Africa Community Access Partnership

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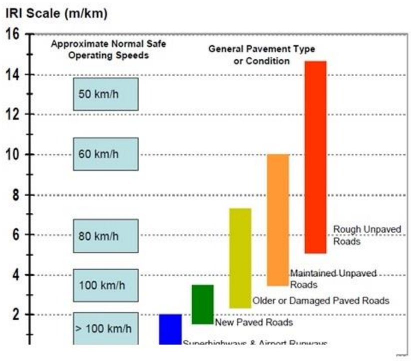
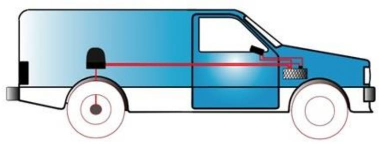
# Guideline for the Monitoring of Experimental and LTPP Sections in Mozambique



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Cover Image: Images from the Initial Site Visit

| Quality assurance and review table | | | |
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| | | | |

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## ReCAP Completion Report Template

| ReCAP Database Details: Economic Growth through Effective Road Asset Management | | | |
|---|---|---|---|
| **Reference No:** | MOZ2093A | **Location** | Mozambique |
| **Source of Proposal** | Tender | **Procurement Method** | Open Competitive Tendering |
| **Theme** | | **Sub-Theme** | |
| **Lead Implementation Organisation** | Civil Design Solutions | **Partner Organisation** | Paige-Green Consultants<br>Independent Software<br>ASCO (Z) (Pvt) Limited |
| **Total Approved Budget** | | **Total Used Budget** | |
| **Start Date** | 1 October 2016 | **End Date** | 15 January 2018 |
| **Report Due Date** | 31 December 2016 | **Date Received** | |

## Acronyms, Units and Currencies

| | |
|---|---|
| $ | United States Dollars |
| AFCAP | Africa Community Access Partnership |
| ANE | Administração Nacional de Estradas; National Road Administration |
| APT | Accelerated Pavement Testing |
| ASCAP | Asia Community Access Partnership |
| CDS | Civil Design Solutions |
| CSIR | Council for Scientific and Industrial Research |
| DFID | Department for Further International Development |
| EU | European Union |
| FHA | Federal Highways Authority |
| FWD | Falling Weight Deflectometer |
| GEIPOT | A Empresa Brasileira de Planejamento de Transportes |
| GPS | Global Positioning System |
| HDM | Highway Design and Maintenance |
| LEM | Engineering Laboratory for Mozambique |
| LTPP | Long Term Pavement Performance (monitoring) |
| LVR | Low Volume Road |
| LVSR | Low Volume Sealed Road |
| PMU | Project Management Unit |
| RAI | Rural Access Index |
| ReCAP | Research for Community Access Partnership |
| SHRP | Strategic Highway Research Program |
| UK | United Kingdom (of Great Britain and Northern Ireland) |
| UKAid | United Kingdom Aid (Department for International Development, UK) |
| VCI | Visual Condition Index |
| VRCS | Visual Road Condition Survey |

## Key Words

Low Volume Sealed Road, Long Term Pavement Performance Monitoring, Visual Condition Index.

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# 1 Introduction

## 1.1 Project Background

Mozambique urgently requires the upgrading of many rural roads to improve accessibility and mobility. Many of these roads carry low volumes of traffic and cannot justify conventional pavement design and material usage standards. The problem is further exacerbated by the lack of any suitable construction materials in many parts of Mozambique and the high costs of locating and procuring appropriate materials.

Experience in the region over the past few decades, however, has shown that there are numerous innovative techniques for using or improving local materials and supplying appropriate and cost-effective bituminous surfacings for such roads.

Before any such techniques are used on a wide scale, it is good practice to construct experimental or demonstration sections that can be monitored over a suitably long period to prove that they are both appropriate and cost-effective. Many such experiments have been constructed over the years, but the experimental design, monitoring frequencies and types and the resulting conclusions from many of these studies have often been inadequate to provide confidence in their wider implementation. It is important that such sections are monitored for sufficient time to obtain useful results and these sections are often referred to as Long-Term Pavement Performance (LTPP) sections.

Roads can take various forms, each with unique performance paths and properties and the guideline needs to take these all into account. The four major types of roads considered in this document are flexible (i.e. with bituminous surfacings), rigid (concrete), block-paved and unpaved (earth or gravel). Most low volume roads will have gravel or bituminous surfacings but occasionally concrete or block paving may be encountered.

## 1.2 Purpose and Scope

This document summarises the background to planning appropriate experimental sections and then monitoring them to ensure that the maximum benefit is obtained, and the findings can be confidently implemented in practice. The scope of the guideline covers the optimal experimental design requirements and the types and uses of various monitoring techniques.

The expected impacts of this guideline include:

- Standardisation of testing and evaluation procedures and equipment to ensure monitoring consistency
- Ability to obtain consistent data from the monitoring of pavements over the long term

- Obtain practical data for the development of improved standards and specifications based on the outcomes of monitoring.

## 1.3 Development of Protocols for Long Term Pavement Performance Monitoring

The monitoring of existing roads over extended periods has been carried out almost as long as roads have been in use. The first "controlled" monitoring was probably the GEIPOT[1] study in Brazil in the late 1970s and early 1980s leading to the World Bank HDM modelling. Many individual roads had, however, been studied prior to this on an ad hoc basis, including in South Africa. In the early 1990s, controlled monitoring of road sections for performance modelling was initiated in the United States, Australia, the United Kingdom, Europe, South Africa and Botswana. In 1997 Australia started monitoring roads for performance modelling. Since then, many countries have carried out LTPP studies. Much of this has been trying to relate Accelerated Pavement Testing (APT) to normal road performance.

The SHRP[2] study initiated in the USA in the late 1980s included the monitoring of 2,400 sections of road in nearly all states initially for five years. A range of detailed documents related to various activities were prepared in order to collect comparable data from each section. These included:

- Distress identification manual
- Falling Weight Deflectometer relative calibration analysis
- Guidance for rehabilitation
- Traffic data collection and processing
- FWD calibration protocol
- Calibrating traffic data collection equipment
- Operational field guidelines for FWD measurements
- Operational field guidelines for profile measurements
- Test method for determining resilient modulus of unbound materials - laboratory start-up and quality control procedure
- Test method for determining the creep compliance, resilient modulus and strength of asphalt materials using the indirect tensile test device
- Test method for determining the resilient modulus of unbound granular base/subbase materials and subgrade soils
- Seasonal monitoring program: Instrumentation installation and data collection guidelines
- Guide for field materials sampling, handling and testing

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[1] A Empresa Brasileira de Planejamento de Transportes.

[2] Strategic Highway Research Program.

- Guide for laboratory material handling and testing
- Traffic monitoring guide
- SPS traffic site evaluation
- IMS reference material
- Climatic database revision and expansion
- IMS quality control checks
- Traffic quality control software.

Following the SHRP programme, monitoring of the roads continued under the auspices of the Federal Highways Authority (FHWA).

Despite the relevant international experience, there is little evidence of standard protocols for monitoring in the literature. Monitoring normally following an ad hoc process according to the projects being monitored.

The first detailed protocol for establishing and monitoring LTPP sections was developed at the CSIR[3] (Jones and Paige-Green, 2004) for the Gauteng Department of Transport. It was part of a programme for relating the information obtained from accelerated pavement testing (APT) with the Heavy Vehicle Simulator (HVS) to full-scale monitoring of actual roads. This is believed to be the first formalised protocol for monitoring of roads and has formed the basis of various monitoring programmes in several countries.

The monitoring protocol for Mozambique is strongly based on the CSIR protocol, but has been extended to include other forms of road (e.g. unpaved roads) and more recent developments in road performance measurement. It also refers extensively to the draft monitoring protocol for Mozambique developed by Verhaeghe et al in 2015.

[3] Council for Scientific and Industrial Research, South Africa.

# 2 Experimental Design

## 2.1 Approach

To maximise the benefits of any experimental, trial, demonstration or LTPP sections, it is essential that the design is such that the trial produces the results that are desired. Trial sections can be developed for several purposes, the main ones of interest in this guideline being to:

- Prove the technical viability of an innovation, or
- Determine the economic viability or cost-effectiveness of an innovation compared with conventional alternatives.

In both cases, it is essential that considerable thought is given to the desired outputs of the experiment and how they will be achieved. In all cases, a **control section** using a conventional alternative technique must be constructed for comparative purposes. A common example in this regard is the "investigation" of proprietary chemical stabilisers where the chemical is frequently used on a section of road without any identical control section. This control should be constructed using the same method and with similar materials from the same source, with the only difference being that no chemical treatment is applied. From investigations without proper controls, whether the trial fails or succeeds, it is not possible to determine whether the chemical produces any beneficial effect over the similar untreated material.

The following are typical types of experimental sections requiring long-term monitoring:

- Replacement materials for traditional ones in structural layers, e.g. an alternative material such as slag or industrial waste
- Innovative treatment of sub-standard materials in structural layers to improve their quality, including the use of mechanical, traditional or non-traditional stabilisation.
- Innovative treatment of subgrades to reduce common subgrade problems, e.g. collapsible, expansive or saline materials
- Different pavement structures such as thinner layers or even omission of specific layers, e.g. For low volume roads
- Alternative surfacings such as Otta and sand seals, polymer slurry seals, hand-laid cold-mix asphalt, etc.
- Different construction methods, e.g. conventional versus in-place recycling.

Each of these types of experiment will have different impacts on overall road performance and will need to be monitored appropriately to determine the impact of the experimental factor on the road performance. Certain experiments may affect the structural capacity and will need to be monitored in terms of their structural effects (e.g. deflection), while others may only affect the surface performance and would need to be assessed in terms of riding quality. Other operational issues such as social, regional economic or environmental impact studies will all require specific design and monitoring requirements.

In many cases, it may be important to monitor the impact of improvements made to the road link on the local social dynamics over time (i.e. impact on local communities) as well. In these cases, a sample of at least 10 to 20 individuals should be questioned every six months to gauge their opinions on questions such as:

- Do they travel on the road?
- If so, how often?
- Do they feel safe travelling or crossing the road?
- To what extent have the improvements made to the road benefitted the community?
- If the improvements benefitted the community, what are the positive attributes?
- If the improvements have not benefitted the community, why not and indicate those aspects that would have benefitted the community?
- Did the community notice any changes in the road over time? e.g. functionality, trafficability and passability?
- Did the changes mentioned above affect driving speeds (increase or decrease), comfort or safety?
- Were there any other social benefits (e.g. better market prices for commodities, improved access to social services, etc.)?

## 2.2 Technical Viability

A short section (or different sections) is usually constructed including the innovation and the section is monitored regularly to determine how the innovation performs. This must be compared with a similar control section using a conventional design that would be implemented in that situation. When a totally new procedure or innovation is proposed, for example using the same material but without an additive such as lime or bitumen emulsion, the standard material/additive combination should be used as the control section.

In some cases, a totally sub-standard material may be treated with an innovative product to show that the product can be useful. In these cases, the untreated sub-standard material should be used in the pavement as a control to determine whether the chemical has any effect. Obviously, in these cases, the risk of failure is high and it is essential that the public is made aware that possible failure is likely.

On low volume roads, many years may be required before the traffic has any influence on the road performance. It may be useful, in these cases to carry out "accelerated testing" by constructing the section on a road with considerably higher traffic (preferably with the same axle load pattern) and thereby obtain 10 or 20 years of traffic in one or two years.

## 2.3 Economic viability

To compare the economic viability, the total life-cycle costs need to be determined and compared with a control section constructed using the conventional design in the situation.

The total life-cycle costs include the construction, maintenance and operating costs, which all need to be monitored for the experimental section as well as the control section, and then discounted over the analysis period. This aspect is discussed in detail in Section 5.

## 2.4 Design process

### *2.4.1 Location*

The location of the experimental sections should be such that the outside influences are as constant as possible:

- Traffic - this should not change between the sections (i.e. no intersections or major turnoffs within the experimental length). The presence of a traffic monitoring station nearby will always enhance the accuracy of the traffic data using the road.
- Subgrade - this should be as consistent as possible and is best "checked" using a Dynamic Cone Penetrometer (DCP) to determine whether the in situ strengths are similar in terms of different layers, localised moisture variations, etc.
- Climate – typically the sections will be adjacent to each other and the climate should be relatively consistent – however, over longer experimental sections, micro-climatic changes could be possible resulting from aspect, grade or local topographic variations. It is also important that climatic records are maintained as close to the section as possible, if possible from a recognised weather station.
- Drainage – the drainage alongside and crossing the experimental sections should be as uniform as possible.

Each experimental section must be clearly identified with some sort of permanent marking (sign boards or roadside cairns), as well as recording the GPS coordinates of the start and end points and any important points within the section. Other fixed points such as culverts, large trees, buildings or service poles/pylons can also be referenced. It should be noted that km posts and chainage markings could change during construction or operation of the road.

Paint markings on the experimental section can be used for short term indications of testing points, etc., but do get lost with time. It is often useful to place long nails in the pavement at such points as more permanent markers, but any distress may lead to loosening of these and damage to vehicles.

It is essential that local road inspectors/foreman and maintenance teams are made fully aware of the reasons and location of experimental sections and are instructed to keep the monitoring team fully informed of any actions affecting the experimental sections, including maintenance activities. Signboards indicating the location and purpose of the test sections, provide useful information for local communities.

### *2.4.2 Experimental section length*

The length of experimental sections will depend on the issue being investigated and the method of construction. Each experimental section should only include one variable from the norm. If there is more than one variable, it is usually not possible or at least very difficult to attribute any change in performance to the specific variable. It is thus preferable to have several shorter trials each with one variable, than longer sections with multiple variables.

Normally, experimental investigations of pavement/structural layers and their materials would be 250 m long, However a length of 250 m to 500 m may be required to provide sufficient sites to carry out the necessary testing, particularly if repeated destructive testing is part of the investigation programme. If accurate measurements of the roughness using automated roughness measuring devices are required, a central section of at least 300 m is required.

Trials will usually be built using conventional plant. The first and last 50 m of each section should be considered as transition zones, with the potential to have properties differing from the actual trial sections. It is essential that monitoring and testing is not carried out in these areas, and any performance problems are not related to the experimental investigation. These zones should be clearly demarcated.

The construction of experimental investigations involving surfacings and surface treatments can be more easily controlled than pavement investigations. Transition zones of only a few metres may be adequate. The length of the sections should be 50 – 100 m, depending on the method of construction, with mechanised methods requiring longer sections.

Other experimental types may require longer sections, depending on the need. For example, an investigation of climate resilience of a specific adaptation measure could require sections of many kilometres, depending on the actual adaptation technique.

However, even these should have a similar control section that excludes the adaptation technique for comparative purposes.

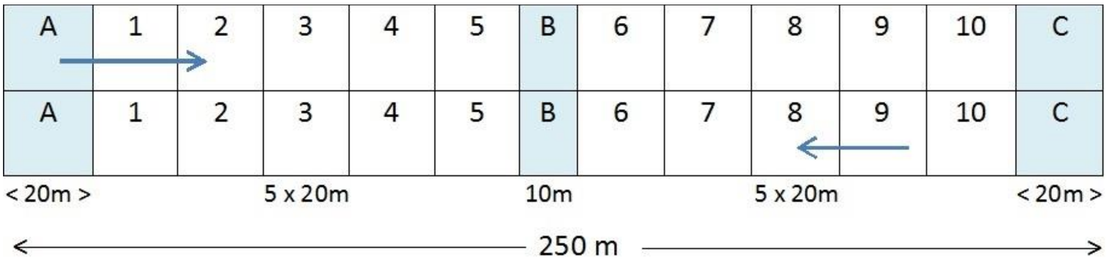


Figure 1 shows a diagram of a homogeneous trial section across two lanes. In this case, the section is 250m long and is divided into 13 panels, with Panels A and C being 20m long and Panel B being 10m long. Panels 1 to 10 are each 20m long.

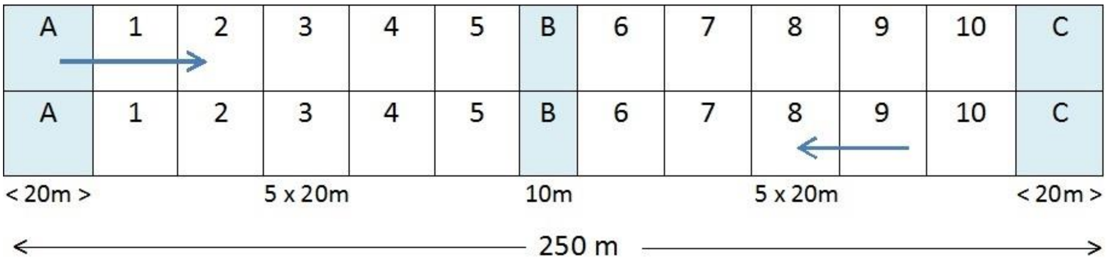


**Figure 1: Typical layout of a Trial Section - not to scale**

Figure 2 shows the layout a typical homogeneous LTPP section. It is recommended that the section should be a minimum of 500m long and be divided into 25 panels, with Panels A to E being each 20m long, and Panels 1 to 20 being each 20m long.

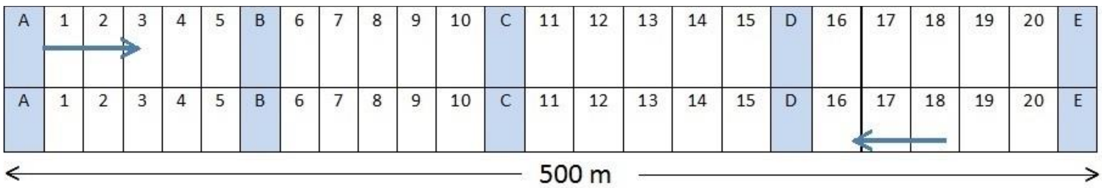


**Figure 2: Layout of LTPP section (two lanes)**

### *2.4.3 Construction*

The construction of experimental sections must be of the highest quality, conforming fully with the local standards or those prepared for a specific project. It is not acceptable that an experimental section fails due to poor construction quality, where the section bears no relationship with the actual procedure or product being investigated. Thus, only experienced contractors should be used for construction of experimental sections, unless the experiment is to investigate a new or different approach compared with conventional designs necessitating non-conventional construction techniques. However, in these cases, the conventional design and construction method should be used for the control.

It is imperative on all experimental sections that the specified layer thicknesses and compaction densities are achieved on both the experimental and control sections and that all materials used comply with the prescribed specifications for those materials. It is unacceptable, for example, that the trial of a new process fails because the thickness of the trial section was inadequate.

Conventional quality control measures based on the ruling requirements in the region must be implemented during construction. It is also recommended that the number of samples and test sites be increased by at least 50% to confirm uniformity of the experimental construction.

