys.
      vii. Where traffic volumes are low record the counts directly on the forms.
      viii. Where traffic volumes are high use handheld counters and then record on the forms.
      ix. Hourly tallies should be made, and this will help to categorise the traffic flow with time to determine pick-hour flows.
      x. Counting should be done by staff in pairs so that they can take turns to do the counts to prevent fatigue.
      xi. The traffic counts should be supervised to ensure good-quality data.
   b. Automatic traffic counts:
      i. Assemble the equipment as directed by the manufacturer.
      ii. Ensure that the equipment is in good working condition and that any faults should be repaired or rectified before use.
      iii. Install the equipment as directed and check that it is counting properly.
      iv. Initial counts should be checked using manual counts which are carried out simultaneously.
      v. For pneumatic tube systems – a passing wheel compresses the tube and a pulse of air triggers the counter. The tubes are laid on the surface and hence easier to install. The tubes are not protected, and interference may occur.
      vi. Buried loop systems – an induction wire loop is connected to a counter encased in a secure metal or concrete cabin for security and placed on the side of the road. A separate loop should be placed in each direction or each lane. Classification of traffic is not possible with this method.
      vii. Piezo systems – piezoelectric sensor encased in an aluminium extrusion or rubberised former. The force applied by a passing wheel load is transformed into an electric pulse, which is proportional to the magnitude of the force. These pulses are interpreted into the number of axles (including their weight) and vehicles by category if necessary. Cut a slot into the pavement perpendicular to the direction of flow of traffic 50 mm deep and 70 mm wide, place the piezo sensors and fill with epoxy so that the sensor is flush with the surface of the road. The surface should be levelled as much as possible with epoxy to minimise the effect of impact loading generated due to irregularities in the surface of the road and installation. It may be necessary to grind the surface to remove any high points or irregularities.
      viii. Cameras and intelligent counting units – These are tailor-made cameras and intelligent traffic counters which are capable of sensing and categorising vehicles in motion including the direction of travel on road sections and junctions. The intelligent counting units used CCTV footage to count and categorise traffic and upload the data wirelessly. Their accuracy is approx. 98%. They are expensive to procure and install and require adequate capacity to maintain.

Maintenance of the automatic counters is of paramount importance to ensure accurate results, and this includes maintenance of the power source, and the tubing. As well as installation should any damage or general wear and tear occur.

3. **Calculations:**
   a. The AADT is the sum of the traffic in both directions. In the first year of analysis, it consists of the current traffic plus an estimate of the diverted traffic. If the total traffic is denoted by $AADT_0$ and the general growth rate is i per cent per annum, then the traffic in any subsequent year, x, is given by the following equation:

$$AADT_x = AADT_0\ (1 + r/100)^x$$

Equation 8.1

   b. For structural pavement design, the cumulative traffic loading of each of the motorised vehicle classes over the design life of the road in one direction is required. For a given traffic class, m, this is given by the following equation:

$$T(\text{m}) = 365 \text{ x } AADT(\text{m})_0 \left[\left(\frac{1+i}{100}\right)^n - 1\right] / \frac{i}{100}$$

Equation 8.2

Where,

T(m) = The cumulative traffic of traffic class m.

$AADT(\text{m})_0$ = The $AADT$ of traffic class m in the first year.

n = The design period in years.

i = The annual growth rate of traffic in percent.

8.1.2 *Traffic Surveys – Determination Axle Loads*

This method describes the standard procedure for the determination of vehicle axle loads.

The procedure involves the measurement of axle loads on one or both sides of the axle in a static mode or weigh-in-motion (WIM) method. Portable or fixed weighbridges can be used for the static mode. Weigh-in-motion equipment is used in cases where axle loads are carried out as vehicle wheels ride over the weighing equipment.

The results are used to determine the traffic loading on pavements in equivalent standard axles (ESAs). The ESAs are used in pavement and rehabilitation design. Axle load surveys are also used for overload control.

Traffic Surveys – Determination of Axle Loads.

1. **Apparatus:**
   a. Portable Weighbridge – with a width of 45 - 55 mm for mobile weighing operations; the maximum limit of weight that can be measured by the device is as specified by the manufacturer, Figure 8.2.
   b. Fixed weighbridges – stationed at a fixed location and provided with a recessed pit, support with a complete assembly and connectivity to a central computer. They can weigh whole axles and can be set up to weigh in motion (WIM).
   c. Display unit – a unit that shows the values of axle load transmitted from the weighbridge.
   d. Computer – for capturing axle load data (and wheel configuration for WIM).
   e. Forms – for recording values of axle loads manually refer to Appendix D: Axle Load Survey Form.
   f. Power source – An appropriate power supply is required for this purpose. For a fixed weighbridge, the power source could be a generator or mains. For a portable weighbridge, a battery or connection to a power source on a vehicle would suffice.
   g. Road signs – signage is required to warn and direct drivers to the weighing position. Assistance may be required from local police.

Figure 8.2 Axle Load Survey

2. **Procedure:**
   a. For potable weighbridges:
      i. Assemble the equipment as directed by the manufacturer.
      ii. Set up the site and put in place all necessary controls to ensure safety i.e., traffic signs, personnel, etc.
      iii. Direct the vehicle such that each wheel assembly sit centrally on top of the weighbridge.
      iv. Weigh and record axle loads.
      v. The transverse slope should not exceed 5 % and the longitudinal slope should not exceed 2 % for the results to be within a reasonable margin of error of 100 kg.
      vi. Weigh all the axles on the vehicle and record the weights separately.
   b. For fixed weighbridges with recess pit:

      These can be weigh-pads in recessed pits or a large weighbridge, which can carry a whole articulated truck. The latter are commonly used for overload control on highways.
      i. Set up the weighbridge as stipulated by the manufacturer.
      ii. Ensure that a recessed pit is provided for weigh pads with a thickness > 60 mm.
      iii. The recessed pits should have good drainage and a secure channel for the cables. They should have a concrete base and allow lateral movement of the pad of approx. 200 mm. This is to allow for the correct positioning of the pads to suit the spacing of the wheels on the axle.
      iv. Experienced contractors should carry out the construction of large weighbridges and the design should ensure adequate support on the approaches and the foundations. The weigh platforms should be connected to a central computer for data capture and processing.
      v. Measure the weight of the axles and ensure that the data is stored for future use.

c. For weigh-in-motions sensors:

These are expensive and less accurate but can weigh a large sample of axle loads. Note that the axle load weighed in motion would be different from axle loads weighed in the static mode. WIN involves significant dynamic loading in the case where undulations are significant. These are mainly recording weighbridges or piezoelectric cables.

i. Recording weighbridges - set up the weigh pads on the surface and connect them to a recording device or computer to capture the data. These weigh pads are thin thus minimising the error of impact loading.

ii. Piezoelectric cables – the cable should be set out as is done for traffic counters. When a wheel load passes, the cable sends a signal and at the same time, the speed of the wheel is captured as it passes. These values are required for weigh-in-motion load calculations.

iii. Calibrate the weigh-in-motion systems. The WIM systems require calibration at the site where they are installed. Site conditions such as roughness and the actual installation influence the impact loading of the wheels on the weighing device. The error is significant and needs to be corrected through calibration.

iv. Measure axle loads for at least 7 consecutive days for 24 hrs/day. Where overnight measurements are not possible surveys should be carried out for at least 16 hrs and not less than 12 hrs.

v. The data should be recorded according to categories of traffic classes.

3. **Calculations:**

Axle load survey data collected from these surveys are used to calculate the mean number of ESA for a vehicle in each class.

The number of equivalent standard axles (ef) of an axle is related to the axle load as follows:

$$ef = \left(\frac{L}{8160}\right)^n \text{ (for loads in kg)}$$

Equation 8.3

or

$$ef = \left(\frac{L}{80}\right)^n \text{ (for loads in kN)}$$

Equation 8.4

Where,

ef = number of equivalent standard axles (ESAs).

L = axle load (in kg or kN).

n = damage exponent (n = 4.5).

The vehicle equivalent factor is the sum ESAs of individual axles on the vehicle.

8.2 Standard Testing Methods for Functional Surveys

8.2.1 Determination of Cracking Index

The method describes the standard procedure for the determination of cracking index (CRI) on road surfacing.

The investigation is conducted through a visual condition survey. The exercise can be conducted by observing cracking from the car travelling at low speed (windscreen survey) or on foot (walkthrough survey) or from test vehicles with pavement cameras and GPS can also be used for road network condition surveys.

The results are used in planning and designing maintenance interventions or rehabilitation. They can also be used in Output and Performance Based Road Contracts (OPBRC) for approval of level of service and payment purposes.

The cracking index can signify pavement failure. Determination of cracking Index for the evaluation of surface defects should be guided by the following aspects:

1. **Apparatus:**
   a. Measuring wheel or tape measure – to demarcate test sections.
   b. Measuring tape / Ruler.
   c. Crack gauge.
   d. Callipers - Digital or manual vernier callipers can be used as an alternative to crack gauges for accurate measurements.
   e. Camera.
   f. Standard forms.
   g. For automated surveys, test vehicle – equipped with GPS laser and pavement cameras and onboard computer.
2. **Preparation of test section:**
   a. Calibration and Verification:

      It's essential to calibrate measuring equipment regularly before using them to ensure accurate results. Calibration should follow the manufacturer's instructions or any specific guidelines provided by local standards. Verification should be performed using a reference standard, such as a known-width object, to ensure the accuracy of the equipment.
   b. For preliminary surveys:
      i. Determine the test chainages to demarcate sections at 100 m or longer using other measuring devices such as the measuring wheel.
      ii. Conduct a windscreen survey (observing from the car) travelling at low speed (not more than 20 km/h)
      iii. When using automated systems equipped with GPS it may not be necessary to prepare the site for investigations, with attention to safety considerations.
   c. For detailed pavement evaluation for rehabilitation:
      i. Mark sections 50 m in length.
      ii. Mark chainages.
      iii. Place temporary road signs indicating works in progress.
      iv. For highly trafficked roads, cordon off the work area.
3. **Procedure for collecting data:**
   a. For preliminary surveys or road network condition surveys:
      i. Determine the type of cracking; L – longitudinal, T-transverse, B-Block, C-crocodile, P-parabolic, see Figure 8.3.
      ii. Determine the extent of cracking in the percentage of the test section that is cracked (see **3.b.i.** below).
      iii. Stop regularly for closer observation and measurements.
      iv. For automated surveys, run the vehicles and collect the data as stipulated in the user manual.
   b. For detailed surveys rehabilitation design:
      i. Type of cracks: L – longitudinal, T-transverse, B-Block, C-crocodile, P-parabolic, see Figure 8.3.
      ii. Severity (S_{cr}).
   c. Units, precision, accuracy, and bias:
      i. Units - Crack width is typically measured in millimetres (mm).
      ii. Precision - The measurement precision depends on the equipment used, typically within 0.1 mm.

iii. Accuracy - The accuracy of the measurements should be within ±0.2 mm or better.
iv. Bias - Minimise bias by following standard procedures, calibrating equipment, and conducting measurements by trained personnel.

d. Crack measurement procedure:
   i. Inspect the pavement surface visually, identifying cracks that need measurement.
   ii. Preparation - Clean the crack surface to remove debris or loose material that might affect measurements.
   iii. Use the measuring wheel or tape measure to measure the distance between crack endpoints.
   iv. Positioning - Place the crack gauge or callipers across the crack, ensuring that they are perpendicular to the crack surface.
   v. Measurement - Record the crack width measurement. Take care to maintain consistent pressure and alignment while measuring.
   vi. Photography (Optional) - If required, take photographs of the cracks with a reference scale (e.g., a ruler) to provide visual documentation.

Severity includes crack width W_c (0 to 5) given in Table 8.1 below:

Table 8.1 Severity Rating

Severity Rating	Standard (mm)
1	Single Crack width ≤ 1,
2	More than one crack but not connected, crack width < 3
3	More than one crack and connected, crack width < 3
4	Crocodile/parabolic cracks, ($Wc \leq 3$), crack width ≥ 3
5	Severe crocodile/parabolic cracks ($Wc \geq 3$) Crack width ≥ 3 + spalling

Extent (E_{cr}), Table 8.2:

Table 8.2 Extent Rating

Extent Rating	Standard (%)
1	0 < area of block affected ≤ 10
2	10 < area of block affected ≤ 20
3	20 < area of block affected ≤ 50
4	50 < area of block affected ≤ 80
5	80 < area of block affected ≤ 100

Position: left (L), centre (C), right(R), outer wheel path (OWP), inner wheel path (IWP)

4. **Calculation:**

Calculate the cracking index using the following equation:

$$Cracking\ Index, CrI = S_{cr}\ x E_{cr}$$

Equation 8.5

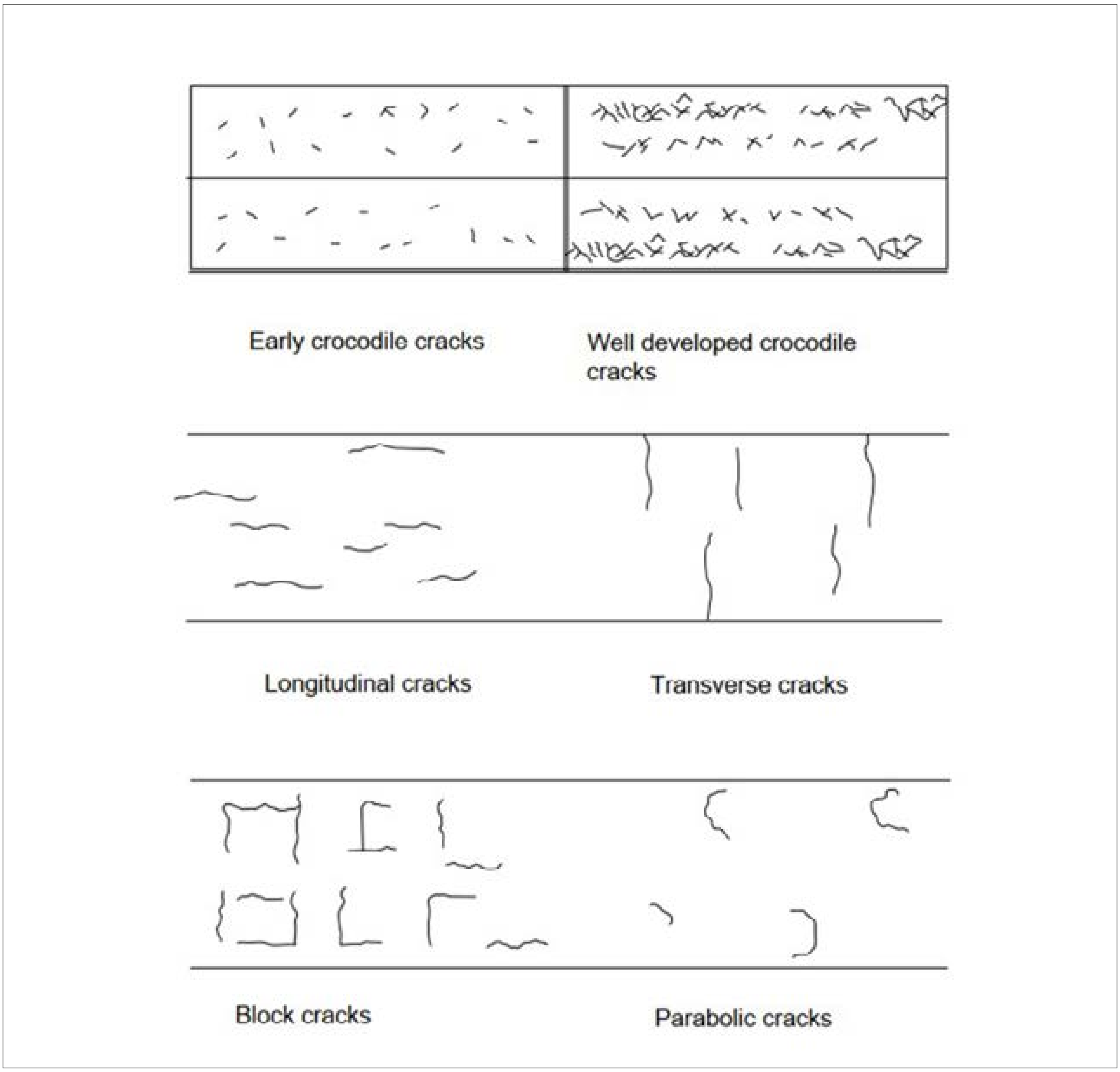
Cracking index (CrI) ranges from 0 – 25

5. **Reporting:**

   The report must include the following information.

   a. Date and location of measurements.
   b. Crack width measurements for each crack.
   c. The equipment used (including calibration details).
   d. Any photographs taken.
   e. Relevant environmental conditions (e.g., temperature, weather).
   f. Any observations or notes about the cracks' condition which include:
      i. Severity rating.
      ii. Extent rating.
      iii. Calculated Cracking Index rating.
   g. If applicable, report the PCI values for the pavement section.

Figure 8.3 Types of Cracking (TRL, ORN 18)



8.2.2 Determination of Pothole/ Patching Index(PPI)

This method describes the standard procedure for the determination of pothole/ patching index (PPI) on road carriageways.

The investigation is conducted through a visual condition survey (VCS). The exercise can be conducted by observing potholes and patching from the car travelling at low speed (windscreen survey) or on foot (walkthrough survey) or from test vehicles with pavement cameras and GPS can also be used for road network condition surveys.

The results are used in designing maintenance interventions or rehabilitation. They can also be used in Output and Performance Based Road Contracts (OPBRC) for approval of level of service and payment purposes. The pothole/patching index can signify pavement failure.

The following are key procedures for the determination of the Pothole/Patching Index when evaluating surface defects:

1. **Apparatus:**
   a. Measuring wheel or tape measure – to demarcate road sections.
   b. Measuring tape.
   c. Camera.
   d. Standard forms.
2. **Preparation of test section:**
   a. For preliminary surveys or road network condition surveys:
      i. Determine the test chainages and demarcate sections (100 m or longer).
      ii. Conduct a windscreen survey (observing from the car) travelling at low speed (not more than 20 km/h).
      iii. Make regular stops for closer observations.
      iv. When using automated systems equipped with GPS it may not be necessary to prepare the site for investigations, but safety should be taken into consideration.
   b. For pavement evaluation for rehabilitation design:
      i. Mark sections 50 m in length.
      ii. Mark chainages.
      iii. Place temporary road signs indicating works in progress.
      iv. For highly trafficked roads, cordon off the work area.
      v. When automated surveys are applied for data collection, the GPS needs to be accurate to within 3 m and should have powerful cameras and profilers.
3. **Procedure for collecting data:**
   a. For preliminary surveys:
      i. Determine the average size of potholes and patching.
         - Diameter - Measure the width and length of the pothole's opening to determine its area.
         - Depth - Measure the depth from the road surface to the bottom of the pothole.
         - Volume - Calculate the overall volume of the pothole, often using mathematical approximations, to estimate the amount of material needed for patching.
      ii. Determine the extent of potholes and patching in the percentage of the area of the test section.
   b. For rehabilitation design:
      i. Estimated area - the sum of pothole and patching area (A_t) in m^2.
      ii. Estimate the average individual pothole or patching area ($A_{average}$).
      iii. Severity of pothole and patching (S_{pp}) using sizes, Table 8.3.

1 2 3 4 5 6 7 8 Standard Testing Methods

Table 8.3 Severity of Potholes by Size

Severity	Standard (m^2)
1	$0 \le A_{average} < 0.2$
2	$0.2 \le A_{average} \le 0.5$
3	$0.5 \le A_{average} \le 1.0$
4	$1.0 \le A_{average} \le 2$
5	$A_{average} \ge 2$

iv. Position / Location left (L), centre (C), right(R), outer wheel path (OWP), inner wheel path(IWP)

v. Extent (Epp) is given in Figure 8.4 and Table 8.4:

Table 8.4 Extent of Defects by the Percentage of Area Affected

Severity	Standard (%)
1	0 ≤ 10
2	10 < area of block affected ≤ 20
3	20 < area of block affected ≤ 50
4	50 < area of block affected ≤ 80
5	80 < area of block affected ≤ 100

4. Calculation

Calculated the cracking index using the following equation:

Pothole and Patching Index, PPI = $S_{pp}\,xE_{pp}$

Equation 8.6

Pothole and Patching index (PPI) ranges from 0 – 25.

5. Reporting

The following information must be included when reporting on potholes and patching defects:

a. Shape of the pothole - Describe the shape of the pothole, whether it is circular, oval, irregular, or exhibits any distinctive geometry. The shape can affect the patching process.

b. Severity - Categorise the severity of the pothole as minor, moderate, or severe based on its size, depth, and potential impact on road safety and vehicle damage based on measurements taken, observations made and calculated PPI.

c. Categorise the severity of the pothole as minor, moderate, or severe based on its size, depth, and potential impact on road safety and vehicle damage.

d. Surrounding Road Condition - Report on the condition of the road surrounding the pothole, noting any additional cracks, surface deterioration, or signs of water infiltration that may contribute to the pothole's formation. This can guide the patching process by addressing underlying issues.

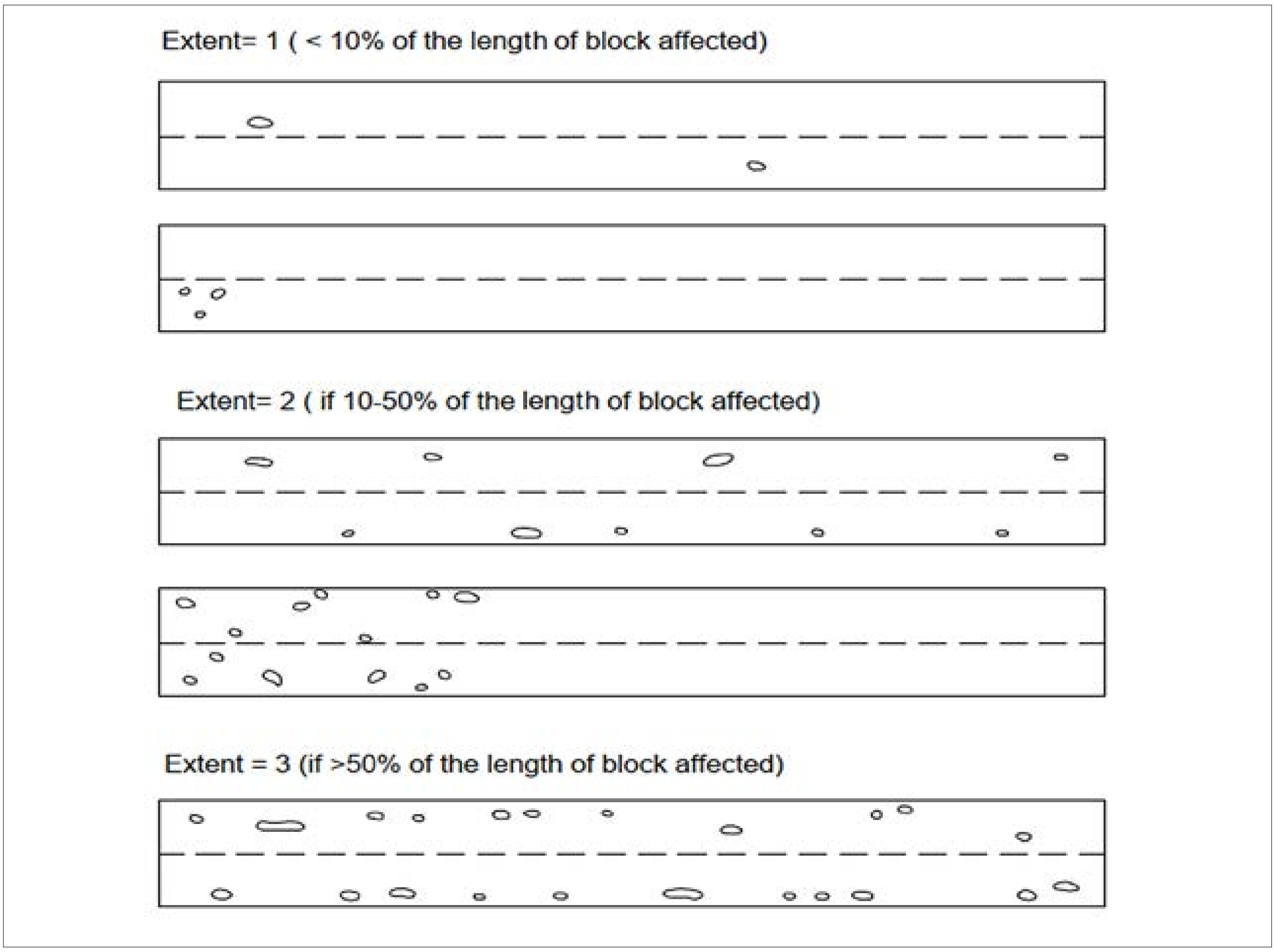
e. Depth of Compromised Layers - Assess how deeply the various road layers (e.g., asphalt, base, subbase) have been affected by the pothole, as this can impact the patching method and materials required.

   i. See Table 8.5

   ii. Record the position or offset left (L), centre (C), right(R), outer wheel path (OWP), inner wheel path(IWP).

   iii. Extent (Ed), Table 6.7:

Figure 8.4 Extent of Potholes and Patching (TRL, ORN 18)



8.2.3 Determination of Deformation Index

This method describes the standard procedure for the determination of the Deformation Index (DDI) on road carriageways. The investigation is conducted through a visual condition survey (VCS) and measurement of depressions. The exercise can be conducted by observing deformation from inside a car travelling at low speed (windscreen survey) or on foot (walkthrough survey).

The results are used in designing maintenance interventions or rehabilitation. They can also be used in Output and Performance Based Road Contracts (OPBRC) for approval of level of service and payment purposes. The Deformation Index can signify pavement failure.

The input required and procedures to be followed to correctly determine the Deformation Index when evaluating road pavement defects:

1. **Apparatus:**
   - **a.** Measuring wheel or tape measure – to demarcate road sections.
   - **b.** Straight edge for measuring defects.
   - **c.** Camera
   - **d.** Standard forms
   - **e.** Road marking paint or equivalent
   - **f.** Road profiler – for automated surveys.
2. **Preparation of test section**
   - **a.** For preliminary surveys or road network condition surveys:
     - **i.** Determine the test chainages to demarcate sections (100 m or longer).
     - **ii.** Conduct a windscreen survey (observing from the car) travelling at low speed (not more than 20 km/h).

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8
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iii. Make regular stops for closer observations and direct measurements.
iv. When using automated systems equipped with profilers, cameras, and GPS, it may not be necessary to prepare the site for investigations, but safety considerations should be considered.

b. For pavement evaluation for rehabilitation:
i. Mark sections 50 m in length.
ii. Mark chainages at the beginning and end of each test section.
iii. Place temporary road signs indicating works in progress.
iv. For highly trafficked roads, cordon off the works area.
v. Mark the deformed areas.
vi. When automated surveys are conducted the GPS needs to be accurate to within 3 m and should have powerful cameras and profilers that are sensitive to less than 5 mm.

3. **Procedure for collecting data:**

a. For preliminary surveys and road network condition surveys:
i. Determine the area and maximum depth of deformation.
ii. Determine the extent of deformation in the percentage of sections that are deformed (see **3.b.vi.** below).
iii. For windscreen surveys, make regular stops for closer observations and direct measurements.
iv. For automated surveys, run the vehicle as specified by the manufacturer if not at traffic speed.

b. For rehabilitation design:
i. Place the straight edge across the depressions, Figure 8.5.
ii. Place the graduated wedge in the gap between the wedge and the road's surface. Probe in various positions, read and record the higher value and express it as the depth of deformation at the test point.
iii. Repeat the test in several pre-marked positions and record the maximum deformation within the test section, d_{max}
iv. Determine the severity of deformation (S_d), Table 8.5.

Table 8.5 Severity of Deformation by Size

Severity	**Standard** (mm)
1	$0 < d_{max} < 10$
2	$10 \leq d_{max} \leq 20$
3	$20 \leq d_{max} \leq 50$
4	$50 \leq d_{max} \leq 100$
5	$100 \leq d_{max}$

v. Record the position or offset left (L), centre (C), right (R), outer wheel path (OWP), inner wheel path (IWP)
vi. Extent (E_d), Table 8.6:

Table 8.6 Extent of Deformation by Size

Severity	**Standard** (%)
1	0 < area of block affected ≤ 10
2	10 < area of block affected ≤ 20
3	20 < area of block affected ≤ 50
4	50 < area of block affected ≤ 80
5	80 < area of block affected ≤100

4. Calculation

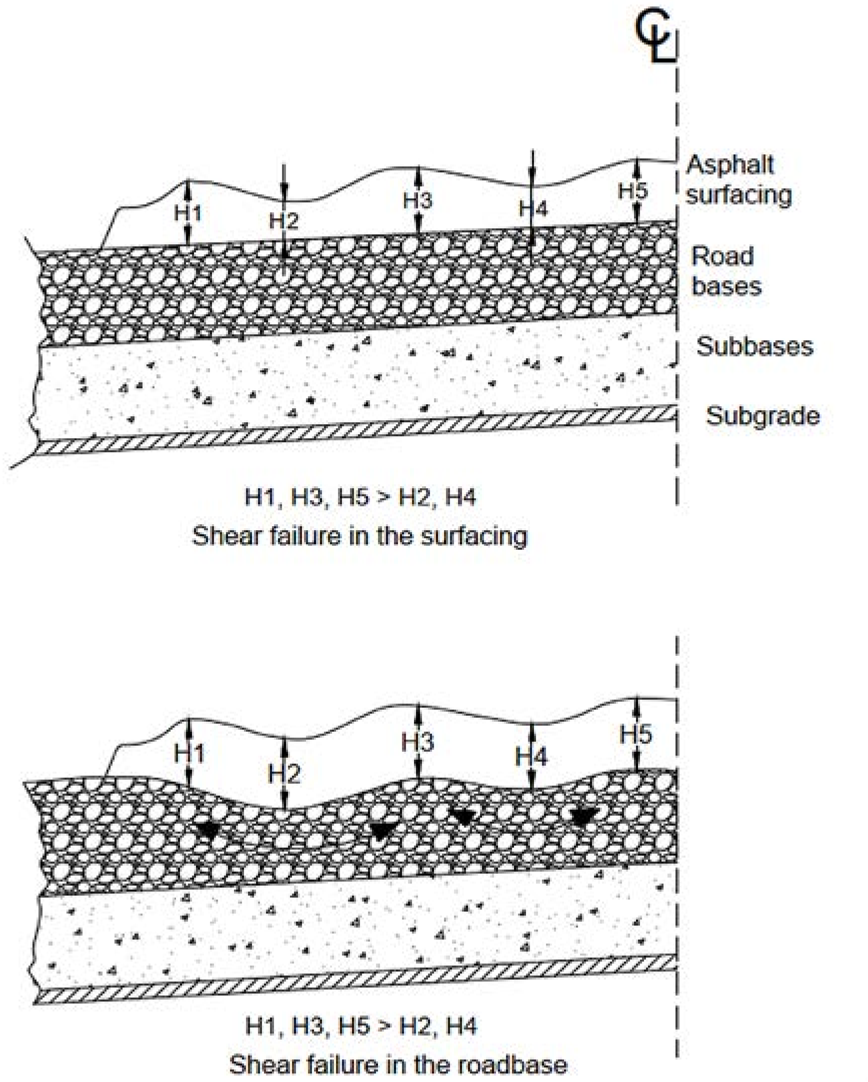
Calculated the cracking index using the following equation:

$$Deformation\ Index, dI = S_d\, x E_d$$

Equation 8.7

Equation Depression/Deformation Index (DDI) ranges from 0 - 25

Figure 8.5 Illustration of Deformation (TRL, ORN 18)



8.2.4 Determination of Rutting Index

This method describes the standard procedure for determining the rutting index (RI) for roads. The test is conducted through a visual condition survey (VCS) and rut depth measurements using a straight edge.

Preliminary assessments of rutting can be conducted visually by observing rutting from inside a car travelling at low speed (windscreen survey) or on foot (walkthrough survey).

The results are used in designing maintenance interventions or rehabilitation designs. The results are also used to determine the structural conditions of pavements.

Rutting is often used to indicate pavement failure and as a performance indicator in Output and Performance Based Road Contracts (OPBRC).

8.2.4.1 Determination Of Rutting Index Using The HB Wedge Rut Depth Measuring Device.

The following procedures guide the determination of the rutting index:

1. **Apparatus:**
   a. Measuring wheel or tape measure – to demarcate road sections.
   b. Straight edge – 2 m or 3 m for measuring defects, Figure 8.6.
   c. Graduated wedge.
   d. Alternatively, an ultrasonic or laser profiler can be mounted on a test vehicle.
   e. Camera.
   f. Standard forms.

2. **Preparation of test section**
   a. For preliminary surveys:
   b. Determine the test chainages to demarcate sections (100 m or longer).
   c. Conduct a windscreen survey (observing from the car) travelling at low speed (not more than 20 km/h).
   d. For pavement evaluation for rehabilitation:
   e. Mark sections 50 m in length.
   f. Mark chainages at the beginning and end of each test section.
   g. Place temporary road signs indicating works in progress.
   h. For highly trafficked roads, cordon off the works area.

3. **Procedure for collecting data**
   a. For preliminary surveys:
      i. Determine the length of rutted sections.
      ii. Determine the extent of surface irregularity (rut depth measurement) in the percentage of the length of the test section (see **3.b.viii.**) below).
      iii. Make regular stops for closer observations and direct measurements.
      iv. When using automated road profilers, run the vehicles as stipulated by the manufacturer, not at traffic speed. The GPS will capture the location information and the cameras will record visual footage.
   b. For rehabilitation design:
      i. Place the straight edge across the rut at 90° to the rut.
      ii. Place the graduated wedge between the road surface and the underside of the straight edge and read the depth of the gap.
      iii. Probe in various positions until and record the higher value at that position.
      iv. Mark the position with rapid-drying road marking, or equivalent paint.
      v. Repeat the measurements on several positions, determine the highest value obtained (R_{max}) and record it as the rut depth for the test section.
      vi. Determine the severity of surface irregularity (rutting) (S_r), guided by Table 8.7.
      vii. Position: left (L), centre (C), right (R), outer wheel path (OWP), inner wheel path (IWP)
      viii. Extent (E_R) (refer to Table 8.8), which shows the extent of surface irregularity (rutting) by size:

4. **Calculation**

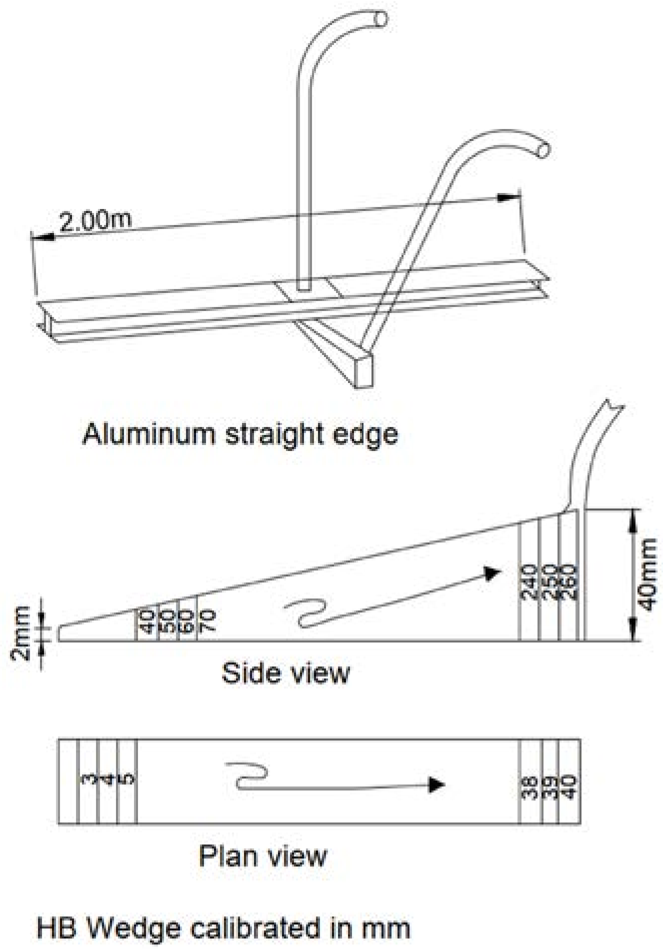
   Calculated the cracking index using the following equation:

$$Rutting\ Index,\ RI = S_R \text{ x } E_R$$

Equation 8.8

Rutting index (RI) ranges from 0 - 25

Figure 8.6 Device for Measuring Rut Depth (TRL, ORN 18)



8.2.4.2 Determination of Rutting Index Using a Pavement Surface Profilometer.

1. **Apparatus:**
   - **a.** Pavement Surface Profiler or Profilometer - This instrument measures the road surface's vertical deviations and records the data.
   - **b.** Survey Vehicle: A vehicle equipped with a profiler or profilometer system.
   - **c.** Computer and Software: To collect and analyse the collected data.
   - **d.** Roadway Markings: To establish the test section and measurement intervals.
   - **e.** Safety Equipment: Cones, signs, and personal protective equipment as needed.
2. **Preparation of Test Section:**
   - **a.** Identify the specific section of the road to be evaluated for surface irregularity (rutting). Ensure that this section represents the typical condition of the pavement.
   - **b.** Mark the test section and measurement intervals on the road using roadway markings. Typically, measurement intervals are spaced at regular intervals along the test section.
3. **Precautionary Measures:**
   - **a.** Ensure the safety of survey personnel and road users during the test by setting up proper warning signs and traffic control measures.
   - **b.** Maintain a consistent speed and avoid sudden stops or accelerations to ensure accurate measurements.
   - **c.** Ensure the equipment is calibrated to maintain accuracy.
   - **d.** Ensure the road surface is dry and free from debris that could interfere with measurements.

4. **Test Procedure:**
   a. Set up the profiler or profilometer on the survey vehicle according to the manufacturer's instructions.
   b. Ensure that the equipment is calibrated for accurate measurements.
   c. Drive the survey vehicle at a constant speed along the designated test section.
   d. The profiler or profilometer will record vertical deviations in the road surface at predefined intervals as you drive.
   e. Ensure consistent and smooth operation of the equipment throughout the survey.

5. **Calculation:**
   a. Calculate the rut depth at each measurement interval by determining the difference between the highest peak and the lowest valley in the vertical deviations recorded by the profiler or profilometer. This is typically done using software provided with the equipment.
   b. The Rut Index (RI) is calculated as the average rut depth within the test section. Use the following formula:

$$RI = \frac{1}{N}\sum_{i=1}^{N} D_i$$

Equation 8.9

Where,

RI = Rut Index.

N = Number of measurement intervals.

D_i = Rut depth at measurement interval i.

6. **Reporting:**
   a. Prepare a comprehensive report that includes the following:
      i. Describe the test section and its location.
      ii. Equipment used, including profiler/profilometer specifications.
      iii. Calibration procedures and verification.
      iv. Data collected, including rut depth measurements at each interval.
      v. Calculation of the Rut Index (RI).
      vi. Interpretation of results and conclusions regarding the pavement's surface irregularity (rut depth measurement) condition.
      vii. Use the information to derive recommendations for maintenance or rehabilitation if necessary.
   b. Include charts, graphs, or visual representations of the surface irregularity (rut depth measurement) data for clarity.
   c. Provide additional information or observations relevant to the test section and surface irregularity (rut depth measurement) condition.

Table 8.7 Severity of Surface Irregularity (Rut Depth Measurement) by Size

Severity	Standard (mm)
1	$0 < R_{max} < 5$
2	$5 \leq R_{max} \leq 10$
3	$10 \leq R_{max} \leq 20$
4	$20 \leq R \leq 50$
5	$R_{max} \geq 50$

Table 8.8 Extent of Surface Irregularity (Rut Depth Measurement) by Size

Extent	Standard (%)
1	0 < length affected ≤ 10
2	10 < length affected ≤ 30
3	30 < length affected ≤ 50
4	50 < length affected ≤ 80
5	80 < length affected ≤ 100

8.2.5 Determination of International Roughness Index (IRI).

This method describes the standard procedure for determining the international roughness index (IRI) for roads. The investigation is conducted through roughness measurements using the MERLIN, Roughness measuring beam, or Vehicle-mounted response type road roughness measuring system (RTRRMS).

The results are used in designing maintenance interventions or rehabilitation designs. The results are also used to determine the structural conditions of pavements. Road roughness is often used to indicate pavement and/or surfacing failure and as a performance indicator in OPBRC.

The following equipment and procedures are key for the determination of international roughness index (IRI):

1. **Apparatus:**
   - **a.** Measuring wheel or tape measure – to demarcate road sections.
   - **b.** GPS – for measuring coordinates.
   - **c.** MERLIN machine (Figure 8.7)/Roughness measuring beam for measuring roughness and calibrating other RTRRMS.
   - **d.** Rapid measuring device for roughness measurement (profilometers, bump integrators, etc.)
   - **e.** Vehicle-mounted camera.
   - **f.** Standard forms.
2. **Calibration of rapid measuring devices for roughness measurement:**
   - **a.** Select at least five sections with incremental roughness starting from smooth to very rough.
   - **b.** Mark the start and end of each section. The length should be at least 300 m.
   - **c.** Drive the vehicle with mounted road roughness measuring device from the beginning to the end of the section slowly while marking the wheel tracks with paint marks every 3-5 m.
   - **d.** Using the MERLIN machine, measure roughness by marking points on the forms at every full-wheel revolution.
   - **e.** Follow the paint marks on the wheel path from start to end.
   - **f.** Repeat the measurements on each wheel path and calculate the average roughness.
   - **g.** Use the formula below to calculate the roughness of the section and record the value as the IRI value for the sections.
   - **h.** Drive the vehicle at the speed(s) with which section of the road will be tested with the mounted road roughness measuring device. Follow the marked wheel paths and record the roughness values (e.g., the bump integrator readings.
   - **i.** Calculate the average value.
   - **j.** Repeat procedure **2.c.** to **2.h.** on each section.
   - **k.** Plot IRI against the average values obtained from the readings on the vehicle-mounted device.
   - **l.** Draw the best-fit straight line through the points.
   - **m.** Determine the calibration equation from the graph:

$$IRI = m(BI) + C$$

Equation 8.10

- **n.** Use the calibration equation to convert all values from the RTRRMS to the international roughness index (IRI).

3. Preparation of test section:

- **a.** For preliminary surveys:
  - **i.** Determine the test chainages to demarcate sections (100 m or longer) using a simple bump integrator.
  - **ii.** For more advanced devices the roughness, the coordinates and chainages are recorded and plotted automatically.
- **b.** For pavement evaluation for rehabilitation:
  - **i.** Mark sections 50 m in length.
  - **ii.** Mark chainages at the beginning and end of each test section.
  - **iii.** Place temporary road signs indicating works in progress.

4. Procedure for collecting data:

- **a.** For preliminary surveys:
  - **i.** Run the vehicle once.
  - **ii.** Download the data from the device.
- **b.** For rehabilitation design:
- **c.** Run the vehicle at least 3 times following the wheel paths as closely as possible.
  - **i.** Download the data from the device.
  - **ii.** Determine the average value of IRI for each section as specified.

5. Calculation:

Calculated the average value of IRI as specified:

$$Average\ IRI = \frac{(IRI_1 + IRI_2 + \ldots + IRI_n)}{n}$$

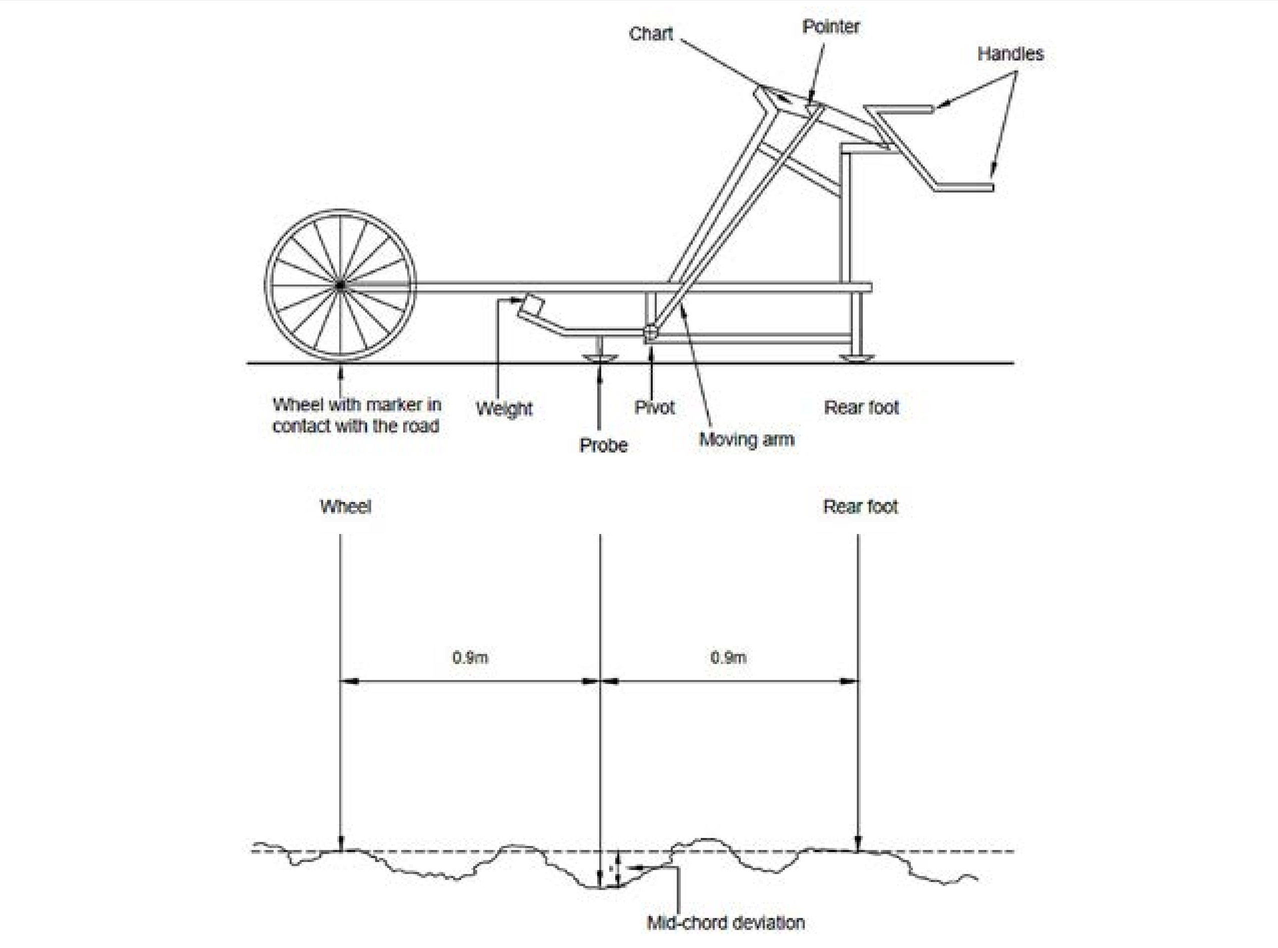
Equation 8.11

The roughness survey rating criteria in the Table 8.9 should be used to standardise the rating:

Table 8.9 Road Roughness Rating Standards for IRI

Roughness, m/km	Rating description
0-2	Very Good
2-4	Good
4-6	Fair
6-10	Poor
Above 10	Bad

Figure 8.7 Roughness Measurements Using a MERLIN Machine (TRL, ORN 18)



8.2.6 Determination of Skid Resistance

8.2.6.1 Using the Portable Skid-resistance Tester

The Portable Skid Resistance Tester is regularly used to test the slip resistance on public highways, pedestrian walkways and flooring, within offices, shopping malls, factories, airports, and on sports field surfaces, both at the design stage, and condition surveys during investigation for road condition to minimise the occurrence of accidents. It is also utilised to test the frictional resistance of new roads and road markings.

The skid resistance test method is based on the Izod principal, which states a pendulum of a known mass rotates about a vertical spindle. The head of the pendulum is fitted with a Rubber Slider, which has a specific hardness and resilience. When released from a horizontal position, the pendulum head strikes the sample surface with a constant velocity. The pendulum swing distance, after striking the sample, is determined by the friction resistance of the sample surface. The skid resistance values, which approximately correspond to the coefficient of friction times 100, are read directly from the engraved reading scale.

This section details the procedure that shall be followed for planning and conducting skid resistance surveys and processing the data.

1. **Apparatus:**

   a. The Portable skid-resistance tester:

   Comprises of multiple critical components described in this section and illustrated in Figure 8.8.

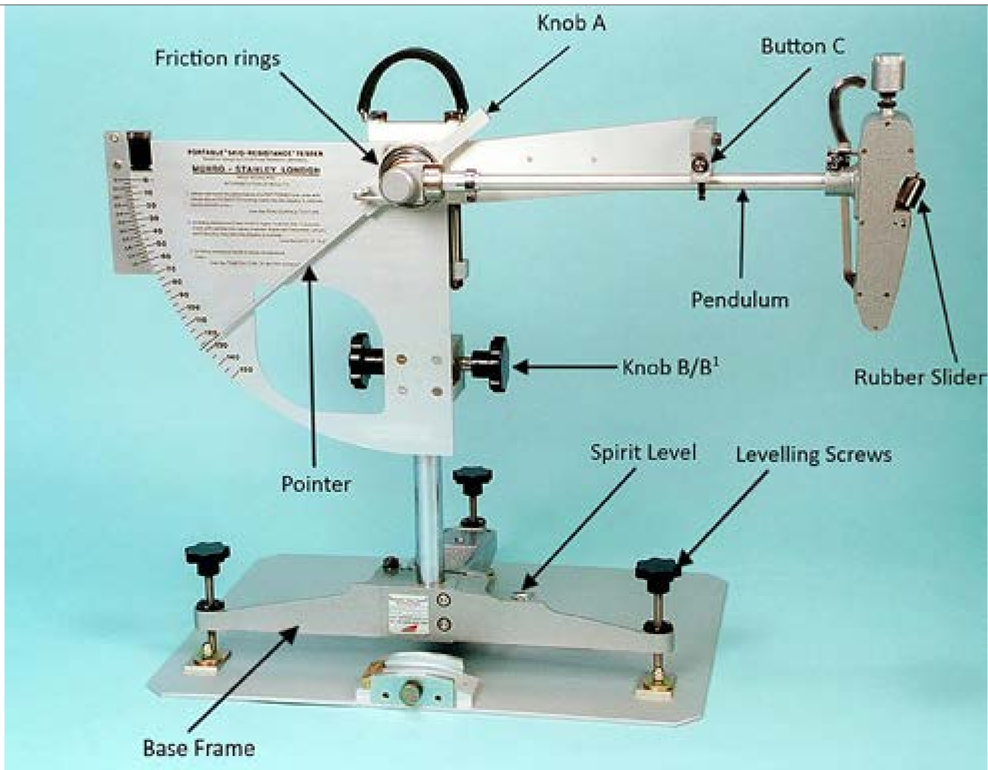
   i. Spirit Level
   It helps position the pendulum vertically to avoid parallax errors and inconsistent swing motions, which affect the accuracy of the measured skid resistance.

ii. Levelling Screws and Lock nuts
The three levelling screws are used to adjust the level of the base frame relative to the test surface. The locking nuts are provided to allow adjustment of the screw tension.

iii. Rubber slider
Represents a model or anticipated skid resistance of a vehicle tyre when it comes in contact with the surface. Various surface conditions are created during the experiment to analyse the respective skid resistance using the rubber slider. Depending on the test application (purpose of the surface being), a rubber tester of the correct hardness (resembling either barefooted pedestrian, shoe sole or car tyre) must be selected.

There are two types of Rubber Sliders available for testing surfaces using the Main Graduated Scale. The TRL (Transport Research Laboratory) Rubber Slider is commonly used on surfaces where the general roughness is greater than that generally found with internal flooring situations. We recommend the designer to correctly reference the applicable standards and specifications of the test surface before choosing a Rubber Slider.

Figure 8.8 Portable Skid Resistance Tester



- TRL Large Rubber Slider

Mounted on a backing plate, this 76 mm wide slider is used mainly on roadways or other surfaces where the general roughness is considered greater than normally found with internal flooring situations. Each Rubber Slider is provided with a certificate confirming the Hardness and Resilience as shown in Table 8.10.

Table 8.10 TRL Large Rubber Slider Hardness and Resilience

Temperature °C	0	10	20	30	40
Lüpke resilience	43 - 49	58 - 65	66 - 73	71 - 77	74 - 79
IRHD hardness	55 ± 5	55 ± 5	55 ± 5	55 ± 5	55 ± 5

- Four S Rubber Slider

  Mounted on an aluminium backing plate, this 76 mm wide slider is most commonly used to test on internal flooring materials. Each Rubber Slider is provided with a certificate confirming the Hardness and Resilience, as shown in Table 8.11.

Table 8.11 Four S Rubber Slider Hardness and Resilience

Temperature °C	5	23	40
Lüpke resilience	21 ± 2	24 ± 2	28 ± 2
IRHD hardness	96 ± 2	96 ± 2	96 ± 2

- TRL Small Slider

  This 30 mm wide slider is used for the Polished Stone Value (PSV) Test and in conjunction with the Detachable Scale and Laboratory Baseplate. Each Rubber Slider is provided with a certificate confirming the Hardness and Resilience, as shown in Table 8.12.

Table 8.12 TRL Small Rubber Slider Hardness and Resilience

Temperature °C	0	10	20	30	40
Lüpke resilience	43 - 49	58 - 65	66 - 73	71 - 77	74 - 79
IRHD hardness	55 ± 5	55 ± 5	55 ± 5	55 ± 5	55 ± 5

iv. Pendulum Arm

Holds the rubber slider in position and guides its swing motion to minimise energy losses that could result from uncontrolled swing motion which could result in wrong resistance readings. It also guides the pointer to the correct resistance reading.

v. Pointer

Gives the skid resistance reading.

vi. Graduated Scale

This is a scale from which the skid resistance readings are taken during the experiment or test.

vii. Friction rings

Friction rings control the resistance to pendulum swing motion at the pivot to correct zero errors on the instrument.

- Thermometer

  Used to record the test surface temperature while recording each skid resistance test reading.

- Water bottle

  A 500 ml water container will be used to create wet conditions on the test surface.

2. Precautions when conducting the test.

a. Rubber sliders should be stored in a cool, dark and consistent environment, preferably below 15 °C.

b. Rubber sliders have a shelf life of 12 months therefore care should be exercised to avoid the use of ageing rubber sliders.

c. The Rubber Slider should always be clean and free from contamination, such as oil or abrasive material to ensure the correct skid resistance measurement.

d. Preparation of the Rubber Slider is important and should be carried out following the manufacturer's specifications and guidelines otherwise, the following procedure should be referred to:

i. When using TRL Rubber Sliders

a). Fix a sheet of 400-grade silicon carbide resin bonded paper to the cleaned face of a piece of hard flat, and robust material. The material must also be smooth, so glass or polished metals are ideal and should have a surface area measuring 150 mm x 200 mm.

b). Examine the Rubber Slider for damage or contamination.

c). Assemble and set the Tester as described in sections 1 and 2.

d). This procedure may be carried out in either wet or dry conditions. Release the Pendulum Arm by pressing the release button 'C' allowing the Rubber Slider to swing over the 400-grade silicon carbide resin bonded paper. Repeat this procedure until ten swings have been completed.

e). The Rubber Slider is now ready for use.

ii. When using Four S Rubber Sliders

a). Complete the procedure for TRL Rubber Sliders as described above.

b). Fix a sheet of 3M261X Imperial Lapping Film Grade 3MIC or an equivalent to the cleaned face of a piece of hard flat, and robust material. The material must also be smooth, so glass or polished metals are ideal and should have a surface area measuring 150 mm x 200 mm. The sheet should be fixed to the plate across one edge only, enabling the rubber slider to contact at least 127 mm of the attached sheet.

c). This part of the procedure must be carried out in wet conditions. Release the Pendulum Arm by pressing Button "C" allowing the Rubber Slider to swing over the 3M 261X Imperial Lapping Film Grade 3MIC. Repeat the procedure until twenty swings have been completed.

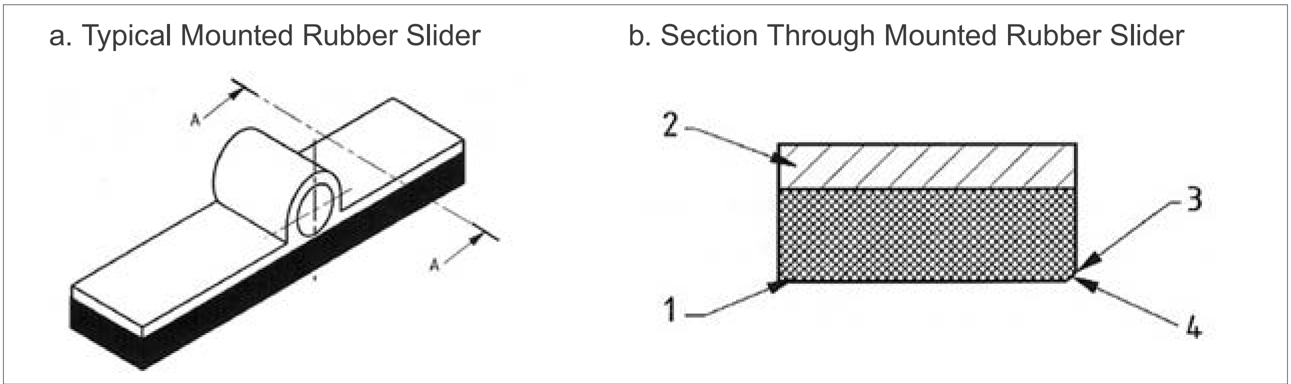
d). The Rubber Slider is now ready for use.

iii. Reconditioning of worn Rubber Sliders

The worn or damaged working edge of a Rubber Slider can be reconditioned by following the procedure described in section '**i**' above. See illustrative Figure 8.9.

a). Usually, a minimum of three swings over the 400-grade silicon carbide resin bonded paper is sufficient to restore a TRL Rubber Slider, with a further twenty swings over the 3M 261X Imperial Lapping Film Grade 3MIC, described in section 'ii', required to restore the Four S Rubber Slider.

Figure 8.9 Typical Mounted Rubber Slider Details



Where,

1. Represents the Rubber Slider Pad
2. Represents the Aluminium Mounting Plate
3. Represents the Working Edge
4. Represents the Worn Width

e. When the width of the working edge of the Rubber Slider exceeds 4 mm. The edge should be disfigured to prevent its further use. Once both working edges have exceeded 4 mm the Rubber Slider should be discarded.

3. **Procedure**

a. Select the surface to be tested.

b. Setting up the apparatus for the test.

i. Place the base frame onto the road surface and set the level using the three levelling screws on the in-built spirit level.

ii. Raise the head so that the pendulum arm swings without touching the surface. The movement of the head of the tester, which carries the swinging arm, graduated scale, pointer and release mechanism, is controlled by a rack and pinion on the rear of the vertical column. After unclamping the locking knob, A at the rear of the column, the head may be raised or lowered by turning either of the knobs B/B1. When the required height is obtained, the head unit must be locked in position by using a clamping knob A.

iii. Check the zero reading. This is done by first raising the swinging arm to the horizontal release position, on the right-hand side of the tester. In this position, it is automatically locked in the release catch. The pointer is stopped in line with the pendulum arm. The pendulum arm is released by pressing the button C. The pointer is carried with the pendulum arm on the forward swing only. Catch the pendulum on its return and note the pointer reading.

iv. Correct the zero setting as necessary by adjusting the friction rings. If the pointer has swung past the zero position, Friction Rings are screwed up a little more tightly. If it has not reached zero, Friction Rings are screwed up a little more tightly. If it has not reached zero, the Knurled Friction Rings should be unscrewed a little. Repeat this procedure until three consecutive zero readings are obtained. **Note:** There are two Knurled Friction Rings; the outer Friction Ring must be unlocked before the inner Friction Ring can be adjusted.

v. With the pendulum arm free, and hanging vertically, place the spacer, which is attached to the base of the vertical column, under the lifting-handle setting screw to raise the slider. Lower the head of the tester, using knob B, until the slider just touches the road surface, and clamp in position with knob A. Remove the spacer.

vi. To accurately set the sliding length of the conditioned rubber slider of the test surface, gently lower the pendulum arm until the slider touches the surface first on one side and then the other side and then the other side of the vertical. The sliding length is the distance between the two extremities where the sliding edge of the rubber touches the test surface. To prevent undue slider wear when moving the pendulum arm through the arc contact, the slider should be raised off the road surface using the lifting handle. If necessary, adjust to the correct length by raising or lowering the Head Unit slightly. If the apparatus is correctly set, the measured sliding length should be between 125 and 127 mm.

vii. Place the pendulum arm in its locked position. The apparatus is now ready for testing.

c. Operation of the tester

i. After ensuring that the road surface is free from loose grit, wet both the surface of the road and slider.

ii. Bring the pointer around to its stop. Release the pendulum arm by pressing button C and catch it on the return swing before the slider strikes the road surface. Record the indicated value.

iii. Return the arm and pointer to the locked position, keeping the slider clear of the road surface using the lifting handle. Repeat the process, spreading water over the contact area with a hand or brush between each swing. Record the mean of five successive swings, provided they do not differ by more than three units. If the range exceeds this, repeat swings until three successive readings are constant; record this value.

iv. Raise the head of the tester so that it swings clear of the surface again and check the free swing for any zero error.

v. Sliders should be renewed when the sliding edge becomes burred or rounded. One slider edge can usually be used for at least 100 tests (500 swings). New sliders should be roughened before use by swinging several times over a dry piece of road.

4. **Analysis**

a. Temperature correction

The effect of temperature on rubber resilience makes it necessary to correct the measured value of skid resistance to standard temperature. The road temperature is measured by recording the water temperature after the test using a digital thermometer and surface probe. It is recommended in tropical climates, that the value should be corrected to a standard temperature of 35°C using the following relationship (Beavan and Tubey, 1978). When calculating the temperature adjustment, the designer must the first three recorded readings, and the slip resistance is calculated as the mean of the last five recorded readings, rounded off to the nearest whole number.

$$SVR_{35} = \frac{100 + t}{135} \text{ x } SVR_t$$

Equation 8.12

Where,

SRV_{35} = Skid resistance value at 35 °C.

SRV_t = Measured skid resistance.

T = Temperature of test (°C).

5. **Reporting**

The Test Report should contain, as a minimum, the following information:

a. Number, description and date of the applicable standard.
b. Location of the site and a drawing showing the position of the test(s).
c. Description of the surface tested and its condition.
d. Whether the test was performed under wet or dry conditions.
e. Slider material used and the batch number.
f. The Skid value obtained at each position tested.
g. Traffic data for the test section.
h. Recorded temperature of the test surface.
i. Operator’s name and Organisation.

8.2.6.2 Using the Circular Friction Meter Equipment (CFME).

Testing skid resistance using the Circular Friction Meter Equipment (CFME) is crucial for evaluating road safety. The purpose of this experiment is to quantitatively measure the skid resistance of a road surface using CFME, providing a basis for road safety assessment and maintenance decisions.

1. **Apparatus:**

a. Circular Friction Meter Equipment (CFME) - A device that measures skid resistance, usually reporting values in British Pendulum Number (BPN) and ensuring the CFME is properly calibrated.
b. Measuring Tape - This is used for measuring the length of the test section.
c. Traffic Cones or Safety Barriers - To establish a safe testing area and protect the testing team.
d. Safety Gear - High-visibility clothing, gloves, safety shoes, and helmets for the safety of the testing team.
e. Notepad and Pen - For recording data and observations.

2. **Preparation:**

a. Site Selection - Choose a representative section of the road, ensuring it's clean, dry, and free from contaminants.

b. Calibration - Verify that the CFME is accurately calibrated according to the manufacturer's guidelines.
c. Safety Measures - Set up safety barriers or traffic cones to protect the testing team and notify passing traffic about the ongoing test. Ensure everyone involved is aware of safety procedures.

3. **Precautions:**
   a. Avoid conducting tests in adverse weather conditions, such as rain or snow.
   b. Maintain a safe distance from moving traffic.
   c. Follow local regulations and safety guidelines for road testing.
   d. Handle the CFME with care to prevent damage or injury.
4. **Procedure:**
   a. Measurement Setup:
      i. Position the CFME at the starting point of the test section.
      ii. Set the CFME to the desired testing parameters, including the wheel load and speed.
   b. Data Collection:
      i. Start the CFME and roll the circular rubber wheel over the road surface within the defined test section.
      ii. Record the measured skid resistance values (typically in BPN) displayed on the CFME after each test run.
      iii. Conduct multiple test runs at various locations within the test section to ensure representative data.
5. **Data Analysis:**
   a. Calculate the average BPN value ($B\overline{P}N$) from the recorded measurements.

$$B\overline{P}N = \frac{\Sigma BPNvalues}{Number\ of\ test\ runs}$$

Equation 8.13

   b. Specific Condition Ratings – Are as shown in Table 8.13 indicating specific condition ratings based on BPN values:

Table 8.13 Skid Resistance Severity Rating

Severity Rating	Skid Resistance (BPN)
1	0-20
2	21-40
3	41-60
4	61-80
5	81-100

6. **Reporting:**
   Prepare a detailed report that includes:
   a. Date, time, and location of the test.
   b. CFME calibration details.
   c. Test section details, including length.
   d. Recorded BPN values.
   e. Average BPN value ($B\overline{P}N$).
   f. The condition rating is based on the average BPN value.
   g. Recommendations for maintenance or improvements if the condition rating suggests road safety concerns.

8.2.7 Determination of Pavement Texture Depth (PTD)

8.2.7.1 Using the Sand Patch Method

1. **Apparatus and material**
   a. Dividers to measure 20 cm. Radius.
   b. Millimetre rule.
   c. Cylinder 8.0 cm high, with an internal diameter of 2.0 cm.
   d. Flat wooden disk of 6.5 cm diameter, with a hard rubber disc, of 1.5 mm thickness of the same diameter stuck to one face. A handle should be fixed to the wooden face.
   e. A 250-cc plastic container to hold sand.
   f. A soft hand brushes.
   g. Sand which will pass a No. 52 BS sieve and be retained on a No. 100 BS sieve. Natural sand with a round particle shape should be used.