Complete and accurate records of the construction process (including photographs and videos where appropriate), material sources and properties, application rates, quality control procedures and results, etc. must be collected and archived for ready access in later years.

### *2.4.4 Costing*

One of the main requirements of experimental sections is to identify and quantify the total life cycle cost of the alternative compared with that of conventional practice. The total life cycle cost consists of many components, including the construction and maintenance costs. It is thus essential that all additional costs associated with the construction of the specific attribute being investigated through the trial sections are fully recognised and recorded and can be compared with the conventional construction costs.

These additional costs may include:

- The cost of any additional plant necessary on site specifically for the experimental construction
- The cost of any additives, chemicals or treatments included in the experimental sections
- The cost of any additional personnel required to implement the alternative construction
- The cost of any additional time necessary to carry out the construction
- Any additional costs related to the alternative, such as laboratory testing, special storage or transportation, etc.

It has frequently been found that contractors tendering for innovative procedures and trials tend to inflate their prices, as they are unsure of timing, equipment requirements and other additional costs. A typical example of this has been the case in areas where asphalt is used routinely – estimates for chip seals have been found to be significantly higher than for the asphalt, although it is known that chip seals are considerably less costly. Issues such as these need to be considered in the costing analyses.

One of the main components of total life-cycle costs is the ongoing maintenance cost. This needs to be carefully recorded and quantified as discussed in Section 6. The time and resources spent on maintenance of the experimental section (including specific issues related to the experiment) must be separated from those of the reminder of the road and analysed separately.

# 3 Sampling and testing

The materials used in the roads should be sampled and tested before, during and immediately after construction. This requires the testing of samples from all layers and not only the "experimental layer" as roads perform in a holistic manner, with each layer contributing to the performance of the layer above.

A standard sampling procedure should be used to ensure that sufficient material of the right type is obtained during the sampling. It is costly and time-consuming to return to a site for the purpose of obtaining additional material. Figure 3 indicates the typical quantity of material required for routine testing as a function of the maximum particle size.

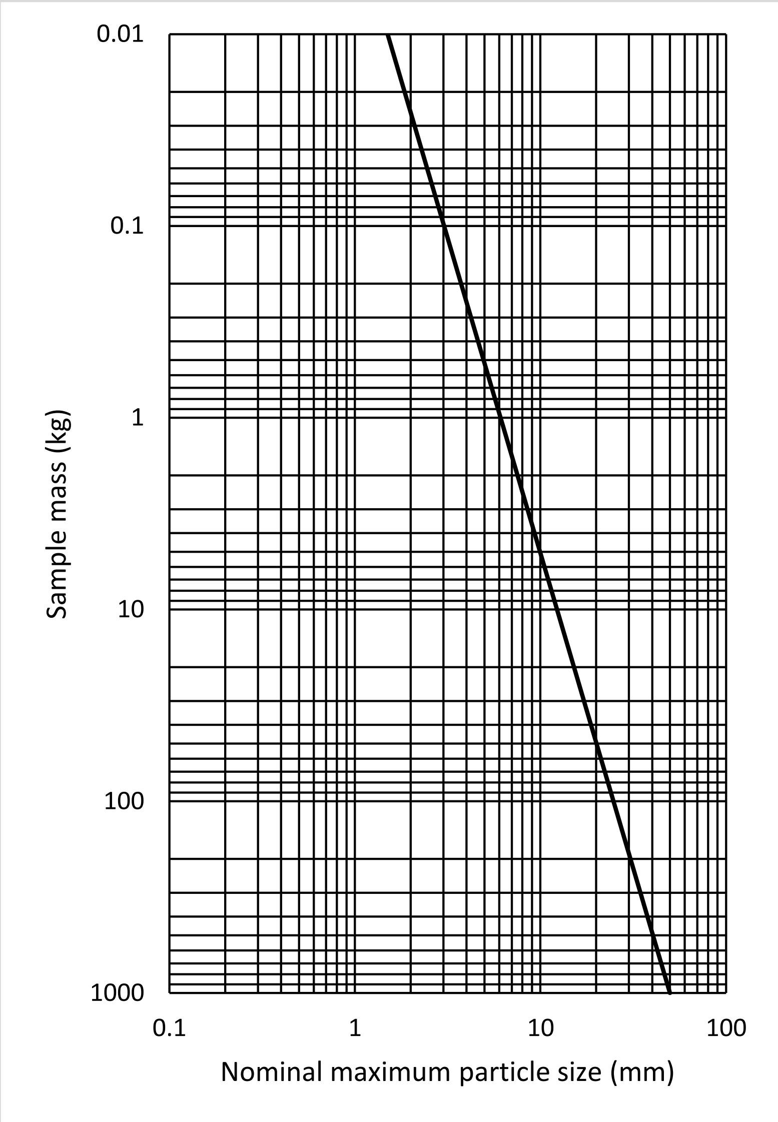


**Figure 3: Guide to estimation of sample size required for road indicator testing based on maximum particle size**

Prior to the experimental section being constructed, samples of potential borrow materials to be used in the road construction must be obtained. This is usually from test pits in the proposed borrow pit, as the borrow pit is seldom exploited prior to construction.

The test pit should be profiled and described as indicated in Appendix B. This normally requires a description of each visibly distinct layer exposed in the side of the test pit using the standard moisture, colour, consistency, soil structure, soil texture and origin (MCCSSO).

Each distinct layer in the soil profile (thicker than 300 mm) must be sampled for the necessary testing, usually road indicator tests for most materials. Road indicators include Atterberg Limits and particle size distribution, compaction characteristics (MDD and OMC) and the California Bearing Ratio (CBR) strength at various compaction efforts.

Samples should be taken during construction after being dumped on the road, as well as after the layer has been worked. Some of these samples should be retained as reference materials in case any additional testing is required later in the project.

It must be borne in mind that standard specifications apply to the material after construction. Borrow pit materials may change in their properties, particularly their gradings, during construction. It has been found that material that has been subjected to a Los Angeles Abrasion test (500 revolutions with steel charge) has similar properties to a material on the road after the process of winning, hauling and processing (mixing and compacting).

The test methods employed must be consistent and follow the local standards precisely.  It is imperative that for experimental section work, all testing is of the highest quality and is only carried out by well-trained and experienced laboratory personnel.

After construction of the road a test pit shall be excavated to subgrade level to ensure that the construction thicknesses comply with the design and all materials used are within specification. The test pit should be profiled and samples collected. Additional information on the nature of the interlayer boundaries (deviations and conditions, e.g. ruts and cracks) should also be recorded. For cemented layers, it is important to assess the in-situ condition of the stabilised layer. This is best done using a phenolphthalein spray on a freshly opened face (<3 minutes exposure to the atmosphere). Observations should be recorded on an LTPP Test Pit Form (Appendix N).

On completion of profiling, the pit shall either be covered with a steel plate (if further investigations or site visits are planned), or reinstated using material and layer thicknesses conforming as closely as possible to those in the respective layers and then sealed ensuring that no water can penetrate the base. The surface of the patch should be such that the riding quality of the section is not affected and that dynamic bounce of vehicles that may affect the adjacent sections is not introduced

Samples from the experimental sections should be taken in a position that does not affect monitoring measurements such as riding quality. Sampling holes must be large enough to provide sufficient material for the required testing – it should be remembered that a 1 x 1 m hole in a layer 150 mm thick will typically yield less than about 300 kg of material, depending on the density. After sampling, the hole should be backfilled with similar materials to those extracted, compacted to the specified layer densities at their respective OMC's and carefully sealed with a suitable material (typically cold-mix asphalt). Good compaction of the asphalt is critical to provide a permeability as close to the existing seal as possible.

Any damage to the surfacing resulting from testing, e.g. DCP holes, moisture or density determination holes, etc., should be filled with compacted cold-mix asphalt or some fine aggregate and bitumen emulsion in the case of small holes. It is essential that ingress of water through such holes is avoided.

# 4 Design of Monitoring

## 4.1 General Considerations

The monitoring requirements and methods for unpaved and paved roads are entirely different. Specific monitoring programmes need to be established for the different types of roads. Unpaved roads are continually changing under variable traffic and climatic conditions and monitoring should take this into account. Unlike paved roads, which generally deteriorate progressively at rather slow rates, unpaved roads can change from a good condition overnight following a severe weather condition or even after high traffic counts for several days (e.g. the harvest season). Paved roads, on the other hand, generally deteriorate at a slow but continuous rate under the effects of cumulative applications of heavy axles, although significant damage can occasionally be done to a paved road during a severe storm event. Flexible, rigid and block paved roads, all within the paved road classification, also deteriorate totally differently and require specific monitoring techniques.

The properties that should generally be monitored for the different road types over the full duration of the selected monitoring period or as long as necessary to acquire the required information are summarised in Table 4.1.

**Table 4.1: Applicability of equipment/methods to pavement types in order of priority**

| Data Parameter | Equipment / Standard | Pavement | | | |
|---|---|---|---|---|---|
| | | Flexible | Concrete | Block | Unpaved |
| **Visual Assessments** | As per Appendix C | ✓ | ✓ | ✓ | ✓ |
| **Environment (traffic and climate)** | | | | | |
| Traffic monitoring | Weigh-in-Motion | ✓ | ✓ | ✓ | |
| | Static weighing | ✓ | ✓ | ✓ | |
| | Automated traffic counts | ✓ | ✓ | ✓ | |
| | Manual traffic counts | ✓ | ✓ | ✓ | ✓ |
| Temperature | Temperature button loggers | ✓ | ✓ | | |
| | Weather station | ✓ | ✓ | | |
| Rainfall | Weather station | ✓ | ✓ | ✓ | ✓ |
| Density and Moisture | Dual-probe hydro density | ✓ | ✓ | ✓ | ✓ |
| Permeability | Falling head in situ permeability testing | ✓ | | ✓ | |
| Wind intensity | Weather station | | ✓(curing) | | ✓ |
| **Profile of the section** | | | | | |

| **Data Parameter** | **Equipment / Standard** | **Pavement** | | | |
|---|---|---|---|---|---|
| | | **Flexible** | **Concrete** | **Block** | **Unpaved** |
| Transverse Profiling | High speed profilometer | ✓ | ✓ | ✓ | |
| | Straight edge and wedge | ✓ | ✓ | ✓ | ✓ |
| | Precision rod and level | ✓ | ✓ | ✓ | ✓ |
| Longitudinal Profiling | High speed profilometer | ✓ | ✓ | ✓ | |
| | Response type devices | ✓ | ✓ | ✓ | ✓ |
| | Walking profilers | ✓ | ✓ | ✓ | ✓ |
| | Face Dipstick | ✓ | ✓ | ✓ | ✓ |
| | Precision rod and level | ✓ | ✓ | ✓ | ✓ |
| **Structural strength** | | | | | |
| Deflection | High speed deflectometer | ✓ | ✓ | ✓ | |
| | Falling weigh deflectometer | ✓ | ✓ | ✓ | |
| | Light Weight deflectometer | ✓ | ✓ | ✓ | ✓ |
| | Automated deflection beams | ✓ | ✓ | ✓ | |
| | Static deflection beams | ✓ | ✓ | ✓ | ✓ |
| In situ strength/ balance | Dynamic Cone Penetrometer | ✓ | ✓ | ✓ | ✓ |
| **Skid resistance and texture** | | | | | |
| Skid resistance | Side force test device (SCRIM) | ✓ | ✓ | ✓ | |
| | Slip/variable slip testers | ✓ | ✓ | ✓ | |
| | Motometer – brake efficiency meter | ✓ | ✓ | ✓ | ✓ |
| | British pendulum tester | ✓ | ✓ | ✓ | |
| Texture Depth | Profilometer - texture depth | ✓ | ✓ | | |
| | Volumetric patch method | ✓ | ✓ | | |
| **Material investigations** | | | | | |
| Soil profiling of borrow pits and pavement sub-structure | Visual profiling | ✓ | ✓ | ✓ | ✓ |
| Asphalt materials | Indicator and performance-related tests | ✓ | | | |
| Concrete materials | Indicator and performance-related tests | | ✓ | (✓) | |

| Data Parameter | Equipment / Standard | Pavement | | | |
|---|---|---|---|---|---|
| | | Flexible | Concrete | Block | Unpaved |
| Stabilised materials | Indicator and performance-related tests | ✓ | ✓ | ✓ | ✓ |
| Granular Materials | Indicator and performance-related tests | ✓ | ✓ | ✓ | ✓ |

Several other techniques are available for performance monitoring (e.g. stress in motion). However, these are costly and it is unlikely that they would ever be used for low volume roads.

Regular visual assessment of all experimental sections is essential. The visual condition of the experiment must always be compared with that of the control section(s) to determine whether there are any differences in performance. The visual assessments should be carried out by the same person or teams for consistency. It is not critical that the standard assessor calibration methods are followed, as long as the assessments are consistent during the monitoring period. The assessment should however, follow a fixed method and the TMH 9 methods are proposed for use (COTO, 2013). These are summarised in Appendix C and the standard field data forms are presented in Appendix D.

## 4.2 Unpaved Roads

The typical performance criteria monitored for a gravel road are the roughness, the visual condition and the progressive gravel loss. These attributes can vary rapidly and widely over a short period.

### *4.2.1 Roughness (riding quality)*

Numerous techniques are available for the monitoring of road roughness, which is a direct indication of riding quality. However, many of the more sophisticated techniques are not suitable for unpaved roads, where extreme roughness and dustiness may render the equipment unsuitable or lead to damage. It is thus better to make use of more robust and simple equipment. Typical of these are bump-integrators or simple response type measurement devices. With this type of equipment, the cumulative movement between the axle and body of a vehicle is typically determined over a specific length of road (100 m or 1 km) and this is compared with readings obtained by the same vehicle under similar conditions on calibrated sections of road. This is discussed in greater detail in Appendix E.

Various applications for roughness measurement are now available for use with "smart phones". These make use of the built-in GPS and accelerometer capabilities. The accuracy is variable and some form of calibration is necessary. Some of the applications are free on the Internet while others require purchasing. The purchased ones generally have greater capabilities and accuracy and are recommended.

Use can also be made of manually operated equipment such as the MERLIN. However, this may not identify longer wave-length deformation such as low frequency corrugations, undulations resulting from expansive clays or collapsible soils, etc.

### *4.2.2 Visual assessment*

The visual assessment of unpaved road experimental sections is the best method of identifying differences between sections and changes with time. It allows direct observation of the typical distress types as they form and develop, which assists in determining the causes of these distresses. Visual inspections must therefore be carried out regularly, with the frequency depending on the traffic, climate and season. The frequency may vary from once every 3 or 4 weeks up to a maximum of once every 3 months.

It is important that all monitoring follows a fixed procedure. The method and a standard form for this is provided in Appendices B and C respectively. Typically, the degree and extent of each attribute is assessed during each inspection. However, it is vital that the assessment is carried out by the same person or team of persons each time, or else by carefully trained and calibrated assessors.

Certain criteria, such as rut and corrugation depths, have over the years been directly measured during visual assessments. Experience has, however, shown that such depths vary too fast and too widely for any meaningful relationships to be determined. Riding quality (roughness) is thus the critical parameter.

### *4.2.3 Gravel loss*

The loss of gravel from unpaved roads under traffic and climatic influences results in a need to replace it. This is one of the most costly maintenance operations for unpaved roads. The rate of loss of gravel is a function of many factors, including climate, pavement shape, traffic, material properties and construction quality and varies from a few mm per year to 40 or 50 mm per year. Many experiments have been carried out on unpaved roads to determine means of reducing the gravel loss and the high costs of gravel replacement. In these cases, it is necessary to measure the gravel loss compared with the control sections.

Gravel loss measurements are complicated and time-consuming and no simple method that is accurate enough to obtain useful readings within a reasonable period (typically about 3 years) is available. Methods, for example, using dips from string lines at fixed points have generally proved to be insufficiently accurate.

The standard method of measuring gravel loss is by using precise levelling surveys of a carefully demarcated section of the road and relating the average height of this section of the road to a few stable bench-marks over an extended period. The actual measurement points at each monitoring should be as close to the pervious monitoring as possible. This is usually best done using two tape measures, one laterally across the road and one longitudinally down the road zeroed at fixed points. The full methodology for this is described in Appendix F.

## 4.3 Paved roads

Characterisation of the performance of paved roads usually requires an evaluation of the road roughness, rut depths, deflection, pavement strength (usually using a DCP), moisture contents and regular visual assessments following a standard technique. The monitoring requirements, however, vary depending on the type of pavement and surfacing as well as whether the factor of interest is functional (mostly surfacing type) or structural, related to pavement strengths and layer thicknesses. The different techniques for each type of pavement are discussed separately below.

### *4.3.1 Bituminous surfaced roads*

The assessment of the performance of bituminous surfaced roads depends on the nature of the experimental section. In some cases, the centre-of interest may be the structural capacity of the pavement, concentrating on layer configurations, thicknesses and strengths (structural performance). In other cases, it may be predominantly the performance of the bituminous surfacings (functional performance). Although the two issues are inter-related, the monitoring requirements may differ significantly.

**Roughness**

The riding quality (road roughness) is primarily affected by the structural capacity of the pavement with the surface expression of deformations caused by differential movements within the pavement affecting the measured roughness. Roughness measurements are thus more important in structural evaluations of roads than in surfacing performance (functional evaluations). In the latter, typically a lack of surfacing maintenance will result in poor riding quality more than the actual performance of the surfacings.

**Deflection**

The structural capacity of the pavement is best estimated from the deflection within the pavement. Deflection is the recoverable surface movement under a standard axle/tyre load and depends on the support (stiffness) provided by the roadbed and pavement layers. This is normally determined from the peak deflection, which is the sum of the deflection occurring in each layer and the subgrade. The measurement of the full deflection bowl (or basin) allows the contribution of individual layers to the peak deflection to be estimated. Details regarding the measurement of deflection are provided in Appendix G.

Thin bituminous surfacings, typical those used on low volume roads, do not generally contribute to the structural capacity of the pavement but provide only a wearing and water-proofing layer. Thicker bituminous asphalt layers, however, can provide some structural capacity to the pavement. However, high deflections can cause premature failure of stiffer surfacings, such as slurries.

**Strength**

The stiffness of the materials in the pavement structure primarily determines its performance. Stiffness is, however, difficult to measure and it is more common that the shear strengths of the layers are measured. This can be done using simple and almost non-destructive testing such as Dynamic Cone Penetration (DCP) tests. The results of DCP tests clearly show differences in layer strengths as well as changes in layer properties (thickness, moisture, density, etc.). The DCP profile has many other useful applications such as indicating the pavement balance, the nature of the structure (deep, well-balanced, etc.) and the presence of weak and strong layers within the structure.