2. **Test procedure.**
   a. The surface to be measured must be dry and should be first swept with a soft brush.
   b. Fill the cylinder with sand. When full, gently tap the base of the cylinder three times on the road surface, then top up and level the top with a straight edge. Pour the sand into a heap on the surface to be tested.
   c. In windy conditions, a tyre is used to surround the sand.
   d. Spread the sand over the surface, using the disc in a circular motion, levelling the sand into a circular pattern.
   e. Measure the radius of the patch (using dividers). Make several tests parallel to the kerb.

3. **Analysis and Computation**
   Formula

$$TD = \frac{V}{\pi R^2}$$

Equation 8.14

V = Volume of Cylinder
R = Radius of Patch
TD = Texture Depth

4. **Reporting**
   a. Texture Depth
   b. Radius of Patch
   c. Volume of cylinder

8.2.7.2 Using the Pavement Surface Profiler / Profilometer

1. **Apparatus Required:**
   a. Pavement Surface Profiler or Profilometer: This instrument measures the road surface's vertical deviations and records texture data.
   b. Survey Vehicle: A vehicle equipped with a profiler or profilometer system.
   c. Computer and Software: To collect and analyse the collected data.
   d. Roadway Markings: To establish the test section and measurement intervals.
   e. Safety Equipment: Cones, signs, and personal protective equipment as needed.

2. **Preparation of Test Section:**
   a. Identify the specific section of the road to be tested for texture. Ensure that this section represents the typical condition of the pavement.
   b. Mark the test section and measurement intervals on the road using roadway markings. Measurement intervals are typically spaced at regular intervals along the test section.
3. **Precautionary Measures:**
   a. Ensure the safety of survey personnel and road users during the test by setting up proper warning signs and traffic control measures.
   b. Maintain a consistent speed and avoid sudden stops or accelerations to ensure accurate measurements.
   c. Calibrate the equipment regularly to maintain accuracy.
   d. Ensure the road surface is dry and free from debris that could interfere with measurements.
4. **Test Procedure:**
   a. Set up the profiler or profilometer on the survey vehicle according to the manufacturer's instructions.
   b. Ensure that the equipment is calibrated for accurate measurements.
   c. Drive the survey vehicle at a constant speed along the designated test section.
   d. The profiler or profilometer will record vertical deviations in the road surface at predefined intervals as you drive. These deviations represent the pavement's texture characteristics.
   e. Ensure consistent and smooth operation of the equipment throughout the survey.
5. **Calculations**
   a. Calculate the Mean Profile Depth (MPD) using the recorded vertical deviations. MPD is a common parameter used to characterise pavement texture. The formula for MPD is:

$$MPD = \frac{1}{N}\sum_{i}^{N} | D_i |$$

Equation 8.15

Where,

MPD = Mean Profile Depth

N = Number of measurement intervals

D_i = Vertical deviation at measurement interval i

   b. Report the MPD value as an indicator of pavement texture. The MPD is typically expressed in millimetres (mm)
6. **Reporting:**
   a. Prepare a comprehensive report that includes the following:
      i. Describe the test section and its location.
      ii. Equipment used, including profiler/profilometer specifications.
      iii. Calibration procedures and verification.
      iv. Data collected, including MPD measurements at each interval.
      v. Interpretation of results and conclusions regarding the pavement's texture characteristics.
      vi. Use the information to derive recommendations for maintenance or rehabilitation if necessary.
   b. Include charts, graphs, or visual representations of the texture data for clarity.
   c. Provide additional information or observations relevant to the test section and pavement texture.

8.3 Standard Testing Methods for Structural Surveys

8.3.1 Determination of Pavement Deflections Using the Falling Weight Deflectometer (FWD)

This method describes the standard procedure for determining pavement strength using the falling weight deflectometer (FWD) to measure deflections on the pavement.

The results determine the structural strength of individual pavement layers and the pavement. The main application of deflection tests is in rehabilitation design, asset management and output- and performance-based road contracts (OPBRC).

The following apparatus/equipment and procedures are key for determining road pavement structure and strength using the falling weight deflectometer (FWD).

1. **Apparatus:**
   - **a.** Falling weight deflectometer (FWD) equipment – capable of exerting an impact load of 40-125kN with 7-18 geophones, Figure 8.12. The components should include a 300 mm diameter loading plate with 5 mm rubber lining at the bottom for distributing the load uniformly on the surface, a falling weight of 50-380 kg and capable of a drop height of 10-600 mm and a load pulse of 15-50 ms to simulate a dynamic wheel load at 60 km/h.
   - **b.** Laptop computer – with appropriate software for assimilating and saving the data from the sensors/geophones.
   - **c.** Vehicle – to tow or house the FWD.
   - **d.** GPS – for measuring coordinates of test points.
   - **e.** Camera (Either integrated or standalone).
2. **Preparation of test section:**
   - **a.** For preliminary surveys:
     - **i.** Determine the test chainages to demarcate sections (200 m – 500 m or longer). Make use of distance measuring equipment (DMI) integrated with the equipment or car odometer, or tape measure.
     - **ii.** Mark test positions, preferably in the outer or the most distressed wheel tracks.
   - **b.** For pavement evaluation for rehabilitation:
     - **i.** Place temporary road signs indicating works in progress.
     - **ii.** Mark chainages at the beginning and end of each test section
     - **iii.** Mark test positions at approx. 50 m spacing to coincide with the chainages demarcating test sections. It is advisable to mark the FWD test point after carrying out the drops. Select test positions with minimal surface distress and avoid areas with severe structural damage, such as deep potholes, to ensure the accuracy of deflection measurements.
3. **Procedure for collecting data:**
   - **a.** For preliminary surveys or road network condition surveys:
     - **i.** Assemble the equipment.
     - **ii.** Check that the FWD is in good working order before taking it to sight.
     - **iii.** Ensure that it is properly calibrated.
     - **iv.** Using the vehicle odometer, select points for testing at the specified intervals (e.g., 100 m, or 500 m or 1 km or as specified.
     - **v.** Use the surface temperature of the road recorded automatically by the FWD during the test, ensuring that it is being captured and recorded.
     - **vi.** At the test position, lower the loading plate and ensure that it sits properly on the road's surface.
     - **vii.** Check to ensure that all the sensors are sitting properly on the road surface.
     - **viii.** The FWD would normally make an initial 1 or 2 drops to settle the loading plate before applying a further 2 to 5 drops while taking deflection measurements.

b. For rehabilitation design:
   i. Assemble the equipment.
   ii. Refer to Table 8.14 below for the correct positioning of the sensors.

Table 8.14 Correct Positioning of FWD Sensors

Flexible Pavements	Distance from load in mm						
	1	2	3	4	5	6	7
Thick AC	0	300	600	900	1200	1500	2100
Thin AC or surfacing	0	200	300	600	900	1500	1800

   iii. Check that the FWD is in good working order before taking it to the site.
   iv. Check that it is calibrated.
   v. At the test position, lower the loading plate and ensure it sits properly on the road's surface.
   vi. Check to ensure that all the sensors are sitting properly on the road surface.
   vii. The FWD would normally make an initial 1 or 2 drops to settle the loading plate before applying a further 3 to 5 drops while taking deflection measurements.
   viii. Once the test has been completed and the plate has been lifted identify the central position under the loading plate and mark it with paint. This mark will be used subsequently when carrying out DCP tests, coring and digging up test/ trial pits, which should be done at the same position for a more complete analysis.
   ix. Check that the deflection results are shown on the screen.
   x. Save the file for subsequent download after all tests have been completed.
   xi. Record supplementary information regarding the condition of the surfacing at the test point e.g., if the surfacing is cracked or not, and if the surface is level or deformed.
   xii. Tests should not be carried out on badly deformed or badly cracked surfaces.
   xiii. Drill a hole using an asphalt drill at only a selection of test points to cover different intervals of the day. Place an asphalt thermometer in the hole to measure the asphalt temperature. The internal temperature of the asphalt is usually much higher than the air or surface temperature, which the FWD measures automatically.
   xiv. For asphalt that is 150 mm thick or less, measure temperature at 40 mm depth and for thicker asphalt, measure at both 40 mm and 100 mm depths.
   xv. Use the temperature values to correct the stiffness and moduli to the specified standard temperature.

4. **Calculation:**
   a. Data cleansing – Outliers and erroneous data should be removed e.g., when deflection values do not decrease with an increase in the radial distance i.e., the distance from the central load.
   b. Prepare deflection profiles, Figure 8.10.
   c. The deflection given by the first sensor, d1 represents the overall pavement strength.
   d. Deflection difference d1-d4 indicates the strength of the bound layers, Figure 8.11.
   e. Deflection d6 to d8 indicates the strength of the subgrade.
   f. Carry out back analysis of FWD data to determine the required indices (i.e. Modulus and SN), preferably using software.

Figure 8.10 Schematic Representation of the FWD Deflection Bowl

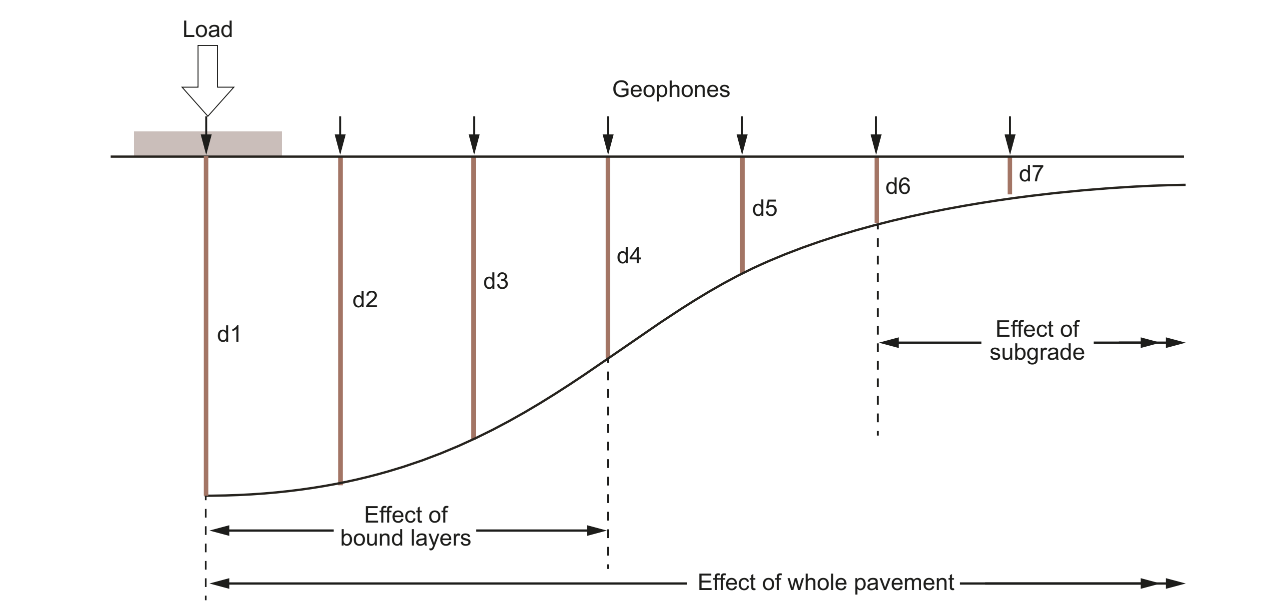


Figure 8.11 Deflection Profiles

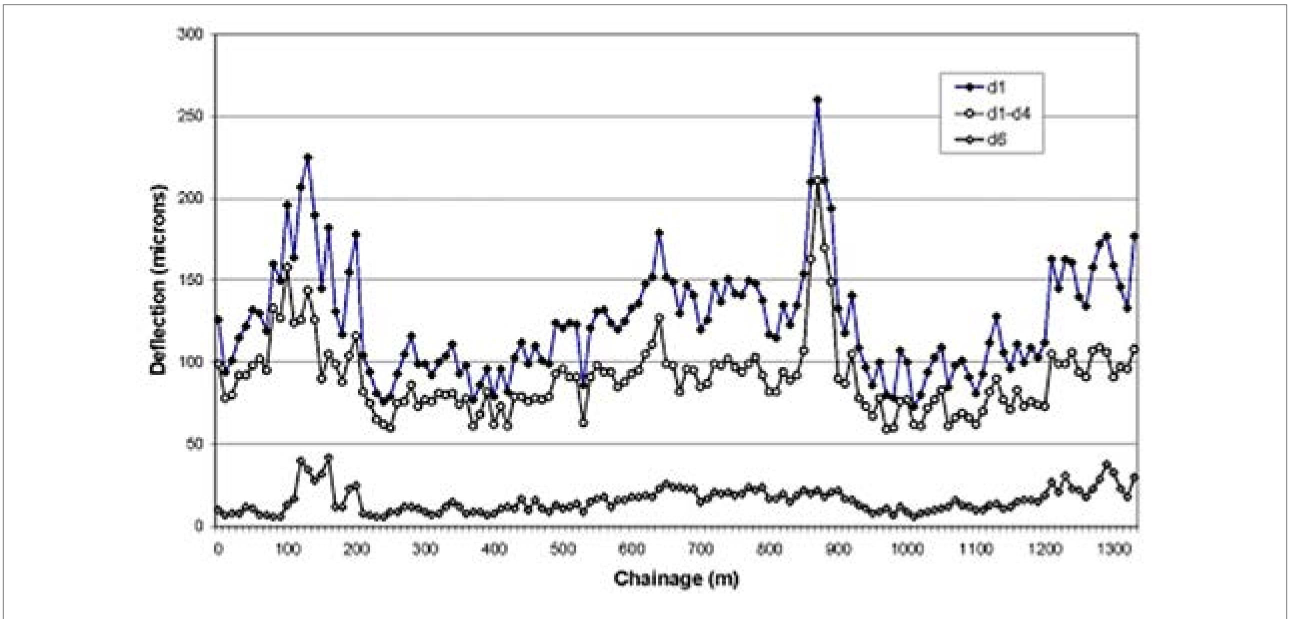
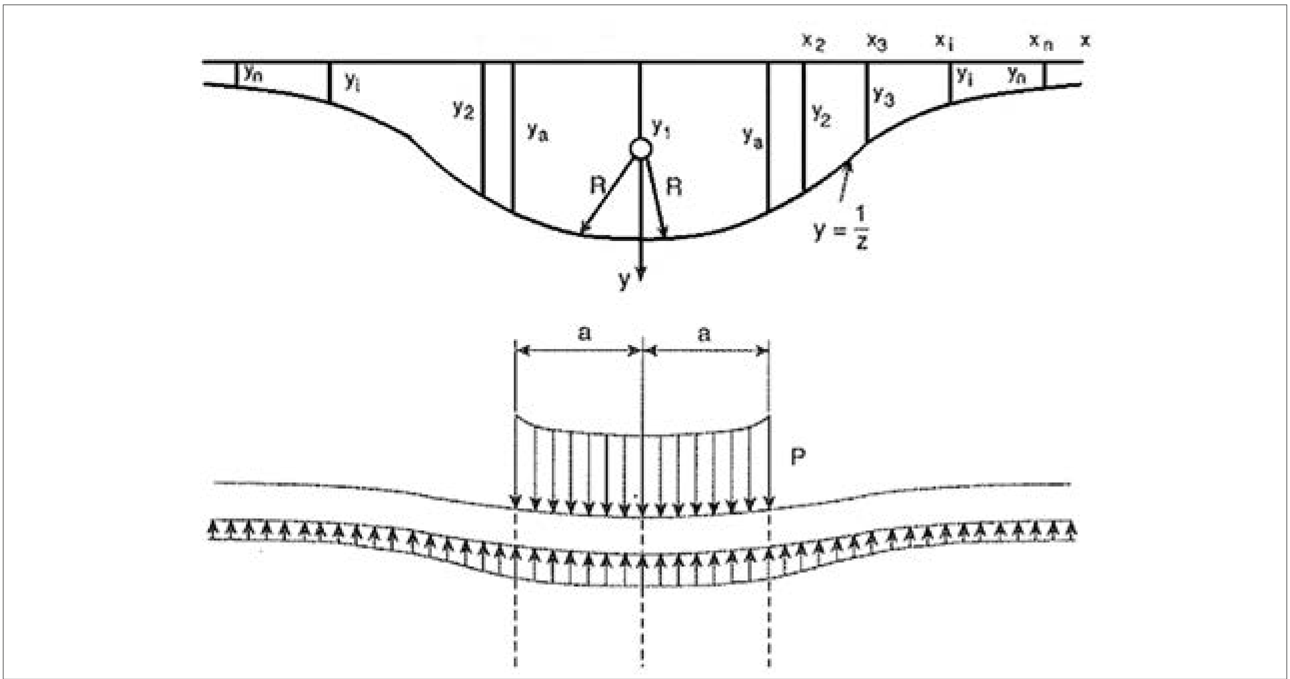


Figure 8.12 Illustration of FWD Equipment (TRL, ORN 18)

Calculation of radius of curvature based on the FWD test method

This section provides a method of manually calculating the radius of curvature, stresses and strains. Figure 8.13 below shows the configuration of the load distribution from the circular plate of the FWD. In essence, the load is expressed as the pressure exerted on the road's surface by the plate resulting from the impulse load generated by the drops of the weights.

Figure 8.13 Configuration of the FWD test for calculation of the radius of curvature, stress and strain



For an uncracked pavement, the assumption is that the load is distributed uniformly under the plate, and the following equations apply:

Plate stiffness

$$K = \frac{EH^3}{12(1 - \mu^2)}$$

Equation 8.16

Bending moment

$$M = KW''(1 + \mu)$$

Equation 8.17

Horizontal stress

$$S = \frac{6M}{H}$$

Equation 8.18

Horizontal strain

$$e = \frac{S(1 - \mu)}{E}$$

Equation 8.19

Where,

K = Bending stiffness of the plate.
E = Elastic stiffness of the asphalt layers.
H = Total thickness of asphalt layers.
μ = Poisson's ratio.
W = Deflection as a function of distance.
W'' = Second derivative of deflection at zero distance.
M = Bending moment under the load zero distance.
S = Maximum stress at the bottom of the asphaltic layer.
e = Maximum strain at the bottom of the asphaltic layer.

The curvature or second derivative is negative

1
2
3
4
5
6
7
8
Standard Testing Methods

If properties of materials like the Poisson's ratio and elastic modulus are unknown, calculate the strain using geometric parameters.

Strain:

$$e = \frac{WxH}{2}$$

Equation 8.20

$$e = \frac{H}{2R}$$

Equation 8.21

Stress:

$$S = \frac{eE}{\left[(1 - \mu)(1 + \frac{S_v}{S})\right]}$$

Equation 8.22

Where,

R = radius of curvature, mm.

S_v = vertical stress (MPa).

Maximum curvature(1/R) or second derivative (W'') occurs at the centre of the asphaltic layer for a circular uniformly distributed load (p)

The maximum curvature at the centre of the plate is given by:

$$W''(0) = -\frac{2(Y_1 - Y_a)}{a^2} - \frac{a^2(8p_0 + p_a)}{288K}$$

Equation 8.23

Where,

$W''(0)$ = second derivative the centre, 1/mm.

Y_1 = maximum deflection in the centre, mm.

Y_a = deflection at the edge of the loaded area (edge of the plate), mm.

a = radius of the loaded area.

p = lar contact pressure from the load, MPa.

P_o = resultant pressure in the centre, MPa.

P_a = resultant pressure at the edge, MPa.

K = plate stiffness.

r = distance from the centre, mm.

Maximum curvature can be expressed as a function of r:

$$W''(0) = -\frac{2(Y_1 - Y_a)}{a^2} - \frac{P_0}{32K}x(a^2 - 6r^2) - \frac{P_a - P_0}{288Ka^2}(a^4 - 15r^4)$$

Equation 8.24

The radius of curvature 'R' can be calculated using Equation 8.25.

$$R = -\frac{(Y_1 - Y_a)^2 + a^2}{2(Y_1 - Y_a)}$$

Equation 8.25

Where,

Y_1 = maximum deflection in the centre.

Y_a = deflection at the edge of the loaded disk, mm.

a = radius of circular loaded area, mm.

r = radius of curvature, mm.

Y_a is obtained through interpolation of the deflections between Y_1 (central deflection) and Y_2 and Y_3 as shown in Figure 8.13.

8.3.2 Determination of Pavement Strength Using a Light Weight Deflectometer (LWD)

This method describes the standard procedure for determining pavement strength using a lightweight deflectometer through the measurement of deflections of the pavement under impulse load.

The test involves dropping a weight through a predetermined height to exert a load of 2-25 kN ±10%.

The results determine the structural strength of individual pavement layers and the pavement. The main application of deflection tests is in rehabilitation design, asset management and OPBRC.

The following apparatus/equipment and procedures are key for determining road pavement structure and strength using a lightweight deflectometer.

1. **Apparatus and forms**
    - **a.** Lightweight deflectometer (LWD) – complete with a changeable load plate 150 mm and 300 mm, a falling weight of 10 kg and graduated rod, load release mechanism, Figure 8.14, Figure 8.19 and Figure 8.12(b).
    - **b.** Geophones – are deflection sensors, one at the centre of the plate that measures central deflection. The machine may have two extra geophones specifically to measure deflections at radial distances of 300 mm and 600 mm from the centre of the load.
    - **c.** Data capturing device – there are two options, (1) a smartphone onto which the App for the device can be downloaded or (1) a hand help device that is supplied with the LWD to capture data. Both should be Bluetooth enabled.
    - **d.** A 2-wheeled trolley – for transporting the LWD from one test point to another.
    - **e.** An external battery – for supplying power to the equipment should testing be required to proceed for long periods of time.
    - **f.** A thermometer with a range capable of measuring up to 100 °C with 1 °C divisions.
    - **g.** An electric drill (100 mm length, 13 mm diameter) is used to make holes into the pavement and place the thermometer during testing.
    - **h.** Oil or glycerol to fill the hole after testing.
    - **i.** Camera.
    - **j.** Standard forms.
2. **Preparation of test section**
    - **a.** For preliminary surveys or surveys necessary for network management:
        - **i.** Determine the test chainages to demarcate sections (200 m – 500 m or longer).
        - **ii.** Mark test positions preferably in the outer wheel paths.
    - **b.** For pavement evaluation for rehabilitation:
        - **i.** Place temporary road signs indicating works in progress.
        - **ii.** Mark chainages at the beginning and end of each test section. Each section should be 50 or 100 m in length.
        - **iii.** Mark positions for the deflection tests - usually it is easier to mark the exact position after the test.
        - **iv.** Mark sections approx. 50 m or 100 m in length, though the latter is preferred because tests are time consuming, and this should be considered in relation to the size of the project. The test positions should coincide with the marked chainages as much as possible.
3. **Procedure for collecting data**
    - **a.** For preliminary surveys or road network condition surveys:
        - **i.** Assemble the equipment.
        - **ii.** Check that the LWD is in good working order before taking it to the site.
        - **iii.** Check Bluetooth connectivity between the LWD and the phone or handheld receptor.

iv. Ensure that all equipment including the LWD, and the geophones are properly calibrated and that they are all giving consistent results.

v. Using the vehicle odometer select points for testing at the specified intervals (e.g., 200 m or 500 m or 1 km as specified).

vi. For asphalt, drill a hole, and put glycerine into the hole.

vii. Place the asphalt thermometer in the hole and record the internal temperature of the asphalt.

viii. Place the LWD on the test position and step around the edges of the plate to check if the plate is sitting firmly or rocking. The LWD will give erroneous results if it rocks during testing.

ix. Move the plate around until it sits properly without the possibility of rocking.

x. Connect the other probes/geophones (usually 2) at 300 mm and 600 mm from the central geophone. Use a measuring tape to check the radial distances.

xi. If other geophones are available, use Table 8.15 for their positioning.

xii. Apply 1 or 2 drops to sit the loading plate firmly on the pavement's surface.

xiii. Apply an extra 3 drops and record the deflections. Most LWDs record the deflections automatically.

xiv. Check that the results are not erroneous before saving the deflection data for the test point. Data may be erroneous if the values are not progressively smaller with the increase in radial distance of the geophones.

b. For rehabilitation design:

i. Assemble the equipment and check that it is in good working order.

ii. Follow steps 3a(i) to 3a(xiv).

iii. Mark test positions at 50 m or 100 m intervals. The former is preferred for greater accuracy. For lower-value projects and very long road sections (> 20 km), the latter is preferred.

iv. Refer to Table 8.15 for positioning the geophones.

Table 8.15 Correct Positioning of Geophones for the LWD

Flexible Pavements	Distance from load in mm						
	1	2	3	4	5	6	7
Thick AC	0	300	600	900	1200	1500	2100
Thin AC or surfacing	0	200	300	600	900	1500	1800

4. Calculation

a. Deflection given by the first sensor, d1 represents the overall pavement strength.

b. Conduct a back calculation of the deflection data to determine the Moduli and SN preferably using software such as LWDmod. The calculations made by the software are premised on the formation of the deflection bowl with a radius of curvature like the FWD.

c. See Table 8.16:, Figure 8.16, Figure 8.17, and Figure 8.19 for the graphical outputs.

Figure 8.14 A Schematic of a Lightweight Deflectometer (LWD) Showing the Test Variables *(P. Fleming, M. Frost, J. Lambert)*

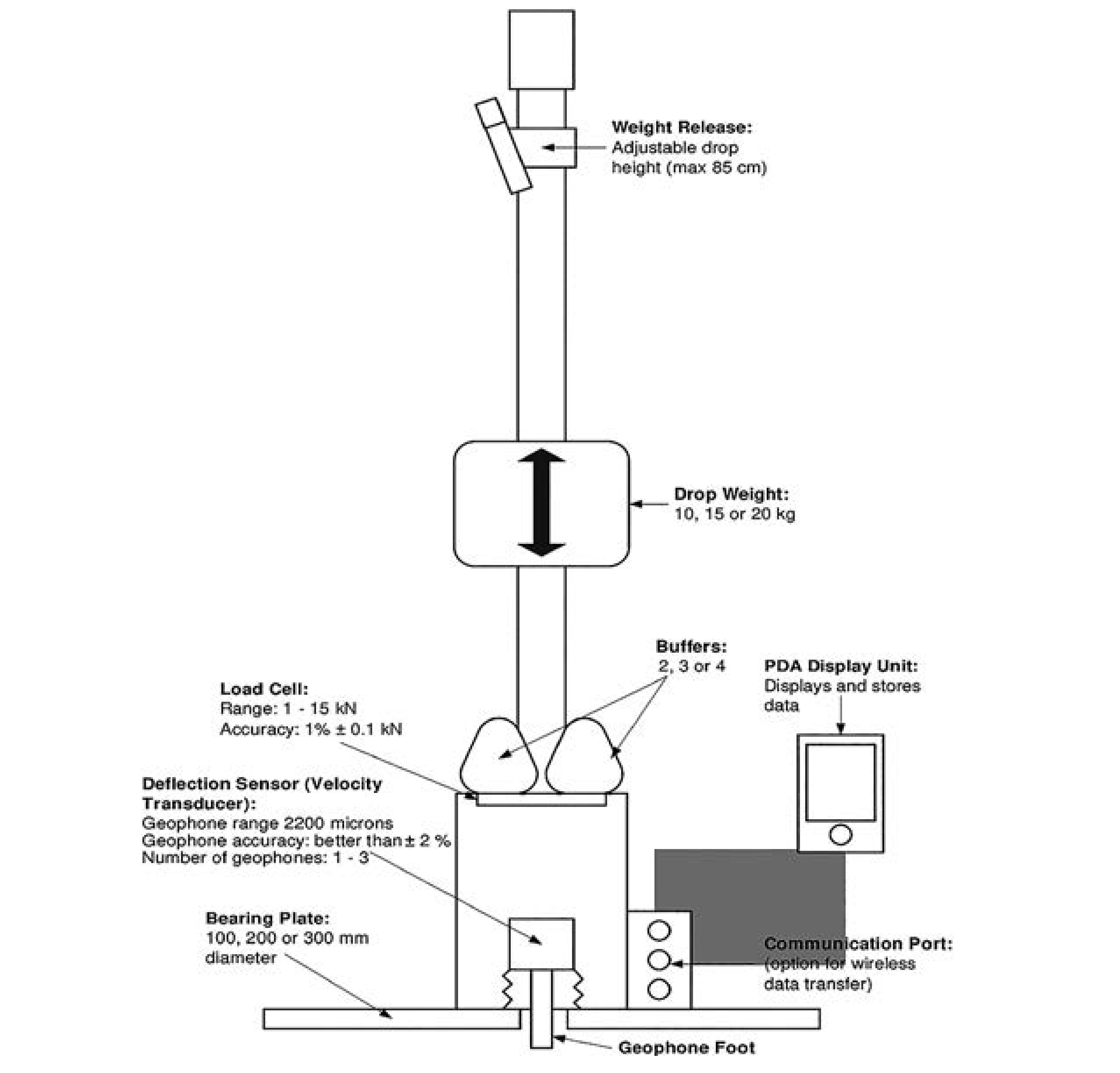


Figure 8.15 Determination of E-moduli From LWD Deflections

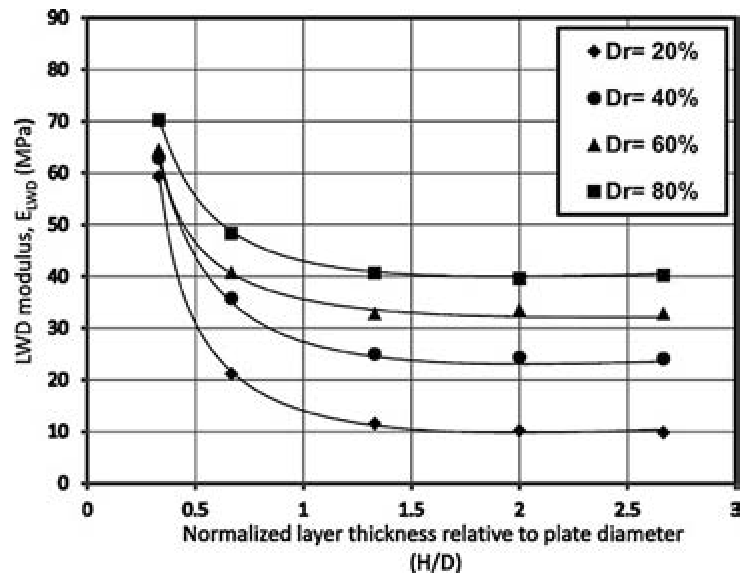


Table 8.16 Example of the Data Including E-moduli From the LWD

Item No.	Temperature	Statistics	Force kN)	Press (kPa)	Pulse Time (ms)	D1 (mm)	E1(MPa)
1	Ambient 21 ± 2°C	Mean	6.91	97.80	19.03	9.02	2442.21
		SD	0.20	2,79	0.08	0,34	68.27
		CoV	2,86	2.86	0.42	3.80	2.80
2	Heat 80 ± 10°	Mean	6.84	96.75	20.20	9.31	2338,49
		SD	0.02	0.24	0.11	0.08	23.94
		CoV	0.25	0.25	0.52	0.52	1.02
3	Cooled -10°C ±10°	Mean	6.700	94.80	18.15	8.70	2453.41
		SD	0.07	0.94	0.41	0.12	34.27
		CoV	0.99	0.99	2.27	1.37	1.40

Figure 8.16 Illustration of the Impulse Generated by the LWD

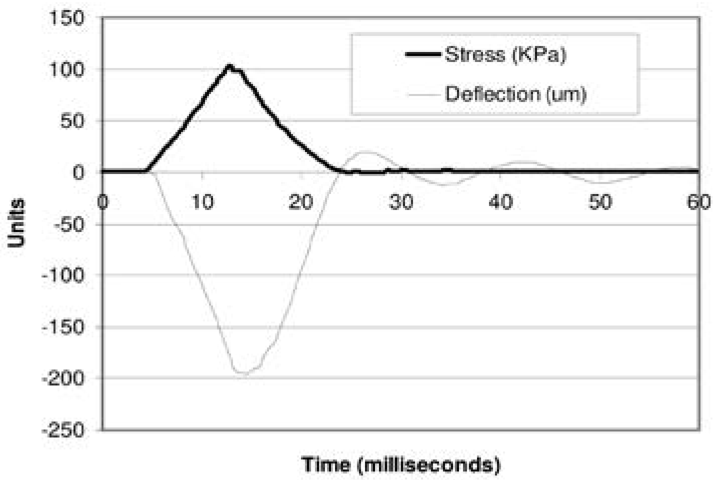


Figure 8.17 Illustrating The Importance Of The Loading Plate Seating Firmly

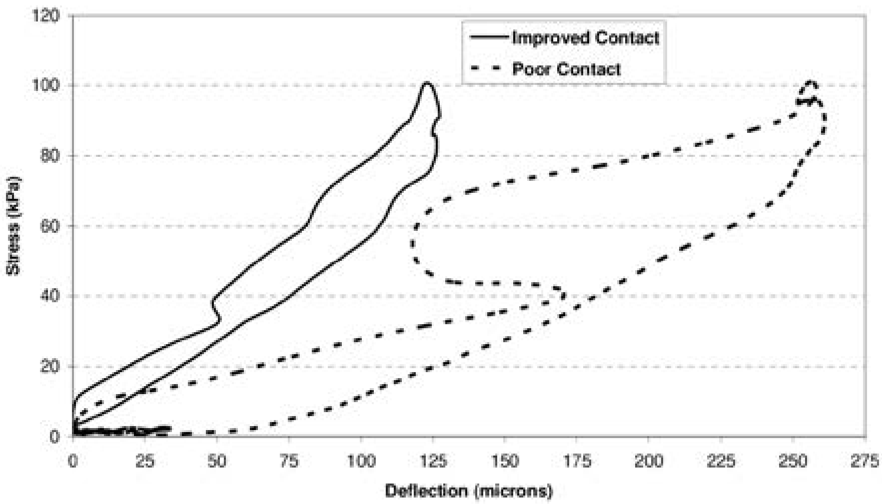


Figure 8.18 Illustrating the Importance of a Few LWD Drops on the Pavement

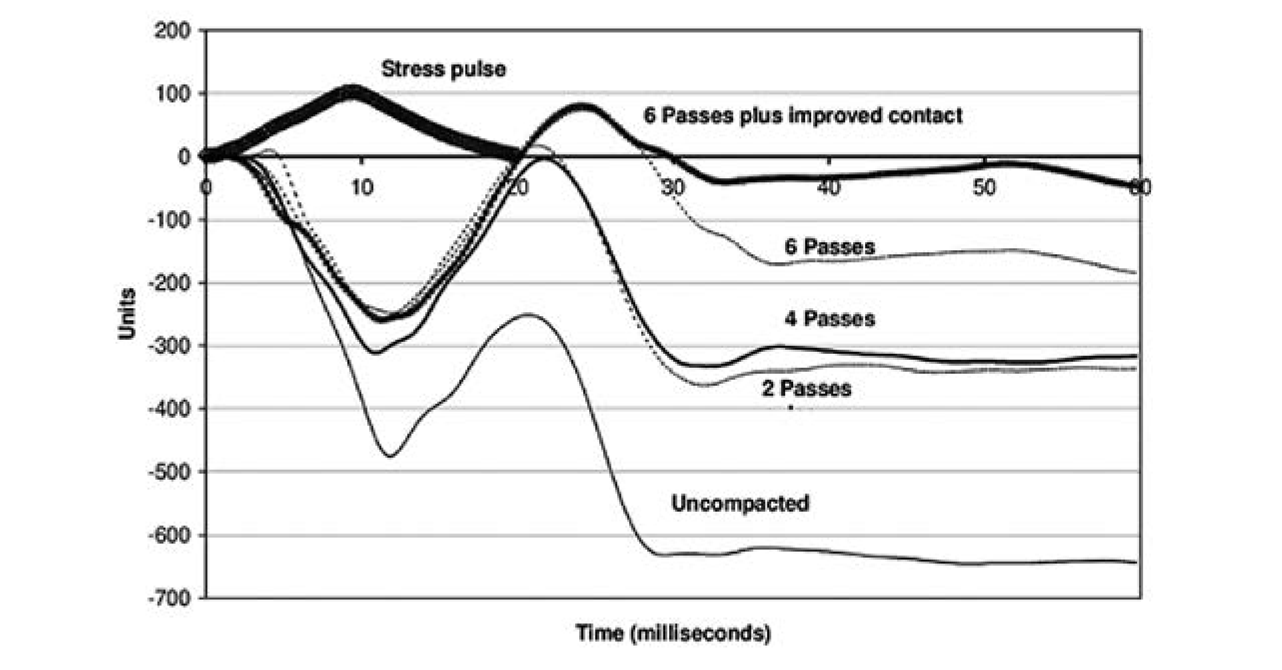


Figure 8.19 Light Weight Deflectometer (LWD) Complete with Additional Geophones

Diagrammatic Illustration of the use of the FWD to be used as guidance for LWD tests is given in Figure 8.12.

Calculation of stress and strain using the radius of curvature based on the FWD test method.

This section provides a method of calculating the radius of curvature, stresses and strains manually. Figure 8.13 shows the configuration of the load distribution from the circular plate of the LWD. In essence, the load is expressed as exerted pressure on the road's surface by the plate resulting from the impulse load generated by the drops of the weights.

1
2
3
4
5
6
7
8
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The method of calculation of the radius of curvature, stresses and strains is similar to that for the FWD outlined in section 8.3.1 based on Equation 8.16 up to Equation 8.25 except that, the load is significantly lower, and the deflection values should be adjusted proportionally to the load.

8.3.3 Determination of Pavement Strength Using a Benkelman Beam

This method describes the standard procedure for determining pavement strength using a Benkelman Beam through measurement of deflections of the pavement under load.

The principle of this technique, which was devised by A. C. Benkelman, is to measure the vertical displacement of the road surface when the double wheel of a loaded lorry passes over it. Deflection beam measurement is a good measurement of the structural response of a pavement to a given axle loading moving at a creep speed. Deflection parameters are used for the following purposes:

1. As a guide to the strength and stiffness of a pavement,
2. As a guide to the future performance of a pavement,
3. As a means of determining how much strengthening/stiffening of a pavement is needed to satisfy specified design criteria,
4. To monitor changes in the structural performance of a pavement resulting from variations in the environment or specific maintenance activities,
5. To locate deficiencies, and assist in the determination of their causes,
6. To assess the uniformity of pavement strength during or shortly after construction, and
7. To monitor long-term pavement performance, as one of the inputs which may be used to describe paveme**nt condition.**
8. Configuration of the Beam

8.3.3.1 Benkelman Beam Test Using the Radius of Curvature Method.

The Benkelman survey is designed to give the maximum deflection and the Radius of Curvature of the road pavement surface under a standard wheel load. This method is used to estimate the Elastic Moduli of the road pavement on the assumption that it is a simple two-layer form.

The two-layer pavement model comprises an upper layer, the thickness of which must be known, supported on a semi-infinite layer. With the assumption that there is no slipping or separation of the layers at their interface, the model permits an Elastic Modulus of each layer and an equivalent modulus for the overall pavement to be estimated. The latter is a measure of the structural capacity of the pavement, and it may be interpreted in terms of the traffic loading (measured in ESA) that the pavement should be able to carry. The two-layer configuration is a reasonable model of the pavement.

1. **Apparatus**
   a. The beam - consists of a long slender arm pivoted one-third of the way along.
   b. The fulcrum - is at a point one-third of the distance between the tip and dial gauge. This causes the movement recorded by the dial gauge to be one half of the actual pavement deflection. The Benkelman Beam is in the ratio 2:1 about the fulcrum. Therefore, the dial gauge reading must be multiplied by 2(x2) to give the deflection at the measured point.
   c. The pivot - is supported by a frame with three adjustable legs that can stand on the road's surface. The longer part of the beam is passed between the double wheels of a loaded lorry, and its tip rests on the road surface.
   d. Dial gauge - A dial gauge (25 mm travelling distance, 0.01 graduations) is mounted on the frame, to measure the vertical movement at the end of the shorter part of the beam. This measurement is related to the movement of the road surface under the tip of the beam.

e. The Lorry - The essential requirement of the lorry configuration is that it should have two axles with twin wheels on each end of the rear axle. The lorry is loaded on a level surface to affect a rear standard axle load of 130 kN 65 kN on each dual wheel). The rear axle should be fitted with 1100 x 20 tyres or 1000 x 20 tyres with a road contact length of 200 mm. The spacing between the walls of the two tyres on each dual wheel should be between 75 and 90 mm.

2. Test Procedure

a. Rebound Deflection Procedure

i. Locate the point to be tested and mark it on the road.

ii. Centre the twin rear wheels of the truck above the selected point.

iii. Insert the probe of the Benkelman beam between the wheels and place it on the selected point.

iv. Remove the locking pin from the beam and adjust the front legs as necessary.

v. Start the buzzer on the beam and zero the dial gauge.

vi. Record the initial dial gauge reading.

vii. Immediately after recording the initial reading, drive the truck forward slowly at a creep speed. Deflection data is recorded at a creep distance of 10cm for five consecutive creep points (10,20,30,40,50). The final reading is recorded when the truck moves 2-3 m from the test point.

viii. Calculate the rebound deflection by subtracting the final gauge reading from the initial one.

b. Transient deflection Procedure

i. Locate the point to be tested and mark it on the road.

ii. Position the truck so the rear wheels are 1.25 m behind the marked point.

iii. Insert the Benkelman beam between the twin rear wheels until the probe toe rests on the marked point.

iv. It helps position the truck and align the beams parallel to the truck axis if a pointer is fixed to the truck 1.25 m in front of each pair of twin wheels.

v. Check the beam's pivot arm for free movement and adjust the foot screws as necessary.

vi. Start the buzzer on the beam and zero the dial gauge.

vii. Record the initial dial gauge reading.

viii. Drive the truck forward slowly at creep speed and, whilst buzzing, note the maximum dial gauge reading and the final gauge reading when the truck wheels have moved 10 m or more, clear of the tip of the beam.

ix. Calculate the deflection by adding the differences between the first and maximum dial gauge readings to the difference between the maximum and final dial gauge readings.

c. Radius of Curvature Procedure

i. Locate the test point to be measured and mark it on the road.

ii. From the selected point, mark 10 points at 100 mm intervals on a straight line parallel to the centre line.

iii. Centre the twin rear wheels above the selected point.

iv. Insert the probe of the Benkelman beam between the twin wheels and place it on the selected point.

v. Remove the locking pin from the beam and adjust the foot crews as necessary.

vi. Start the buzzer on the beam and zero the dial gauge.

vii. Record the initial dial gauge reading.

viii. Drive the truck slowly forward at creep speed and record the dial gauge reading each time the pointer passes over the marked points.

ix. Stop the truck 10 m or more from the selected point and record the final dial gauge reading.

3. Calculation - Analysis of data for overlay design

a. Characteristic Deflection

Overlay design for a given section is based, not on individual deflection values, but on a statistical analysis of all the measurements in the section corrected for temperature and seasonal variations. This involves the calculation of mean deflection, standard deviation, and characteristic deflection. The characteristic deflection for design purposes shall be taken as given in Equation 8.26 and Equation 8.27. The formulae to be used in the calculation are as follows: -

i. Mean deflection,

$$y = \frac{\Sigma x}{n}$$

Equation 8.26

ii. Standard deviation,

$$\delta = \frac{\Sigma(x-y)}{n-1}$$

Equation 8.27

The overlay design for a given section that is **not** based on individual deflection.

i. $D_c = y + 2\delta$ (for major arterial roads)

Equation 8.28

ii. $D_c = y + \delta$ (for all other roads)

Equation 8.29

b. The Principle of Moving Averages

The moving averages for deflection values consist of calculating for a transverse profile 'k', the average of the deflections measured on profiles k, k-1, k-2, k-3,… and on the 'm-1' preceding profile. The number of profiles 'm' is chosen by the designer:

For example, if six profiles are chosen, the averages for these profiles would be:

i. K - 5, k - 4, k - 3, k - 2, k - 1, k

ii. K - 4, k - 3, k - 2, k - 1, k, k + 1

iii. K - 3, k - 2, k - 1, k, k + 1, k + 2

iv. K - 2, k - 1, k, k + 1, k + 2, k + 3

Schematic presentation of the 'Moving Average' Method

k-5	k-4	k-3	k-2	k-1	k	k+1	k+2	k+3	
+	+	+	+	+	+	+	+	+	Wheel-path 1
+	+	+	+	+	+	+	+	+	Wheel-path 2
+	+	+	+	+	+	+	+	+	Wheel-path 3
+	+	+	+	+	+	+	+	+	Wheel-path 4

Simultaneously with the average, the characteristic deflection D_{90} is calculated, and both values may be used to categorise the homogenous sections.

c. Pavement Structural Analysis

The structural analysis entails the determination of the pavement characteristic strength parameters, which are determined by keying in all the deflections obtained into a computer which automatically evaluates the strength parameters. The program determines the Radii of curvature, the product of Radius and Deflection (RxD), and characteristic deflection D_{90}, which are used to determine the Strength Design parameters (Modulus of Elasticity $E1$, $E2$, Eq). The formulae used in the program to calculate the various parameters, as stated above, are as follows: -

The Radius of curvature is calculated from the equation.

$$D_i = \frac{2.R.d^2}{2.R.d + x^2}$$

Equation 8.30

Where,

D_i = Deflection at x distance.

d = Maximum rebound deflection.

x = Distance from the selected point.

R = Radius of curvature.

Characteristic deflection D_{90} and characteristic Radius of curvature R_{10} are obtained from calculating moving averages, which are determined from the maximum deflection (D_{max}) obtained from the road. Moving averages and D_{90} are obtained as follows:

i. Step 1: Moving average D = Sum of D_{max} values for 6 chainages ÷ 24 *(2)*

ii. Step 2: Characteristic deflection $D_{90} = D + 1.3S$ *(3)*

Where S is the standard deviation for the D_{max} values

Steps 1 and 2 are repeated for the whole road each time omitting the first chainage and adding one more chainage after the last one. The principle of moving averages and the characteristic deflection D_{90} is used to determine the homogenous sections of the road.

The plots of D and D_{90} against the Chainage are plotted. For each section, the upper layer thickness is determined as existing and utilised in determining of strength parameters.

Characteristic Radius of curvature and Modulus parameters are determined from the following equations:

$$\text{Log } R10 = m^*(\text{Log } R - 1.3S \text{ Log } R)$$

Equation 8.31

$$(E1)^B = R_{10} \div 0.056^*(D_{90}/5800)^A$$

Equation 8.32

$$(E1/E2)^{x\text{-}y} = R_{10} \text{ x } D_{90} / 3248$$

Equation 8.33

$$Eq = 10^{(a\text{-}1)} E1(R_{10}/D_{90})^{a/2} \quad \{\text{For } E1 \geq E2\}$$

Equation 8.34

or,

$$Eq = 580000 \ D_{90} \quad \{\text{For } E1 \leq E2\}$$

Equation 8.35

1 2 3 4 5 6 7 8 Standard Testing Methods

Where,

D = mean of maximum deflections (D_{max}) for 6 No. of chainages for the wheel paths.

x = 0.860 Log h – 0.474

y = 0.493 Log h – 0.410

A = (1 – X) ÷ (1 – Y)

B = 1 – A

a = 1 ÷ { 1+ Log (E1/1018) }

m Log R = Mean of Log R.

S Log R = Standard deviation of Log R.

D_{90} = Characteristic deflection.

R_{10} = Characteristic Radius of curvature.

H = upper layer thickness.

$E1$ = Elastic modulus of the upper layer (surfacing, base, sub-base).

$E2$ = Elastic modulus of the lower layer (improved sub-grade & sub-grade).

Eq = Equivalent modulus.

8.3.3.2 Benkelman Beam Test Using the Rebound Method.

This test method sets out the procedure for measuring the deflection of a flexible pavement using the Benkelman Beam. The method is derived from RTA NSW T160.

1. Apparatus

- **a.** The Benkelman beam apparatus is fitted with a suitable vibrator.
- **b.** Truck:
  - **i.** Load – the vehicle must have an 8.2 ± 0.2 tonne load over the rear axle equally distributed by each set of dual wheels. The rear axle mass of the test vehicle shall be determined with full fuel tanks and chains on board.
  - **ii.** Tyres – the following guidelines should be followed concerning tyres for Benkelman Beam vehicles. These requirements apply to the tyres on the dual wheels of the ballasted axle.
    - Size - 10 x 20, preferably 12 ply, but higher ply ratings are acceptable, i.e. 14 ply.
    - Construction - Diagonal ply (i.e., cross-ply or bias ply).
    - Tread Pattern - “Highway” type. Lug type is not acceptable.
    - Pressure: 550 kPa ± 10 kPa.
    - Spacing: Tyres should be 300 mm apart, measured centre to centre of the dual wheels.
    - Wear: It is essential that all four tyres on the rear axle show the same degree of wear.
    - Tyre pressure gauge.
- **c.** Thermometer (0-100 ºC) with ten divisions.
- **d.** Asphalt hole punch and light oil.
- **e.** 10 m tape.
- **f.** Notebook, worksheets.
- **g.** Camera.

2. Definition.

The rebound deflection bowl is the shape of the deflection profile as the truck moves off the test point. It is determined from measurements of deflection using the Benkelman Beam, at 0 mm, 300 mm, 600 mm, 900 mm and 2700 mm and 6000 mm spacing.

3. **Preparation**
    a. Obtain a truck capable of carrying 8.2 tonnes over the back axle, with the correct axle tyre configuration.
    b. Ensure the truck has chains and blocks to secure the load.
        i. Check tyre pressure.
        ii. Arrange for a forklift or crane to load the ballast to equal 8.2t.
        iii. Ensure the distribution of 4.1t load over near wheel by measuring with mobile scales or otherwise.
    c. Benkelman Beams
        i. Ensure beams are calibrated.
        ii. Ensure both beams are functioning satisfactorily.
        iii. Ensure dial gauges are working.
        iv. Ensure that the dial gauge vibrators are functioning.
    d. Traffic Control
        i. Arrange suitable traffic control measures, including staff, signs, flashing lights and radios where required.
        ii. Staff:
            - - 1 x distance measure and caller.
            - - 1 x Truck Driver.
            - - 2 x Beam Operators.
    e. Conduct a test run to ensure all equipment is functioning correctly.
    f. Setting out – determine and record the following.
        i. Pavement Temperature.
        ii. Air Temperature.
        iii. Thickness of asphaltic concrete layer, if appropriate.
        iv. Road name.
        v. Road number from PRP Register.
        vi. Lane No. Inbound or Outbound.
        vii. Date and Time.
        viii. Test Location, Chainage, Wheel-path, Distance and Pavement Width.
        ix. Lanes are numbered from left to right, looking in the direction of traffic flow with lane 1 being the outer or slow lane. Where there is a change in the number of lanes over the length under test, care must be taken to indicate the direction and lane number. A sketch plan is to accompany the test results.
        x. Spacing of the test sites should be such that at least 10 measurements are taken in each length over which the pavement and surrounding conditions appear uniform. The spacing of the test sites is dependent on the length and uniformity of the section and the following table below may be used as a guide:
            - 10 m for all construction control testing, otherwise.
            - 25 m for section length less than 1 k.
            - 50 m for section length between 1 to 2 km.
            - 100 m for section length between 2-5 km.
            - 200 m for a section length of more than 5 km.
        xi. Deflections shall be measured in the wheel paths.

4. **Procedure**
   a. Select and mark the point on the pavement, that is to be tested. See Note 1.
   b. Centre the dual wheels of the truck approximately 1.5 m behind the selected test site.
   c. Insert the probe of the Benkelman beam between the dual wheels and place it on the selected test site (1.5 m from the tip of the beam to the axle), ensuring that the truck's tyres will not touch the beams.
   d. Remove the locking pin from the beam and adjust the rear leg until the dial gauge is in the midrange of its travel.
   e. Turn on the vibrator.
   f. Set the dial gauge at zero.
   g. Creep the truck slowly forward and take readings of the Benkelman beam gauge as the truck moves past the 0 mm, 200 mm, 400 mm, 600 mm, 900 mm, 1,200 mm and 1,500 mm spacing. Stop the truck 2.7 m from the zero point and record the gauge reading when the recovery rate is equal to, or less than 25 µm per minute.
   h. Drive the truck forward to 6 m and record the gauge reading when the recovery rate is equal to, or less than 25 µm per minute.
   i. Turn off the vibrator.
   j. For asphaltic concrete pavement, record the pavement and air temperature at least once every hour.
   k. Record the air and road temperature approximately every 1-2 hours.
   l. At each test site, record and rate the pavement shape and condition, including the surface type and any cracking etc.

NOTES: *1. The truck should be parked for at least 3 minutes and the entire test should be completed within approximately 4 minutes. 2. Check the truck tyres every 2-3 hrs and, if necessary, adjust to specified pressure. 3. For chip seal surfaces, pavement temperature is not required.*

5. **Data collection**
   a. Obtain traffic data records (if required) such as:
      i. Traffic counts
      ii. Percent commercial vehicles
      iii. Traffic distribution
      iv. Past traffic
      v. Future traffic predictions
   b. Obtain information on the pavement configuration from previous records or conduct pavement dip.

6. **Data analysis**
   a. Analysis of Field Data
      Analyse the data to break the subject section of the road into areas with similar values.
   b. Required Deflection Data
      i. Determine the maximum deflection: (2 x dial gauge reading at 0 mm distance)
      ii. Determine the Datum: (6000 mm reading)
      iii. Determine the residual rebound: (maximum deflection – datum reading x 2)

      Note: can be + or -

      iv. Determine the rebound deflection: (maximum deflection - residual deflection)
      v. Determine the D300: (300 mm reading - datum) x 2.
      vi. Determine the D600: (600 mm reading - datum) x 2.
      vii. Determine the D900: (900 mm reading - datum) x 2.
      viii. Determine the CBR: (D900 read off from Chart 5)

ix. Determine the tolerable deflection.

x. Determine the D 200: (((300 mm reading – 0 mm reading)/300) *200) + 0 mm reading).

xi. Determine the D 250: (((300 mm reading – 0 mm reading)/300) *250) + 0 mm reading).

c. Outliers

i. Using the following procedure, determine whether any of the results are outliers.

- Check for very large values.

Arrange the data in decreasing order, and calculate a statistic,

$$\gamma = \frac{\text{(max value) - (next max value)}}{\text{(max value) - (min value)}}$$

Equation 8.36

$$\gamma = \frac{\text{(max) - (max - 1)}}{\text{max - min}}$$

Equation 8.37

If γ exceeds the critical value given below, then discard max. (i.e., is an outlier)

n	3	4	5	6	7	8	9	> 10
γ (n.05)	.941	.765	.642	.560	.507	.468	.437	.412

ii. Similarly, we can test for very small values.

$$\gamma = \frac{\text{min + 1 – min}}{\text{max x – min}}$$

Equation 8.38

again, if γ exceeds the value in the table, then we discard it.

iii. Remove any outliers from any further calculation and recalculate all valves, (with the outliers removed).

7. Calculation

Determine if, over the full length tested, there are distinct changes in the level of deflection over significant lengths to warrant splitting up these lengths for separate analysis.

NOTE:

These variations may be due to changes in surfacing type, pavement thickness, drainage conditions, or topography.

After splitting the tested section into significant lengths, calculate the average (u), standard deviation (s), characteristic deflection (u+fs) and coefficient of variation (CV) values for each wheel path and length.

Abnormally high or low readings should be omitted from the statistical analysis.

8. Reporting

The following test results and general information shall be included in the report:

a. All beam testing field data recordings.

b. All deflection data test results

c. Pavement surface and shape recordings

d. Pavement temperature

e. Pavement air temperature

f. Checks for outliers.

g. Location plans

h. Photographs.

i. Road name.

j. Road number.

k. Lane No's.
l. Inbound / Outbound.
m. Test direction.
n. Date and time of investigation.
o. Test location, chainage and offset.
p. Length of project and spacing of test sites.
q. Pavement width.

8.3.3.3 Benkelman Beam Test Based on the FWD Concept

This method describes the standard procedure for the determination of pavement strength using a Benkelman Beam through measurement of deflections of the pavement under load at points similar to the configuration of the FWD, Figure 8.12.

1. **Apparatus:**

The same apparatus / equipment described above are used for this test.

2. **Preparation of test section:**
   - a. For preliminary surveys or surveys necessary for network management:
     - i. Determine the test chainages to demarcate sections (200 m – 500 m or longer).
     - ii. Mark test positions preferably in the outer wheel paths.
   - b. For pavement evaluation for rehabilitation:
     - i. Place temporary road signs indicating works in progress.
     - ii. Mark chainages at the beginning and end of each test section. Each section should be 50 or 100 m in length.
     - iii. Mark positions for the deflection tests - usually it is easier to mark the exact position after the test, including the different positions of the wheel required during the test before taking deflection readings.
     - iv. Mark sections approx. 50 m or 100 m in length, though the former is preferred because tests are time-consuming, and this should be considered in relation to the size of the project. The test positions should coincide with the marked chainages as much as possible.
3. **Procedure for collecting data:**
   - a. For preliminary surveys or road network condition surveys:
     - i. Assemble the equipment:
     - ii. Check that the Benkelman beam is in good working order before taking it to the site.
     - iii. Ensure that all equipment, including the Benkelman beam, weighbridge and pressure gauge, is properly calibrated.
     - iv. Using the vehicle odometer, select points for testing at the specified intervals (e.g., 200 m or 500 m or 1 km as specified).
     - v. Check tyre pressure at the start and 3-hour intervals. Tyre pressure should be 585 kPa, and their size should be 8.25x20
     - vi. Weigh the load on the rear wheels, ensuring both tyres sit properly on the portable weighbridge. Conditions stated in **1.c.** should be satisfied for an 8.2 tonne load.
     - vii. For asphalt, drill a hole, place the asphalt thermometer in the hole and record the internal temperature of the asphalt.
     - viii. Drive the truck to the test position – following marks that have been previously marked.
     - ix. Insert the Benkelman Beam in between the dual tyres with the toe of the probe of the beam positioned at the test point.
     - x. Position the test wheel 1.3 m behind the test point, in other words, the toe of the probe would be 1.3 m in front of the wheel.

xi. Unlock the beam.
xii. Adjust the foot screws to level the frame of the beam.
xiii. Make adjustments such that the plunger is in contact with the dial gauge.
xiv. Zero the gauge and switch on the vibrator.
xv. Record the dial gauge reading (it should be zero ± a small deviation)
xvi. Where measurements of deflections are required on both wheel tracks, place another beam between the other dual wheels.
xvii. Drive the truck slowly forward and record the maximum reading when the wheel is at the test point and the final reading when the wheel is 5 m in front of the test point.
xviii. Discard the test if the wheels touch the beam.

b. For rehabilitation design:
   i. Assemble the equipment and check that it is in good working order.
   ii. Follow steps **a.i.** to **a.iii.**.
   iii. Mark test positions at 50 m or 100 m intervals. The former is preferred for greater accuracy. For lower-value projects and very long road sections (> 20 km) the latter is also preferred.
   iv. Refer to Figure 8.12 and mark the points to position the wheels before testing.
   v. For the initial measurement, the probe should be at position 1, and the wheel at position 7. Take and record the value on the gauge.
   vi. Take and record measurements of deflection at designated points until point 1 i.e., at the toe or probe position. This will be the maximum deflection.
   vii. Move the wheel further to a point 5 m from the probe and take a reading. This would be the rebound reading and will be used for correct the deflection measurement.
   viii. Alternatively, the first position could be when the wheel is started off at position 1 (probe position), which would be the maximum deflection.
   ix. Move the wheel to subsequent pre-marked positions as given in the in Figure 8.20.
   x. Take and record readings at each position (rebound values).
   xi. Also, take a reading when the wheel is at a dial distance of 5 m, wheel the load is expected to cause any deflection at the probe position.

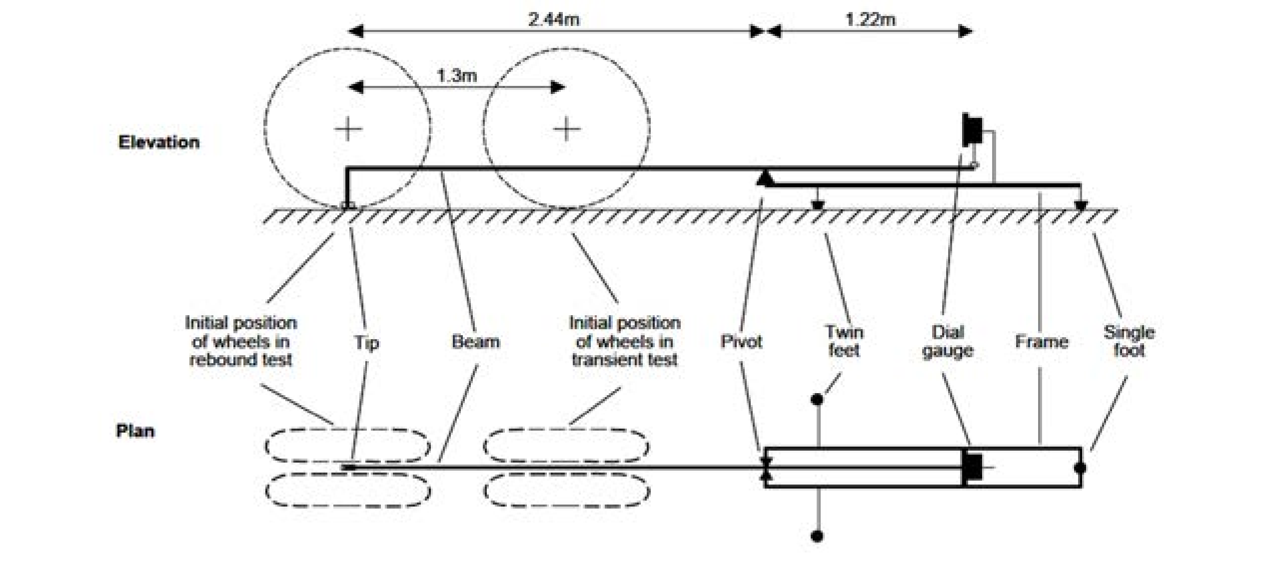
Table 8.17 Correct Positioning of Benkelman Beam

Flexible Pavements	Distance from load in mm						
	1	2	3	4	5	6	7
Thick AC	0	300	600	900	1200	1500	2100
Thin AC or surfacing	0	200	300	600	900	1500	1800

4. Calculation

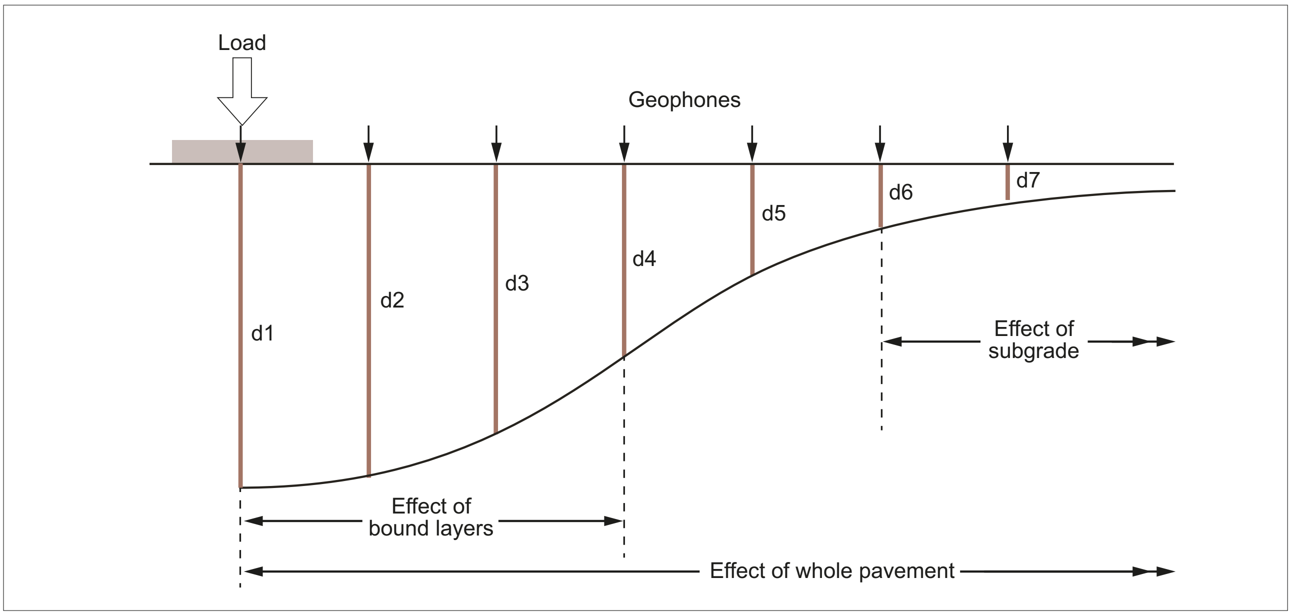
a. Deflection given by the first sensor, $d1$ represents the overall pavement strength.
b. Deflection difference $d1$-$d4$ indicates of the strength of the bound layers.
c. Deflection $d6$ and $D7$ give an indication of the strength of the subgrade.
d. Carry out a back calculation of the deflection data to determine the Moduli and SN, preferably using the software as per the procedure given in RDM 5.2.

Figure 8.20 Diagrammatic Representation of the Benkelman Beam (TRL, ORN 18)



Note: *Refer to Figure 8.12for FWD test positions to be used as guidance for Benkelman Beam Test Positions*

Figure 8.21 FWD test positions to be used as guidance for Benkelman Beam Test Positions



8.3.4 Coring and Core-logging

This method describes the standard procedure for the determining of characteristics of layers of asphalt concrete, cement concrete, or other strata through profiling and sampling for detailed assessment and laboratory testing.