In the back analysis of deflections (Appendix G), the estimation of layer stiffnesses requires iterations based on seed values. The data from DCP testing can be used as an ideal starting point for the estimation of these seed values.

**Moisture and density**

The strength (and stiffness) of most pavement layers is severely affected by the moisture content and the density of the materials comprising the layers. Standard road construction procedures require a specified density and this should always be achieved. After construction and during monitoring of experimental sections, the density can be checked using any of the standard methods available (sand replacement, nuclear density measurement, etc.). This should be carried out, although it is a destructive testing method.

Apart from slow increases in density in the wheel paths due to trafficking, the density of properly compacted materials usually shows minimal change with time. However, the moisture content within pavement layers can vary significantly with time. In most pavements, the central section under the seal stabilises within a few months after construction at the equilibrium moisture content for that material and environment, typically at between 60 and 80 percent of its optimum moisture content (OMC). The moisture content in the outer metre or so of the road varies seasonally and usually has the dominant effect on the performance of the outer wheel tracks of the road. In most experimental sections, it is important to monitor the changes in moisture content across the road profile so that any distress can be potentially related to increased moisture contents and to identify minimum strengths necessary for the traffic carried.

It is thus useful to establish moisture monitoring points transversely across the road in the outer and inner wheel tracks, between the wheel tracks and on the centre-line. The moisture contents should then be monitored at the beginning and end of any wet or dry cycles.

**Visual Assessment**

The surface appearance of any experimental or LTPP section must be assessed visually on a regular basis for comparison with the control section. The standard for this is provided in Appendix C.

#### *4.3.2 Concrete roads*

Most of the strength of concrete pavements is provided by the concrete layer. Deterioration is usually in the form of cracking and faulting and monitoring is mostly confined to a visual assessment of the condition of the concrete. When concrete experiments are constructed, the control section will either be the conventional flexible pavement construction or a similar concrete pavement if an innovation to the concrete mix or type is being investigated.

Non-visual monitoring in these cases is restricted to riding quality. The use of deflection testing for comparative purposes is usually almost meaningless due to the strong load-distribution effect of the concrete slab (high modular ratio between the concrete and the relatively weak underlying layers) compared with the more localised loading under a flexible pavement.

#### *4.3.3 Other surfacing types*

Other “surfacing” types such as block paving, cobble-stones or hand-packed stone are best monitored visually, with riding quality measurements to support this information. It is useful to periodically remove the surfacing for a small area and carry out DCP testing to assess the structural condition of the support layers.

### 4.4 Safety

It is important that normal safety precautions are taken during monitoring, both for the monitoring team and road users. It must be noted that the assessors will be on the roads during monitoring, often concentrating on the task being carried out and not necessarily on the traffic using the road. In most countries, there are regulations that ensure the safety of workers and road users through the enforcement of measures such as the use of high visibility apparel, barriers and cones. The design of warning signs is specified, together with the distances and the locations of where these are to be placed to warn drivers of any road works or investigations taking place on the road. It is recommended that conspicuous and properly trained “flag-persons” are used on both sides of the assessor or assessment teams.

The involvement of local traffic police is recommended during the establishment and monitoring of trial and LTPP sections, since the construction/monitoring of those will cause disruptions to the normal flow of traffic and the teams involved in such activities need to be safeguarded.

# 5 Monitoring Techniques and Equipment

## 5.1 Axle Load Monitoring

### *5.1.1 Purpose*

Axle load data, combined with other data (e.g. pavement structure), are required to determine the cumulative axle counts on the experimental section. This is necessary for accurate life-cycle cost analysis.

### *5.1.2 Weigh in Motion (WIM)*

Axle load monitoring can be undertaken by using High-Speed Weigh-in-Motion (HS WIM) equipment. Several HS WIM technologies are available and include bending plate systems, piezo-electric and quartz sensors, fibre optic cables and load cells.

### *5.1.3 Static Weighing (Stationary and Mobile Weighbridges)*

Axle load monitoring may also be undertaken using static/stationary or mobile weighbridges. Due to the 24-hour requirement of the axle load surveys, a team of about 15 people working on a three-shift basis with 4 to 5 people on each shift is normally necessary. The number of people on site will, however, vary depending on site conditions.

When selecting the location of mobile weighbridge sites, the following should be considered:

- Traffic must be surveyed in both directions
- Traffic safety is paramount (the local police must be informed prior to the surveys)
- There should be no alternative routes that allow vehicles to bypass and avoid the survey site
- The site should be as level as possible (a maximum gradient of 2% is allowed)
    - The scale should not be placed on a crown or hollow
    - The space between the scale and the ground should not exceed 10mm.

Figure 4 illustrates potential sources of error at the weighing site depending on surface unevenness.

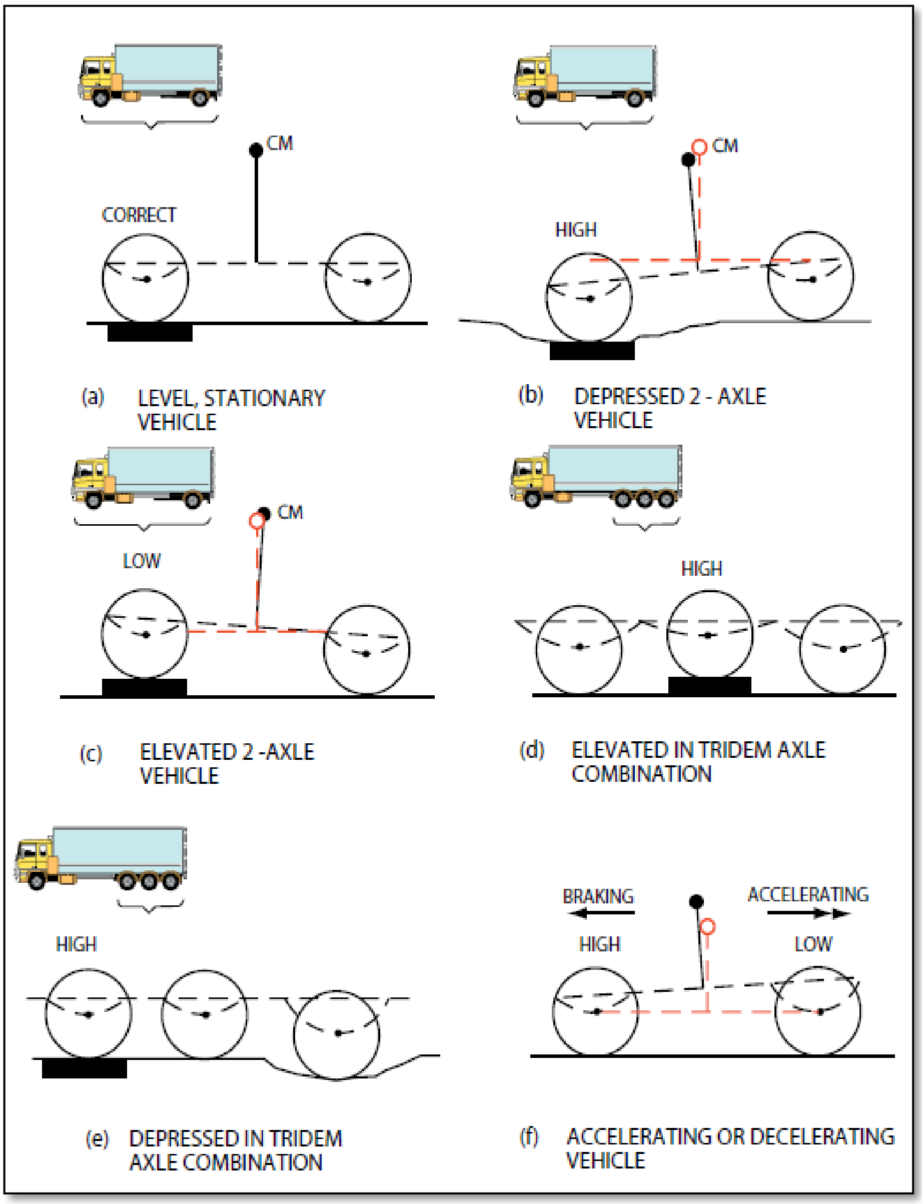


**Figure 4: Sources of error at weighing site - surface unevenness and consequences**

The following points should be noted with regards to weighing vehicles:

- Axle load surveys should be carried out for 7 consecutive days and for 24 hours a day
- Two clearly visible flag men wearing safety vests are required, situated at least 30 metres on either side of the weigh bridge
- It is essential that loaded as well as empty truck are weighed for axle load surveys on stationary weighbridges.

## 5.2 Traffic Counts

### *5.2.1 Manual Traffic Counts*

Manual traffic counts are recommended where automatic traffic count equipment is not available or the cost of the equipment is very high. Manual traffic counts are usually used for short-term traffic counts – typically less than one week (24 hours a day for 7 days). Each passing vehicle is recorded on a survey form by vehicle type and the time it was observed (See Appendix H: Traffic Tallying Form). Traffic is counted in both directions for the duration of the survey. Quality control is a major issue with manual traffic counts.

Several technologies are available to improve the quality of manual traffic counts including:

- Mechanical manual counters (clickers) used with clipboards.
- Electronic manual counters in which the passage of each vehicle is recorded.
- Video recorders that are used to record the traffic stream (with time and date stamps). Video recordings have the advantage that a permanent record is available that can be used for quality control purposes.

For traffic counts undertaken over a short-term, extrapolation based on a predetermined percentage of heavy vehicles is to be used to determine the total E80s for the required design period.

The monitoring period (24-hour day for 7 days) is to be chosen carefully and should not include "Abnormal" days. Abnormal days can be defined as the following:

- Public holidays
- Days influenced by public holidays
- School holidays anywhere in the country
- December recess, measured from the last week in November up to the end of the school holidays in January of the following year anywhere in the country.

### *5.2.2 Automated Traffic Counts*

Many technologies are available for automatic traffic monitoring (i.e. monitoring traffic flow characteristics, such as traffic volumes and operating speeds). Such technologies include Inductive Loop Detectors, Magnetic Sensors or Detectors, Laser Radar Sensors, Microwave Rader Sensors and Video Detection Systems. Automatic traffic count systems may be classified as intrusive and non-intrusive detectors. Intrusive detectors are those that must be embedded or placed on the road pavement. Non-intrusive detectors are those that are placed outside the traffic stream. Each of these technologies has certain limitations that must be considered when developing a traffic monitoring programme.

It is important that traffic monitoring and WIM systems or equipment are tested and certified to ensure that the equipment complies with the necessary functional requirements. This will ultimately guarantee the provision of good quality data. It is recommended that traffic and WIM monitoring systems should be assessed according to the procedures contained in TMH 3 (COTO, 2015).

Automatic traffic monitoring systems can be grouped into four types (A to D) and two accuracy levels (1 and 2) as described below.

- **Type A** traffic monitoring systems provide for vehicle, axle, single/dual tyre and speed detection.
    - **Type A1** systems with the highest levels of detection and vehicle classification accuracy.
    - **Type A2** systems with relatively high levels of detection and vehicle classification (categorisation) accuracy.

- **Type B** traffic monitoring systems with vehicle, axle and speed detection but without single/dual tyre detection
    - **Type B1** systems with the highest level of detection and a relatively high level of vehicle classification accuracy.
    - **Type B2** systems with a relatively high level of detection and a medium to high level of vehicle classification accuracy.

- **Type C** traffic monitoring systems with vehicle and speed detection but without axle and single/dual tyre detection.
    - **Type C1** systems with a relatively high level of vehicle detection and a medium to low level of vehicle classification accuracy, and where axle data are not required.
    - **Type C2** systems with a medium level of vehicle detection and a relatively low level of vehicle classification accuracy, and where axle data are not required.

- **Type D traffic monitoring systems without speed, axle and single/dual tyre detection. This is the most basic of the traffic monitoring systems.**
    - **Type D1** systems with a medium level of detection accuracy and either no vehicle classification, or a low level of vehicle classification accuracy.
    - **Type D2** systems with a relative low level of detection accuracy and either no vehicle classification, or a low level of vehicle classification accuracy.

Tolerance limits for the traffic monitoring types are shown in Table 5.1Table 5.1 Table 5.4:

**Table 5.1: Tolerance limit for invalid detection- TMH3 (COTO, 2015)**

| Characteristics | Travel | Tolerance limits for various traffic monitoring types | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | A1 | A2 | B1 | B2 | C1 | C2 | D1 | D2 |
| Vehicle detection | Normal travel | 0.5% | 1% | 0.5% | 1% | 1% | 5% | 5% | 10% |
| | Straddling vehicles | 5% | 10% | 5% | 10% | 10% | 20% | 20% | 35% |
| Trailer detection | Normal travel | 1% | 2% | 1% | 2% | - | - | - | - |
| Axle detection | Normal travel | 0.5% | 1% | 0.5% | 1% | - | - | - | - |
| Wheel detection | Normal travel | 2.5% | 5% | - | - | - | - | - | - |
| Single/dual tyre | Normal travel | 0.5% | 1% | - | - | - | - | - | - |

**Table 5.2: Tolerance limit for vehicle categorization- TMH3 (COTO, 2015)**

| Vehicle Category (class) | Tolerance limits for various traffic monitoring types | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | A1 | A2 | B1 | B2 | C1 | C2 | D1 | D2 |
| Vehicles not categorized, or which were wrongly categorized by the monitoring system | 2% | 3.5% | 3.5% | 7% | 10% | 15% | - | - |
| Vehicles that should have been categorized as light but were not categorized or categorized as heavy | 1% | 2% | 2% | 4% | 6% | 10% | - | - |
| Vehicles that should have been categorized as heavy but were not categorized or categorized as light | 3% | 6% | 6% | 12% | 20% | 30% | - | - |
| Heavy vehicles wrongly categorized into one of the heavy vehicle subclasses (excluding buses) | 4% | 8% | 8% | 15% | - | - | - | - |

**Table 5.3: Tolerance limit for traffic characteristics- TMH3 (COTO, 2015)**

| Characteristics | Range of reference values | Vehicle Types | Tolerances limits for monitoring types | | |
|---|---|---|---|---|---|
| | | | A1, A2, B1, B2, C1 | C2 | D1, D2 |
| Vehicle Speed | > 30 km/h | Light and Heavy | ± 5% | ± 10% | - |
| Vehicle length | 3.0 to 5.0m | Light only | ± 15% | ± 30% | - |
| | > 5.0m | Light and Heavy | ± 10% | ± 20% | - |
| Axle spacing | 1.0 m to 3.0 m | Light and Heavy | ± 10% | - | - |
| | > 3.0m | Light and Heavy | ± 5% | - | - |

HS WIM monitoring systems are grouped into three classes as described below.

- Class I with relatively high level of accuracy. This level of accuracy is recommended for use on very smooth road surfaces where dynamic effects will be low. This class should be used when it is critical to achieve a relatively high level of accuracy.
- Class II with higher level of accuracy. This level of accuracy is recommended for roads that carry medium to high volumes of heavy vehicle traffic and where a higher level of accuracy is required.
- Class III with lower level of accuracy. This level of accuracy is recommended for roads that carry low volumes of heavy vehicle traffic and where a lower level of accuracy is acceptable.

**Table 5.4: High Speed Weigh in Motion tolerance intervals for load measurements - TMH3 (COTO, 2015)**

| Load | Minimum Value Tested | Tolerance intervals for different accuracy classes | | |
|---|---|---|---|---|
| | | Class 1 | Class 2 | Class 3 |
| Gross vehicle mass | 3 500 kg per axle | ± 8 % | ± 10 % | ± 15 % |
| Axle group load (*1) | | ± 12 % | ± 15 % | ± 20 % |
| Single Axle load (*2) | | ± 12 % | ± 15 % | ± 25 % |
| (*1) – Excluding groups with one axle, (*2) – Single axles in single axle groups | | | | |

## 5.3 Weather Data

Temperature, rainfall and wind data of the LTPP sections are usually necessary for most experimental section monitoring.to be recorded using a small portable weather station. LTPP sections are to be strategic positioned near an existing weather station, if possible. A weather station comprising of at least a thermometer (maximum and minimum) and a rain gauge should be available.

If the site is within a municipal boundary then the closest official recording station could be used if no other suitable location can be found. Failing the above, the establishment of an automated weather station in a secure location adjacent to the LTPP section should be considered. Data are to be collected daily.

Temperature button loggers (or equivalent) are recommended to monitor the temperature. The loggers are designed to continuously monitor the temperature and to store this information in their memory. The data logger is preferred since assessors do not have to go to the site daily to capture the data.

Temperature buttons should be placed in the air and in the pavement to capture both ambient and pavement temperatures. The buttons to be placed in the pavement should be installed in the centre of panels A to E (see Figure 2).

The buttons will record temperature continuously at selected intervals as set up. To obtain the temperature records, the buttons are removed from their position and the data is downloaded to a computer, after which the buttons are replaced in their positions.

## 5.4 Density and Moisture content (dual/mono-probe Hydro density meter)

The density and moisture content of individual layers can be measured with a dual-probe hydro density meter. The following points should be noted when conducting density and moisture content analysis.

- Permanent holes are drilled and lined with a thin aluminium or plastic tube (1.0 mm)
- The holes are sealed immediately after testing.
- The hydro-density meter is calibrated against a gravimetric moisture content sampled with a hand or power auger near the hole.
- The machine wet and dry densities and moisture content should be recorded at 50 mm increments to a depth of 600mm.
- Strict operating, maintenance and transport procedures supplied with the equipment must always be followed
- The meter is calibrated on standard blocks according to the manual supplied with the instrument.

The following procedure should be followed:

- Remove the cap of the predrilled holes
- Place a 1.0 m X 10 mm wooden dowel into the holes to check that there is no standing water or mud in the holes
- If the holes have standing water/mud, new holes must be drilled 30 cm along the wheel track from the previous hole
- Measure the density and moisture at 50 mm intervals, starting at 600 mm and moving towards the surface.
- The specific operating and safety instructions provided with the gauge are to be strictly followed
- Testing is to be completed in panels A, B, C, D and E on the inner and outer wheel paths as well on the centre lane (between two lanes)
- Surveys are to be conducted at least at the end of the wet and dry periods
- Data should be recorded in LTPP Density and Moisture Content form (see Appendix I).

## 5.5 Transverse and Longitudinal Profile of the section

### *5.5.1 High-speed Profiling (general)*

If the LTPP section is of a reasonable length and/or the section is not too remotely located from the nearest service provider, the use of a calibrated high-speed profilometer is recommended because of both the density and accuracy of data produced. The following points are to be considered when profiling the section with a high-speed profilometer:

- Depending on their configuration, high-speed profilometers can be used to measure the longitudinal profile (roughness, usually expressed in IRI), texture depths and transverse profiles (rut shapes and depths).
- Because of the density of data being captured, rutting, roughness and texture depth parameters can be reported at 10 m intervals or averaged over longer distances (e.g. 100m), depending on the requirements.
- Ultrasonic point sensors are typically spaced at 100 mm centres over the measurement width and can cover a full lane width of 3.6 m
- Laser point sensors are faster than ultrasonic sensors and can be placed as close as every 10 mm along the road.
- It is recommended that three runs be conducted by the profilometer: two in the direction of increasing chainage and one in the direction of decreasing chainage (for movement logistical purposes).
- Monitoring should be conducted at least every 6 months.

Ideally, for each high-speed profilometer survey, the following data should be provided:

- Latest calibration verification
- Operator’s name
- Date of record
- Section details (section, name, lane, direction, region)

- Surface type
- Start and end km position of record
- GPS coordinates (longitude, latitude, and elevation if available)
- Measurement speed
- Road geometry (grades, cross fall and curvature).

It should be noted that, since LTPP sections are often short and located remotely, high-speed profiling, although desirable, is seldom considered to be the preferred option from a cost-benefit perspective and, hence, alternative surveillance techniques are usually considered.

### *5.5.2 Transverse Profiling*

*Straight edge and wedge*

If the use of a high-speed profilometer is not considered feasible, the use of the straight edge and wedge approach is recommended.

A two-metre straight edge and wedge can be used for profile measurements to be taken every 100 mm from the centre of the lane to both the road edge and the road centreline as per ASTM E 1703/E 1703M – 95 (2005). The rut width is measured with a measuring tape, while the rut depth, which is the maximum measured perpendicular distance between the bottom surface of the straight edge and the contact area (Figure 5), can be measured with a calibrated wedge (Figure 6). The wedge is usually made of aluminium and should be 20 mm wide.

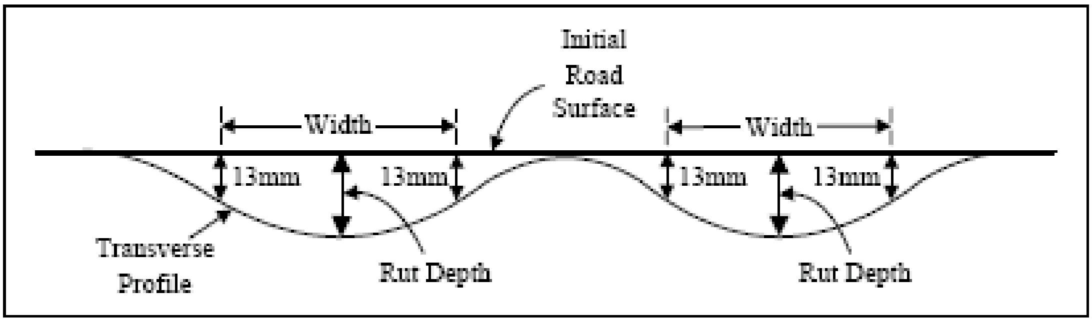


**Figure 5: Rut definition and measurement**

**Figure 6: Calibrated aluminium wedge for rut depth measurement**

It should be noted that different authorities specify different lengths of straight edge, varying from 1.2 m to 5 m. The length of the straight edge has a significant influence on the depths measured and it is suggested that the ASTM standard of 2m be accepted. This length provides adequate accuracy but is still convenient for transporting in normal vehicles.

Sampling is to be conducted every 6 months. Appendix J, provides a pro-forma Profiling Assessment Form.

*Precision rod and level*

A precision rod and level survey is recommended if the straight edge and wedge are not available. Levels are taken at regular intervals along the transverse profile of the road, at the discretion of the researcher. This method is considerably more time consuming than the straight edge and wedge method. The same assessment form as the one recommended for the straight edge and wedge can be used (Appendix K).

*Analysis of Rut Depth*

Data capture of rut measurements is to include general information as well as rut data (

Table 5.5).

**Table 5.5: Data capture for rut measurements**

| General | Rutting parameters (each wheel path) |
|---|---|
| Operator Name | Rut depth and width at each measuring point |
| Date and time of record | Average rut depth (per panel and per lane) |
| Section details (name, lane, direction, region) | Maximum rut depth (per panel and per lane) |
| Km position (start and end) | $90^{th}$ percentile rut depth (per lane) |
| GPS coordinates (preferably at each measuring point for future reference) | Average pond width (per lane) |
| | Average pond depth (per lane) |

### *5.5.1 Assessment of roughness (riding quality):*

The following factors can have an impact on the measured roughness: presence of cracks (especially crocodile and transverse cracks), coarseness of texture, potholes and patching, surface contaminants, as well as seasonal variations such as wind, extreme temperatures and surface moisture. These should be considered when analysing the test data.

The International Roughness Index (IRI) scale is usually used as the basis for roughness measurement. A guideline relating the IRI scale to pavement condition and safe operating speeds is shown in Figure 7.

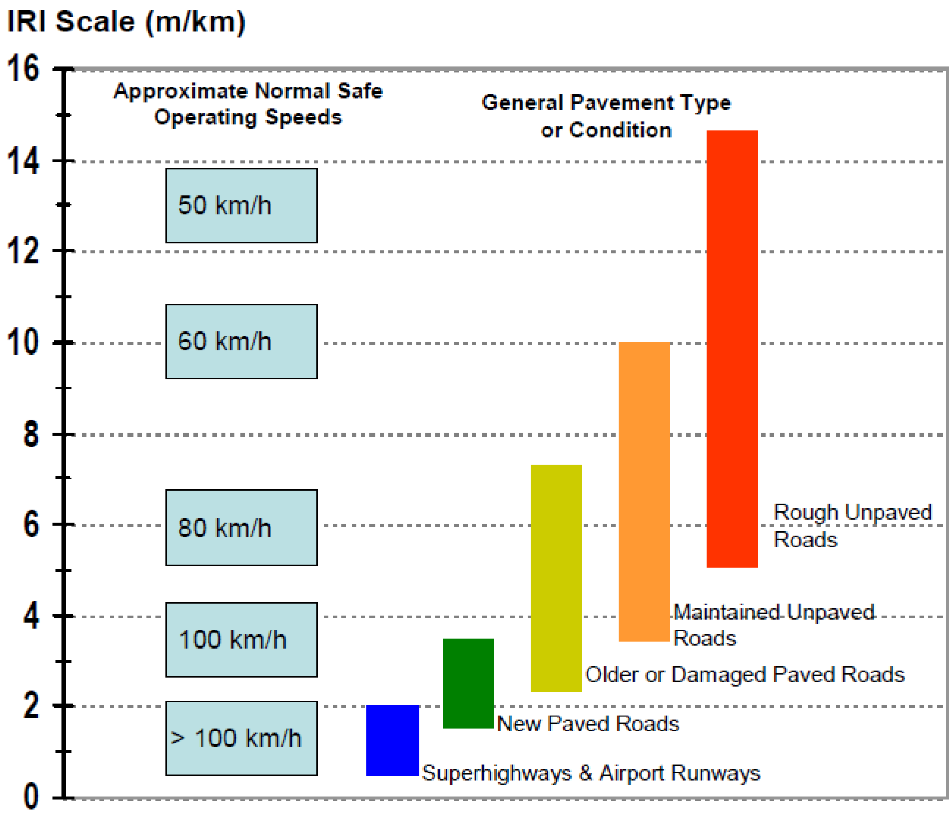


**Figure 7: IRI scale**

If the use of a high-speed profilometer is not cost-effective, several other means to capture the longitudinal profile to a high level of accuracy are available. These are more time consuming and labour intensive. These include: response type devices, walking profilometers, face dipsticks and precision road and level. These are detailed below.

*Response Type Devices*

Response Type devices are recommended over inertial profilers and static methods for unpaved and block paved roads. They should only be used for flexible and concrete paved roads if profilers are unavailable.

Response type devices integrate the vertical movement of the recording unit relative to the suspension. A response type system consists of a measurement vehicle, a transducer, a recording system and accurate speed and distance measuring instruments. Correlation by calibration is used to convert the measured unit to IRI.

Response type devices provide a continuous data set. Data should be captured at 20m intervals at panels 1 to 20, including panels A to E. Surveys are to be conducted every 6 months for paved roads and every 3 to 4 weeks for unpaved roads. A typical example is the Bump Integrator (BI) available in Mozambique (Appendix E).

*Other methods*

Static profiling devices include a precision rod and level, the Face Dipstick™ and the ARRB Walker Profiler. The precision rod and level is slow and can only profile approximately 600m per day The Face Dipstick™ can profile about 200m an hour and the ARRB Walker Profiler about 800m an hour. As in the case of the response type devices, data should be captured at 20m intervals at panels 1 to 20, including panels A to E. Surveys are to be conducted every 6 months.

The MERLIN (A Machine for Evaluating Roughness using Low-cost Instrumentation) device is available in Mozambique (Appendix E). This device can be used for unpaved and block paved roads when response type or static devices are unavailable.

The results are recorded on a data chart mounted on the machine. By recording measurements along the wheel path, a histogram of "y" can be built up on the chart. The width of the histogram can be used to determine the IRI. To determine the IRI, 200 measurements are usually made at regular intervals. When the 200 measurements have been done the distribution is graphically marked on the chart. The procedure is repeated for the other end of the distribution. The width of the scatter of the 200 marks, excluding the outer 10 marks at each end of the scatter is then measured in millimetres and denoted D. For earth, gravel, surfaced dressed and asphaltic concrete roads, the IRI can be determined using the following equation:

$$IRI = 0.593 + 0.0471\,D$$

A standard error in the IRI value is to be noted and can be up to 10%. Data is to be collected at panels 1 – 20 including panels A – D (see Figure 2).

## 5.6 Structural Capacity

### 5.6.1 Deflection

It should be noted that deflection measurements are useful on flexible paved roads but are of limited value on rigid and unpaved roads.

*High Speed Deflectometer*

High Speed deflectometers are not readily available and are normally not appropriate for low volume roads, despite their high production rate and the density of data they capture. Points to consider when using high speed deflectometers are:

- High speed deflectometers consist of either the use of a Rolling wheel deflectometer (RWD) or a Traffic Speed Deflectometer (TSD).
- Deflections are to be recorded on the LTPP section at 6 month intervals.

*Falling Weight Deflectometer*

The use of the Falling Weight Deflectometer (FWD) (Appendix G) is recommended.

The following are to be considered when conducting FWD testing:

- For flexible pavements, the test location of the surface deflection bowl is to be taken at inner and outer wheel paths (20m intervals), as well as centre lanes.
- A target load of 40 kN (to simulate an 80 kN dual-wheel axle) is typically used, although at least three different load levels, and at least three repetitions at each load level are recommended.
- The three target load levels recommended in standard European practice are 40kN, 50kN and 60kN.
- The positions of the sensor are to be fixed at standard offsets from the centre (under the load) and should be maintained as such at each survey. The recommended offsets are: 0, 200, 300, 450, 600, 900, 1200, 1500 and 1800 mm.
- The duration of the load pulse should be between 20 and 30 milliseconds.
- The load or pressure needs to be kept constant from one survey to the next
- All deflections are to be normalized to the target reference load, and are not to deviate more than 10% from the actual applied load.
- The longitudinal gradient of the test location should not exceed 10% to ensure accuracy.
- Testing should not be executed within 800mm of the pavement edge.
- The entire loading plate must be in contact with the surface.
- Deflection bowls should be normalised to a standard reference temperature of 25°C. An appropriate method is to be used to normalise the deflection measurements to the temperature of 25°C.
- Analysis of deflections is to be conducted every 6 month.

A more recent innovation is the Light Weight Deflectometer (LWD) which is essentially a portable FWD. Although the loads are lower, the device has been calibrated for use on conventional roads. The LWD is particularly useful for comparing the structural capacity of different sections and is thus eminently suitable for monitoring LTPP and experimental sections. Additional discussion is included in Appendix G.

*Automated deflection beams (Deflectographs)*

Automated deflection beams, generally known as Deflectographs are more appropriate for the analysis of roads on a network level but can be useful on LTPP sections as well. Deflectographs provide a high coverage but traffic control is required due to slow operating speeds.

The following points are to be noted regarding deflectographs:

- They have a daily survey capacity of 15 to 20 kilometres with operating speeds of 2 to 4 km/h
- The deflection beams and reference frame are stationary during the deflection measurement cycle and remain stationary until the maximum deflection has been recorded.
- The reference frame is then pulled forward at twice the vehicle speed by a clutch and winch system to the initial position for the next measurement cycle. With the reference frame again at rest, the measurement cycle is repeated.
- Data are collected in both wheel paths at about 4 metres at a time
- The deflectograph must be calibrated before each days testing
- A standard rear axle loading (6 – 10 tonnes) is achieved using ballast fitted to the vehicle chassis.

Deflection data is to be taken at panels 1 to 20 along the inner and outer wheel paths. Analysis of deflection is to be conducted every 6 months.

*Static deflection beams (e.g. Benkelman Beam)*

The Benkelman Beam can be used on all road types, including segmented block pavements. The device operates on a lever arm principle and is used with a truck that provides a constant specified axle load of approximately 80kN. The following points are to be noted when conducting deflection surveys using the Benkelman Beam:

- Data are to be collected at inner, outer and between wheel paths at panels 1 to 20 (Figure 3).
- No deflection data are to be taken at panels labelled A, B, C, D and E (Figure 3).
- Deflection sampling using a Benkelman beam is to be conducted every 6 months.

The principle operation of the equipment is to measure surface deflection between the dual wheels of an axle loaded to 8,175 kg. If this axle load cannot be applied for any reason, the readings shall be adjusted linearly to the values of an 8,175 kg. The following should be observed with regards to the wheels:

- 11 x 20 or 10 x 20 tyre dimensions
- Road contact length: 200 mm
- Spacing between the walls of the tyres in the dual wheel combination: 75 – 90 mm
- Tyre pressure 590 kN/m2 (85 psi)

Appendix L is to be used to capture Deflection data.

### *5.6.2 In situ strength/balance (Dynamic Cone Penetrometer)*

DCP measurements should be taken regularly approximately 1.0 m longitudinally from the density/moisture content sampling areas in panels A, B, C, D and E. DCP measurements can be followed by density/moisture measurements taken at the same location and using the DCP "hole" as one of the moisture probe holes.

The following procedure should be followed:

- Measurements should be recorded as the penetration rate per number of blows (usually 5 at a time) appropriate to each pavement layer to a depth of 800mm.
- Cemented or strong layers should be drilled through if penetration with the DCP is found to be difficult or near impossible. The depth of layer drilled must be carefully recorded.
- Disposable or fixed cones may be used. Disposable cones reduce the likelihood that damaged cones will be used repeatedly and reduce the possibility of damage to the apparatus during extraction after testing. The condition and shape of the cones is to be checked prior to the test being carried out.
- All DCP holes should be sealed properly with an appropriate filling material, usually bitumen emulsion and sand (at least for the top 30mm).

Attention needs to be drawn to:

- The condition of the apparatus (cone not worn, rods not bent, all fasteners tight)
- The device should be vertical for the full duration of the test, and the rod shall not be jammed towards the sides of the hole during testing, two conditions that easily occur where there are large stones in the sub-surface.
- Large stones affect the readings.
- The shoulder of the cone should be flush with the road surface prior to the release of the first impact load recorded.

Surveys on in situ strength are to be conducted every 6 months. References for DCP testing include ASTM D6951

The DCP Form in Appendix L is used to capture DCP data.

## 5.7 Skid resistance and Texture

### *5.7.1 Skid resistance*

Although skid resistance is commonly carried out during routine monitoring, it is only required for low volume experimental sections when surfacing aggregates or types are being investigated and compared. Various techniques are available for estimating skid resistance.

*SCRIM Device*

The SCRIM device typically operates at 50 km/h, with lower speeds on tighter curves. The apparatus "drags" a solid rubber wheel at an angle to the direction of travel, usually after applying water to the road surface. The SCRIM device can be fitted with additional sensors to allow simultaneous measurement of skid resistance and texture depth, and possibly rut depth. Analysis of skid resistance should be conducted on panels 1 – 20 (Figure 3) every 6 months.

*Slip / Variable Slip Testers*

Fixed and variable slip devices consider the effect of brake force on friction. A brake force is applied to the test wheel, but at a force lower than that which would lock the wheel completely. Regarding fixed slip devices, a brake force allowing between 10 and 20 % brake slip is applied. The Grip Tester is a three-wheeled trailer and a typical example of a fixed slip device. The Grip Tester is typically used at 50 km/h. Variable slip devices do not apply a fixed brake slip, but sweep through a range of braking slip ratios.

If selected as the preferred method, analysis using a slip tester should be conducted on panels 1 to 20 (see Figure 3) every 6 months. ASTM E 1859 prescribes data on variable slip testers.

*British Pendulum Tester*

The British Pendulum Tester (BPT) is recommended for skid resistance testing on all types of surfaced roads. The BPT should be used every 20m over the length of the LTPP/test section. The BPT is used to derive the friction co-efficient in terms of a British Pendulum Number (BPN).

The following procedure should be followed regarding setting the tester:

- Set the base level by means of the spirit level and levelling screws on the base
- Raise the head so that the pendulum arm swings freely
- Check the zero setting
- Check the sliding length of the rubber slider. The sliding length should be between 125 and 127 when the apparatus is correctly set
- Place the arm in its release position and release for testing.

The following testing procedure should be followed:

- On surfaces bearing a regular pattern, such as rigid or brushed concrete, tests should be made with the slider operating at 80° to the ridges.
- Sweep the surface ensuring it is free from loose grit
- Wet the road surface and slider

- Set the pointer at its zero stop. Release the pendulum arm by pressing the button and catch it on the return swing before the slider strikes the road surface.
- Return the arm and pointer to the release position and keep the slider clear of the road surface in this operation by means of the lifting handle.
- Spread water over the contact area with hand or brush and repeat the swings.
- The contact area and the slider mush be wet between each swing.
- Testing is to be conducted at panels 1 to 20 every 6 months.

### 5.7.2 Surface Texture

*Surface Profilers*

Surface profilers are recommended for the measurement of surface texture depth. Mobile profilers (continuous measurement) are preferred to stationary methods (Volumetric Patch Method).

It is recommended that a minimum of two runs be performed on the LTPP section in both directions of travel at each speed level. Testing should be done at three or four different speeds. The mean profile depth (MPD) should be determined for each 10m segment wheel path.

The mean profile depth (MPD) which is the average value of the profile depth over a predefined distance is called the baseline. A standard baseline of 100 mm is to be used. The definition of mean profile depth is shown in Figure 7. Sampling is to be conducted every 6 months.