The procedure involves careful selection of the size of the coring cylinder (100 and 150 mm or as specified) and determination of test positions that are representative of the layer under investigation. This is followed by carefully coring into the layer using the coring machine while ensuring a constant flow of water to cool the coring cylinder. After coring through the layer(s), the cylinder is lifted slowly, and the core is extruded by tamping the cylinder with a rubberised hammer. The core is then photographed and examined, with features and characteristics recorded.

The results are used to determine the engineering characteristics of the layer, including thickness, constituent materials and their characteristics, and any defects such as cracking, piping and pumping or de-bonding, delamination in the case of multiple layers, etc.

The following apparatus/equipment and procedures are key for the Sampling of AC and concrete cores and core-logging.

1. **Apparatus:**
   a. Coring machine – complete with drill adaptors, Figure 8.21.
   b. Cylindrical drills – cylindrical core bits with diamond tips.
   c. Rubberised hammer – for extrusion of cores from coring bit.
   d. An elevated water tank is fitted with a pipe connection to the coring machine to cool the bit.
   e. Callipers – for measuring the dimensions of the cores once extruded.
   f. Plastic sample bags – to place the cores and seal for further tests in the laboratory.
   g. Measuring tape – 30 m length to measure the off-sets of the test points from the centreline.
   h. Measuring tape – 5 m steel tape to measure crack widths and other features.
   i. An appropriate tray is used to hold and prevent the samples from getting damaged on rough roads during transportation from the site to the laboratory.
   j. Camera – to take photos of the cores.
   k. Forms – for logging cores.
   l. A vehicle to transport the machine and samples.

Figure 8.22 Coring of Asphalt Layers

2. **Procedure**

Coring is conducted to extract undisturbed samples of bound materials, such as asphalt and concrete or soil cement with high cement content. For coring to be successful the core should remain intact during the process.

   a. Assemble the equipment as directed by the manufacturer.
   b. Check that the cylindrical coring bit is in good condition.
   c. Select the right size of coring bit (100 mm or 150 mm diameter or as specified).
   d. Attach and fasten the coring bit to the coring machine.

e. Move the coring machine into to a position with the coring bit directly over the test point.
f. Lower the coring bit to a height of about 5 mm above the surface of the layer to be cored.
g. Attach the water pipe from the tank to the coring machine and ensure that water flows freely from the tank to the coring bits.
h. Start the machine and ensure that it is running as specified.
i. Ensure the water is streaming down the coring bit before commencing the coring.
j. Lower the spinning coring bit gently to the surface and apply a constant but gentle force to press the coring bit into the layer. Observe the colour of the turbid water coming out of the cutting. Any change of colour indicates that the coring bit has started cutting a different layer, e.g., when cutting asphalt, the colour would be black and grey. When cutting through crushed stone, the colour would lighten to greyish or cream-grey. When cutting through soil or soil-cement, it turns brownish or orange.
k. Pull out the drill gently while spinning.
l. Extrude the core by tamping on the coring bit with a rubberised hammer.
m. Collect the core and measure its height with a pair of callipers on four positions for its height and three positions for its diameter.
n. Weigh the core if the balance is available. Carry out initial logging of the core.
o. Label the core.
p. Take photographs on all sides, the top and bottom and
q. Place the core in the sealed plastic bag.

3. Core Logging

Core logging shall be carried out in a logging form illustrated in the Figure 8.22.

Figure 8.23 Illustration of Core-Logging

CORE LOG	25+050	Layers					Aggregate		General Remarks			PAK test
		No.	Top (mm)	Btm (mm)	Thickness (mm)	Material type	Max size (mm)	Type	Condition	Bond	Voids (Yes/No)	+VE / -VE
		1										
		2										
		3										
		4										
		5										
		6										
		7										
		8										
		9										
		10										

Abbreviations: TS=Thin Surfacing; HRA=Hot Rolled Asphalt; DBM =Dense Bituminous Macadam; AC = Asphaltic Concrete; HBM=Hydraulically Bound Material; GS=Gritstone; GNT=Granite; LST=Limestone; GVL=Gravel; PQC=Pavement Quality Concrete, GSB=Granular Sub-base		Core Dia (mm)	
		Core Ref:	
Client:		TRL LMS Ref:	
Project:		Project Code:	
Location:		Coring Date:	
Section:	Offset	Logged by:	
	Lane	Checked by:	

8.3.5 Determination of Road Pavement Structure and Strength Using the Dynamic Cone Penetrometer (DCP)

This method describes the standard procedure for determining pavement strength using the dynamic cone penetrometer (DCP). The DCP test is conducted by hammering a steel rod fitted with a 30-degree or 60-degree cone into the pavement and measuring the rate of penetration per blow, which is the resistance of the pavement layer to penetration.

The results are used to determine layer thicknesses and their structural strength, as well as that of the pavement. This is the main application of DCP data in rehabilitation design.

Reference: *Overseas Road Note 18*

The following apparatus/equipment and procedures are key for the determination of road pavement structure and strength using the dynamic cone penetrometer (DCP)

1. **Apparatus:**
   a. DCP Equipment – consisting of a steel rod, 8 kg hammer with a free falling height of 575 mm, 30-degree cone, 60-degree cone and a graduated rule, Figure 8.24.
   b. Measuring tape – to measure offset distances.
   c. GPS – for measuring coordinates of test points.
   d. Coring machine – where there is thick surfacing – to remove surfacing before conducting the test.
   e. Hand tools and containers are used to sample soils for a moisture content test.
   f. Camera.
   g. Standard forms.
2. **Preparation of test section**
   a. For preliminary surveys:
      i. Determine the test chainages to demarcate sections (200 m – 500 m or longer).
      ii. Mark test positions preferably in the outer wheel paths.
   b. For pavement evaluation for rehabilitation:
      i. Mark sections of 50 m in length.
      ii. Mark chainages at the beginning and end of each test section.
      iii. Place temporary road signs indicating works in progress.
      iv. Mark positions for the DCP tests, usually at the same points as the deflection tests.
3. **Procedure for collecting data**.
   a. For preliminary surveys:
      i. Assemble the equipment.
      ii. Check the cone to ensure it is in good condition with a sharp tip.
      iii. Carry out DCP tests at 200 m to 500 m intervals staggered left-centre-right, preferably on the centreline and in the wheel tracks or as specified by the Engineer.
      iv. Follow the detailed procedure given in 2(b).
      v. Apply one blow for the first two to three readings.
      vi. Adjust the number of blows so that the difference between subsequent readings lies between 5 mm and 10 mm, except when one blow gives a reading that is ≥ 10 mm, in which case, one blow should be applied before taking a reading.
      vii. Penetrate the pavement to 800 mm depth from the surface or as specified by the Engineer.
      viii. For more details on how to conduct the tests refer to 3(b) below.

b. For rehabilitation design:

i. Assemble the equipment.

ii. Check the cone to ensure it is in good condition, i.e., free of deformation and with a sharp tip. A gauge, a metal with a 60-degree slot and a 20 mm hole, may be used to gauge the dimensions of the cone and check its condition.

iii. Check that the rod is straight.

iv. For roads with thick surfacing, such as asphalt, use the coring machine to remove the surfacing or bituminous and heavily cemented bases.

v. Position the DCP vertically at the test point.

vi. Fill in the details of the road and test position – the chainage, lane number, offset, condition of the surfacing (cracked or not cracked), moisture condition of the base, etc.

vii. Record the zero error, the reading taken where the DCP is at zero penetration. To obtain this value, place the DCP on a flat/plane and hard surface ensuring that it is plum and then take a reading. This is referred to as the zero error.

viii. Take and record the reading at zero blows on the rule.

ix. Apply one blow and take a reading.

x. Apply the second and third blows and record both penetration readings.

xi. Calculate the difference in subsequent readings i.e., the penetration. The penetration between readings should be between 5mm and 10mm to determine layer boundaries more accurately.

xii. Increase the number of blows before taking a reading if the penetration is less than 5 mm and reduce the number of blows if the penetration is more than 10mm.

xiii. Apply 1 blow each time before taking a reading if the penetration is 10 mm or more per blow.

xiv. Continue the penetration until it reaches a minimum of 200 mm into the subgrade. Usually, a total penetration of 800 mm would suffice, but the engineer's instructions take precedence.

xv. For deeper pavements, use extension rods.

xvi. Once the desired penetration has been reached, a slight tap with the hammer on the upper anvil is applied to loosen the DCP rod and cone.

xvii. Turn the rod clockwise.

xviii. Accept the test if the DCP rod turns with little effort.

xix. Reject the test if the DCP requires significant effort to turn or does not turn at all. This implies that the rod is stuck and there is additional resistance to penetration from side friction. This usually happens when materials are stony or have boulders.

xx. Use the data to plot a graph of penetration against the number of cumulative no of blows, Figure 8.23.

xxi. Determine the layer boundaries by marking positions on the graph where the slope changes.

xxii. Alternatively, analyse DCP data using appropriate software.

4. **Calculation**
   a. Carry out the analysis using the software to obtain the layer thicknesses, CBR, and SN values for the layers and overall pavement.
   b. Alternatively, manually calculate the layer thicknesses from the layer boundaries, which should be marked where the gradient of the curve changes.
   c. Manual CBR Calculations can be done using Smith and Pratt, Kleyn, Van Vuuren or TRL Equations shown in Appendix J.
   d. Calculate the structural number from the following equation:

$$SN = 0.0394\sum_{0}^{i} a_i\, d_i$$

Equation 8.39

Where,

a = Layer strength coefficient obtained from the RDM5.2.

d = Thickness of the layer, mm.

   e. Calculate the corrected structural number, SNC, which considers the variations in subgrade strength.

$$SNC = SN + 3.51(\log_{10} CBR) - 0.85(\log_{10} CBR)^2 - 1.43$$

Equation 8.40

Figure 8.24 A Plot of Penetration Against Number of Blows

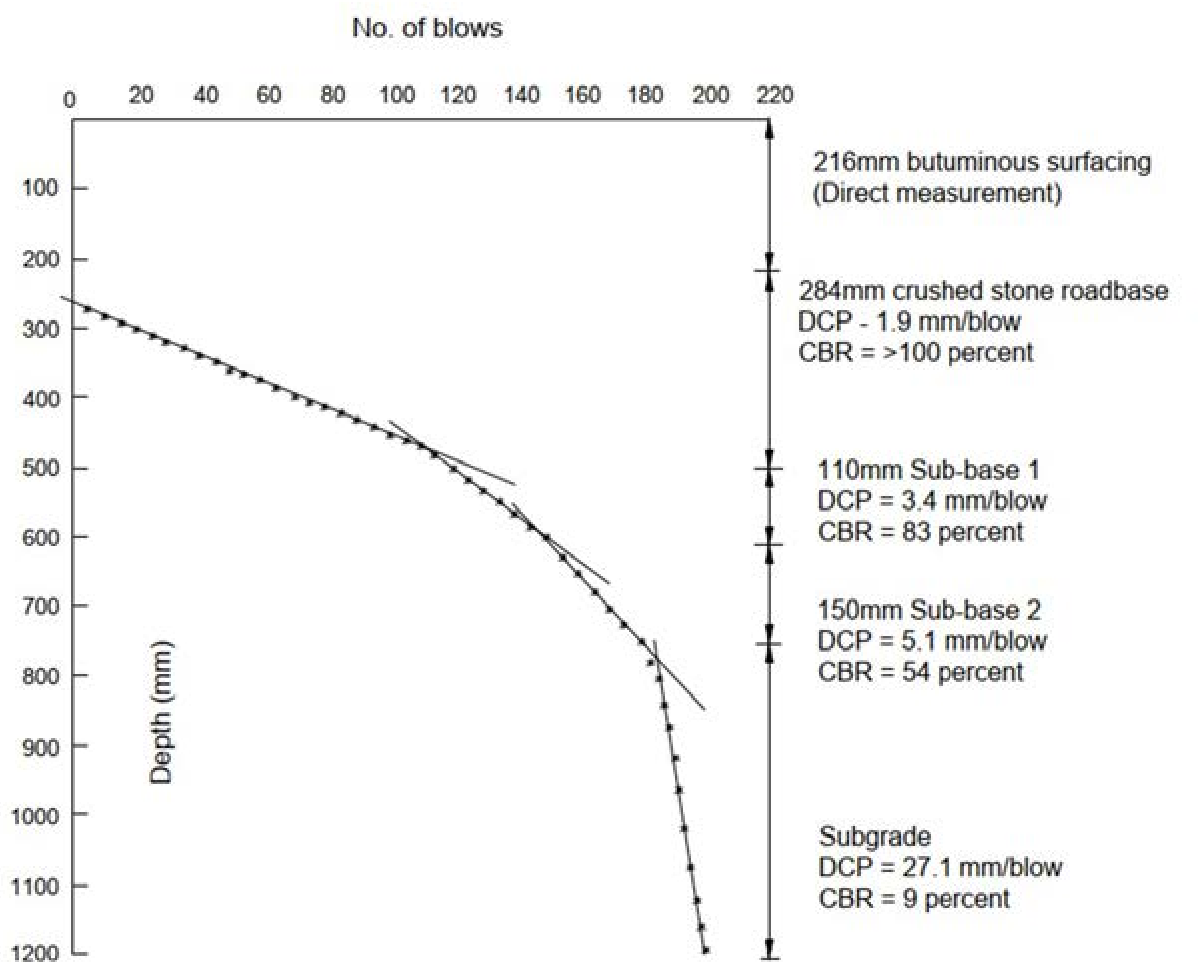
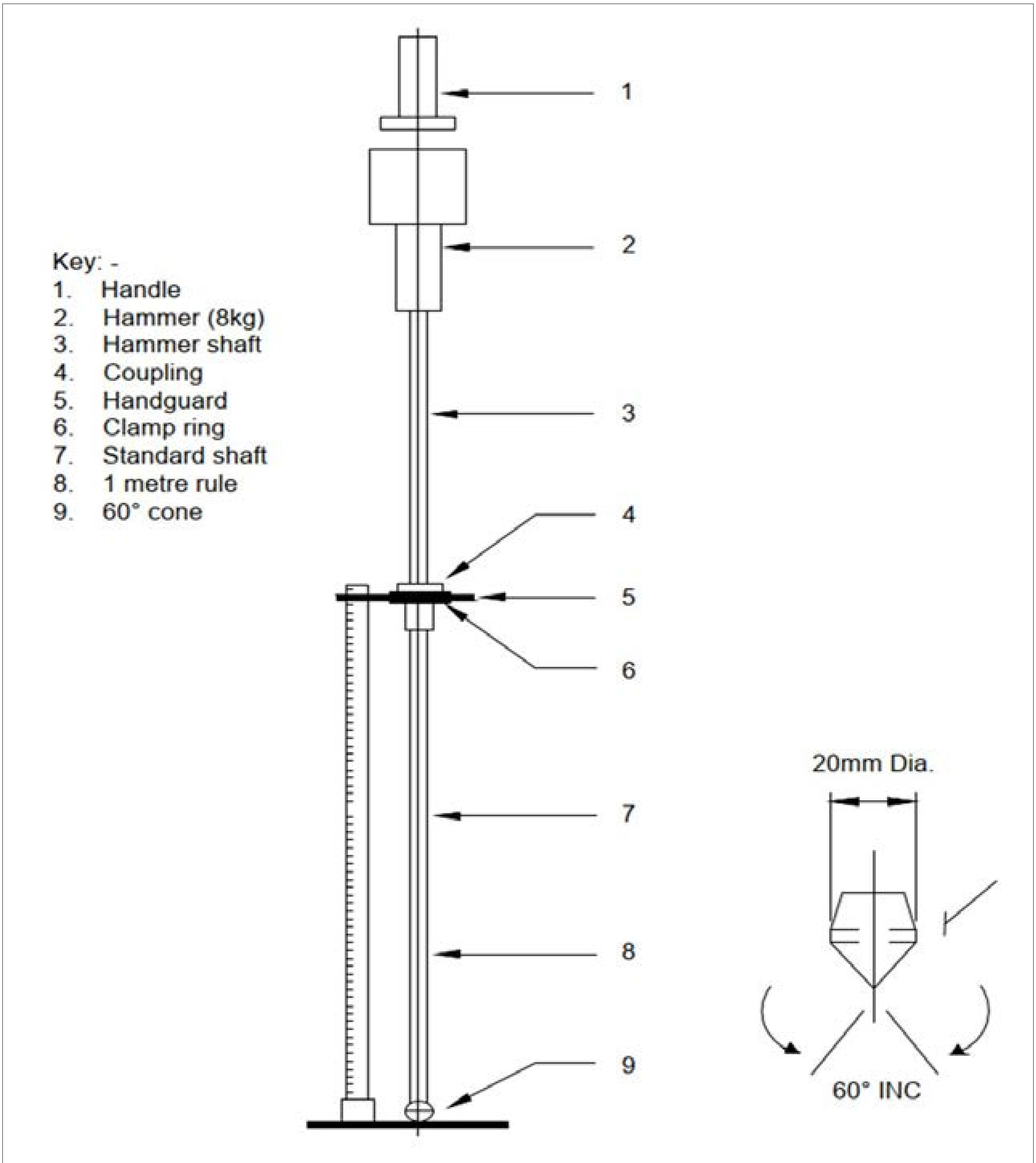


Figure 8.25 DCP Equipment (TRL, ORN 18)



8.3.6 Determination of Road Pavement Structure and Evaluation of Pavement Materials through Test/Test/ Trial Pits

This method describes the standard procedure for excavating of test/test/ trial pits, logging and sampling pavement materials.

The process involves the removal of surfacing. Asphalt saw cutters should be used for the removal of asphalt and other thick surfacing. The underlying pavement layers are then excavated taking care not to mix the materials from different layers. Samples of materials are collected from each layer in quantities sufficient for the intended tests. Refer to standard test procedures for soils, aggregate and surfacing for guidance. For soils 30 to 50 kg of sample materials would suffice. The profile of the pavement structure is logged, and the depths and thicknesses of pavement layers are recorded.

The results are also used to determine the structural strength of pavement layers and the pavement as a whole including the quality, classification and strength of materials, which constitute the road pavement under investigation.

The following apparatus/equipment and procedures are key for the determination of road pavement structure and evaluation of pavement materials through test/test/ trial pits.

1. **Apparatus:**
   a. Backhoe – for mechanical excavations.
   b. GPS – for measuring coordinates of test/ trial pits.
   c. Hand tools – 2 picks, 1 spade, 1 shovel, 1 trowel, containers for sampling soils for moisture content test, sample bags (10 kg and 50 kg).
   d. Measuring tape – to measure depths, thicknesses of layers and off-set distances.
   e. Labels – hard paper or aluminium foil.
   f. Camera.
   g. Standard test/ trial pit logging forms.
2. **Excavation of test/ trial pit and sampling of** materials
   a. For new construction:
      i. For highways, position test pits at 20 m to 50 m intervals along the centreline.
      ii. For secondary and other low-volume roads, position test/ trial pits at 50 m to 100 m intervals. Any intervals greater than 100 m should be approved by the Engineer.
      iii. Depth of excavation should be at least 1 m.
   b. For pavement evaluation for rehabilitation:
      i. Use the FWD deflection data to select two points with the highest deflection (weakest points) and one with the lowest deflection (strongest point).
      ii. From the DCP data, select the point on the two weakest points with the smaller structural number and/or weakest subgrade if the difference in the structure numbers is not significant.
      iii. Position the test/ trial pit on the weakest point to determine the minimum strength of the pavement within the test section.
      iv. Mark the test/ trial pit in a rectangular form 1.0 m x 1.2 m for thicker pavements and 0.8m x 0.8m, generally.
      v. Take photos showing the condition of the surfacing.
      vi. Remove the surfacing using an asphalt saw cutter for thick surfacing and hand tools for thin surfacing.
      vii. Sample part of the surfacing in sufficient quantities for subsequent testing (refer to materials testing standards for soils, aggregate, bitumen asphalt and concrete).
      viii. Label the samples appropriately, including the intended tests.
      ix. Clean the surface of the base course, remove any contamination from the binder or prime coat, and take photos.
      x. Excavate a little and collect samples for moisture content tests.
      xi. Level out the top and conduct in-situ density tests, preferably in 2 positions within the test/ trial pit.
      xii. Excavate the first layer avoiding contamination with materials from the bottom layer.
      xiii. Collect samples in sufficient quantities to carry out specified tests. Note that the base layer could consist of a crushed stone base (GCS) or crusher run, for which an Apparent Density Test would be required.
      xiv. Repeat procedure **2.a.x.** to **2.a.xiii**. for subsequent pavement layers including subgrade.

xv. Fill out the test/ trial pit logging form. Record the depth and thicknesses of the layer, depth of the test/ trial pit, colour of materials in the different layers, description of the type of materials, etc.

xvi. Once completed, backfill the test/ trial pit with the same or better-quality pavement materials

xvii. For highways, stabilise all layers with cement because only light compaction equipment can be used, and higher densities are impossible to achieve when backfilling test/ trial pits.

xviii. For low-volume roads, only stabilise the base course.

xix. Use cold or hot mix asphalt to seal the test/ trial pit and compact sufficiently.

8.3.7 Determination of Field Density Using the Sand Replacement Method

This method describes the standard procedure for the determining of in-situ field density and moisture content of materials. The process involves the preparation of sand to be used for the test, excavating a test hole, collecting the excavated material, and weighing it to determine its mass. The density apparatus is then filled with sand, weighed and placed on the excavated hole. The sand is released to flow into the hole to determine the mass of sand that is required to fill the hole. Using the predetermined bulk density of the sand and the mass and the volume of the sand used to fill the hole and hence the volume of the hole is determined. The density of the soil is then determined from the mass of the excavated soil and the volume of the soil i.e., the volume of the hole). A small portion of the excavated soils is collected for moisture content test. The moisture content is then used to determine the dry density of the excavated soil.

The results are used to determine the density of pavement layers for compaction control or investigate pavement layer strengths in-service.

The following apparatus/equipment and procedures are key for the determination of field density by sand replacement method.

1. **Apparatus:**
   a. Density equipment – 4L cylinder with an orifice of 12.7 mm in diameter fitted with a cylindrical valve and a conical funnel below the valve.
   b. Base plate – with a diameter equal to that of the hole to be excavated in the pavement layer to be tested.
   c. Sand Cone Funnel - A funnel that fits on top of the sand pouring cylinder, allowing the controlled release of sand into the hole excavated in the soil.
   d. Sand – uncemented free-flowing dry sand (0.075 mm < particle size ≤ 2.00 mm); variation in bulk density shall be ≤ 1%. Balance – with a capacity of more than 5 kg, a balance capable of accuracy of 0.01 g Drying Oven – capable of maintaining 105 °C.
   e. Hand tools – picks, shovels, spoon, chisel, air-tight containers for moisture content samples, sample bags for density test on soils, small paint brush, measuring tape for measuring depth of test hole and pavement layer thickness.
   f. Pen and markers.
2. **Procedure:**
   a. Determine the bulk density of the sand (calibration):
      i. Place the empty apparatus on a firm-level surface.
      ii. Close the valve and fill the funnel with sand.
      iii. Open the valve, maintain the level of sand in the funnel above half, and fill the apparatus.
      iv. Close the valve and empty the excess sand.
      v. Weigh the mass of the sand and the apparatus.
      vi. Calculate the mass of sand by subtracting the mass of the apparatus.
      vii. Calculate the bulk density by dividing the mass of the sand by the volume of the apparatus containing the sand.

b. Excavation of the test hole:

- **i.** If a surfacing layer exists – remove the surfacing layer and if necessary, skim off the surface of the layer to be tested to make it regular and level.
- **ii.** Place the base plate and secure it with steel or concrete nails to restrict movement.
- **iii.** Excavate the hole guided by the size of hole in the base plate – the walls of the hole should be vertical.
- **iv.** Place the excavated soil from the hole into a container making sure not to lose any.
- **v.** Excavate to a depth of 100 mm or to the depth of the respective pavement layer.
- **vi.** Place the empty density apparatus on the balance and weigh to the nearest 0.01g.
- **vii.** Close the valve.
- **viii.** Fill the apparatus with calibrated sand and weigh the apparatus with the sand to the nearest 0.01g.
- **ix.** Place the apparatus over the excavated hole with the base plate still in place.
- **x.** Open the valve and allow the sand to flow into the hole until it stops flowing then close the valve sharply.
- **xi.** Avoid any layer vibrations by testing personnel, equipment or passing vehicles.
- **xii.** Lift the density apparatus and weigh the apparatus again with the remaining sand.
- **xiii.** Weigh the material that was excavated from the test hole.
- **xiv.** Mix the material, collect, and weigh a representative sample to determine moisture content.
- **xv.** Determine the sample size for the moisture content test using Table 8.18.
- **xvi.** Carry out the moisture content test.

Table 8.18 Determination of Maximum Size of Sample for Moisture Content Tests

Maximum Particle Size (mm)	**Minimum Moisture content sample** (g)
4.75	100
12.5	250
25	500
50	1000

c. Calculations

- **i.** Calculate the volume of the density apparatus, $V1$:

$$V_1 = M_1 \, x T$$

Equation 8.41

Where,

V_1 = Volume of density apparatus (cm^3).

M_1 = Weight of water required to fill the density apparatus(g).

T = Volume of water /unit mass at given temperatures (cm^3/g), Table 6.15.

Table 8.19 Volume of Water per Gram in Relation to Temperature

Temperature (°C)	**Volume of water** (cm^3/g)
12	1.00048
14	1.00073
16	1.00103
18	1.00138
20	1.00177
22	1.00221
24	1.00268
26	1.00320
28	1.00375
30	1.00435
32	1.00497

Calculate the volume to the nearest 0.00001 cm^3

ii. Calculate the bulk density of sand, ρ_s:

$$\rho_s = \frac{M_2}{V_1}$$

Equation 8.42

Where,

M_2 = the weight of sand required to fill the density apparatus, cm^3.

V_1 = the volume of the density apparatus (= the volume of the sand required to fill the density apparatus), cm^3.

Calculate the bulk density of the sand to the nearest, 0.01g/cm^3.

iii. Calculate the moisture content of the soil, w (%).

$$w = \frac{M_3 - M_4}{M_4} \text{ x } 100$$

Equation 8.43

Where,

M_3 = mass of the wet sample, g.

M_4 = mass of the dry sample, g.

iv. Calculate the dry density of the soils from the hole, ρd (cm^3/g)

$$\rho_d = \frac{\rho_w}{1 + w}$$

Equation 8.44

Where,

ρ_w = Density of wet soil from the hole.

w = Moisture content of soil from the hole (%).

Calculate the dry density of the soil from the hole to the nearest 0.01 g/cm^3 (equivalent to 0.01 kg/m^3)

v. For compaction assessment - calculate the average density and standard deviation of the test results for the section under investigation after taking out outliers.

vi. Plot the average density and standard deviation on the Compaction judgement chart given in Appendix K.

3. **Reporting**
   a. Road name and chainage.
   b. Position, including off-set distances.
   c. Pavement layer.
   d. Visual description of material.
   e. Bulk density of sand.
   f. Wet density of soil.
   g. In-situ moisture content.
   h. Dry density of the soil.
   i. Average density for the section under investigation and the standard deviation of the density results.
   j. For Compaction – apply the compaction judgement chart in Appendix K and report Acceptance, Conditional Acceptance or Rejection.
4. **Precautions**
   a. The walls of the hole must be vertical.
   b. The test does not give accurate results when the materials have large stones. This affects the regularity of the hole and moisture content tests.

8.3.8 Determination of Field Density Using a Nuclear Density Gauge.

This method describes the standard procedure for the determining in-situ field density and moisture content of materials using a nuclear density gauge.

The process involves the preparation of the nuclear density gauge to ensure that it is in good working order. Such checks include verifying that the instrument is calibrated (calibration is required every 12 months) and that the calibration curves are available or that any corrections are built into the software or provided before the start of field tests.

The surface of the materials to be tested should be levelled out so that the nuclear density gauge can sit properly on the surface without leaving gaps between the base of the gauge and the material's surface. Any gaps should be filled with sand. However, the total area to be covered by the sand should not exceed 30% of the area of the base of the gauge. The nuclear density gauge is placed on the prepared area over the material to be tested. The test is then carried out through counts of radiation of radioactive particles detected by the sensor. The counts are converted to field density and moisture content values through calibration relationships, which may be in the form of curves or in-built software algorithms.

The results are used to determine the in-situ density and moisture content of pavement layers for compaction control or to investigate pavement layer strengths in service. The dry density can be calculated using in-situ moisture content obtained from the readings or determined in the laboratory on moisture content samples.

The relative density can be obtained by inputting the value of the maximum dry density of the same material obtained from the laboratory through a moisture density relationship test.

The gauge will be calculated, and the relative compaction will be displayed as a percentage (%).

Reference Test Method is AASHTO T310.

The following apparatus/equipment and procedures are key for determining field density using a nuclear density gauge.

1. **Apparatus:**
   a. Nuclear Density/Moisture Gauge (Figure 8.25) with:
      i. Source of high energy gamma rays.
      ii. Gamma ray detector.
      iii. Fast neutron source.
      iv. Slow neutron source.
      v. A standardisation testing block – for correction of radiation and to check that the gauge is operating properly.
   b. A plate used to prepare a level surface to sit the gauge; it has the same dimensions as the base of the gauge.
   c. A graduated drive rod – diameter not more than 3 mm greater than the diameter of the probe. It is hammered into the layer of materials to prepare a hole for the probe.
   d. The drive rod extractor is a handle that pulls the pin out without damaging the hole.
   e. A hammer – 1 kg or more to drive the rod into the ground.
   f. Hand tools are used to level the material's surface to be tested.
   g. Sample bags – to collect samples for moisture content and density-relationship tests.
2. **Procedure**
   a. Check calibration of the nuclear density/moisture gauge:
      i. Check that the gauge is calibrated.
      ii. If the gauge is out of calibration, the procedure for calibration stipulated by the manufacturer should be followed. It should include standard blocks of constant density to obtain the calibration response of ± 16 kg/m^3 for wet density.
      iii. When calibrating using standard blocks the accuracy of the results i.e., the difference between the known density of the block and the measured value should be ± 0.2%.
      iv. For verifying existing calibration, the accuracy should be ±32 kg/m^3.
      v. For water content calibration and when standard blocks of constant moisture are used, the accuracy should be ± 16 kg/m^3.
         - A certified entity should calibrate per the manufacturer’s instruction.
         - Verification of calibration and standardisation should be carried out by the user.
         - Nuclear density gauges are safe when handled properly. The manufacturer’s safety instructions should be strictly adhered to prevent exposure to harmful radiation. The equipment must be kept in its container unless it is being used. Under no circumstance should the probe containing the radioactive material be exposed or tampered with.
   b. Preparation of the test position:
      i. Check to ensure no vertical wall within 600 mm of the test position. If this is unavoidable, then apply the corrections procedures provided by the manufacturer.
      ii. Check that no devices emit radioactive materials within 10 m of the test position.
      iii. Using hand tools, make the sitting position of the gauge as plane as possible. Any irregularities should not be more than 3 mm, and the area with irregularities should not be more than 30% of the sitting area of the gauge.
      iv. Level off the irregularities with sand to ensure that there is no gap between the surface of the layer and the base of the gauge during testing. The plate should be used during the preparation of the test position.

v. Decide on the method of testing to be used:
   - Direct transmission method of in-situ nuclear density and moisture content – the radioactive source is placed at a given depth in the layer, and the sensor/counter is at the surface.
   - Backscatter or Backscatter/Air Gap Ratio method of in-situ nuclear density and moisture content – in this method, the radioactive source and the sensor/counter are placed at the surface of the layer.

vi. For the direct transmission method, place the plate in the test position. Place the drive rod in the guide hole of the plate, and hammer it into the layer, to a depth more than 50 mm below the intended depth at which the radioactive probe will be place during testing. Use the graduation marks on the rod to determine the depth of penetration. Mark the plate's position and use the drive rod extractor to extract the rod while rotating back and forth to avoid damaging the hole.

vii. For the backscatter or backscatter/air gap ratio method – use the plate to make sure that the surface of the material/layer is plane.

c. Testing using the direct transmission method:

i. Place the gauge on the block and initiate the standardisation procedure.

ii. Place the gauge on the test position and within the marks placed on the surface during the preparation process.

iii. Lower the probe to the required depth in the layer.

iv. Initiate the test procedure.

v. The gauge will provide the counts and make the conversions automatically. If this cannot be done automatically the calibration curves or coefficients should be used to convert counts to wet density and moisture content.

vi. Record 1 or more 1-minute readings as specified.

d. Testing using the backscatter or air backscatter/ air gap method:

i. Sit the gauge firmly on the test position.

ii. For the backscatter method, initiate the tests and record 1 or more 1-minute readings.

iii. For the back scatter/air gap ration method, follow the manufacturer's instructions. Take the same number of readings for the air gap position, as in the backscatter position, and then divide the counts from the air gap position by the counts in the backscatter position. Usually, these are automatically calculated.

iv. Record the readings for the wet density and moisture content. If these are not calculated automatically, use the calibration curves or predetermined coefficients to determine the in-situ wet density and moisture content.

e. Determination of relative density/compaction

i. Before testing, the moisture-density relationship tests in the laboratory are carried out to determine the maximum dry density (MDD) and optimum moisture content.

ii. Input the MDD value in the gauge before commencing the tests.

iii. The relative compaction is computed automatically.

iv. Record the relative density/compaction in percentage (%).

f. Calculations

i. Calculate the limits of the standardisation count upper and lower limits:

$$Ns = N_0 \pm 1.96\sqrt{\left(\frac{N_0}{F}\right)}$$

Equation 8.45

Where,

N_s = Current standardisation count.