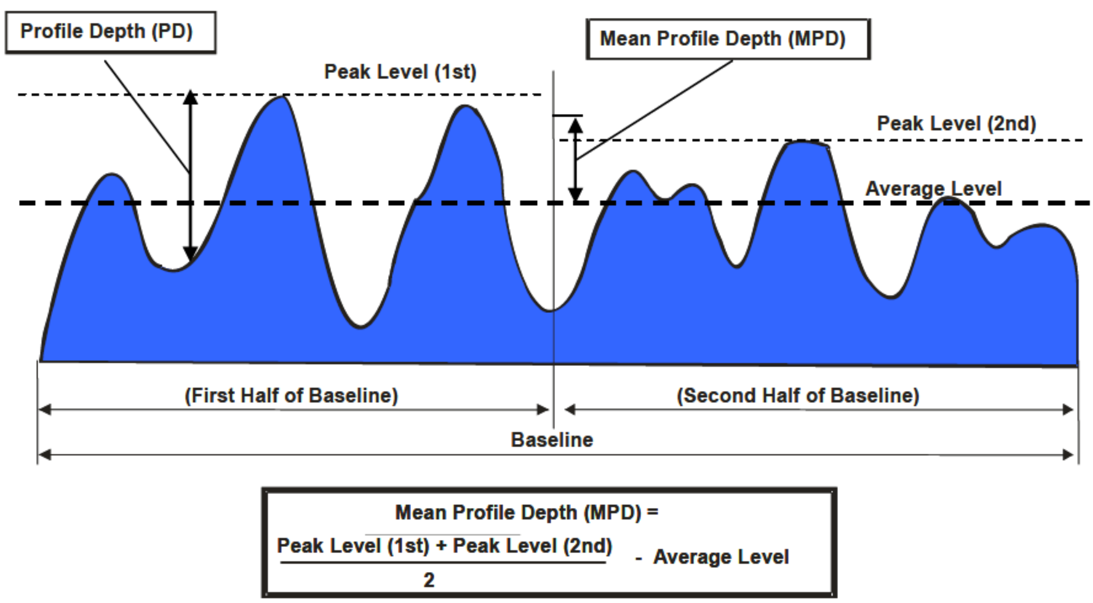


**Figure 8: Schematic diagram of mean profile depth**

*Volumetric (Sand) Patch Method*

If no surface profile is available, the Volumetric (Sand) Patch Method should be used to measure surface texture. A fixed quantity of sand material is spread out with a rubber pad in a circular (or rectangular patch) and the average diameter (or length and width) is used to calculate the area. Due to its lower accuracy and time consuming test duration, this method is only used when other options are unavailable. The method defines the Texture Depth (TD) and is measured in millimetres (mm).

## 5.8 Laboratory testing

Every type of experimental investigation will require high quality laboratory testing. The requirements depend on the materials and the intent of the investigation. A unique testing regime is necessary, whether the materials are subgrade soils and gravels, natural borrow materials, processed layer aggregates, surfacing chippings and bitumen, asphalt aggregates and binders, cemented materials and cementing agents, etc.. It is up to the researcher carrying out the experiments to define which tests are necessary and how many should be done.

These aspects are not covered in detail in this report, but have been highlighted by Verhaeghe et al (2015).

# 6 Analysis and Reporting

## 6.1 Approach

Each time an experimental section or other section of road is monitored, the data should be fully captured in the field on field forms. This data should be entered into a spread-sheet or data base as soon as possible and the field forms digitally scanned and saved to a reliable storage medium. All input data should be checked for accuracy.

Reporting of the data follows two formats. Initially, the data are reviewed, checked and analysed in terms of its basic properties and statistics. This is the descriptive phase of the analysis and reporting and is based solely on the data provided without drawing any conclusions by way of interpreting the meaning of the data. This phase of analysis can be easily defended by a review of the information at hand.

The second level of analysis of the data is the interpretative analysis. Meaning is extracted from the data in terms of cause and effect. This is often related to the experience and knowledge of the analyst. The analyst will base conclusions on the data, but these may differ from the conclusions of another analysts and can only be defended by the specific analyst based on their knowledge and interpretation of the information collected.

The relevance and usefulness of both types of analysis depend on the quality of the information obtained. For accurate and meaningful analyses, the field and laboratory information need to be of the highest quality.

## 6.2 Visual condition assessment

The visual condition of the experimental section in comparison with the control section is the initial most important comparative indicator. A review of the changes in extent and degree of the different condition parameters over time and comparison with those from the control sections will allow a qualitative assessment of the success of the experimental section compared with the control section. A disadvantage of visual condition assessments is that numerous criteria are described, not all of which can be considered equally important the behaviour of the road. This problem can be overcome by using Visual Condition Indices.

These are calculated using various weightings for the selected parameters and combining these weightings with the degree and extents of the performance parameters. There are various ways of manipulating these values either by summing them or deducting them from 100. Recommended weightings for use in Mozambique are included in Appendix C.

There are many different VCI values in use around the world and even within regions, making comparison of the values difficult. It is important that one system is identified as being suitable and used for local monitoring purposes.

## 6.3 Life-cycle costing

The analysis of the total life cycle costs of a proposed solution is the primary objective of almost any experiment. It involves the comparison of the discounted total cost of the option with that of a conventional or alternative design. Included in this analysis are the full construction cost, all maintenance and rehabilitation costs, all operating costs and benefits and the savage value of the option at the end of the analysis period.

In general, the initial objective is to obtain a road of similar standard to the conventional design at a lower construction cost. Optimally, this should be operated at the same or a lower maintenance cost as the conventional design and should provide at least the equivalent level of service.

It is thus essential that all the costs associated with the experimental road are conscientiously collected, and to carry out accurate discounting, the time that these costs were incurred needs to be recorded if monitoring continues over periods of more than 4 or 5 years. After such periods, the discounted costs becoming increasingly less important.

Routine maintenance activities such as grass cutting and drain cleaning will not normally be included in the cost comparisons between the experimental and control sections. These costs are common to both sections, unless aspects such as comparisons between the construction and operation of V-drains and flat table drains, for instance are being investigated or the impact of different species of grasses are the centre of interest.

However, all additional or reduced costs related to pothole patching, crack sealing or edge-beak repair need to be carefully quantified.

Similarly, on unpaved roads routine graded blading needs to be controlled carefully. If the investigation is comparing a modified or processed material with a conventional as-dug material, the potential for reduced grader maintenance is strong, and the maintenance must be programmed differently for the control and experimental section. Riding quality measurements must also be made immediately prior to and after maintenance.

# 7 REFERENCES

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COTO. 2013. Draft TMH 9 Standard Visual Assessment Manual Part C: Concrete Pavements. Committee of Transport Officials, Pretoria.

COTO. 2013. Draft TMH 9 Standard Visual Assessment Manual Part D: Block Pavements. Committee of Transport Officials, Pretoria.

COTO. 2013. Draft TMH 9 Standard Visual Assessment Manual Part E: Unpaved Roads. Committee of Transport Officials, Pretoria.

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Roads Department. (2000). Pavement Testing, Analysis and Interpretation of Test Data. Ministry of Works, Transport & Communications, Gaborone, Botswana. (Guideline No. 2)

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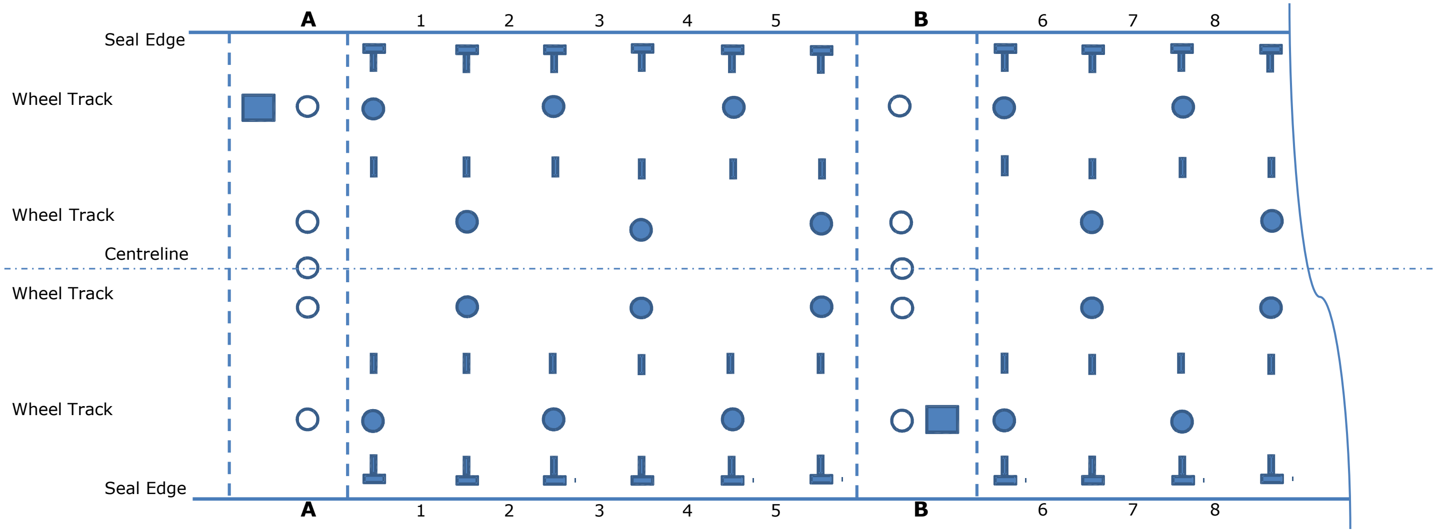
# APPENDIX A: Experimental and LTPP Section Setting Out Details

## Research and LTPP Section Markings




**NOT TO SCALE**

**Notes**

a) Wheel tracks should have deflection test points marked but DO NOT MARK a continuous straight line along the wheel track
b) For a Research Section A and C are 20 m wide and B is 10m wide, 1 to 10 are each 20m wide
c) For a LTPP Section A to E are 20 m wide, and 1 to 20 are each 20 m wide
d) Total section length for a Research Section is 250 m, for a LTPP Section it is 500m and for a Gravel Control Section 300 m
e) The edges of grids A to E must be marked fully across the road width
f) Grids A to E are mainly for trial pits, DCP tests, sampling for lab testing, layer thicknesses, and layer moistures

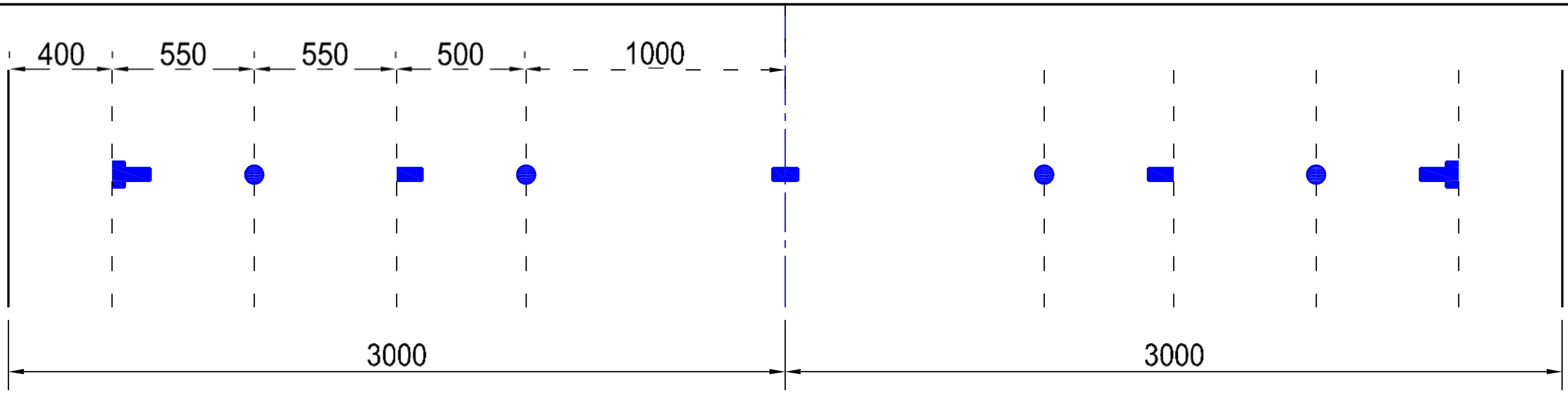
FWD measurement point, on existing wheel paths or if no wheel tracks visible then it should be estimated

Straight edge placement guidelines for measuring rut depths

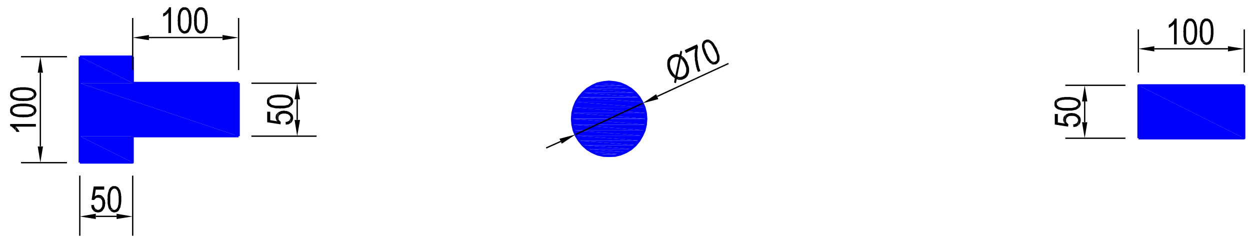
Straight edge placement guidelines for measuring rut depths

FWD, DCP, and Base Moisture Content test locations **(TEMPORARY MARK WITH CHALK)**

FWD, DCP, and Trial-Pit locations **(TEMPORARY MARK WITH CHALK)**




Marking plan for 6 m wide sealed surfacing.




All dimensions in mm

Marking Details

**RESEARCH AND LTPP SECTION MARKINGS – CROSS SECTION**

## APPENDIX B: Soil Profile Description

It is imperative that all descriptions of soil profiles in borrow pits, test pits in the road or anywhere else related to the pavement are carried out in a consistent and repeatable manner. The process widely employed in southern Africa is based on a revision of the Jennings, Brink and Williams (1973) method by Brink and Bruin (1990) and six primary parameters are described as summarised below.

**Moisture condition**

Assessment of the moisture condition is a precursor to the estimation of consistency which is largely dependent on the moisture content at the time of inspection. The following descriptors are used for the moisture evaluation.

*Dry*, *slightly moist*, *moist*, *very moist*, *wet*.

Slightly moist materials are near the optimum moisture condition while very moist soils require drying to attain optimum moisture content. Wet soils generally come from below the water table. The moisture content is, however, highly dependent on the grain size of the soil, e.g., a sand with a moisture content of 5% to 10% will be observed to be wet, while a clay at the same moisture content would may be dry or only slightly moist.

**Colour**

A repeatable description of the predominant colours of the soil assists with the correlation of different layers/strata on a site. The description should be limited to two colours, e.g., reddish brown or blue-green. Secondary colour patterns can be described according to their size limits as shown in Table A-1. A typical description for an alluvial clay would be 'light grey mottled yellow'.

Colour as observed in the soil profile is difficult to describe and few observers agree when their observations are made subjectively. The use of Munsell colour charts and a soil wet to a standard degree makes the results more consistent. An experienced observer, however, will describe colour consistently without recourse to colour charts.

**Table A-1: Description of secondary colour term**

| Term | Description |
|---|---|
| Speckled | Very small patches of colour (< 2 mm) |
| Mottled | Irregular patches of colour (2 - 6 mm) |
| Blotched | Large irregular patches of colour (6 - 20 mm) |
| Banded | Approximately parallel bands of varying colour |
| Streaked | Randomly orientated streaks of colour |
| Stained | Local colour variations: associated with discontinuity surfaces |

### Consistency

The consistency is a measure of the hardness or toughness of the soil. It is based on observation of the effort required to dig into the soil, or alternatively to mould it with the fingers. Since these operations involve shearing, the assessment of consistency is, in fact, a rough measure of its shear strength.

The separation of soils into cohesive and non-cohesive classes to describe consistency arises because of differences in permeability or drainage characteristics which profoundly affect their shear strengths.

Tables A-2 and A-3 summarise the descriptors for the consistency of granular and cohesive materials respectively.

**Table A-2: Description of consistency of granular materials**

| Consistency | Gravels and clean sands. Generally free-draining (cohesionless materials) | Typical dry density (kg/m$^3$) | Saturated SPT Blow counts (N) |
|---|---|---|---|
| Very loose | Crumbles very easily when scraped with a geological pick | < 1450 | <4 |
| Loose | Small resistance to penetration by sharp end of geological pick | 1451 - 1600 | 5 – 10 |
| Medium dense | Considerable resistance to penetration by sharp end of geological pick | 1601 - 1750 | 11 – 30 |
| Dense | Very high resistance to penetration by sharp end of geological pick: requires many blows of pick for excavation | 1750 - 1925 | 31 – 50 |
| Very dense | High resistance to repeated blows of geological pick: requires power tools for excavation | >1925 | >50 |

**Table A-3: Description of consistency of cohesive materials**

| Consistency | Silts and clays and combinations thereof with sand. Generally slow draining (cohesive materials Φ = 0) | Unconfined compressive strength (kN/m²) | Saturated SPT Blow counts<br><br>Sensitive silts and clays (N) | Saturated SPT Blow counts<br><br>Insensitive silts and clays (N) |
|---|---|---|---|---|
| Very soft | Pick head can easily be pushed in to the shaft of the handle: easily moulded by fingers | < 50 | <2 | <5 |
| Soft | Easily penetrated by thumb; sharp end of pick can be pushed in 30 – 40 mm; moulded with some pressure | 50 - 125 | 2 - 4 | 6 - 10 |
| Firm | Indented by thumb with effort; sharp end of pick can be pushed in up to 10 mm; very difficult to mould with fingers; can just be penetrated with an ordinary hand spade | 126 - 250 | 5 - 8 | 11 - 25 |
| Stiff | Penetrated by thumb nail; slight indentation produced when by pushing pick point into soil: cannot be moulded by fingers; requires hand pick for excavation | 251 - 500 | 9 - 15 | 26- 50 |
| Very stiff | Indented by thumb nail with difficulty; slight indentation produced by blow of pick point: requires power tools for excavation | 501 - 1000 | 16 - 20 | 51 - 80 |

**Structure**

This term indicates the presence (or absence) of discontinuities in the soil and their nature. Non-cohesive soils exhibit a granular structure and since this is an invariable feature it is usually not recorded. Cohesive soils exhibit several types of structural characteristics (Table A-4).