N_0 = Average of 4 N_s values taken in standardisation in a previous test.

F = factory pre-scale factor (provided by the manufacturer).

g. Calculate in-situ dry density using the following equation:

$$\rho_d = \frac{\rho_w}{1 + w}$$

Equation 8.46

Where:

ρ_w = density of wet soil from hole.

w = moisture content of soil from hole (%).

Figure 8.26 Measuring Field Density using a Nuclear Density Gauge

8.3.9 Determination of Field Permeability of Soil Masses

This method describes the standard procedure for the determination of field permeability of soil masses. Permeability of a material is the measure of its ability to allow a fluid to pass through it. In the case of soils, rocks, pavements, underlying subgrade, surrounding natural ground, and filter materials, the movement of water into, through and out is determined by the permeability of these materials.

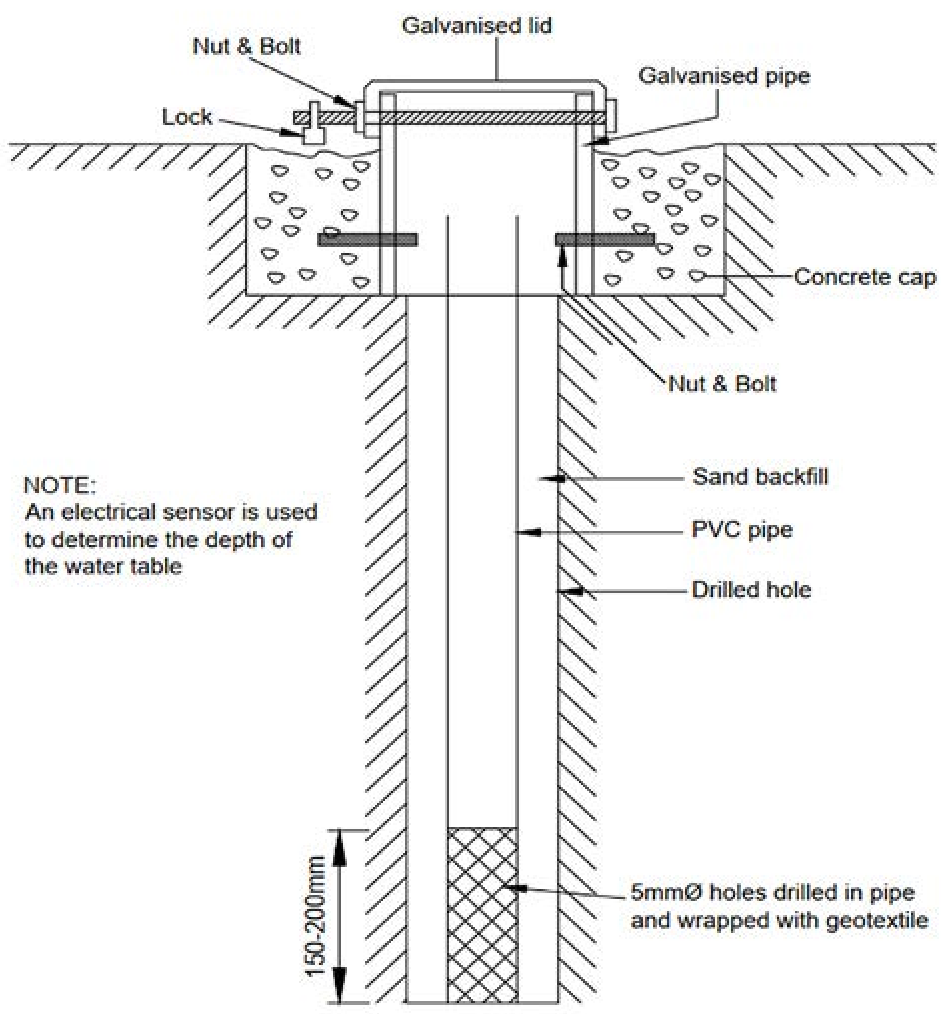
The procedure involves drilling a borehole. The level of the water table is measured, and water is allowed to seep into the borehole to the level of the water table. Water is then drained to a specified depth in the borehole. Groundwater is then allowed to seep in and the rate at which the water level rises in the borehole, indicating the permeability of the soil mass. The permeability coefficient of the soil mass is calculated from these measurements.

The results are used to determine the permeability of the soil masses which is used in the design of subsurface drainage as well as seepage of surface water into the ground.

The following apparatus/equipment and procedures are key for the determination of field permeability of soil masses:

1. **Apparatus:**
   a. Borehole drill complete with truck or other mounting: Open-ended with the capability to extract the core of materials and leave an open hole.
   b. A water level measuring device/meter: Measure the water levels in the borehole during testing.
   c. Perforated tubing: Which allows the free flow of groundwater into the hole, Figure 8.26.
   d. A water pump: A submersible water pump of minimum 600W fitted with flexible pipes.
   e. Extruder: Used for removing materials after coring.
   f. Hand tools: Are used to prepare the site for testing, handling materials and clearing the site after tests.

Figure 8.27 Field Measurement of Permeability of Soil Masses



2. **Procedure**

The procedure below is called the borehole method.

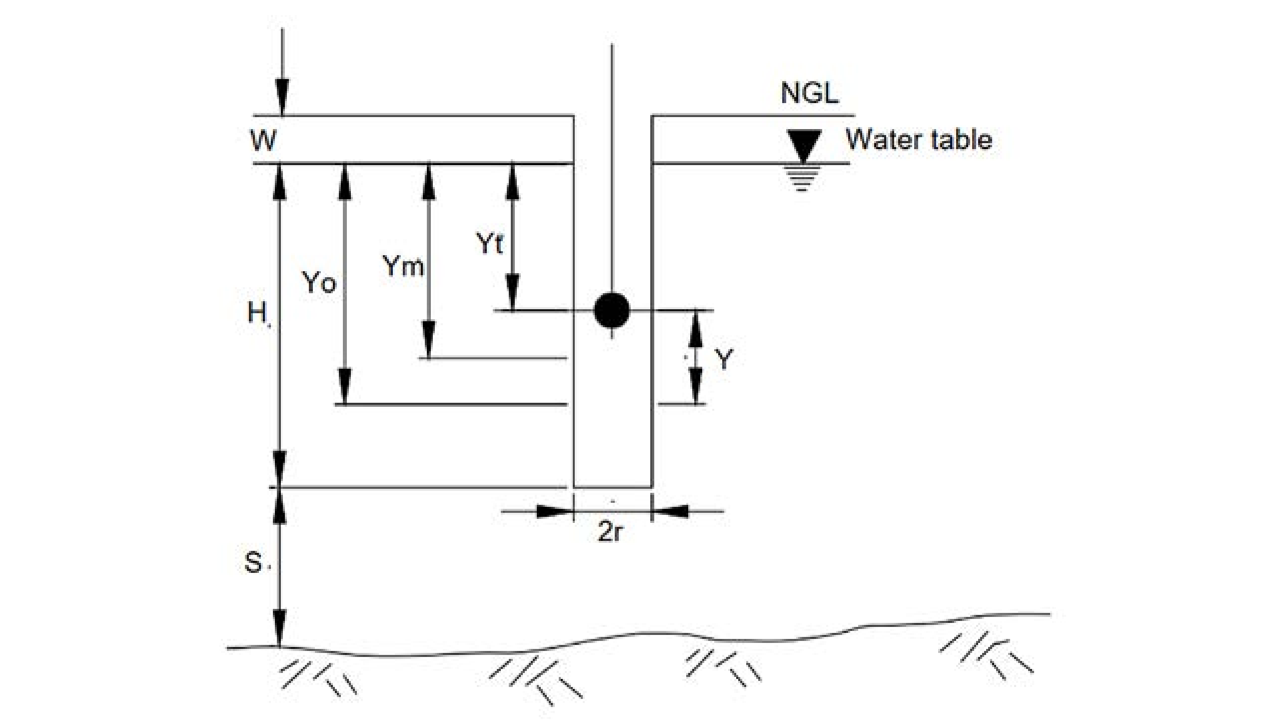
a. Drill a borehole to a depth of approximately 600 mm (the depth shall be between 200 mm and 2000mm) below the water table.

b. Wait until the water level in the hole has been restored to the natural water table. This may take approximately 2 hours for sand and 12 hours for clay materials.

c. Pump the water out rapidly to a depth of approximately 300 mm or as appropriate and allow the water to rise to the natural water table.

d. Record the rate at which the water table returns by measuring the height and time.

Figure 8.28 Permeability Tests for Soil Masses



3. **Calculations:**

Refer to Figure 8.28.

H = Depth of hole below the original water table after pumping out water

R = Radius of hole in mm

ΔY = Y_0-Y_t = the height (mm) at which the water rises in a given time ΔT (seconds)

Ym = $\Delta Y/2$ +Y_t = Distance from the original water table to the average water level (in mm) in time interval ΔT (in seconds).

S = Depth of impervious layer below the depth of the hole.

The following conditions should be met:

a. 30 mm < r < 70 mm

b. 200 mm < H < 2000 mm

c. $\Delta Y \leq 0.25\ Y_o$

d. 0.2H < Y_m

Permeability coefficient in m/day

If $S > H$:

$$K = \frac{\frac{400r^2}{(H + 20r)(2 - \frac{Y}{H})}\left[\frac{\Delta Y}{\Delta T}\right]m}{day}$$

Equation 8.47

If $S = 0$:

$$K = \frac{360r^2}{(H + 10r)(2 - \frac{Y}{H})} \frac{\left[\frac{\Delta Y}{\Delta T}\right]m}{day}$$

Equation 8.48

Length in mm and time in seconds.

See Determination of Permeability Coefficient K through Head Permeability Test, MTM L6-13.

8.3.10 Subsurface Surveys Using Ground Penetration Radar (GPR)

This method describes the standard procedure for surveying subsurface features using Ground Penetrating Radar (GPR).

The procedure involves transmitting electromagnetic signals into the ground. The signals are reflected where there is a change in material densities, types or obstacles. The penetration depths of electromagnetic waves are dependent on their wavelengths. The longer the wavelength, the deeper the penetration. However, shorter wavelength leads to sharper images while longer wavelengths lead to lower-resolution images.

The results are used to determine the positions and depths of pavement layer boundaries, as well as service lines under the pavement, e.g., drainage and water reticulation pipes, power and communication cables, etc. Materials that can be detected include metal, plastics, changes in ground strata and geological features, concrete and air pockets, excavated and/or backfilled areas, and ground disturbances, which can be identified and mapped.

The following apparatus/equipment and procedures are key for carrying out Subsurface Surveys using Ground Penetration Data (GPR).

1. **Apparatus:**
   a. Equipment for ground penetration radar (Figure 8.29) complete with the following:
      i. Antennas – capable of transmitting electromagnetic signals (radar) at high and low frequencies (2.9 GHz to 16 Hz). The range may be determined based on the purpose of the surveys. High frequency implies higher resolution and shallower penetration.
      ii. Receivers are capable of detecting the rebound signals to distinguish and interpret the results.
      iii. GPS capability to locate the measurements of the position of subsurface features on the roads.
      iv. Pedometer for determining chainages.
   b. Pedometer for chainages where distance measuring device is not integrated in the GPR equipment.
   c. A GPS if the GPR equipment does not have GPS capability.
   d. A measuring tape to measure the offset of subsurface features from surface references such as the shoulder or centreline of the road.
   e. A camera to record visual images of locations.
   f. A coring or boring machine for verification of profiles at selected positions for correlating with GPR measurements
   g. Laptop with GPR software for analysis of GPR data.

Figure 8.29 Typical Ground Penetrating Radar Equipment (Guideline Geo)

2. Procedure:

a. Prepare and set the GPR equipment for the required survey.

i. Penetration depth – select the general penetration depth required and order to set the antenna appropriately. Guidance is given in the Table 8.20 below.

ii. The resolution of the images is dependent on the frequency of the radar signal, as shown in Table 8.21.

iii. Select and mark the site to be surveyed – mark the section of the road pavement of the structure to be surveyed.

Table 8.20 Determination of Depth of Penetration of Radar

Option	Antenna frequency (MHz)	Typical maximum penetration depth (mm)	Application
1	2600	300	Investigation of reinforcement bars and concrete slab thickness in rigid pavements. This produces high-resolution images, but can only scan up to shallow depth.
2	1500	450	Reinforced concrete slabs, conduits and underlying pavement layer thicknesses.
3	900	900	Detection of underground services such as pipes, cables, and pavement layers. Suitable for scanning shallow soil thickness.
4	400	2000	Survey of utilities and shallow underlying geology.
5	200-16	30,000 – 40,000	For detection of groundwater tables and bedrock, mapping of landfills and assessment of sand and gravel deposits

Table 8.21 Showing Penetration and Resolution of Various Radar Frequencies

Dielectric Constant	450 MHz			900 MHz		
	Wavelength (mm)	Depth of Resolution (mm)	Depth of Penetration (mm)	Depth of resolution (mm)	Wavelength (mm)	Depth of Penetration (mm)
5	298	75	894	149	37	447
6	272	68	816	136	34	408
7	252	63	756	126	31	378
8	235	59	705	118	29	353
9	222	56	668	111	28	333
10	211	53	632	105	26	316
11	201	50	603	101	25	302
12	192	48	577	96	24	289
	1 GHz			1.5 GHz		
5	134	34	402	89	22	267
6	122	31	366	82	20	245
7	113	28	339	76	19	227
8	106	27	318	71	18	212
9	100	25	300	67	17	200
10	95	24	284	63	16	189
11	90	23	271	60	15	181
12	87	22	260	58	14	173
	2 GHz			4 GHz		
5	67	17	201	34	8	101
6	61	15	184	31	8	92
7	57	14	170	28	7	85
8	53	13	159	27	7	80
9	50	13	150	25	6	75
10	47	12	141	24	6	71
11	45	11	136	23	6	68
12	43	11	130	22	5	65

iv. Select test positions – i.e., references from which the test path the GPR equipment will follow, including for roads, the off-sets and chainages and for structures it can be reference dimensions of features on the structure.

v. Cleaning – ensure that the test path is free of debris or obstacles that may interfere with the readings, and the surface should be free of water.

vi. Precautions – take precautions that GPR cannot penetrate through heavy metals or dense reinforcement, and does not work with heavy clays or water with high mineral content, such as seawater.

vii. For road pavements - place the GPR equipment at the start point and run the test traversing the pavement, preferably along the wheel paths. Ensure that the system captures the right data and stores it in the designated files. Mark key positions interest i.e., positions where further investigation might be required and proofing through test/ trial pit or coring might be required.

viii. Once completed, transfer the data from the machine to the computer with relevant software for analysis.

1 2 3 4 5 6 7 8 Standard Testing Methods

3. **Analysis:**
   The analysis should be carried out by an experienced person who is able to interpret the GPR data. The GPR data consists of reflections of electromagnetic pulses and the amount of reflection depends on the Dielectric Constant, K, Table 8.22.

Table 8.22 Dielectric Constant, K Values for Different Materials

Item	Material	*K*
1	Air	1
2	Gasoline	2
3	Ice	3
4	Dry sand	5
5	Granite	6
6	Dry salt	6
7	Limestone	8
8	Shale	15
9	Saturated sand	25
10	Silts	30
11	Clays	40
12	Distilled water	80
13	Freshwater	80
14	Sea water	80
15	Metal	∞ infinity

The amount of reflection (R%) is determined by the contrast between the 2 adjoining layers e.g., the top layer (K_1) and bottom layer (K_2), using Equation 8.49 and Table 8.23.

$$Reflected\ R(\%) = \frac{\sqrt{K_1} - \sqrt{K_2}}{\sqrt{K_1} + \sqrt{K_2}}$$

Equation 8.49

Table 8.23 Examples of How to Determine the Reflectivity of Materials

Material 1	*K*1	Material 2	*K*2	Reflectivity
Dry sand	5	Rock	6	-5%
Wet sand	25	Rock	6	34%
Dry sand	5	Wet sand	25	-38%
Rock	6	Air	1	42%
Water	80	Rock	6	57%
Ice	3	Water	80	-67%
Soil	12	Metal	∞	100%

GPR detects metal or substances in a pipe for utility assessment.
Metal R = 100%,
Soil ($K1$ = 5) to non-metallic pipe with water in the pipe ($K2$ = 80) R = 60%
Wet soil ($K1$ - 25) to non-metallic pipe with water in the pipe ($K2$-80) R = 28%
Soil ($K1$ = 5) to non-metallic pipe with gas in the pipe ($K2$ = 1) R = 38%
Wet soil ($K1$ - 25) to non-metallic pipe with gas in the pipe ($K2$ = 1) R = 67%

Shape of GPR signals

Reflections and their strengths are controlled by the electrical conductivity of the materials including the soils in which they travel. Materials with high electrical conductivity absorb the signals (referred to as signal attenuation) and may make subsurface objects invisible to radar. Shapes of subsurface objects, Figure 8.30.

- **i.** Long linear cylindrical objects (pipes, cables, tree roots, re-bars).
- **ii.** Large diameter pipes or tanks (horizontal).
- **iii.** Large diameter metal or plastic drums (vertical).
- **iv.** Long linear rectangular objects (pipes, cables, tree roots, re-bars).
- **v.** Small objects (spheres, cubes, rocks, debris).
- **vi.** Material boundaries.
- **vii.** Hyperbolic shape is when the GPR crosses a point or linear object (perpendicularly).

Figure 8.30 Shapes of GPR signals

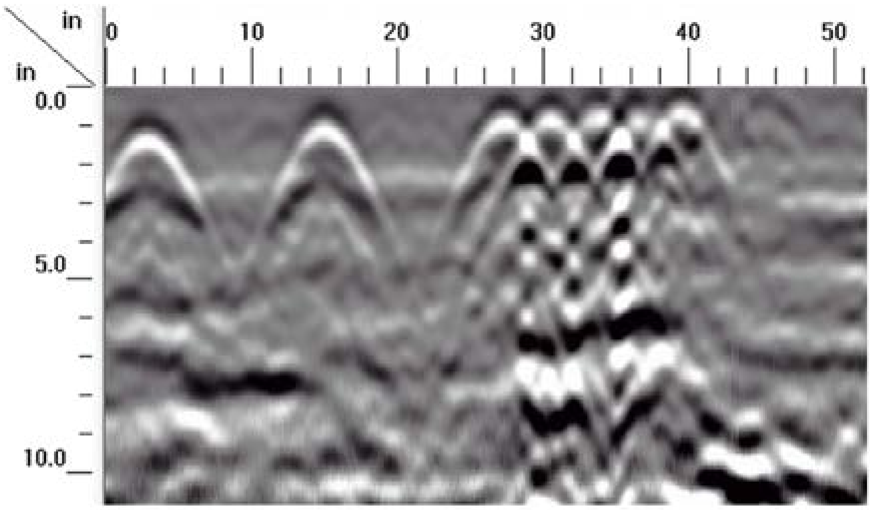


Figure 8.31 Typical Two-dimensional Radargram of Road Pavement *(top)* and Corresponding Layer Interpretation *(bottom)*

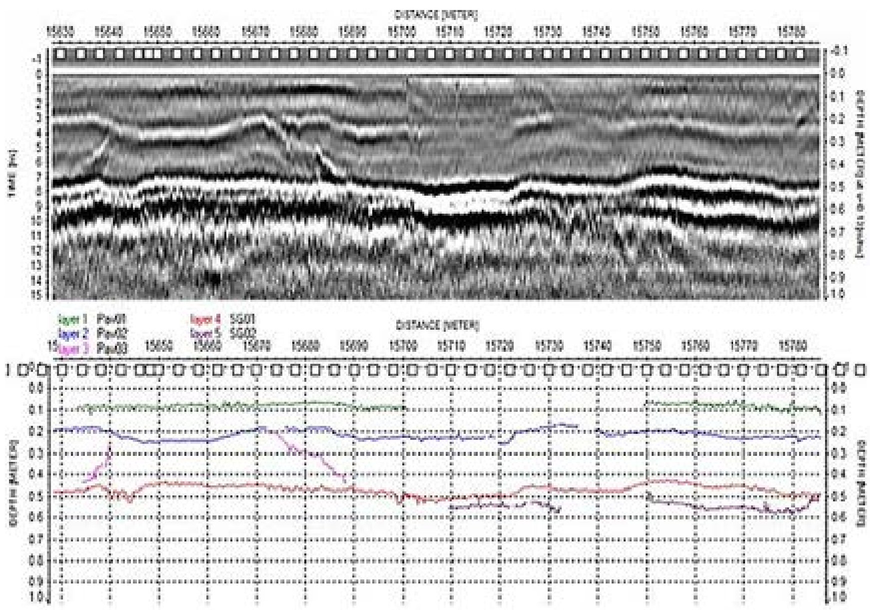


Photo Credit - PRM, Transport and Main Roads Australia, February 2020

viii. Check the recurrence of the hyperbola at the same chainage and if it shows a similar shape, intensity and depth, it is a strong indicator of a utility line.
ix. Identify similar utilities at different depths.
x. If the GPR travels along the linear object you get a straight line instead of a hyperbola
xi. An object that shows a sharper hyperbola is shallower, and a wider hyperbola with less sharpness means the object is deeper.
xii. A fading line could show a pipe that is dipping, or it could be a layer boundary of a fill. It is best to measure both in the longitudinal and then transverse (at the location showing the presence of objects) to be able to distinguish whether the longitudinal lines are layer boundaries (which will show lines in the transverse direction) or linear objects which will show hyperbolas in the perpendicular direction or pavement layer boundaries which would show lines in both the transverse and longitudinal directions.
xiii. The top of the GPR plot will show sharp white and black bands showing waves that have travelled through the air and on the ground (i.e., direct air and ground waves) or together called direct arrivals. Use the background subtraction filters to remove direct arrivals to see the subsurface.
xiv. Direct arrivals can change because of the different materials at the surface.
xv. At the bottom you get the background radio frequency (RF) noise but is very weak
xvi. Determine the depth of penetration which is where the strength of the GPR becomes weaker than the background RF noise.

Use all other information like photos, maps, Google Maps to put the results into context.

8.3.11 Determination of Load Transfer at Joints of Concrete and Void Intercept of Rigid Pavements

This method describes the standard procedure for carrying out surveys on load transfer efficiency (LTE) of concrete pavement joints and the void intercept (VI). The procedure involves loading one side of the joint measuring deflections on either side of the joint and compare the results of loaded side with results of the unloaded side.

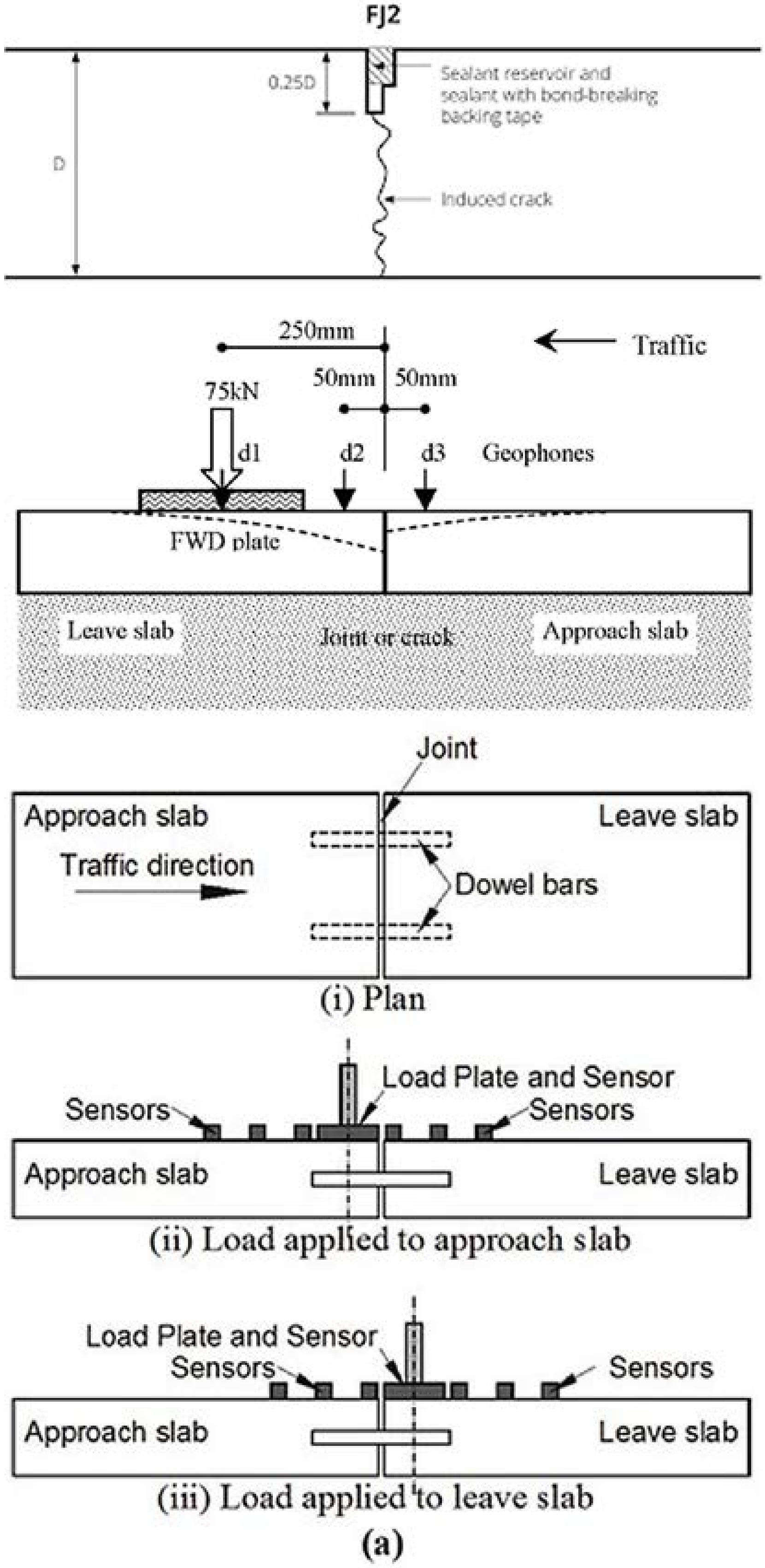
Several types of equipment can be used to measure the load transfer function of the joints including the FWD and Benkelman Beam equipment.

The results are used to determine the effectiveness of the joint's ability/capacity the transfer the load. Effective load transfer is a good indicator of its resilience to failure and rapid deterioration, which is essential in the design and in-service performance of joints and rigid pavement in general.

The following apparatus/equipment and procedures are key for the determination of Load Transfer Function at Joints of Rigid Pavements

1. **Apparatus:**
   a. Equipment for testing deflections:
      i. FWD complete with accessories + extra sensor to place before the loading plate and just on the other side of the joint, OR
      ii. Benkelman Beam complete with accessories. Ideally, 2 Benkelman beams are required. The first beam will measure the deflection at the wheel load close to the joint. The second beam will measure the deflection on the other side of the joint.
   b. Pedometer for measuring chainages.
   c. A GPS.
   d. A measuring tape to measure the positions of geophones and distance from the central load and offset from the load to the point before the joint i.e., on the other side of joint.
   e. A camera to record visual images of locations.
   f. A coring or boring machine for verification of profiles at selected positions for correlating with GPR measurements (optional).

Figure 8.32 Transfer Efficiency (LTE) and Void Intercept



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2. **Procedure:**
   a. Load Transfer Efficiency (Figure 8.31) at across joints or cracks in rigid pavements.
      i. Clean the area around the joint or crack to remove any spalled material and water.
      ii. Please the load plate such that the centre of the load plate is 250 mm from the discontinuity/joint. The load plate should be on the leave slab considering the direction of the flow of traffic. Usually, the underlying pavement and slab are weakest on the entry to the leave slab.
      iii. Place the geophone $d2$ on the leave slab 100 mm from the joint or crack.
      iv. Place geophone $d3$ on the approach slab 100 mm from the joint/crack.
      v. Note that measurements should be made at mid slab measured in the transverse direction.
   b. Void Intercept Testing (VI)
      i. Position the load plate as in the test for LTE, Figure 8.31.
      ii. Apply a settling/sitting load.
      iii. Apply 3 loads, the first at 50 kN, the second at 75 kN and the 3rd at 100 kN.
3. **Analysis:**
   Carry out an analysis of the results.
   a. Load Transfer Efficiency and across joints or cracks in rigid pavements.
      i. Tabulate values of $d1$, $d2$ and $d3$.
      ii. Used the following equation to calculate the load transfer equation.

$$LTE = \frac{d_3}{d_2} \text{ x } 100\%$$

Equation 8.50

Where,
d_3 = deflection of unloaded slab (approach slab)
d_2 = deflection of loaded slab (leave slab)

   b. Analysis of FWD Data for Void Intercept (VI)
      i. Plot deflection vs load
      ii. Carry out a linear regression and plot a line of best fit.
      iii. Determine the value at which the line intercepts the y-axis i.e., load = 0. This is the void intercept (VI).
4. **Reporting**
   a. Load Transfer Efficiency (LTE) and across joints or cracks in rigid pavements.
      i. Tabulate load, deflection and LTE values
      ii. Graphs of LTE values
   b. Analysis FWD Data for Void Intercept (VI)
      i. Tabulate VI values.
      ii. Graphs of VI values.

9 References

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8. Pavement Rehabilitation Manual, Transport and Main Roads Australia, February 2020].

10 Appendices

Appendix A: Catalogue of Defects

A1. Surface Defects:

Surface cracking is normally limited to the surfacing layer / bituminous layer only. Surface cracks are common and easy to identify in dense and fine-textured surfaces. They usually spread across the carriageway and are not restricted to the wheel path. This phenomenon can be applied to distinguish between severe surface cracks and structural (crocodile) cracks depending on the crack width or depth.

1. SHRINKAGE CRACKING:

Defect Description:

Refers to cracks that occur when surfacing is placed on cement stabilised base. The cracking is exacerbated by poor curing during construction. The cracks can be progressive or non-progressive and the latter is more prevalent. These cracks are often closely spaced and can extend in the longitudinal or transverse direction of the road Transverse cracks tend to be predominant over longitudinal ones. Check that cracks are extending into the base course.   the formation of interconnected cracks on the surface or within the HMA layer of a flexible pavement.

Defect Rating and Indicative Pictures:

1. Minor

Light or faint cracks with no potential to host foreign objects and debris.

2. Moderate

Random light cracks near/at corners of intersecting main cracks. Moderate spalling. Potential to contain foreign objects /debris.

3. Severe

Cracks with severe spalling with foreign objects and debris. Crocodile crack pattern fully developed.

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Possible Causes:

1. Temperature Changes: Temperature fluctuations also contribute to shrinkage cracking. This cyclic action induces stress on the pavement, which eventually leads to the formation of cracks.
2. Moisture Loss: Moisture loss in the hot mix asphalt or bitumen binder during curing leads to a reduction in volume, causing the HMA to shrink. The shrinkage strains can exert tensile stresses on the pavement, resulting in the development of cracks.
3. Insufficient Thickness: Inadequate pavement thickness can exacerbate shrinkage cracking. If the asphalt layer is too thin, it may lack sufficient strength to resist tensile stresses generated during the shrinkage process. This makes the pavement susceptible to cracking.
4. Lack of Proper Control Joints: Control joints are planned locations where cracks can form in a controlled manner. If these joints are not properly incorporated into the pavement design or are absent altogether, the tensile stresses caused by shrinkage have no designated release points. As a result, cracks form randomly in the pavement surface.
5. Low-Quality Materials: The quality of the materials used in the pavement construction can affect its susceptibility to shrinkage cracking. If the asphalt mix lacks adequate flexibility or is poorly compacted, it may be more prone to shrinkage and subsequent cracking.
6. Construction Practices: Inaccurate construction practices, such as improper compaction techniques or inadequate rolling patterns, can contribute to shrinkage cracking. Inadequate compaction leads to air voids within the asphalt layer, reducing its resistance to shrinkage stresses and increasing the likelihood of cracking.

2. STRIPPING/AGGREGATE LOSS:

Defect Description:

Stripping also known as aggregate loss is the dislodging of aggregates from a seal leaving the binder exposed to wheel contact. The process starts off as the loss of individual stones and eventually the complete loss of stone in a localised area. This defect commonly occurs soon after construction or during the first cold dry seasons. Aggregate loss can be described as active if the aggregate loss is continuing and as non-active if the loss of aggregate has stopped. In Asphalt aggregate loss first causes disintegration which is followed by cracking and eventually develops into a pothole. In thin surfacing types, aggregate loss results in the exposure of the pavement layers.

Defect Rating and Indicative Pictures:

1. Minor Very minimal loss of aggregate which requires close inspection to identify

2. Moderate Scattered but distinct loss of aggregate.

3. Severe The disintegration of the asphalt layer. Loss of stone on chip and spray surfacing patches of slurry loss in the slurry seal.