**Table A-4: Description of soil structure**

| Term | Identification |
|---|---|
| Intact | Structureless, no discontinuities identified |
| Fissured | Soil contains discontinuities which may be open or closed, stained or unstained and of variable origin |
| Slickensided | The term qualifies other terms to describe discontinuity surfaces which are smooth or glossy and possibly striated |
| Shattered | Very closely to extremely closely spaced discontinuities resulting in gravel-sized soil fragments which are usually stiff to very stiff and difficult to break down. |
| Micro-shattered | As above, but sand-sized fragments |
| Stratified, laminated or foliated | These and other accepted geological terms may be used to describe sedimentary structures in transported soils and relict structures in residual soils |
| Pinholed | Pinhole-sized voids or pores (up to about 2 mm) which may require a hand-lens to identify |
| Honeycombed | Similar to pinholed but voids and pores > 2 mm; (pore size may be specified in mm) |
| Matrix-supported | Clasts supported by matrix |
| Clast-supported | Clasts touching (matrix may or may not be present) |

**Soil texture**

The soil texture is a representation of grain size and the classes are shown in Table A-5.

In describing boulders, cobbles and gravels, care should be given to the description of the matrix and in particular the percentage it occupies. The shape of larger particles often aids the interpretation of origin:

- well-rounded (nearly spherical)
- rounded (tending to oval shape)
- sub-rounded (all corners rounded off)
- sub-angular (corners slightly bevelled)
- angular (corners sharp or irregular)

Most natural soils are a combination of one or more textures. The adjective is used to denote the lesser type, e.g. a silty clay is a clay with some silt whereas a silt-clay has approximately equal proportions of silt and clay.

**Table A-5: Description of soil texture**

| Grain size (mm) | Classification | Individual particles visible using | Mineralogical composition | Identification test |
|---|---|---|---|---|
| <0.002 | Clay | Electron microscope | Secondary minerals (clays and iron oxides) | Feels sticky or soapy. Soils hands. Shiny when wet |
| 0.002 - 0.06 | Silt | Microscope | Primary and secondary minerals | Chalky feel on teeth. When dry rubs off hands. Dilatant |
| 0.06 – 0.2 | Fine sand | Hand lens | Primary minerals (mainly quartz) | Gritty feel on teeth |
| 0.2 – 0.6 | Medium sand | Naked eye | Primary minerals (mainly quartz) | Observed with naked eye |
| 0.6 – 2.0 | Coarse sand | Naked eye | Primary minerals (mainly quartz) | Observed with naked eye |
| 2.0 – 6.0 | Fine gravel | Naked eye | Primary minerals (mainly quartz) | Observed with naked eye |
| 6.0 – 20.0 | Medium gravel | Naked eye | Primary minerals (mainly quartz) | Observed with naked eye |
| 20.0 – 60.0 | Coarse gravel | Naked eye | Primary minerals (mainly quartz) | Observed with naked eye |
| 60.0 - 200 | Cobbles | Naked eye | Primary minerals (mainly quartz) | Observed with naked eye |
| >200 | Boulders | Naked eye | Primary minerals (mainly quartz) | Observed with naked eye |

**Origin**

An attempt should be made to determine the origin of the soil in each layer of the soil profile. This is generally quite easy in the case of residual soils below the pebble marker (where one exists), but may prove more difficult in the transported soil zone.

## REFERENCES

Brink, ABA and Bruin, RMH. (Editors). 1990. Guidelines for Soil and Rock Logging in South Africa, 2nd Impression 2001, Proceedings, Geoterminology Workshop organised by AEG, SAICE and SAIEG.

Jennings, JE and Brink, ABA. 1961. A guide to soil profiling for civil engineering purposes in South Africa. Trans. South Afr. Instn Civ Engnrs., Vol 3 (8), 145-151.

Jennings JE, Brink ABA & Williams AAB (1973) Revised guide to soil profiling for civil engineering purposes in southern Africa, The Civil Engineer in South Africa, Jan 1973 Trans SAICE, Vol 15 No 1.

# APPENDIX C: Visual Assessment Methodology

## C.1 General (TMH9, Part A)

### C.1.1 Introduction

The visual assessment guidelines presented in this document are a synthesis of the Draft Technical Methods for Highways no. 9 (TRH9; COTO, 2013). TRH9 is the product of over 30 years of experience in the evaluation of the condition of roads as input for a road asset management system at both strategic and tactical level.

TMH9 consists of five parts:

- ***Part A*** *provides general information on aspects such as: the attributes of distress, segment lengths and segment information required, assessment procedures and quality assurance, and risk assessment;*
- ***Part B*** *provides visual assessment guidelines for flexible pavements (cf. Section 2);*
- ***Part C*** *provides visual assessment guidelines for concrete pavements (cf. Section 3);*
- ***Part D*** *provides visual assessment guidelines for block pavements (cf. Section 4); and*
- ***Part E*** *provides visual assessment guidelines for unpaved roads (cf. Section 5).*

The appearance of distress is varied and often complex. The task of describing this is achieved by recording its main characteristics, which are: (a) type, (b) degree, (c) extent and (d) spacing or activity (where applicable).

The **degree** of a particular distress is a measure of its severity. The following scale from 0 to 5 is used for that purpose:

- *0 – None: no distress visible*
- *1 – Slight: distress difficult to concern. Only first signs of distress are visible.*
- *2 – Slight to Warning: distress clearly visible but not at degree 3.*
- *3 – Warning: start of secondary defects. (Distress notable with respect to possible consequences.)*
- *4 – Warning to Severe: secondary defects clearly visible but not at degree 5 yet.*
- *5 – Severe: secondary defects are well developed (high degree of secondary defects) and/or extreme severity of primary defects*

The **extent** of a distress is a measure of how widespread the distress is over the entire length of the road segment. Table B.1 depicts the general description of extent classification, which is also illustrated in Figure B.1.

**Table B.1: General Description of Extent Classification**

| Extent | Description | Percentage of length |
|---|---|---|
| **1** | Isolated occurrence. Not representative of the segment length being evaluated. | < 5 |
| **2** | Occurs over parts of the segment length. More than isolated | 5 – 10 |
| **3** | Intermittent (scattered) occurrence over most of the segment length (in general), or extensive occurrence over a limited portion of the segment length. | 10 – 25 |
| **4** | More frequent occurrence over a major portion of the segment length. | 25 – 50 |
| **5** | Extensive occurrence over the entire segment. | > 50 |

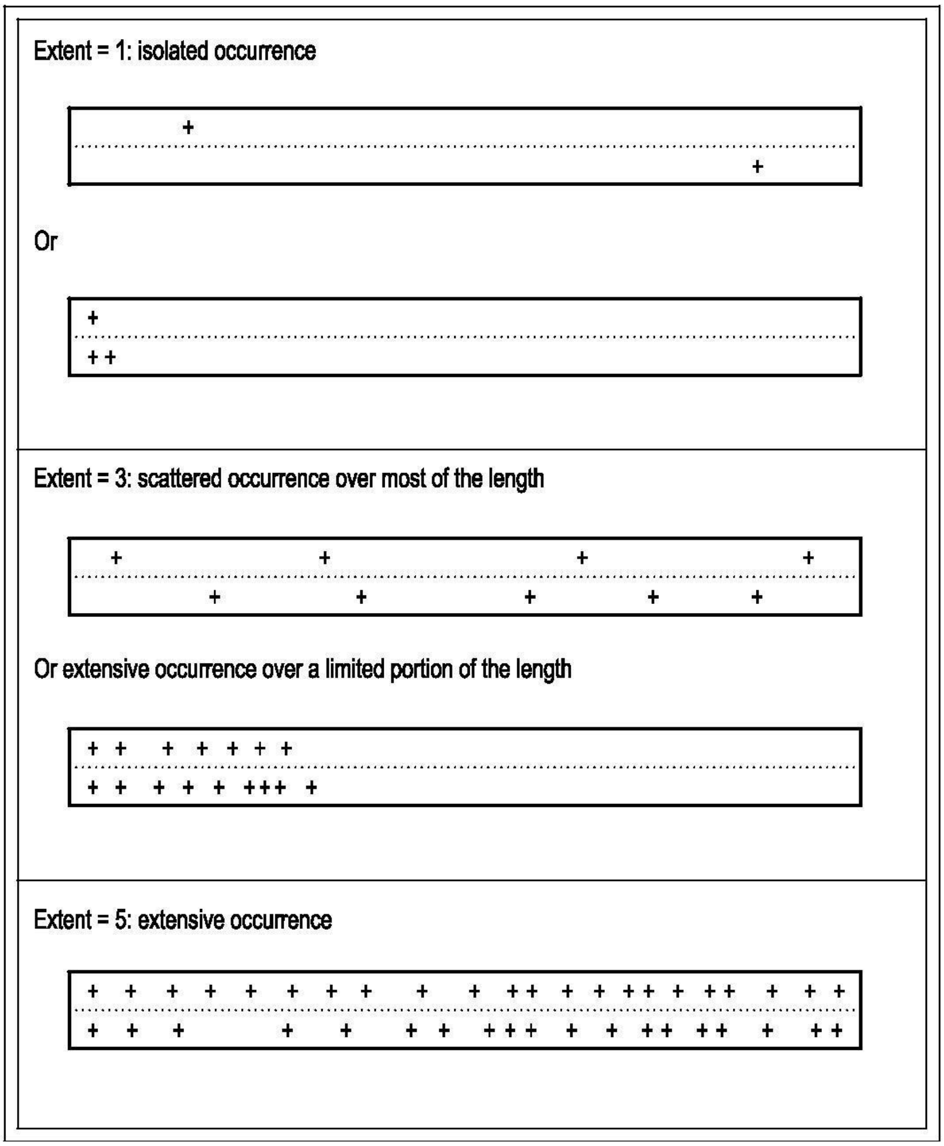



**Figure B.1: Illustration of Extent**

Road segment lengths may vary according to various parameters. From the perspective of a trial section or LTPP section, the full length of a section (typically between 250 and 500 metres) could be classified as a segment, or each of the panels could be assessed individually.

Road segment information to be recorded could include the following (where appropriate):

- *Road number/Street name*
- *Road Referencing – kilometre markers, GPS coordinates*
- *Section – a length of road or street with a unique identifier*
- *Link – a length of road from one intersection or interchange to the next*
- *Segment – the length of road for which one assessment rating is recorded*
- *LTPP/trial section panel number*
- *Start and end kilometre distance of the segment concerned*
- *Date of assessment*
- *Name of assessor*
- *Segment description – physical description of the segment start and end points*
- *Node type – based on the abbreviated codes provided in Table B.2*
- *Road Classification – Rural/Urban; Commercial/Residential, Major/Minor, Distributor/ Arterial/Collector.*
- *Route class – Principle arterial (1), major arterial (2), minor arterial (3), collector road (4) or local street (5)*
- *Ownership – National, provincial or local, or private*
- *Segment length and width (preferable to the nearest 0.1m)*
  *Terrain – Flat (grades less than 3%), Rolling (grade between 4 and 7%) or Mountainous (grades more than 7%).*

**Table B.2: Node Types**

| | | | |
|---|---|---|---|
| Intersection | X | End of paved segment | EP |
| T-Junction | T | Start of paved segment | SP |
| T-junction left | TL | Start of segment (no node) | ST |
| T-Junction right | TR | End of segment (no node) | EN |
| Towns/villages | V | Borders/boundaries | BO |
| Maximum segment length used as segment end | | | MX |

## C.1.2 Assessment Procedure and Quality Assurance

### C.1.2.1 *Assessment Procedure*

Visual assessments of trial sections and LTPP sections should be conducted at 6-month intervals, ideally before and after the rainy season (where applicable).

Because of their relatively short length, the trial sections and LTPP sections should be assessed on foot. If the LTPP section forms part of a longer road section of same design and construction as that of the LTPP section, the sections outside the LTPP section can be assessed by the assessor while driving at a speed not exceeding 20km/h on the shoulder, where possible.

Assessments can be carried out by one assessor (e.g. the Project Engineer) or by one assessor and one or more assistants (e.g. Field Technicians). Assistants should be used when complexity or safety are an issue. The first segment to be evaluated on a road requires a thorough orientation to adjust the assessor to the prevailing conditions, because the position of the sun (preferably from the rear), the amount and variability of cloud cover and a wet surface will influence the visibility of the defects, (e.g. cracks). When the road is wet, it is difficult to observe distress, and this leads to erroneous ratings; visual surveys shall therefore be carried out under dry conditions only.

#### C.1.2.2 *Quality*

Assessors should be well trained in the appropriate use of the guidelines and visual assessment procedures before undertaking an assessment. Ideally, the same assessment team should be used throughout the full duration of the LTPP programme.

A Quality Management Plan for visual assessments should be drafted and should include quality control and quality acceptance components.

Quality control must start with a calibration session which highlights issues specific to the LTPP sections, lists any additional items to be collected and discusses challenges faced during previous assessments. Quality control must also include allowances for contingencies regarding vehicles and data capture devices, safety of assessors, regular data backup and other operational issues.

Quality acceptance comprises the assessment of the data obtained from the last survey conducted with those of previous surveys to validate the trends in the condition data.

## C.2 Flexible Pavements (TMH9, Part B)

### C.2.1 General

This section deals with the degree of defects observed on flexible pavements (i.e. pavements that are surfaced with a bituminous bound layer such as an asphalt layer or a surface treatment). The extent of the defects is as per the descriptions provided in Section 1.

For flexible pavements, the visual assessment is divided into three categories:

1. Engineering assessment (surfacing)
2. Engineering assessment (structural)
3. Functional assessment

Appendix C provides a typical form for the visual assessment of flexible pavements (Form 1).

### C.2.2 Engineering Assessment (Surfacing)

The following surfacing defects are addressed in this section: surface texture, surfacing failures, surfacing patching, surfacing cracks, aggregate loss, binder condition, bleeding/flushing and surface deformation.

As part of the survey, the assessors need to classify the type of surfacing. The following surfacing types and codes could be used for that purpose: continuously-graded asphalt (AC), gap-graded asphalt (AG), semi-gap-graded asphalt (AS), open-graded asphalt (AO), single seal (S1), multiple seal (S2), sand seal (S3), Cape seal (single seal and slurry; S4) and slurry seal (S5).

#### C.2.2.1 *Surface Texture*

Surface texture need be classified as being coarse, medium, fine and varying. A ‘Coarse’ texture will be selected if the coarse aggregates are clearly visible, a ‘Medium’ texture if the coarse aggregate are visible but the surface does not appear coarse (e.g. fine aggregate present between coarse aggregate), and a ‘Fine’ texture if the surface appears smooth and the coarse aggregate (if present) is not visible. The texture will be classified as ‘Varying’ if the texture varies across the lane width (e.g. the surface appears smooth in the wheel path and different elsewhere).

#### C.2.2.2 *Voids*

Void classification includes none, few, many and varying. ‘None; suggests the surface is dense (or bleeding) and no voids are visible, ‘Few’ if some voids are visible and the surfacing is fairly dense, and ‘Many’ if the voids are visible, the surfacing is open and aggregates are well proud of binder. The surface will be considered ‘Varying’ if there is variation of the voids in the cross section of the road section.

#### C.2.2.3 *Surfacing Failures*

Surface failures exclude structural failures, which are evaluated in Section 2.3. They typically include (shallow) surface related potholes caused by spalling around cracks, localised loss of surfacing due to poor bonding with the underlying layer, disintegration of weak surfacing aggregates and distress to the surfacing due to salt damage.

The defects are rated on a scale of 1 to 5, where:

- *Degree 1: Failures difficult to discern from moving vehicle. Small areas of surfacing are lost (diameter < 50mm)*
- *Degree 3: Significant failure is visible from a moving vehicle (diameter ≈ 150mm)*
- *Degree 5: Failure occurs over large areas and/or secondary defects have developed owing to the failure (diameter > 300mm)*

### C.2.2.4 *Surfacing Patching*

Surfacing patches can be described as minor patching with no distinct joint cuts on asphalt patches. Patches that are cut square or with distinct square edges are deemed structural but exceptions do exist. Geotextile patches are rated as surfacing patches.

If patches or failures occur outside the wheel paths, these should be assessed as surfacing patches. Patches occurring in the wheel paths should normally be assessed as structural defects such as crocodile cracking, deformation and rutting.

The defects are rated on a scale of 1 to 5, where:

- *Degree 1: Patching difficult to discern from a moving vehicle. Small areas of surfacing are patched (diameter < 100mm)*
- *Degree 3: Significant patches visible from a moving vehicle (Diameter ≈ 300mm)*
- *Degree 5: Patches occurs over large areas (diameter > 500mm)*

### C.2.2.5 *Surface Cracks*

Surfacing cracks are caused mostly by shrinkage of the bituminous surfacing as a result of decreased binder volume. This occurs when the binder ages and loses its lighter oils and aromatics. These cracks are also sometimes referred to as map cracks, star cracks and amorphous cracks. These cracks are more commonly found in dense surfacing such as sand seals, slurry seals, etc. and are more easily observable on finely textured surfaces.

The initial cracking consists of short longitudinal and transverse cracks randomly spaced over the full road width. The severity of the cracking increases with ageing, to form a map pattern. In this state, secondary cracking induced by traffic around the shrinkage cracks is often evident. If maintenance is poor the condition can deteriorate so that the basic pattern of shrinkage cracks is not obvious.

When surface treatments older than about eight years have areas of crocodile cracking over most of the road width, it is necessary to inspect less severely cracked areas for evidence of the characteristic map crack pattern resulting from binder shrinkage. Surfacing cracks are normally not confined to the wheel paths, as is the case with traffic associated crocodile cracks. This behavioural feature should be used to help distinguish this crack type from crocodile cracking. However, when in doubt, record the distress as crocodile cracking.

The defects are rated on a scale of 1 to 5, where:

- *Degree 1: Faint cracks. In some instances small cracks appear in a star pattern.*
- *Degree 3: Distinct cracks. Slight spalling may be visible. Can be observed when driving slowly. Emergence of a map crack pattern.*
- *Degree 5: Open cracks with severe spalling. Map crack pattern complete.*

### C.2.2.6 *Aggregate Loss*

Aggregate loss (ravelling) is the crumbling and loss of surfacing aggregate, usually as a result of traffic abrasion.

The defects are rated on a scale of 1 to 5, as shown below for slurry seals, single or multiple seals, and asphalt surfacing.

**Table B.3: Aggregate Loss**

| Degree | Description | | |
|---|---|---|---|
| | **Slurry Seals** | **Stone Seals** | **Asphalt Surfacing** |
| 1 | Very little discernible loss of aggregates. Loss of individual aggregate visible on close inspection. Difficult to discern from a vehicle. | Very little discernible loss of stone. Loss of individual stones visible on close inspection. Difficult to discern from a vehicle. | Very little discernible loss of aggregate or pre-coated chips. Difficult to discern from a vehicle. |
| 3 | Distinct aggregate loss in small areas, easily discernible from moving vehicle. Also general pitted appearance through distinct but scattered loss of aggregate. | Distinct stone loss in small areas, or general pitted appearance through scattered loss of aggregate clusters, losing shoulder to shoulder matrix. | Distinct disintegration of asphalt layer in small areas and/or general loss of pre-coated chips. Distinct pitted appearance. |
| 5 | General loss of slurry in large patches. | General loss of stone from all layers in large areas. | General disintegration of total asphalt layer. |

The activity of aggregate loss should also be assessed. Aggregate loss should be rated as 'Active' if aggregate loss is continuing or 'Non-Active if no continuing aggregate loss is visible.

### C.2.2.7 *Binder Condition (dry/brittle)*

The bituminous binders in surface treatments and asphalts become increasingly dry and brittle with time. This parameter measures the degree by which the bituminous binder has become dry and brittle over time.

The defects are rated on a scale of 1 to 5, where:

- *Degree 1: Binder not fresh but is sticky. Colour still bright black and/or very difficult to dislodge aggregate from the seal. (No shrinkage crack yet.)*
- *Degree 3: Binder appears dull (brownish) and brittle. Binder is brittle owing to hardening and/or aggregates can be dislodged from seal with relatively little effort. (Shrinkage cracks may have appeared in slurries or asphalt.)*
- *Degree 5: Binder is dull (brown) and very brittle (not sticky at all). binder elasticity is very low and/or aggregate can be dislodged from seal without effort. (Except surface cracks in asphalt and slurries, and aggregate loss on stone seals.)*

The extent of binder condition should be determined according to the definitions given in Section B.1. If the degree of binder condition is rated as > "0", then the extent should be rated as "5", unless there are significant variations in binder condition over the length and width of the road segment.

#### C.2.2.8 *Bleeding/Flushing*

Bleeding occurs when excess binder moves upwards relative to the aggregate, therefore reducing surface texture depth.

The defects are rated on a scale of 1 to 5, where:

- *Degree 1: Surface is slightly rich in excess binder. Stones well proud of binder.*
- *Degree 3: Surface is rich in excess binder. Smooth appearance, but stones visible in binder.*
- *Degree 5: Surface very rich in excess binder, giving pavement surface a wet look. Film of excess binder covering all stones in wheel parts. Surface is tacky during hot weather and/or wheel prints are visible in binder with possible pickup of binder.*

#### C.2.2.9 *Surface Deformation/Shoving*

This is also a common defect in urban areas specifically at intersections where acceleration and/or braking of trucks cause shoving of the surfacing. It is best assessed from within a moving vehicle at the average speed of the road.

The defects are rated on a scale of 1 to 5, where:

- *Degree 1: Visible, but not felt in a light vehicle*
- *Degree 3: Can be felt and speed reduction is necessary*
- *Degree 5: Drivers avoid the defect by selecting a different path and drive very slowly*

### C.2.3. Engineering Assessment (Structural)

This section provides guidelines for the evaluation of the current condition of the pavement structure as manifested through visible distress.

The defects are the result of deterioration of the strength of the pavement structure caused by, for example, a poor surfacing, ingress of water, traffic, climate, quality of material in pavement layers and the age of the pavement.

The following modes of distress which indicate the defects in the pavement structure are to be evaluated with regard to degree and extent: cracks (block, longitudinal/slip, transverse and crocodile), pumping, rutting, undulation/settlement, patching, potholes and failures.

#### C.2.3.1 *Cracks*

The following cracks are to be noted based on their pattern produced on the pavement.

- *Block cracks – create a definite block pattern although the longitudinal and transverse cracks do not always meet. Generally caused by the shrinkage of treated (stabilised) pavement layers.*
- *Longitudinal/slip cracks – longitudinal cracks are line cracks that run longitudinally along the pavement and are often located near the edge of the pavement. Slip cracks often occur in circular patterns. Both these cracks are not restricted to the wheel paths and may occur because of poor construction techniques (e.g. asphalt overlay construction joint), settlement or movements of embankments or active clay subgrades. A difference in height between affected and adjacent unaffected areas, separated by a crack at the tension zone between the two areas, could indicate subsidence or slip.*
- *Transverse cracks – line cracks across the pavement, potentially caused by shrinkage in a cement-stabilised base or subbase, active clay in the subgrade or temperature-associated fatigue and seasonal effects. Often occur at drainage structures or where services were installed (poor/differential compaction).*
- *Crocodile cracks – often limited to the wheel paths. Occur as a result of fatigue failure of surfacing or base layers and are related to the inability of the pavement to carry the traffic load. Initially appear as fine, irregular longitudinal cracks, then grows progressively closer and eventually interconnect to form the familiar crocodile pattern.*

The above-mentioned cracks, with the exception of crocodile (fatigue) cracks are to be assessed on a scale of 1 to 5, where:

- *Degree 1: Faint cracks.*
- *Degree 3: Distinct, open cracks (≈ 3 mm) with slight spalling, deformation or secondary cracking at corners in the form of triangles.*
- *Degree 5: Open cracks (> 3 mm) with significant spalling, secondary cracking or deformation evident around open cracks, or wide open cracks (> 10 mm) with little or no secondary defects.*

In the case of crocodile cracking, the following descriptions apply:

- *Degree 1: Faint cracks in wheel paths. Only visible on close inspection.*
- *Degree 3: Distinct cracks with slight deformation/movement of cracked areas and/or slight spalling of the edges.*
- *Degree 5: Open cracks with severe deformation/movement of cracked area and/or extensive spalling of edges. Crocodile cracking has spread outside the wheel paths. High density of crocodile crack pattern.*

#### C.2.3.2 *Pumping*

Pumping occurs when active pore pressure under traffic loading pump fine material from within the pavement to the surface, normally through existing cracks.

The defects are rated on a scale of 1 to 5, where:

- *Degree 1: Pumping faintly visible on close inspection.*
- *Degree 3: Pumping clearly visible from vehicle. Only slight or no deformation of road surface next to the crack.*
- *Degree 5: Extensive deposits of fines alongside the cracks and/or severe deformation at cracks.*

#### C.2.3.3 *Rutting*

Rutting results from compaction or deformation through the action of traffic and is limited to the wheel paths. When the rutting is fairly wide and even-shaped, the problem is normally in the lower pavement layers. When rutting is narrower and more sharply defined, the problem normally lies within the upper pavement layers. Assessors are not expected to measure the rut depths using a straight edge, but for calibration purpose rutting is defined as the maximum deviation measured under a two metre straight edge placed transversely across the rut.

The defects are rated on a scale of 1 to 5, where:

- *Degree 1: Difficult to discern unaided (< 5mm)*
- *Degree 3: Just discernible (≈ 10 - 15mm)*
- *Degree 5: Severe, dangerous. Very obvious from moving vehicle, even at high speeds (>30mm)*

#### C.2.3.4 *Undulation/Settlement*

Undulation is a wavy form of deformation usually associated with adverse foundation conditions (e.g. differential settlements). Note: unevenness caused by patches, potholes, corrugations and failures should not be assessed as undulation.

The defects are rated on a scale of 1 to 5, where:

- *Degree 1: Causes slight unevenness of road profile, ride is still smooth and comfortable.*
- *Degree 3: Clearly visible and has an effect on ride quality. Motorists may have to reduce driving speed if extent is more than merely localised.*
- *Degree 5: Ride very poor and very uncomfortable. Road unsafe at normal speed limit.*

#### C.2.3.5 *Patching*

Structural patches indicate the existence of previous defects. The average size of the patches provides an indication of the severity of the distress type that was repaired with the patch. Distress types within the patch should be rated separately.

Assessing of patches is to be based on the average size of the patches, rated on a scale of 1 to 5, where:

- *Degree 1: Average Size < $2m^2$*
- *Degree 3: Average Size ≈ $5m^2$*
- *Degree 5: Average Size > $10m^2$*

The number of patches is also to be recorded; small, medium and large based on the above areas. Rut filling, services crossings and repair work greater than 50m are not to be recorded as patches. If a patch has failed, it should be assessed as a structural failure/pothole.

#### C.2.3.6 *Potholes*

Potholes (loss of material from the base layer) refer to structural failures and exclude surfacing failures (owing to loss of surfacing) described in Section B.2.2.3. They are generally a secondary form of distress that develops from cracking or extreme loss of aggregate. They are traffic induced and normally develop from structural cracking in the wheel paths. Moisture enters into the pavement resulting in the formation of potholes.

The degree of potholes is expressed by the average diameter and depth of potholes, rated on a scale of 1 to 5, where:

- *Degree 1: Diameter < 100mm*
- *Degree 3: Diameter > 200 mm and of significant depth (> 25mm)*
- *Degree 5: Diameter > 300mm and of serious depth (> 50mm) and/or severe secondary defects*

The number and average diameter of potholes are also to be recorded.

#### C.2.3.7 *Failures*

These are structural failures mostly manifested as lateral displacements of the surfacing and base course, generally caused by a loss of shear strength in the base course (or sometimes underlying layers). They are traffic induced and form mounds towards the edge of the road adjacent to depressions in the wheel-paths.

Failures to be assessed using the following degrees, rated on a scale of 1 to 5, where:

- *Degree 1: Failure initiated. Minor depression (< 30mm). Start of surface distress and shoving.*
- *Degree 3: Failure developing. Visible depression (± 50mm). Surface cracked and shoving with obvious mounting.*
- *Degree 5: Severe failure with loss of surfacing and base material or severe depression (100mm), cracking of seal and significant shoving and mounting.*

### C.2.4. Functional Assessments

The functional requirements of a road reflect the service it provides to the road user. They are predominantly those that govern to comfort, safety and speed of travel.

The various functional features to be assessed are: riding quality, skid resistance, surface drainage, condition of the shoulders and edge defects.

#### C.2.4.1 *Roughness (Ride Quality)*

The riding quality of a pavement is defined as the general extent to which road users, through the medium of their vehicles, experience a ride that is smooth and comfortable, or bumpy and therefore unpleasant or perhaps unsafe. This is determined by the unevenness of the road profile (longitudinal deformation, rutting in wheel paths, etc.), the loss of surface or base layer material (potholes, extreme ravelling, etc.) and uneven patching.

The degree of ride quality is rated on a scale of 1 to 5, where:

- *Degree 1: Ride very smooth and very comfortable, no unevenness of the road profile, no rutting, revelling or uneven patching.*
- *Degree 2: Ride smooth and comfortable, slight unevenness of the road profile, slight rutting, ravelling or uneven patching.*
- *Degree 3: Ride fairly smooth and slightly uncomfortable, intermittent moderate unevenness of the road profile, moderate rutting, ravelling or uneven patching.*
- *Degree 4: Ride poor and uncomfortable, frequent moderate unevenness of the road profile, frequent rutting, ravelling or uneven patching, comfortable driving speed below speed limit.*
- *Degree 5: Ride very poor and very uncomfortable, extensive severe unevenness of the road profile, extensive rutting, ravelling or uneven patching, comfortable driving speed much lower than speed limit, road unsafe owing to severe unevenness.*

Problems associated with ride quality to be noted (potholes, patching, undulations, corrugation).

#### C.2.4.2 *Skid Resistance*

Skid resistance is the ability of the road surface to prevent skidding when wet. Two important characteristics are the surface texture depth and the hardness or roughness of the stones themselves.

The degree of skid resistance is rated on a scale of 1 to 5, where:

- *Degree 1: Skid resistance adequate for roads carrying high speed traffic, surface texture coarse, many voids. Stones very rough, edges sharp to the touch.*
- *Degree 3: Skid resistance intermittently inadequate for high speed traffic and/or surface texture medium to fine, few voids. Stones not very sharp or very rough to the touch.*
- *Degree 5: Skid resistance inadequate for all traffic and/or texture fine, no voids, film of binder covering all stones. Stones rounded and smooth to the touch.*

Problems to be noted in the event of poor skid resistance (bleeding, polished aggregates)

#### C.2.4.3 *Surface Drainage*

The surface drainage of the road is a measure of the general ability of the road to keep the riding surface clear of water.

The degree of surface drainage is rated on a scale of 1 to 5, where:

- *Degree 1 ("adequate"): no visible problem that could retard the run-off of water from the road and shoulders.*
- *Degree 3 ("inconsistent"): problems exist that could lead to general slight ponding or severe localised ponding.*
- *Degree 5 ("inadequate"): problems exist that could lead to widespread severe ponding in the wheel paths.*

### C.2.4.4 *Side Drainage*

Side drainage is not to be rated as a 'degree', but should be noted where drains are overgrown, blocked and non-existent.

### C.2.4.5 *Untraveled Way (Shoulders)*

The unpaved shoulder is rated in terms of the availability of the shoulder as a safe recovery area. Several problems might render the unpaved shoulder unsafe, for example: erosion of the shoulder by water; wearing out by traffic; level differences between edge of carriageway and shoulder; width of the shoulder is too narrow; cross-sectional slope of the shoulder is too steep; or sight distances are obstructed by vegetation.

These problems can be indicated on the assessment form by marking the appropriate block(s):

- *None: If the edge of the road is defined by a kerb or there are no shoulders (e.g. in a mountain pass).*
- *Safe: Shoulder can be safely used as stopping area at the posted speed limit.*
- *Warning: Problems may be expected if the shoulder is used as stopping area at the posted speed limit (routine maintenance required).*
- *Unsafe: Shoulder is unsafe to be used as stopping area at the posted speed limit.*

If the paved shoulder width is less than 2 m, the verge (unpaved area) should be rated as part of unpaved shoulder.

### C.2.4.6 *Edge defects*

Edge defects are more common on narrow roads due to traffic moving closer to the edges. Defects occurring within 300mm from the edge are assessed as:

- *Edge breaks: They are caused by the breaking away of the surfacing at the outside edges of the surfacing. This is often due to poor unpaved shoulder maintenance. The degree is rated by measuring the average distance from the edge of the pavement to the maximum points of breakage.*
- *Short transverse cracks: These cracks are initiated at the edge of the road and migrate inwards.*
- *Drop-off: This is the step between the surfacing and the shoulder caused by erosion.*

The defects are rated on a scale of 1 to 5, as per the table below.

**Table B.4: Edge Defects**

| Degree | Description | | |
|---|---|---|---|
| | **Edge break** | **Short transverse crack** | **Drop-off** |
| **1** | < 50 mm | Faint | < 50mm |
| **3** | ≈ 150 mm | Distinct (up to 3mm) | ≈ 75mm |
| **5** | > 300 mm<br><br>Safety hazard to traffic | Open (> 3mm) with spalling | > 100mm |

Note: Edge breaks extending into the wheel path should be classified as potholing.

### C.2.5 Overall condition of the pavement

A general rating for the condition of the pavement is useful for data verification. The following scale can be used for this purpose:

- *Very Good: Very few or no defects. Degree of defects < 3 (less than warning)*
- *Good: Few defects. Degree of structural defects mostly less than warning*
- *Moderate: A few defects with degree of defects seldom severe. Extent is only local if degree is severe (excluding surface defects).*
- *Poor: General occurrence of particular structural defects with degrees warning to severe*
- *Very Poor: Many defects. The degree of the majority of structural defects is severe and the extent is predominantly general to extensive.*

### C.2.5 Weightings for Condition Parameters

The recommended weightings to be applied to the condition parameters for calculation of the VCI for lox volume sealed roads in Mozambique are given in the Table below.

**Weightings for Visual Condition Index (Paved Roads)**

| Parameter | | Weighting |
|---|---|---|
| Surfacing (Current) | Surface (Texture) | 0.7 |
| | Surfacing (Voids) | 0.7 |
| | Surfacing Failures | 0.7 |
| | Surface Patching | 0.7 |
| | Surfacing Cracks | 0.7 |
| | Aggregate Loss (A/N) | 0.7 |
| | Binder Condition (Dry/Brittle) | 0.7 |
| | Bleeding/Flushing | 0.7 |
| | Surface Deformation/Shoving | 0.7 |
| Structural | Block Cracks | 1.2 |
| | Longitudinal Cracks | 1.2 |
| | Transverse Cracks | 1.2 |
| | Crocodile Cracks | 1.2 |

| | | |
|---|---|---|
| | Pumping | 1.2 |
| | Rutting | 2.0 |
| | Undulations/Settlements | 1.2 |
| | Patching | 1.2 |
| | Potholes | 1.2 |
| | Failures | 1.2 |
| Functional | Roughness | 2.0 |
| | Skid Resistance | 1.0 |
| | Surface Drainage | 1.2 |
| | Shoulders (Unpaved) | 1.2 |
| | Edge Defects | 1.2 |
| Overall Pavement Condition | | 2.0 |

## C.3. Concrete Pavements (TMH9, Part C)

### C.3.1 General

This Section deals with the degree of defects observed on concrete pavements. These include jointed concrete (plain (CJP) and dowelled (DJP)) and continuously reinforced concrete (CRC) and ultra-thin continuously reinforced concrete (UTCRC) pavements. The extent of the defects is as per the descriptions provided in Section 1.

For concrete pavements, the visual assessment is divided into two categories:

1. Engineering assessment, and
2. Functional assessment

Appendix C provides a typical form for the visual assessment of concrete pavements (Form 2).

### C.3.2 Engineering Assessment

All crack parameters are to be assessed by degree, extent and percentage area of narrow and wide cracks. The percentage area is required for modelling analysis.

#### C.3.2.1 *Cracks*

The cracks assessed can be defined as:

- *Random: Map, crazy or crocodile cracking occurs in any type of concrete pavement, normally initiates from the top of the slab, and is associated with shrinkage occurring in the early age of the pavement.*
- *Transverse: Cracks parallel to joints, are recorded under this distress type. Transverse cracks normally develop jointed concrete pavements because of joints not functioning properly. However unplanned transverse cracks can also occur in CRC and UTCRC pavements. They*

*usually are because of poor construction techniques close to construction joints, subgrade movements or crack reflection from lower layers.*

- *Longitudinal: Cracks parallel to joints. They normally develop in all types of concrete pavements as a result of longitudinal joints not functioning properly. However unplanned cracks can also occur because of subgrade movements or crack reflection from lower layers.*
- *Corner: They occur where two joints meet, normally observed in JCP pavements. At least one leg of the triangle formed where the crack and the two adjacent joints meet must be shorter than 1.0 m.*
- *Cluster: This is a group of transverse cracks more closely spaced than planned for. For CRCP where transvers cracking is designed to occur at a spacing of 1.5m to 2.0m, cluster cracking is a group of transverse cracks spaced at less than 0.5m.*

All cracks are to be assessed on a scale of 1 to 5, where:

- *Degree 1: cracks are narrow, not clearly visible and without spalling*
- *Degree 3: cracks are wide, clearly visible with minor spalling*
- *Degree 5: cracks are wide, clearly visible and serious spalling occurring*

The extent of cracking is recorded by the percentage of segment length exhibiting the worst degree of a particular distress.