Possible Causes:

The primary cause of ravelling in flexible pavements is the deterioration of the asphalt binder that holds the aggregates together. Some common causes include:

1. Aging and Oxidation: Over time, exposure to sunlight, air, and moisture causes the asphalt binder to age and oxidise. This leads to a loss of its adhesive properties and makes it more brittle, resulting in the dislodgement of aggregates.
2. Traffic Loads: High traffic and heavy loads place significant stress on the pavement surface. This repeated loading can cause the asphalt binder to weaken and fail, leading to ravelling.
3. Insufficient Binder Content: If the asphalt mix used does not contain adequate binder, there may not be enough binder to effectively hold the aggregates together, resulting in ravelling.
4. Low bitumen affinity: this is caused by inherent chemical properties of the binder and aggregate that prevent adequate bonding.
5. Water hammer effect in porous and permeable asphalt: the pressure build-up under a passing wheel can be so great as to strip the binder off the aggregate letting the chippings loose. Stripping advances more rapidly during rains.
6. Poor Construction Practices:
   - i. Inadequate compaction during the construction phase can leave air voids within the pavement structure. The voids accumulate moisture, weakening the bond between the binder and aggregates thus contributing to ravelling.
   - ii. Dusty aggregate – a coating of dust around the aggregate diminishes bonding between the aggregate and binder. Stripping occurs not long after construction.
7. Inadequate Maintenance: Lack of timely and appropriate maintenance, such as seal coating or crack sealing, can allow water and other contaminants to penetrate the pavement surface. This accelerates binder deterioration and increases the likelihood of ravelling.

3. PEELING OR DELAMINATION

Defect Description:

Loss of binder and aggregate in surfacing causes clear separation or detachment of one or more later within the pavement structure. This can be between the wearing course and the underlying layer or original surface of a resurfaced road. This defect starts as a surface defect, however, if not repaired it exposes the underlying layer to significant distress resulting in structural deformation.

Defect Rating and Indicative Pictures:

1. Minor

Small areas are damaged, and the defect is difficult to identify from a distance <50mm

2. Moderate

Scattered Distinct and visible with areas of diameter ≈ 150mm.

3. Severe

The area covered by the defect >300mm and the defect starts causing secondary defects.

Possible Causes:

The main cause of delamination in flexible pavements is usually related to the loss of adhesion between the layers. Several factors can contribute to this defect:

1. Inadequate or no tack coat applied between subsequent AC layers, especially, between the binder course and wearing course.
2. Flaw in the construction sequence where the wearing course application is delayed and the tack coat has cooled significantly and is partially set before the wearing course is applied. The bonding provided by the tack coat is thus compromised.
3. Heavy traffic on thin asphalt surfacing (<40 mm).
4. Disintegrating base underneath the surfacing.
5. Insufficient prime on the base. Thin surfacing is not properly bonded to the base course.
6. Problematic base materials such as basalt that degrade over time to create clayey fines. This may cause surfacing on the base to peel off.
7. Salt panning in the base – accumulation of salts in the base may cause the surfacing to peel off.
8. Aged and brittle surfacing over a binder course or base course. Old surfacing cracks and peels off.

4. SURFACE PATCHING

Defect Description:

The Repaired sections of pavement usually range from less than 1m up to several meters equivalent to half or full pavement width. This can also be described as minor patching with indistinct edges (Edges are not cut into distinct shapes as done with structural patching.). The type, shape, size of and frequency of patching provides information on the serviceability of the existing surfacing. These characteristics distinguish surfacing patching from structural patching. Surfacing patches typically occur outside the wheel path whereas structural patches are normally located within the wheel paths.

Defect Rating and Indicative Pictures:

1. Minor

Edges are not straight. Previously implemented as temporary repairs. Widely spaced small patches Patch ø ≤ 100mm

2. Moderate

Patch ø ± 300mm

3. Severe

Closely spaced patches. Patch ø ≥ 500mm

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Possible Causes:

1. Traffic Loads: Heavy traffic loads, especially when coupled with overloading or excessive axle loads, can cause surface patching defects. The repeated stress and pressure from vehicles can lead to cracking, surface irregularity (rutting), and other forms of pavement distress.
2. Environmental Factors: Environmental conditions such as extreme temperatures, freeze-thaw cycles, and moisture infiltration can contribute to surface patching defects. Water can penetrate the pavement layers, weakening the subgrade and causing cracks and potholes when it expands and contracts with temperature variations.
3. Insufficient Pavement Design: Poor initial pavement design, including inadequate thickness of the asphalt layers or improper materials selection, can make the pavement more prone to surface defects. Inadequate structural support leads to premature distress and deterioration.
4. Aging and Deterioration: As pavements age, they naturally undergo deterioration. The asphalt binder can oxidise, making it more brittle and prone to cracking. This ageing process, coupled with ongoing traffic loads, can result in surface patching defects over time.
5. Construction Deficiencies: Errors or deficiencies during the construction process can contribute to surface patching defects. Inadequate compaction, improper mix design, or inadequate curing can lead to weakened pavement sections, making them susceptible to damage.
6. Utility Cuts: When underground utilities require maintenance or repairs, sections of the pavement may be cut and later patched. These utility cuts can create localised weak points and may require proper patching to maintain pavement integrity.

5. BINDER CONDITION

Defect Description:

This section considers how the elastic and viscous properties of bitumen binders change with temperature and time, thereby resulting in the development of defects in the surfacing layer. During engineering assessments, it is key to note the resultant visible effects of these changes in order to determine the relevant repair methods.

In thick surfacing, deterioration starts with the loss of the volatile oils and aromatics and oxidation in the surface. The products from the oxidation process dissolve in water and tend to shrink, which then increases with every rainfall event triggering continued oxidation which penetrates deeper into the binder film.

To assess the extent of deterioration of the binder, the Pavement Expert should remove pieces of aggregate within the wheel path to check the binder for dryness. If the binder is still in good condition, it will show a bright black colour and be dull if the binder is dry. It is important to avoid carrying out this test when the temperature is below 20°C because some binders appear dry if the temperature is low.

Defect Rating and Indicative Pictures:

1. Minor

Bright, black and sticky binder. Easy to remove coarse aggregate,
No shrinkage cracks.

2. Moderate

Minor shrinkage cracks in asphalt and slurry seal. Effort required to remove aggregate,
Dull and Brittle binder

3. Severe

Aggregate loss in stone seals and cracks in Asphalt and Slurry Seals. Aggregate becomes difficult to remove, Dull and very brittle.

Possible Causes:

It's important to note that binder condition defects can be influenced by multiple factors, including binder type, aggregate quality, construction practices, traffic loads, environmental conditions, and maintenance strategies. Proper binder selection, mix design, construction techniques, and routine maintenance can help mitigate these defects and ensure the longevity and performance of flexible pavements. Key contributing aspects are discussed below.

1. Aging: Over time, binders undergo ageing due to exposure to environmental factors such as sunlight, oxygen, and moisture. This ageing process causes the binder to become brittle, lose its elasticity, and reduce its ability to withstand traffic loads and temperature fluctuations. Ageing can be accelerated by inadequate binder selection, poor construction practices, or inadequate pavement maintenance.
2. Poor binder quality: improper binder-aggregate adhesion or insufficient compaction during construction can cause stripping, while insufficient binder stiffness, inadequate binder content, or poor binder-aggregate adhesion causes binder-related surface irregularity (rutting) and ravelling.
3. Traffic loads and high temperatures: these exacerbate the problem by causing the binder to soften and deform, leading to rut formation.

6. BLEEDING

Defect Description:

It occurs when excessive bitumen (the binder in asphalt) rises to the surface and forms a sticky and shiny surface. This defect is also known as "flushing" or "tyre tracking." Bleeding occurs when excess bituminous binder fills the aggregate voids and expands onto the pavement surface during hot weather. The process is irreversible meaning in cold weather the binder is absorbed back into the voids but rather accumulates on the surfacing creating a shiny black surface film. This compromises skid resistance and ultimately road safety. Rehabilitation and maintenance largely involve road safety.

Defect Rating and Indicative Pictures:

1. Minor

The surfacing has slightly excess binder.
Surfacing still has adequate skid resistance.

2. Moderate

Smooth appearance on the surfacing with excess binder and visible aggregates.

3. Severe

Aggregates in the wheel path are covered with excess binder. No skid resistance / slippery
Sticky surface during hot weather. Visible tyre marks in the binder.

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Appendices

Possible Causes:

Several factors can contribute to the occurrence of bleeding in flexible pavements:

1. Flaws in the design or construction of a bituminous layer or surfacing where the binder content is excessive. The binder is supposed to be contained in the voids between adjacent aggregates. If the voids are all filled with binder during construction any further densification or close packing of the aggregate under traffic loading will push the binder to the surface.
2. Use of low viscosity binders on slopes – during hot periods the binder will flow and accumulate in place leading to fatting of the surface.
3. Use of binder with a high content of volatiles such as cutback bitumen can lead to fatting of the surface of the road.
4. Excessive bitumen content: When the asphalt mixture contains an excessive amount of bitumen, the excess binder tends to migrate to the surface, resulting in a glossy and sticky appearance.
5. High temperatures: Elevated temperatures soften the bitumen in the pavement, causing it to become more viscous. The bitumen flows upwards, leading to bleeding. Hot weather conditions, particularly in regions with high ambient temperatures, can exacerbate this issue.
6. Inadequate compaction: If the asphalt mixture is not properly compacted during construction, air voids can be trapped within the pavement. When the pavement is exposed to traffic loads and high temperatures, the trapped air can expand, pushing the bitumen to the surface and causing bleeding.
7. Poor drainage: Insufficient drainage can contribute to the accumulation of water on the pavement surface. Water can displace the bitumen, resulting in bleeding. Additionally, the presence of moisture can reduce the cohesion between aggregate particles, making the pavement more susceptible to bleeding.
8. Aging and oxidation: Over time, bitumen undergoes ageing and oxidation processes, which can increase its viscosity and promote bleeding. This is more likely to occur in older pavements that have been exposed to weathering and UV radiation.

A2. Engineering Assessment – Functional Defects

Over and above the need to assess the structural performance of the pavement, defects that affect the perception of the road user which include speed of travel, comfort and safety need to be evaluated.

The following section discusses the functional defects prevalent in flexible pavements:

7. RIDING QUALITY / ROUGHNESS

Defect Description:

Roughness is defined as the condition of the road profile in relation to surface irregularity (rutting) variance and longitudinal deformation in the wheel path. The road user's perception of the road condition whilst driving is based on their experience measured by the smoothness of the surface and the riding comfort emanating from irregularities in the pavement surface.

Defect Rating and Indicative Pictures:

1. Minor

Slight unevenness in the road profile Slight ravelling and uneven patching, There are no visible potholes, or rutting. Smooth and comfortable ride.

2. Moderate

Moderate unevenness of the road profile, variation in rutting, ravelling / uneven patching and surface irregularity (rutting). Slightly uncomfortable riding quality.

3. Severe

Extensive unevenness of the road profile, variation in rutting, ravelling / uneven patching. Frequent and extensive potholes, Very uncomfortable riding quality, Significant speed reduction when driving,

Possible Causes:

1. Initial Construction: Improper compaction of pavement layers during construction can lead to unevenness and roughness. Inadequate surface preparation, improper mix design, or improper application of asphalt can also result in a rough pavement surface.
2. Traffic Loads: Repeated traffic loading, especially heavy axle loads or overloaded vehicles, can cause deformation and surface irregularity (rutting) in the pavement surface. This can lead to increased roughness over time.
3. Environmental Conditions: Factors such as temperature variations, moisture infiltration, and freeze-thaw cycles can affect the stability of the pavement layers. As a result, the pavement surface may deteriorate and become rough.
4. Lack of Maintenance: Inadequate maintenance practices, such as failure to repair potholes, cracks, or pavement distress, can contribute to roughness. Regular maintenance, including timely patching and resurfacing, helps to minimise roughness and maintain a smoother pavement surface.

8. SKID RESISTANCE

Defect Description:

Skid resistance in flexible pavements refers to the ability of the pavement surface to provide adequate friction between vehicle tyres and the road, particularly during braking and cornering manoeuvres. It plays a critical role in ensuring road safety by reducing the risk of skidding and maintaining vehicle control.

Defect Rating and Indicative Pictures:

1. Minor

Slight unevenness in the road profile. Slight ravelling and uneven patching. There are no visible potholes, or rutting. Smooth and comfortable ride.

2. Moderate

Moderate unevenness of the road profile, variation in rutting, ravelling / uneven patching and surface irregularity (rutting) Slightly uncomfortable riding quality.

3. Severe

Extensive unevenness of the road profile, variation in rutting, ravelling / uneven patching and surface irregularity (rutting). Frequent and extensive potholes. Very uncomfortable riding quality. Significant speed reduction when driving. Severe unevenness of the road profile.

Factors affecting skid resistance:

1. Poor Surface Texture: The texture of the pavement surface is crucial for providing friction. It is typically characterised by macrotexture and microtexture. Macrotexture helps in removing water from the tire-pavement interface, while microtexture provides contact points for tire grip.
2. Aggregate Properties: The type, size, shape, and angularity of the aggregates used in the asphalt mixture impact skid resistance. Aggregates with rough surfaces and good angularity tend to enhance frictional characteristics.
3. Polishing: Over time, traffic loads and environmental conditions can cause pavement surfaces to become polished, reducing skid resistance. Polishing occurs due to the wearing off of surface texture by tires.
4. Surface Contamination: Accumulation of debris, oil spills, leaves, or water on the pavement surface can significantly reduce skid resistance.

9. EDGE DEFECTS

Defect Description:

Edge defects refer to the deterioration or damage that occurs along the edges of the road surface. These defects represent the structural integrity and functionality of the pavement. Here are some common edge defects in flexible pavements:

Edge defects can be categorised as follows:

1. Edge Breaking: This is the formation of cracks along the edge of the pavement.
   - i. It can occur due to inadequate support, poor construction practices, or lack of proper drainage.
   - ii. Edge cracking allows water to infiltrate the pavement, leading to further damage.
2. Shoulder drop-off: Shoulder drop-off happens when there is a difference in elevation between the pavement and the shoulder. This defect can be hazardous to drivers, especially during lane changes or in emergencies. The vertical distance from the surface of the seal at the edge to the surface of the shoulder. Not usually considered a deflect if the drop-off is less than 10 mm to 15 mm.
   - i. It often occurs due to poor compaction, erosion, or lack of proper maintenance.
   - ii. An inadequate road alignment or sealed pavement width, which causes vehicles to traffic the pavement edge.
   - iii. Omission of a shoulder re-sheet following pavement overlay
   - iv. Erosion of the shoulder by wind and/ or water
   - v. Growth of vegetation at the edge of the seal.
3. Edge feathering: Edge feathering refers to the gradual thinning or deterioration of the pavement at the edge, starting as short transverse cracks from the road edge and spreading into the lane.
   - i. It can occur due to erosion, ageing, or traffic loads. Edge feathering can result in a weakened edge, making it prone to further damage and deterioration.
4. Vegetation growth: If vegetation, such as grass or weeds, grows along the pavement edge, it can cause damage. The roots of plants can penetrate the pavement, leading to cracking and deterioration. Vegetation growth can also impede proper drainage and increase the risk of moisture-related issues.

a. Edge Breaking

1. Minor ≤ 50mm into surfaced shoulder

2. Moderate 50mm – 300mm into surfaced shoulder

3. Severe >300mm into the surfaced shoulder

b. Shoulder Drop-off

1. Minor Step: ≤ 50mm

2. Moderate Step: 60mm-100mm

3. Severe Step: >100mm

c. Edge Feathering

1. Minor	Faint crack width	
2. Moderate	Distinct crack up to 3mm	
3. Severe	Crack >3mm	

d. Vegetation Overgrowth

1. Minor Grassroots in surfacing

2. Moderate Grass and small shrubs

3. Severe Overgrown shrubs and trees obstructing vision

Possible Causes:

1. Lack of maintenance: Insufficient or delayed maintenance, such as neglecting to repair cracks, regravelling unsurfaced shoulders or addressing drainage issues, can allow edge defects to worsen over time.
2. Inadequate design: If the pavement design does not adequately account for the anticipated traffic loads, environmental conditions, or the presence of weak soils, it can result in edge defects.
3. Poor construction practices: Inadequate compaction, insufficient thickness, inadequate edge support, or inadequate drainage during construction can lead to edge defects in flexible pavements.
4. Environmental factors: Extreme temperature variations, freeze-thaw cycles, excessive moisture, or prolonged exposure to water can contribute to the development of edge defects.

10. UNPAVED SHOULDER CONDITIONS

Defect Description:

An unpaved shoulder works as an additional safe recovery space for a paved road. Verges of roads that have paved shoulders that are less than 2m wide are unpaved shoulders. Unpaved shoulder defects in flexible pavements refer to the deterioration or degradation of the shoulder area located outside the paved portion of the road. These defects can manifest in various forms and can be caused by several factors. Here are some common unpaved shoulder defects:

Edge defects can be categorised as follows:

1. Erosion: Erosion occurs when the shoulder material is washed away or displaced by natural forces such as rainwater or wind. It can lead to the formation of rutting, gullies, or uneven surfaces on the shoulder.
2. Shoulder Settlement: Shoulder settlement refers to the sinking or subsidence of the shoulder area. It can occur due to inadequate compaction of the underlying soil during construction, weak subgrade soils, or prolonged exposure to heavy loads.
3. Vegetation Encroachment: When vegetation, such as grass or weeds, grows excessively on the shoulder, it can cause defects. The roots of these plants can penetrate the pavement structure and cause cracking or lifting of the shoulder.
4. Shoulder Rutting: Shoulder rutting is characterised by the formation of depressions or channels in the shoulder area. It can occur due to the repeated passage of vehicles with heavy axle loads or inadequate pavement design that does not consider the shoulder's load-carrying capacity.

Defect Rating and Indicative Pictures:

1. Minor

The shoulder has a few defects but can still be used for safe stopping at the posted speed.

2. Moderate

Maintenance is required. The shoulder has significant defects making it undesirable to stop at the posted speed

3. Severe

The shoulder has become unsafe and substantial maintenance is required to reinstate the gravel shoulder's function.

Possible Causes:

1. Lack of Maintenance: Neglected or infrequent maintenance of the shoulder can contribute to its deterioration. Lack of timely repairs and regravelling, drainage maintenance, or vegetation control can exacerbate existing defects and lead to further degradation.
2. Poor Construction Practices: Defects in the shoulder can result from poor construction techniques, including inadequate compaction, insufficient shoulder thickness, improper material selection, or improper drainage design.
3. Environmental Factors: Environmental factors such as freeze-thaw cycles, excessive rainfall, extreme temperatures, and exposure to chemicals or corrosive substances can accelerate the deterioration of the shoulder.

11. SURFACE DRAINAGE

Defect Description:

Surface drainage is defined by the ability and rate at which the road geometry clears off water away from the surface during and after any rainfall event. The surface drainage can also be rated by its ability to keep away grit washed unto the road surface from the verges. This defect can easily be rated according to the extent of ponding especially within the wheel paths and the volume of water splashes when driving.

Defect Rating and Indicative Pictures:

1. Minor The surface drains nicely very low volumes of water splash off the wheel path with every pass

2. Moderate Distress causing localised slight ponding.

3. Severe Widespread and severe ponding along the wheel path. Pavement slipperiness and aquaplaning when driving through.

Possible Causes:

1. Insufficient cross slope: If the cross slope is inadequate or poorly designed, it can impede water runoff and cause water to accumulate on the pavement surface.
2. Lack of longitudinal slope: If the pavement lacks proper longitudinal slope, water may not flow or drain efficiently, resulting in ponding or accumulation of water on the surface.
3. Clogged or inadequate drainage systems: Poorly designed drainage systems, including gutters, catch basins, pipes, or culverts, obstruct water flow and prevent effective drainage. Accumulated debris, silt, or vegetation growth within the drainage infrastructure can exacerbate the problem.
4. Pavement settlement or deformation: Settlement or deformation of the pavement surface causes localised depressions or low spots where water tends to accumulate. This can occur due to inadequate compaction during construction, weak subgrade soils, or heavy traffic loads.

5. Surface irregularities and rutting: uneven pavement surfaces with rutting or irregularities can disrupt the flow of water and create areas of water ponding. These surface defects can be caused by heavy traffic, inadequate maintenance, or insufficient pavement thickness.
6. Insufficient or damaged pavement seals: Flexible pavements typically rely on surface seals or bituminous layers to provide waterproofing and protect the underlying layers. If these seals are insufficient, damaged, or deteriorated, they can allow water infiltration and reduce the effectiveness of surface drainage.
7. Inadequate maintenance practices: Poor maintenance, such as failure to clean drains, remove debris, or repair cracks and potholes in a timely manner, can contribute to surface drainage defects. Lack of routine maintenance can worsen existing issues and create new drainage problems.
8. Lack of Maintenance: Neglected or infrequent maintenance of the shoulder can contribute to its deterioration. Lack of timely repairs and regravelling, drainage maintenance, or vegetation control can exacerbate existing defects and lead to further degradation.

A.3 Engineering Assessment – Structural Defects

This part of the manual provides an assessment of existing pavement condition to identify potential signs of distress. Visible defects signify pavement deterioration typically caused by stresses induced by traffic loading, climate, environmental impact, surfacing defects, and pavement material quality.

A detailed outline of all the defects related to the deterioration or failure of pavement structural layers is discussed in this section:

12. TRANSVERSE CRACKING

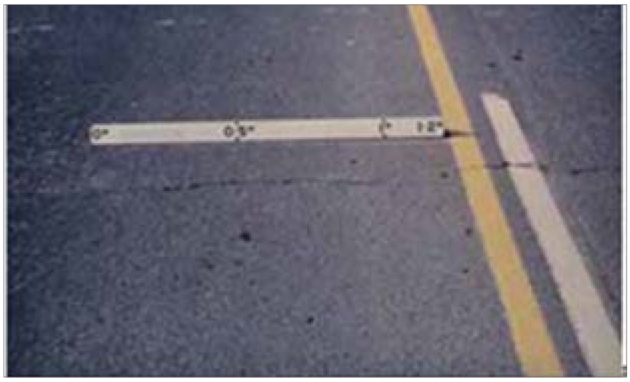
Defect Description:

Unconnected cracks running across o/ perpendicular to the direction of travel. Transverse cracks are related to shrinkage in cement-stabilised bases or subbases, temperature-related fatigue and climate. They can also be a sign of poor compaction in the pavement structure along the edges of the section where after the reinstatement of the pavement layers following the installation of services across the road. The assessor should be able to distinguish surface cracks and edge defects from transverse cracks.

Defect Rating and Indicative Pictures:

1. Minor — Light or faint cracks ± 1 mm wide.

2. Moderate — Open crack with spalling and displaying evidence of deformation. ± 3mm wide.



3. Severe — Wide open cracks > 3mm wide cracks with spalling. Wide Open cracks >10mm with less secondary defects.

Possible Causes:

Transverse cracking is caused by a combination of factors, including:

1. Thermal Stresses: Fluctuations in temperature cause the pavement materials to expand and contract, inducing stresses. Over time, these repetitive stresses can lead to the formation of cracks perpendicular to the pavement's direction.
2. Aging and Hardening of Asphalt Binder: As asphalt ages, it undergoes oxidation and hardening. This process reduces the flexibility and resilience of the asphalt binder, making it more susceptible to cracking.
3. Poor Design or Construction: Inadequate pavement design or construction practices can also contribute to transverse cracking. If the pavement thickness, mix design, or layer interfaces are not properly designed or constructed, it leads to localised stress concentrations, making the pavement vulnerable to cracking.
4. Insufficient Pavement Thickness: Pavements with inadequate thickness lack the necessary structural capacity to resist the stresses imposed by traffic loads and temperature changes. As a result, the pavement develops transverse cracks as it fails to withstand the applied forces.
5. Traffic Loads: Heavy or excessive traffic loads accelerate the development of transverse cracking. The repeated loading and stress from vehicles weaken the pavement structure and contribute to crack initiation and propagation.

13. LONGITUDINAL CRACKING

Defect Description:

Longitudinal cracks usually start forming in the wheel path at its early development stage and spread across the entire cross-section, running parallel to the direction of travel with the occurrence of limited branching in some cases. They can vary in length, width, and severity. The assessor should ably distinguish between surface cracks and edge defects from transverse cracks.

Defect Rating and Indicative Pictures:

1. Minor

Light or faint cracks ± 1 mm wide.

2. Moderate

Open crack with spalling and displaying evidence of deformation. ± 3mm wide.

3. Severe

Wide open cracks > 3mm wide cracks with spalling. Wide Open cracks >10mm with less secondary defects.

Possible Causes:

Several factors can contribute to the development of longitudinal cracks in flexible pavements:

1. Heavy wheel loading: on an embrittled surfacing or a base with insufficient strength. These tend to be irregular and are progressive if untreated.
2. Cracking at construction joints: these develop when construction joints are not constructed properly especially in asphalt and stabilised bases. They tend to be regular with well-defined geometry. These may or may not be progressive.
3. Shrinkage cracking: these occur when surfacing is placed on cement stabilised base. The cracking is exacerbated by poor curing during construction. The cracks can be progressive or non-progressive and the latter is more prevalent. Transverse cracks tend to be predominant over longitudinal ones. Check that cracks are extending into the base course.
4. Cracks caused by geotechnical movements: these cracks would be associated with deformation or progressive irregularity and would normally be localised rather than widespread. When surveying, it is important to check for any potential for geotechnical instability or differential settlement. Such cracking is often mistaken for pavement failure.
5. Cracking caused by fatigue: this is caused by repetitive passages of the wheel loads causing repetitive stresses and strains. While the ultimate load limit may not be exceeded such repetitions can cause micro-cracks to develop and subsequently grow to macro-cracks.

14. BLOCK CRACKING

Defect Description:

Interconnected cracks form a series of definite block patterns. Typically distributed over a large area of pavement. In the early stages of their development, do not necessarily signify pavement deterioration, but the potential of deterioration. However, with further exposure to traffic action, secondary cracks are formed, which eventually leads to severe distress.

Defect Rating and Indicative Pictures:

1. Minor

Light or faint cracks ± 1 mm wide.

2. Moderate

Open crack with spalling and displaying evidence of deformation. ± 3mm wide.

3. Severe

Wide open cracks > 3mm wide cracks with spalling. Wide Open cracks >10mm with less secondary defects.

Possible Causes:

1. Fatigue Loading: One of the primary causes of block cracking is repetitive loading from traffic. Over time, the repeated wheel loads impose stress on the pavement surface, leading to the development of cracks. This type of cracking is often observed in areas with heavy traffic or where there is a high concentration of truck or bus traffic.
2. Aging and Drying of Asphalt Binder: As flexible pavements age, the binder material within the asphalt mixture undergoes oxidation and loses its elasticity. This ageing process makes the pavement more susceptible to cracking. Additionally, exposure to the sun's ultraviolet (UV) radiation accelerates the drying of the asphalt binder, reducing its flexibility and contributing to the formation of block cracks.
3. Inadequate Pavement Design: Poor design practices, such as insufficient pavement thickness or improper selection of materials, can result in inadequate structural integrity. When the pavement is unable to withstand the applied loads, it can lead to distress like block cracking.
4. Subgrade Settlement: If the subgrade soil beneath the pavement undergoes settlement or consolidation, it can cause the pavement layers to deform and crack. Subgrade settlement can occur due to a variety of factors, including weak or poorly compacted soils, moisture changes, or underground utilities.
5. Temperature and Climate Effects: temperature variations, cause thermal cyclic action which causes cracking.
6. Construction Defects: Improper construction practices, such as inadequate compaction of the asphalt layers, incorrect mix design, or poor bonding between layers, can lead to block cracking. Insufficient compaction reduces the pavement's ability to withstand traffic loads and increases the likelihood of crack formation.
7. Lack of Maintenance: Neglected maintenance practices, such as delayed crack sealing or seal coating, can allow water infiltration into the pavement structure. Water penetration weakens the pavement layers, leading to accelerated cracking, including block cracking.

15. CROCODILE CRACKING

Defect Description:

Interconnected or interlaced cracks that usually form within the wheel path indicating failure of surfacing or base layer. Crocodile cracks typically signify the end of the pavement design life. Crocodile cracking is often confined to the wheel paths and may have a noticeable longitudinal grain. Crocodile cracking usually indicates that the surfacing has reached the end of its design life.

Defect Rating and Indicative Pictures:

1. Minor

Light or faint cracks ± 1 mm wide. Crocodile pattern not fully developed.

2. Moderate

Distinct cracks with slight deformation, movement, pumping and slight spalling around the edges of each polygon. ±3mm wide.

3. Severe

Cracks > 3mm with severe deformation. Defects spread outside the wheel paths and formation of densified crocodile crack patterns.

Possible Causes:

1. Fatigue Loading: Over time, the repeated application of heavy loads, especially in areas of high traffic volume or at locations with stop-and-go traffic patterns, leads to the development of crocodile cracks.
2. Structural Weakness: Structural weakness due to inadequate design, poor construction practices, and poor layer work material quality results in pavement structure being unable to withstand the imposed loads.
3. Aging and Deterioration: Embrittlement of the surfacing due to ageing. This loss of flexibility makes the pavement susceptible to rapid cracking under load.
4. Environmental Factors: Factors such as temperature variations, moisture intrusion, and freeze-thaw cycles contribute to the formation and propagation of cracks in the pavement.
5. Poor Maintenance: Insufficient or improper maintenance practices can exacerbate crocodile cracking. Lack of timely crack sealing, seal coating, or pavement rehabilitation can allow water and debris to penetrate the pavement layers, accelerating the deterioration process.
6. Subgrade Issues: Weak underlying soil or subgrade can also contribute to crocodile cracking. If the subgrade is weak or experiences excessive moisture changes, it can lead to differential settlement and pavement distress which manifests as crocodile cracks.
7. Overloading: Excessive axle loads or overloaded trucks can cause localised stress concentrations, leading to the development of crocodile cracking. This is particularly prevalent in areas with heavy industrial or commercial traffic.

16. DIAGONAL CRACKS

Defect Description:

Unconnected crack running diagonally to the wheel path.

Defect Rating and Indicative Pictures:

1. Minor — Light or faint cracks ± 1 mm wide.

2. Moderate — Distinct cracks with slight deformation, slight spalling around the edges of each polygon ±3mm wide.

3. Severe — Cracks > 3mm with severe deformation.

Possible Causes

There are several causes of diagonal cracking in flexible pavements:

1. Fatigue Loading: Fatigue loading, also known as repetitive loading, is one of the primary causes of diagonal cracking. It occurs when the pavement is subjected to repeated traffic loads over time, leading to the development of cracks. The cyclic stresses caused by heavy vehicle loads weaken the pavement structure and initiate cracks that propagate diagonally.
2. Insufficient Thickness: Inadequate pavement thickness or inadequate design for the expected traffic loads can result in diagonal cracking. When the pavement thickness is insufficient to withstand the applied loads, it becomes more susceptible to cracking, including diagonal cracks.
3. Subgrade Settlement: The settlement of the underlying subgrade can induce diagonal cracking in the pavement. Subgrade settlement can occur due to poor soil conditions, improper compaction during construction, underground services or inadequate drainage. As the subgrade settles unevenly, it creates differential movements that cause diagonal cracks to form in the pavement.
4. Temperature Variations: Temperature fluctuations, particularly in regions with significant temperature variations, can contribute to diagonal cracking. Asphalt is sensitive to temperature changes, expanding in hot weather and contracting in cold weather. Repeated expansion and contraction can lead to thermal stresses that result in diagonal cracks.
5. Lack of Maintenance: Inadequate or delayed maintenance can exacerbate the development of diagonal cracking. If pavement distresses like potholes, edge cracking, or longitudinal cracks are not promptly repaired, they can propagate and transform into diagonal cracks over time.
6. Construction Deficiencies: Poor construction practices, such as inadequate compaction during asphalt placement or improper joint construction, can lead to diagonal cracking. If the asphalt layers are not compacted properly, the pavement becomes susceptible to cracking under traffic loads. Similarly, improper joint construction or cold joints can create weak points that initiate diagonal cracks.

17. REFLECTIVE CRACKS

Defect Description:

This type of cracking appears in the overlayed pavement systems in which the overlay mirrors the crack pattern in the underlying pavement layer. Reflective cracks manifest in overlaid pavements, especially when asphalt overlays are placed over distressed rigid or flexible pavements.

Defect Rating and Indicative Pictures:

1. Minor Light or faint cracks ± 1 mm wide.

2. Moderate Distinct cracks with slight deformation, slight spalling around the edges of each polygon ±3mm wide.

3. Severe Cracks > 3mm with severe deformation.

Possible Causes

There are several causes of diagonal cracking in flexible pavements:

1. Thermal Stresses: Pavements expand and contract with temperature changes. If the old pavement and the new overlay expand and contract at different rates, or if the old cracks move due to temperature variations, this can lead to the development of cracks in the overlay.
2. Movement in Underlying Layers: The original pavement may have cracks due to various reasons such as traffic loading, temperature variations, and ageing. When the new overlay is subjected to traffic loads or temperature changes, the old cracks move, causing stresses in the overlay. This leads the overlay to crack directly above the old crack.
3. Differential Settlement: If there is uneven settlement in the base or subgrade layers, it can cause the overlay to crack.
4. Load-Associated Stresses: Traffic load induces stresses and strains in the pavement. Existing cracks or joints in the old pavement can cause a concentration of these stresses in the overlay, leading to the development of cracks.
5. Inadequate Pavement Structure: If the original pavement structure was not designed to adequately support the imposed loads, it might have developed cracks. Overlaying such a pavement without addressing the structural issues can lead to reflective cracks.
6. Ageing and Hardening of Binders: As the binder in the asphalt mix ages, it becomes more brittle, making the pavement less resilient to traffic load and temperature changes.
7. Inadequate Bonding Between Layers: If the overlay doesn't bond well with the layer beneath it (perhaps due to dirt, water, or a lack of tack coat), it may not distribute loads effectively, leading to reflective cracking.
8. Joint Movement in Underlying Concrete: in rigid pavements, if an asphalt overlay is placed over concrete, the movement at the concrete slab joints can lead to reflective cracking in the overlay.
9. Poor Construction Practices: Inadequate compaction, improperly prepared surfaces, or not properly sealing existing cracks can all contribute to premature reflective cracking.
10. Moisture Penetration: When moisture enters existing cracks, it can weaken the underlying layers.
11. Incompatibility of Materials: Using materials with vastly different stiffness values can induce additional stresses. For instance, placing a very stiff overlay on a very flexible base can make the pavement system more susceptible to reflective cracking.

18. PUMPING AND PIPING

Defect Description:

Pumping is a phenomenon where a mix of water and fine aggregates is forced out from the underlying pavement layers onto the surface through existing cracks under traffic load. Heavy Goods Vehicles (HGV) generate dynamic wheel loads that cause the pavement layers to deform and recover repeatedly. This cyclic loading creates a pumping action, especially in the presence of water-saturated or poorly drained subgrade soils. The process of pumping involves the upward movement of fine particles, water, and air through the cracks or joints in the pavement structure

Piping occurs in a similar way. The difference is that water enters from a place of higher elevation to a lower elevation and oozes out through the cracks from under the road onto the surface of the road.

The signs to look out for are the stains of fines washed out onto the surface of the road. Piping and pumping degrade the pavement significantly and quickly.

Defect Rating and Indicative Pictures:

1. Minor Not easily visible when driving.

2. Moderate Clearly visible fines next to the cracks.

3. Severe Extensively visible deposits of fines next to the cracks.

Possible Causes:

1. Heavy or repetitive traffic loads: Frequent heavy vehicle loads, or high traffic volumes can exacerbate pumping in flexible pavements. The repetitive loading induces cyclic movement and dynamic stresses that promote the upward displacement of fine materials.
2. Weak subgrade or base: If the subgrade or base materials beneath the pavement are weak or poorly compacted, they may deform under traffic loads. This deformation can create voids or spaces, allowing fine materials to be forced upward during the load cycles.
3. Inadequate drainage: Poor drainage or inadequate provision for the collection and removal of water from the pavement structure can contribute to pumping. Accumulated water can soften or weaken the underlying materials, increasing the potential for pumping to occur.
4. High water table: When the water table is close to the pavement surface or above it, the hydraulic pressure exerted by the water can cause the upward movement of fine materials through cracks and joints. The repeated loading from traffic induces a pumping action, displacing the fines.
5. Insufficient or ageing pavement structure: If the pavement layers, such as the asphalt surface or base course, are deteriorated, cracked, porous, or aged, they may provide pathways for the fines to be forced out. As traffic loads pass over the weakened areas, the fines can be pushed upward through the cracks or joints.

19. MEANDERING CRACKS

Defect Description:

Unconnected irregular crack, varying in line and direction: This usually occurs singly.

Defect Rating and Indicative Pictures:

1. Minor Light/faint cracks ± 1mm wide.

2. Moderate Distinct cracks with slight deformation, slight spalling around the edges of each polygon ±3mm wide.

3. Severe Cracks > 3mm with severe deformation.

Possible Causes

The causes of meandering cracking in flexible pavements can be attributed to various factors, including:

1. Fatigue and aging: Flexible pavements are subjected to repeated traffic loads, which lead to the accumulation of stress over time. This stress, combined with aging and deterioration of the pavement materials, can cause the formation of meandering cracks.
2. Environmental factors: Temperature variations and moisture infiltration play a significant role in the development of meandering cracks. Thermal cycling, where the pavement expands and contracts due to temperature changes, can induce tensile stresses that contribute to cracking. Similarly, moisture infiltration into the pavement layers can weaken the material and reduce its load-carrying capacity, leading to cracking.
3. Insufficient pavement design: Inadequate design considerations, such as inadequate thickness of the pavement layers or improper selection of materials, can result in meandering cracking. If the pavement structure is not designed to withstand the expected traffic loads and environmental conditions, it becomes more susceptible to cracking.
4. Poor construction practices: Deficiencies in construction techniques, such as inadequate compaction of the asphalt layers, improper joint construction, or inadequate bonding between layers, can contribute to meandering cracking. These issues can create weak zones within the pavement, making it more prone to cracking.
5. Subgrade-related issues: Meandering cracking can also be influenced by subgrade-related problems. Poorly compacted or unstable subgrade soils can lead to differential settlement, which causes stress concentrations and ultimately leads to cracking in the pavement layers.

20. PARABOLIC / CREST SHAPED CRACKS

Defect Description:

Unconnected irregular parabolic crack, varying in direction. This usually occurs singly, and they are often found in areas where the pavement has undergone rehabilitation or overlay, indicating a structural or material compatibility issue between the new and existing layers. These occur when the surfacing moves horizontally particularly where stresses are generated on climbs and steep descends.

Defect Rating and Indicative Pictures:

1. Minor

Light/faint cracks ± 1mm wide.

2. Moderate

Distinct cracks with slight deformation, slight spalling around the edges of each polygon ±3mm wide.

3. Severe

Cracks > 3mm with severe deformation.

Possible Causes

The causes of meandering cracking in flexible pavements can be attributed to various factors, including:

1. Traction or breaking forces: Surfacing to slip horizontally and much more along the centre of the force and less on the side causing the crescent cracks.
2. Poor bonding between the surfacing and the underlying layers: This may occur when a tack coat is applied in the interface.
3. Too much tack coat or prime coat applied in the interface: Causes the wearing course to slide under lateral stress. Check through the cracks for excessive binder in the interface.
4. Localised slope failure of landslide: Occurs where there is an embankment or pronounced downslope. If required, remove vegetation and debris to visualise the extent of slope failure.
5. Too much binder in AC and micro-surfacing, etc.: Excess binder causes instability in the surfacing. The cracks tend to be fine and partially close in hot weather.

21. SHOVING

Defect Description:

The shoving is the upward displacement or deformation of the pavement surface, typically near the wheel paths. It is characterised by a series of parallel ridges or waves that can significantly impact the ride quality and safety of the road. This defect manifests as bulging in the pavement surfacing layer due to plastic flow. Surface deformation is common in high-shear stress zones. This type of defect will occur in either the transverse or longitudinal direction. The deformation in the transverse direction should not be confused with rutting.

Defect Rating and Indicative Pictures:

1. Minor

No need to reduce speed when driving a light vehicle. Curve crest / depth is <10mm

2. Moderate

Reducing speed is necessary. Curve crest/ depth is between 10 mm and 20 mm.

3. Severe

Motorists start avoiding the affected sections. Curve crest/depth >20mm.

Possible Causes:

The primary cause of shoving in flexible pavements is related to shear stress and excessive horizontal movement of the pavement layers. Several factors contribute to this problem, including:

1. Shoving in Asphalt:
   - i. Caused by heavy loading on AC with low percentage voids.
   - ii. AC with low resistance against flow.
   - iii. Overloading of asphalt with an underlying rigid base and low viscosity binder.
2. Shoving of bases overlaid with thin bituminous surfacing:
   - i. Poorly compacted base course
   - ii. Base softened with ingress of excessive moistures in the case where the base material is moisture sensitive i.e., with high plasticity modulus (PM) of plasticity product (PP)
   - iii. Overlading.
   - iv. Over-compacted pedogenic bases such as laterite and calcrete. In this case, failure is rapid and may be pronounced after the first heavy truck on the new road. It is caused by the degradation of the materials during compaction.
3. In wearing course of unpaved roads:
   - i. Wet-wearing course that is poorly compacted
   - ii. Wet-wearing course materials with low CBR.
   - iii. Overloading.

22. POTHOLES

Defect Description:

Potholes are bowl-shaped depressions or cavities that form on the surface of flexible pavements, as a result of Loss of material in the wearing course and underlying pavement layers mostly in the wheel path. Potholes signify structural failure induced by traffic action. They develop from cracking or severe loss of aggregate and therefore they are a secondary form of distress which starts from the top of the pavement downwards. Potholes vary in size and depth, ranging from small indentations to large craters that can pose a hazard to vehicles and pedestrians.

Defect Rating and Indicative Pictures:

1. Minor

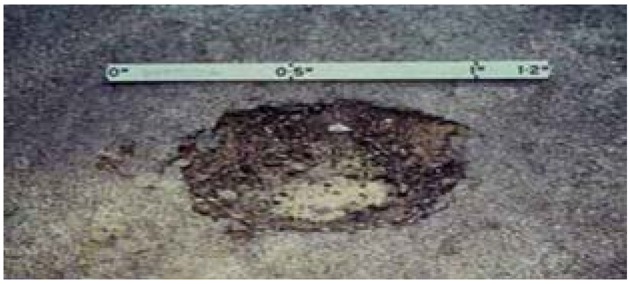
Diameter ≤ 250mm
Depth < 30mm.

2. Moderate

Diameter 250mm – 500mm
60mm – 75mm deep.
Moderately spaced.

3. Severe

Diameter >500mm
<30mm deep.
Many.



Possible Causes

1. Traffic Load: Overloading can cause the pavement, particularly the surfacing to break up. Over time, repeated loading weakens the pavement structure, causing cracks to form.
2. Cracking: Causes discontinuities in the surfacing which lead to spalling and causing holes to develop from the surfacing downward and down into underlying layers.
3. Water hammer effect: This is the immense pressure that builds up in water that is sitting or flowing in the cracks, as well as the surface when a wheel passes at high speed within milliseconds creating the water-hammer effect. This is the reason potholes initiate and develop more quickly during the rainy season. This is also why cracks should be filled without fail before the beginning of the rainy season. The shock wave created by the water-hammer effect causes:
   i. The bonding in the interface of layers gets ripped off.
   ii. Stripping of binder from aggregate thus removing the interparticle bonds.
   iii. Increase in porosity and permeability by opening up water pathways in the layers.
   iv. Dramatic or exponential growth of the potholes when the wheel hit the ponded water further exacerbating the water hammer effect on the sides of the pothole.
4. Sponges or weak spots in the pavement: These could be spots in the pavement that are highly voided or poorly compacted. Initial cracking allows ingress of water causing breakup of the surface or severe shoving leading to the development of potholes. This normally happens in the early stages of the life of the road.
5. Poor Construction or Maintenance: Inadequate construction practices, such as inadequate compaction of the asphalt layers or insufficient thickness of the pavement, can contribute to the development of potholes. Similarly, if routine maintenance activities like crack sealing and pothole patching are neglected, small cracks can quickly evolve into larger potholes. Excessive heating of the binder during construction due to weather, causes rapid oxidation, hardening the binder until eventually causing cracks under the traffic load.
6. Ageing or embrittlement of the surfacing: The is a cause that bears on the condition of the pavement and surfacing rather than an external factor. To identify this check for the following:
   i. The original cross-sectional profile of the pavement remains intact – a straight-edge or tight string can be used to show this when held from the centre to the shoulder. Be mindful of the normal rutting in wheel parts.
   ii. Surfacing breaks up while the surface of the base remains intact.
   iii. The penetration of the recovered binder has exceptionally low penetration and very high softening points.
   iv. The surfacing splinters rather than deform when hammered or pressurised to indicate ductility of the binder.
7. Subsurface Issues: Potholes can also be caused by problems in the underlying layers of the pavement. Poor soil compaction, inadequate drainage, or weak base layers can lead to the development of potholes, as these issues affect the overall stability and integrity of the pavement.
8. Mechanical damage: Mechanical impact during vehicle accidents or breakdowns weakens the surfacing or underlying layer, exposing it to further deterioration caused by traffic loading and moisture ingress. If not repaired this eventually develops into a pothole.
9. Chemical action: Oil spillages and chemicals, especially those with corrosive properties, react with the binder and aggregates in the asphalt or bitumen, causing softening, cracking, or disintegration of the pavement surface. This leads to the loss of skid resistance, roughness, and a decrease in overall pavement integrity. Oil spillages weaken the surfacing layers and expose them to moisture damage, accelerating deterioration under the traffic load.

23. RUTTING

Defect Description:

Rutting is deformation irrecoverable displacements in the wheel paths due to repeated passages of wheel loads on the road. Rutting can be narrow or wide and of varying depth along the carriageway. Measure the maximum depth of the rut at each point. Also, measure the maximum rut depth in the test segment/section. The data is used as follows:

1. Maximum rut depth in a section is used for structural analysis and design as well as terminal condition determination for the pavement. Some standards use 20mm and others 30mm rut depth thresholds, beyond which the pavement is considered terminal.
2. Average rut depth is used in condition assessment for pavement condition monitoring and prioritisation of interventions.

Defect Rating and Indicative Pictures:

1. Minor

Difficult to notice because the rut depth <5mm

2. Moderate

Easily to notice when driving. Rut depth ranges between 10mm-15mm

3. Severe

Severe deformation which affects vehicle stability at high speed– Rut depth >20mm.

Possible Causes:

1. Secondary compaction and densification of pavement layers with time – this can be severe if pavement layers are poorly compacted.
2. Deformation caused by miniscule but incremental permanent strain under load – this is exacerbated by overloading and/or moisture ingress.
3. Inadequate bearing strength resulting from under-design of pavement or any of its layers.
4. Trafficking asphalt concrete while the internal temperatures are close to the softening point of the binder, such as during a severe heat wave.
5. Low air voids content in asphalt that causes reduction in the interparticle interlock resulting in aggregate suspension in viscous binder. In this case, ruttings develop rapidly with minimal cracking. There may also be significant shoving.

24. CORRUGATIONS

Defect Description:

Transverse undulations in the pavement surface or base, most associated with spray seal or unsealed pavements but can occur in thin asphalt surfaced roads too. They are characterised by a repetitive pattern of waves or ripples in the pavement surface, typically running parallel to the direction of traffic flow. Wavelengths of undulations can range between 0.3 and 2 metres.

Defect Rating and Indicative Pictures:

1. Minor — Visible but not felt when driving light vehicles.

2. Moderate — Requires speed reduction.

3. Severe — Vehicles will use alternative wheel path and drive slowly to avoid discomfort.

Possible Causes:

The main cause of corrugations is usually the accumulation of vertical and horizontal deformations within the pavement layers. These deformations can arise from a variety of factors, including:

1. Traffic Loads: High volumes of heavy traffic, especially when coupled with braking or acceleration forces, can lead to the development of corrugations over time.
2. Inadequate Compaction: If the pavement layers were not properly compacted during construction, they may be prone to deformation and the subsequent development of corrugations.
3. Insufficient Pavement Thickness: Pavements that are too thin or lack adequate structural support may be more susceptible to deformation and the formation of corrugations under traffic loads.
4. Weak Subgrade: A weak or poorly compacted subgrade can result in differential settlement, leading to localised deformations and corrugations.

1
2
3
4
5
6
7
8
9
10
Appendices

25. STRUCTURAL PATCHING

Defect Description:

A structural patching comprises repaired potholes as a result of localised disintegration of the pavement. The surrounding pavement may exhibit signs of cracking, rutting, or fatigue, indicating a loss of structural integrity in that specific area. Existing localised repair patches give information on the historic distress. The type and average size of the patch gives the assessor an idea of the extent, type and severity of the distress that was previously repaired.

Defect Rating and Indicative Pictures:

1. Minor Area < 2m²

2. Moderate Area ± 5m²

3. Severe Area > 10m²

Possible Causes:

1. Construction Issues: Inadequate construction practices during the initial pavement installation or subsequent repairs can result in structural patching defects. Improper compaction of the layers, insufficient thickness of the pavement sections, or inadequate bonding between layers can all lead to localised failures. Additionally, inadequate or low-quality materials used during construction can contribute to premature deterioration.
2. Environmental Factors: Environmental conditions can contribute to the formation of structural patching defects. Freeze-thaw cycles, where water infiltrates the pavement and expands upon freezing, can lead to cracking and weakening of the pavement layers. Additionally, excessive moisture, poor drainage, or prolonged exposure to moisture can soften the pavement materials and cause instability.
3. Traffic Loads: Heavy traffic loads exert significant stress on flexible pavements. Over time, repeated axle loads from vehicles can exceed the pavement's design capacity, leading to the development of structural deficiencies. This is especially true in areas with high truck traffic or improper load distribution.
4. Aging and Lack of Maintenance: Over time, flexible pavements naturally age and deteriorate. Lack of regular maintenance, such as timely crack sealing, seal coating, or overlaying, can accelerate the development of structural patching defects. Without proper maintenance, cracks and other pavement distresses can progress, allowing water infiltration and further deterioration.
5. Subgrade Issues: The underlying subgrade soil provides support to the flexible pavement. If the subgrade is weak, expansive, or poorly compacted, it can lead to differential settlement and deformation, causing localised structural failures in the pavement layers above.

Appendix B: Traffic Counts Survey Form

CLASSIFIED SECTION COUNTS FORM					
Consultant/ Institution:			Project Name:		
Date:		Day:		Day/Night:	
Direction From:		Direction to:		Station Name:	
Enumerator Name:		Phone Number:		Supervisor Name:	

Hour	Motorcycle	Tuk-tuk	Cars	Pick-up, Vans, Jeep, SUV	Micro-bus (10-14 seater)	Minibus (15-25)	Bus (26-53)	Omni bus (>53)	Light Trucks (<3.5 tonnes load) unladen	Medium Trucks (2 axles, 3.5-7.5 tonnes load) unladen	Heavy Trucks (3 & 4 axles, 7.5-12 tonnes load) unladen	Articulated and Draw-back Trucks (5-7 axles)	Others (Tractors, etc)
5:00-6:00 AM													
6:00-7:00 AM													
7:00-8:00 AM													
5:00-6:00 PM													
TOTAL													

1 2 3 4 5 6 7 8 9 10 Appendices

Appendix C: Origin Destination Survey Form

ORIGIN DESTINATION SURVEY FORM					
Consultant/ Institution:			Project Name:		
Date:		Day:		Sheet No:	
Direction From:		Direction To:		Station Name & ID:	
Enumerator Name:		Phone Number:		Supervisor Name:	

SN No	Vehicle Reg No.	Vehicle classification	Axle type	Origin *(from)*	Destination *(to)*	Frequency of trip	Commodity/goods carried	Remarks/ notes
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								

NOTES:
Additional columns can be added based on the objective of the survey. For example, motorists could be asked on perception of quality.

Appendix D: Axle Load Survey Form

AXLE LOAD SURVEY FORM					
Consultant/Institution:			Project Name:		
Date:		Day:		Sheet No:	
Direction From:		Enumerator Name:		Station Name & ID:	
Direction To:		Phone Number:		Supervisor Name:	

SN No.	Vehicle Reg No.	Vehicle Classification	Axle Configuration	Loading 1. *Unladen (goods)* 2. *Half laden* 3. *Fully laden* 4. *Empty (passengers)* 5. *Half full* 6. *Full*	Wheel Loads (Tonnes)							Comments
					1	2	3	4	5	6	7	
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												

Appendix E: Visual Condition Survey Form

VISUAL CONDITION SURVEY FORM					
Road Name:				General Remarks:	
Date of Survey:		Direction:			
Road Width:		Road Surfacing Type:			
Weather Condition:		Phone Number:			

***I.C:** Longitudinal cracks, **AC:** Crocodile, **TC:** Transverse cracks, **PH:** Potholes, **DD:** Depression & deformation, **R:** Rutting, **SH:** Shoving, **PT:** Patches, **ST:** Stripping, **CW:** Corrugations*
***NB:** For every defect report intensity, extent, position and size, **SD:** Surface dressing*

LHS					RHS			
Chainage Km	Side ditch	Drainage Structure	Shoulders	Carriageway	Carriageway	Shoulders	Drainage Structure	Side ditch

Appendix F: Rut Depth Measurement Form

VISUAL CONDITION SURVEY FORM			
Project:		**Date:**	
Road Section:		**Length of Straight edge:**	
Chainage (reference):		**Section:**	
Direction of Travel:		**Upstands:**	

Section /Remarks	Chainage (Km)	LHS LANE								RHS LANE							
		Rut Depth Measurements (mm) Corrected for upstands								Rut Depth Measurements (mm) Corrected for upstands							
		Pos.1	Pos. 2	Pos. 3	Pos. 4	Pos.5	Pos. 6	Pos. 7	Maximum	Pos.1	Pos. 2	Pos. 3	Pos. 4	Pos.5	Pos. 6	Pos. 7	Maximum
		0.0m	0.5m	1.0m	1.5m	2.0m	2.5m	3.0m	Depth	0.0m	0.5m	1.0m	1.5m	2.0m	2.5m	3.0m	Depth

Appendix G: Present Serviceability Rating Form

PRESENT SERVICEABILITY RATING (PSR) - Form 1				
Project name:				
Section:			Wearing Course:	
Towards:			Binder Course:	
Pavement Structure:			Base:	
Survey Date:			Sub-base:	

Sub- section	Length (mm)	General Appearance	Surface Texture	Bitumen Condition	Potholes	Surface Irregularity	Rutting	Cracking	Sum of Points A-G Max: 40	Average points	%	Remarks	PSR
1. Km 0+000-10+000											0.0		0.0
2. Km 10+000-18+000											0.0		0.0
3. Km 22+000-23+750											0.0		0.0
Total rd. length and ∑ PSR											0.0		0.0
Average PSR		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0

A. General Appearance

Grade	Points
V. good	4 to 5
Good	3 to 4
Fair	2 to 3
Poor	1 to 2
V. Poor	0 to 1

B. Texture

Grade	Points
V. Coarse	0 to 2
Coarse	2 to 4
Preferable	4 to 5
Smooth	2 to 4
V. smooth	0 to 2

C. Bitumen Condition

Grade	Points
V.Stiff (brittle)	0 to 2
Stiff	2 to 4
Intermediate	4 to 5
Soft	2 to 4
V.soft (plastic)	0 to 2

D. Potholes

Grade	Points
0 Potholes	5
1 Potholes	4
2-3 Potholes	3
4-6 Potholes	2
7-10 Potholes	1
> 10 Potholes	0

E. Surface Irregularity

Grade	Points
Even	5
1 Location	4
2-3 Locations	3
4-5 Locations	2
Over 5 Locations	1
Entire road bumpy	0

F. Rutting

Grade	Points
No Rutting	5
1 Location	4
2-3 Locations	3
4-5 Locations	2
Over 5 Locations	1
Entire length	0

G. Cracking

Grade	Points
No cracks	5
1 Location	4
2-3 Locations	3
4-6 Locations	2
7-10 Locations	1
> 10 Locations	0

PSR Rating

Average Point	%	Rating
4.5 to 5.0	80-100	V.Good
3.5 to 4.5	60-80	Good
2.5 to 3.5	40-60	Fair
1.5 to 2.5	25-40	Poor
0 to 1.5	0-25	V.Poor

Appendix H: Photos Record Form

PRESENT SERVICEABILITY RATING (PSR) - Form 1		
No:	Observations noted during the survey	Photographs showing the defect and surface appearance

Appendix I: Core Log Form

CORE LOG FORM			
Client:		Core Diameter (mm)	
Project:		Core Ref:	
Location:		TRL LMS Ref:	
Section:		Project Code:	
Offset:		Coring Date:	
Lane:		Logged by:	
		Chcked by:	

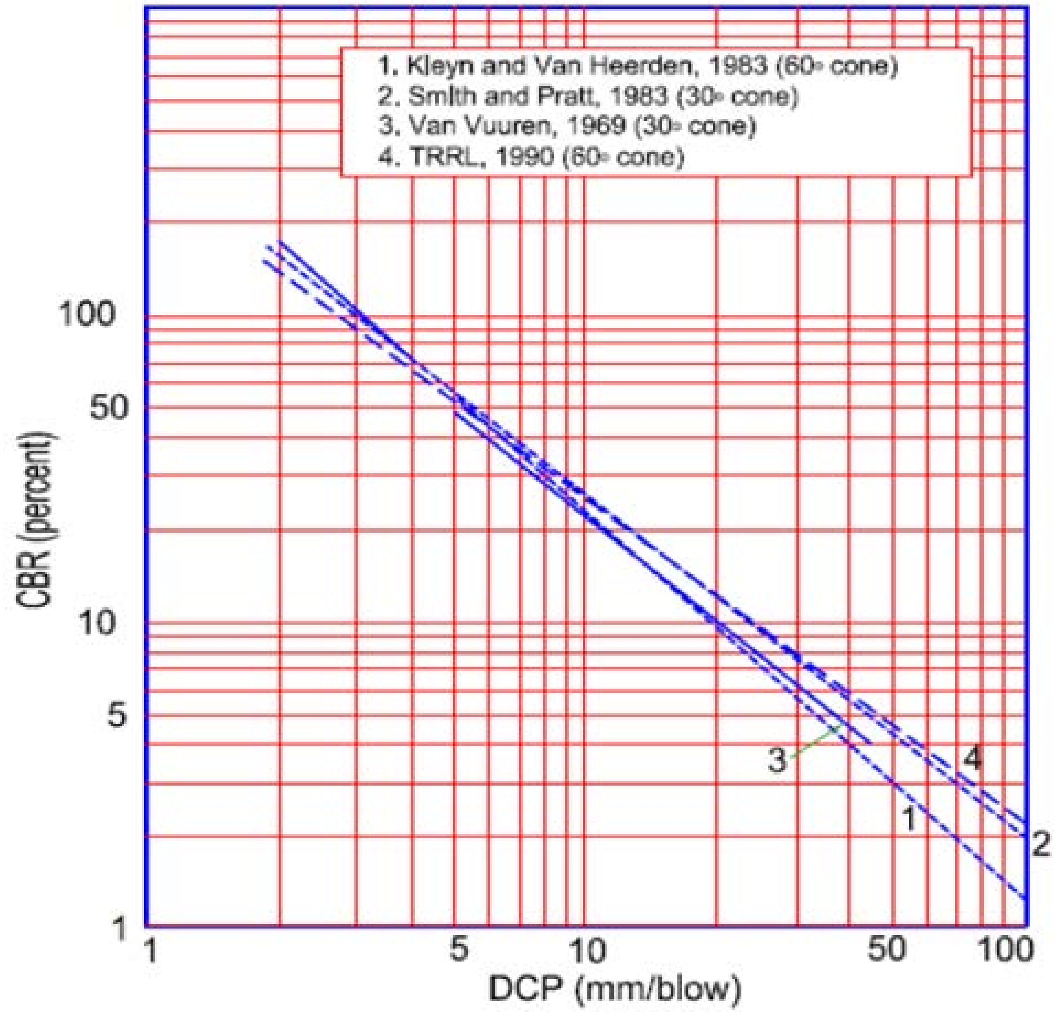
***Abbreviations: TS:** Thin Surfacing, **HRA:** Hot Rolled Asphalt, **DBM:** Dense Bituminous Macadam, **AC =** Asphaltic Concrete, **HBM:** Hydraulically Bound Material, **GS:** Gritstone, **GNT:** Granite, **LST:** Limestone, **GVL:** Gravel, **PQC:** Pavement Quality Concrete, **GSB:** Granular Sub-base.*

Core Log:	
Main Image	Top View
	Bottom view

Layers					Aggregate		General Remarks			PAK test
No.	Top (mm)	Btm (mm)	Thickness (mm)	Material type	Max size (mm)	Type	Condition	Bond	Voids (Y/N)	+VE/ -VE
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										

Appendix J: DCP CBR Relationship

Figure J.1 DCP-CBR Relationship



Kleyn Equation:

$$Log_{10}\, CBR = 2.632 - 1.28 log_{10} \left(\frac{mm}{blow} \right)$$

Equation 0.1

Smith and Pratt Equation:

$$Log_{10}\, CBR = 2.632 - 1.145 Log_{10} \left(\frac{mm}{blow} \right)$$

Equation 0.2

Van Vuuren Equation:

$$Log_{10}\, CBR = 2.632 - 1.150 Log_{10} \left(\frac{mm}{blow} \right)$$

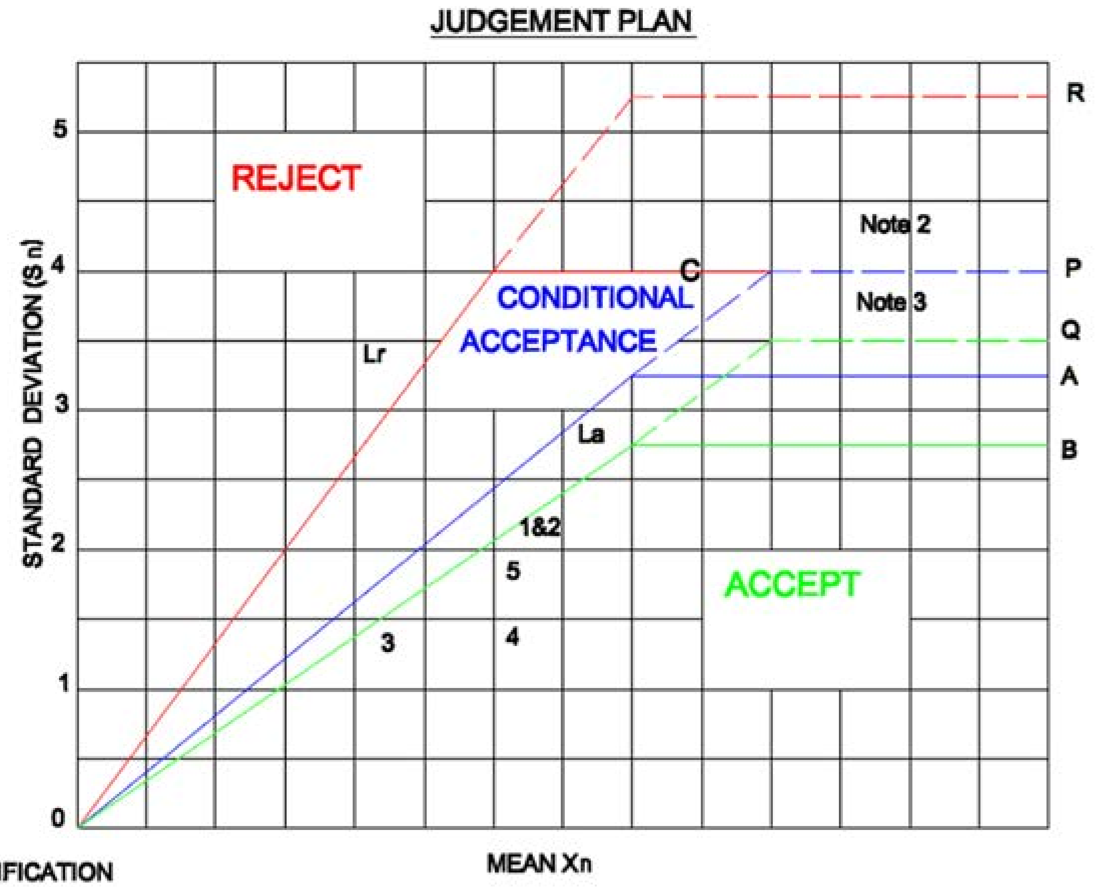
Equation 0.3

TRL (TRRL) Equation:

$$Log_{10}\, CBR = 2.48 - 1.057 Log_{10} \left(\frac{mm}{blow} \right)$$

Equation 0.4

Appendix K: Compaction Judgment Form



SPECIFICATION LIMIT (1) Ls

	87	88	89	90	91	92	93	94
2&3	89	90	91	92	93	94	95	96
1	91	92	93	94	95	96	97	98
5	93	94	95	96	97	98	99	100
4	95	96	97	98	99	100	101	102
	97	98	99	100	101	102	103	104
	99	100	101	102	103	104	105	106

VARIABLE SCALE FOR RELEVANT L_s

A = Initial submission limit $L_s \geq 93$ P = Initial submission limit $L_s \leq 91$

B = Resubmission limit $L_s \geq 93$ Q = Resubmission limit $L_s \leq 91$

C = Rejection limit $L_s \geq 93$ R = Rejction limit $L_s \leq 91$

NOTE (1) Circle relevant L_s and put reference number of lot next to L_s

(2) Reject for $L_s \geq 93$ Conditional for $L_s \leq 91$

(3) Conditional for $L_s \geq 93$ Accept for $L_s \leq 91$

Appendix L: Skid Resistance Form

Chainage	LHS *d* Resistance Measurements				RHS *d* Resistance Measurements			
	Pos. 1	Pos.2	Pos.3	Average	Pos. 1	Pos.2	Pos.3	Average