#### C.3.2.2 *Pumping*

Pumping of fine material occurs whenever relative vertical movements occur at cracks or joints or at the edge of the pavement.

The defects are rated on a scale of 1 to 5, where:

- *Degree 1: Slight discolouring of the concrete at the sides of the joint or crack*
- *Degree 3: Discolouring of the concrete and signs of fine material at the sides of the joint or crack*
- *Degree 5: Fine material being pumped from below the concrete slab and disposed at the sides of the joint or crack.*

#### C.3.2.3 *Joint Seal Condition*

Joint seal defects include seals that stand proud of the surrounding concrete surface, loss of bond with the concrete, seals that have been torn or damaged and obvious loss of elasticity.

The defects are rated on a scale of 1 to 5, where:

- *Degree 1: Seal still functional well but some indication of aging and loss of elasticity*
- *Degree 3: Not functional, i.e. sagging into the joint, protruding above the surrounding concrete and not adhering to concrete or torn*
- *Degree 5: Seal dislodged from joint allowing water to freely enter the pavement*

#### C.3.2.4 *Faulting at Joints and Cracks*

This is the difference in elevation across a joint or a crack and develops when eroded material from under the leave slab builds up under the approach slab at a joint or crack. Faulting generally only occurs on jointed pavements where there is no or poor load transfer between the slabs. The rocking, warping or curling of the slab contributes to the joint faulting and could also lead to cracking as a secondary effect.

Degree of faulting is rated on a scale of 1 to 5, where:

- *Degree 1: The fault or step is less than 3mm*
- *Degree 3: The fault is between 6 and 10mm*
- *Degree 5: The fault is more than 15mm*

#### C.3.2.5 *Undulations/Settlements*

Undulations and settlement of concrete pavements is defined as surface areas having elevations lower than those of the surrounding pavement. There generally is significant slab cracking in these areas due to uneven settlement. This distress type is usually associated with another type of distress. Pumping at the joints would lead to joint faulting and this might result in settlement. Consolidation of the lower layers could lead to settlement where compaction was uneven during construction, frequently above culverts or bridge approaches. Unevenness can also develop where pavements have been constructed over swelling or expanding clay subgrades. Settlement of concrete pavements usually occurs over a couple of meters because of the rigid nature of concrete.

The degree of undulations/settlements is rated on a scale of 1 to 5, where:

- *Degree 1: Slight unevenness in road profile, ride is still smooth and comfortable*
- *Degree 3: Clearly visible and influences riding quality. Motorists may have to reduce driving speed if extent is more than merely localised.*
- *Degree 5: Riding quality very poor and very uncomfortable owing to undulations, road unsafe at normal speed limit.*

#### C.3.2.6 *Punch Outs (UTCRCP and CRCP only)*

Punch-outs occur in CRC and UTCRC pavements once cluster cracking has reached the degree 4 stage and load transfer at cracks has been lost to a high degree. At this stage the transfer cracks of the cluster are linked by longitudinal cracks in the wheel paths of traffic and pumping start to develop.

The degree of undulations/settlements is rated on a scale of 1 to 5, where:

- *Degree 1: Longitudinal crack develops between two transfer cluster cracks*
- *Degree 3: Several longitudinal cracks between two transverse cluster cracks. Need to be repaired*
- *Degree 5: Several cracks leading to a loose block. Urgent repair needed.*

#### C.3.2.7 *Shattered Slabs*

When a slab contains two or more random cracks of degree 3 or higher the slab is recorded as shattered. The cracks, other than joint associated cracks, divide the slab into three or more distinct pieces that moves under traffic and need to be repaired by patching. Note: When a slab is recorded as shattered it cannot be recorded as cracked.

The degree of shattered slab is rated on a scale of 1 to 5, where:

- *Degree 1: The slab is fractured into not more than 3 fragments*
- *Degree 3: The slab is fractured into 5 fragments but no movement is evident*
- *Degree 5: The slab is fractured into 7 fragments or more and/or movement is clearly evident (i.e. the fragments are independent of each other).*

#### C.3.2.8 *Patching*

Structural patches indicate the existence of previous defects. The average size of the patches provides an indication of the severity of the distress type that was repaired with the patch.

The degree of shattered slab is rated on a scale of 1 to 5, where:

- *Degree 1: Isolated partial depth patch (not full depth and small)*
- *Degree 3: Isolated full depth patch (patch of significant size)*
- *Degree 5: Full depth patches (patches of significant size)*

The average degree of the patches is to be recorded as well as the number of small, medium and large patches.

#### C.3.2.9 *Texture*

Texturing of the pavement is required to ensure skid resistance under wet weather conditions. The degree of texturing is rated in accordance with the texture type:

- *Coarse: The surfacing has a coarse appearance with significant texture, tinned finish*
- *Medium: significant texture, probably heavy brush finish*
- *Fine: The surfacing is smooth. No texture, probably only float finish*
- *Varying: Variation of texture in the cross section of the road surface (e.g. smooth in wheel paths with different texture elsewhere)*

### C.3.3 Functional Assessment

The functional condition of a road reflects the service it provides to the road user in terms of aspects such as comfort, safety and speed of travel.

#### C.3.3.1 *Roughness/Ride Quality*

The roughness of a pavement is defined as the general extent to which road users, through the medium of their vehicles, experience a ride that is smooth and comfortable, or bumpy and therefore unpleasant or perhaps unsafe. This is determined by the evenness of the road profile and uneven patching.

The description of degrees of roughness is provided below:

- *Degree 1: Ride very smooth and very comfortable, no unevenness of the road profile, no uneven patching*
- *Degree 2: Ride smooth and comfortable, slight unevenness of the road profile, slight uneven patching*
- *Degree 3: Ride fairly smooth and slightly uncomfortable. Intermittent moderate unevenness of the road profile, moderate uneven patching*
- *Degree 4: Poor riding quality and uncomfortable, frequent moderate unevenness of the road profile, frequent uneven patching, comfortable driving speed below the speed limit*
- *Degree 5: Ride very poor and very uncomfortable, extensive severe unevenness of the road profile, extensive uneven patching, comfortable driving speed much lower than the speed limit, road unsafe owing to severe unevenness*

Problems relating to poor roughness are to be noted (shattered slabs, punch outs, undulations, patching and faulting).

#### C.3.3.2 *Skid Resistance*

Skid resistance is the ability of the road surface to prevent skidding when wet, in all manoeuvres generally executed by vehicles. The property that largely determines skid resistance is the surface texture, consisting of two elements: macro texture (i.e. texture depth) and micro texture (i.e. smoothness of exposed aggregate).

The degree of skid resistance is rated on a scale of 1 to 5, where:

- *Degree 1: Skid resistance adequate, coarse surface texture. Exposed aggregates rough with tinning depth > 1mm.*
- *Degree 3: Skid resistance intermittently inadequate. Surface texture medium to fine. Texture depth < 1mm)*
- *Degree 5: Skid resistance inadequate. Exposed aggregates polished and surface smooth to the touch*

#### C.3.3.3 *Surface Drainage*

The surface drainage of a road is a measure of the general ability of the road to keep the riding surface clear of water.

The degree of surface drainage is rated on a scale of 1 to 5, where:

- *Degree 1: No visible problem that could retard the run-off of water from the road and shoulders*
- *Degree 3: Problems exist that could lead to general slight ponding or severe localised ponding*
- *Degree 5: Problems exist that could lead to widespread severe ponding in the wheel paths*

#### C.3.3.4 *Unpaved Shoulders*

The unpaved shoulder is rated in terms of the availability of the shoulder as a safe recovery area. Several problems might render the unpaved shoulder unsafe, for example: erosion of the shoulder by water; wearing out by traffic; level differences between edge of carriageway and shoulder; width of the shoulder is too narrow; cross-sectional slope of the shoulder is too steep; or sight distances are obstructed by vegetation.

These problems can be indicated on the assessment form by marking the appropriate block(s):

- *None: If the edge of the road is defined by a kerb or there are no shoulders*
- *Safe: Shoulder can be safely used as stopping area at the posted speed limit*
- *Warning: Problems may be expected if the shoulder is used as stopping area at the posted speed limit (routine maintenance required)*
- *Unsafe: Shoulder is unsafe to be used as stopping area at the posted speed limit*

If the paved shoulder width is less than 2 m, the verge (unpaved area) should be rated as part of unpaved shoulder.

### C.3.4 Overall Pavement Condition

A general rating for the condition of the pavement is useful for data verification. The following scale can be used for this purpose:

- *Very good: Very few or no defects. Degree of defects less than 2*
- *Good: Few defects. Degree of engineering defects mostly less than 3*
- *Moderate: A few defects of degree 3 occur locally or seldom*
- *Poor: General occurrence of defects with degree 3*
- *Very Poor: Many defects. The degree of the majority of engineering defects is above 3 and the extent is predominantly general to extensive.*

## C.4. Block Pavements (TMH9, Part D)

### C.4.1 General

This Section deals with the degree of defects observed on block pavements. The extent of the defects is as per the descriptions provided in Section 1.

For block pavements, the visual assessment is divided into two categories:

1. Engineering assessment, and
2. Functional assessment

Appendix D provides a typical form for the visual assessment of block pavements (Form 3).

Prior to the assessment of the condition of the block pavement noting down the defects, some general information needs to be provided on the segmented block characteristics and lay pattern of the surface. These include the block shape, the lay pattern, the block thickness and chamfers:

#### C.4.1.1 *Block Shape*

Three block shape codes are to be used based on their degree of interlock that can be achieved between vertical faces of adjacent blocks:

- *S-A: Blocks which allow geometric interlock between ALL vertical faces of adjacent blocks*
- *S-B: Blocks which allow geometric interlock between some faces of adjacent blocks*
- *S-C: Blocks which allow no geometric interlock between adjacent faces*

### C.4.1.2 *Lay Pattern*

Block lay patterns are determined by performance and aesthetic requirements (see Figure B.2). The pattern code must be recorded on the visual assessment form.

- *HB: Herring bone*
- *SB: Stretcher-board*
- *BW: Basket weave*
- *OT: Other*

Numerous other patterns are also possible. Permeable paving, where the pavement structure is designed to allow entry of water into the pavement structure would be classified as OT (other). The herringbone pattern ensures the best resistance to both horizontal and vertical forces and is generally recommended for industrial and trafficked pavements.

### C.4.1.3 *Block Thickness*

Concrete paving block thickness varies between 50 and 80mm. However brick or burnt clay blocks tend to be thicker. The thicker the blocks the better the pavement will resist vertical deformation and horizontal creep.

The visual assessor is required to estimate the block thickness unless it is possible to physically measure it, e.g. at missing or loose blocks.

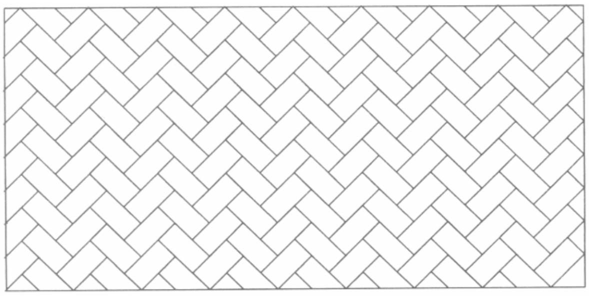
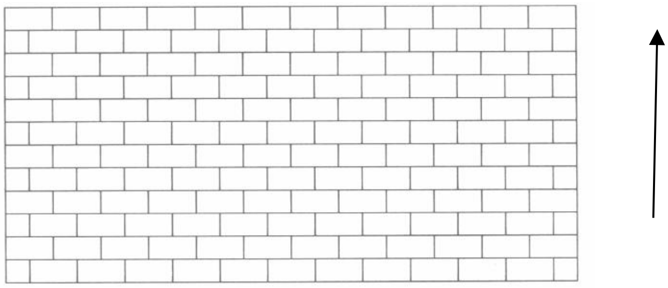
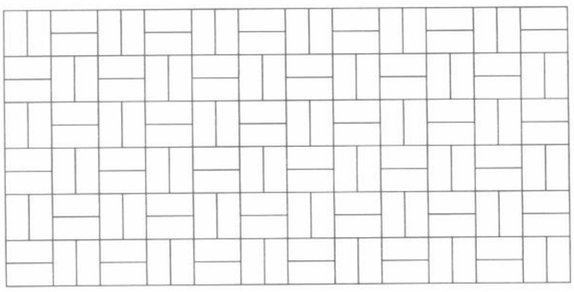
| | |
|---|---|
|  | **Herring-bone Lay Pattern** |
|  | **Stretcher –bond Lay Pattern** |
|  | **Basket Weave Lay Pattern** |

**Figure B.2: Illustration of Block Lay Patterns**

### C.4.1.4 *Chamfer*

Chamfering the top edges of blocks improves their service performance and appearance. Paving block chamfer reduces stress concentration at the surface. The absence of a chamfer may result in accentuated spalling. Chamfers can either be at a 45° angle, rounded or 90° angle (i.e. none). The chamfer codes are given below:

- *45: 45° angle chamfer*
- *R: Rounded Chamfer*
- *90: 90° chamfer (i.e. none)*

### C.4.2 Engineering Assessment

This section provides guidelines for the evaluation of the current condition of the pavement structure as manifested through visible distress.

The following modes of distress are to be evaluated with regard to degree and extent: spalled/ cracked/broken blocks, block surface integrity, loss of jointing sand, edge restraints, rutting, potholes/patching/reinstatements, and undulations/shoving.

#### C.4.2.1 *Spalled/Cracked/Broken Blocks*

Spalled blocks have chips out of the edges on the surface, generally because of stress concentration because blocks are deforming too much or the joint between adjacent blocks is unfilled or too narrow. Spalling is generally a precursor to cracking. Cracked blocks refer to block pavers that are cracked, and when extensively cracked or shattered these would be termed broken.

The degree is rated on a scale of 1 to 5, where:

- *Degree 1: single cracks or chips per block with minimal spalling at cracks*
- *Degree 3: more than one crack or chip occurring on individual blocks, and spalling at cracks*
- *Degree 5: shattered blocks losing parts of the blocks*

#### C.4.2.2 *Block Surface Integrity*

Under severe chemical and or mechanical conditions the upper surface of the blocks may wear away. Blocks are generally manufactured with a durable and wear resistant topping layer. When this layer starts to wear away it could affect the integrity of the blocks, and thus the structural capacity.

Block surface integrity is rated on a scale of 1 to 5, where:

- *Degree 1: Minimal evidence of wear visible*
- *Degree 3: Evidence of aggregate loss on surface, and some loss of the chamfer profile*
- *Degree 5: rounding of the upper block surface as a result of severe aggregate loss*

#### C.4.2.3 *Loss of Jointing Sand*

Jointing sand in the joints assists with keeping the water out of the pavement, and provides load transfer between adjacent blocks. The loss of jointing sand is probably one of the most common defects on block pavements. The loss of jointing sand could be as a result of inadequate filling at the time of construction or loss of sand through the action of wind or water. The result of a loss of jointing sand is that water readily enters into the pavement layers as the joints serve as water reservoirs and under the action of traffic the fine material in the bedding sand layer or even the subbase is pumped out. This leaves an uneven surface with steps between adjacent blocks. With the opening of the joints the blocks move horizontally, increasing the joint size and allowing even more water to enter the pavement structure. In this condition the blocks are loose, and rattle when vehicles pass over the surface.

The degree of assessment of loss of jointing sand is rated on a scale of 1 to 5, where:

- *Degree 1: The jointing sand is less than 10mm below the surface of the blocks, block paving is integral and has achieved lock-up*

- *Degree 3: Jointing sand is more than 20mm below the surface of the blocks. Paving blocks loose lock-up and joints widen with differential levels between blocks. Blocks move under loading and pumping occurs.*
- *Degree 5: A limited amount of jointing sand present in the joints, joint widths are variable and the blocks can be rocked by standing on them. The levels of adjacent blocks are not even and pumping occurs.*

### C.4.2.4 *Edge Restraint*

Edge restraints consist of kerbing, channels or other similar edge strips, or anchor beams on steep gradients to prevent creep of the paving. The objective of edge restraints is to prevent any lateral movement of pavers located along the edge of the pavement. This ensures that the overall integrity of the pavement is maintained. Edge restraints or anchor beans must not trap water. Sections displaying lack of drainage show up as pumping adjacent to the edge restraint or beam.

Degree of defects at the edge restraint is rated on a scale of 1 to 5, where:

- *Degree 1: Cracks visible without obvious lateral displacement of restraint*
- *Degree 3: Severe cracking visible, lateral displacement of restraint present*
- *Degree 5: Edge restraint not functional – sections missed or severely displaced*

### C.4.2.5 *Rutting*

Rutting is parallel depressions of the surface in the wheel paths and is to be rated on a scale of 1 to 5, where:

- *Degree 1: Difficult to discern unaided. Deformation under a 2m straight edge is less than 5mm.*
- *Degree 3: Readily discernible, and typically between 10 and 15mm under a 2m straight edge*
- *Degree 5: Severe and dangerous, with rutting exceeding 30mm under a 2m straight edge*

### C.4.2.6 *Potholes/Patching/Reinstatements*

Any hole in the surface should be indicated as a pothole. A patch is an area where the original pavement showed signs of distress and was subsequent replaced with new pavement materials. The deterioration severity could be in terms of an open pothole or a deteriorated patch with a foreign material.

Potholes, patching and reinstatements are rated on a scale of 1 to 5, where:

- *Degree 1: No missing blocks or minimal distress on the foreign patch*
- *Degree 3: Single blocks missing with deformation/damage of support layers, or patches showing significant distress on the foreign patch (e.g. deformation and/or cracking)*
- *Degree 5: Five or more blocks missing with deformation/damage of support layers, patches showing severe distress on the foreign patch (e.g. deformation and/or cracking)*

#### C.4.2.7 *Undulations/Shoving*

Undulations refer to structural failures that extend through the surface layer and into the underlying layers, with the accompanying shoving of blocks. Should the supporting layer (subbase) below the bedding be damaged or disturbed, the distress should be recorded as undulations / shoving. This defect is localised whereas rutting is in the direction of traffic and occurs in the wheel paths.

Undulations are rated on a scale of 1 to 5, where:

- *Degree 1: Minor shoving (< 10mm), no mounding*
- *Degree 3: Undulations/shoving started. Minor depressions (< 30mm). Start of surface distress and shoving.*
- *Degree 5: Severe undulations/shoving with loss of blocks and subbase material or severe depressions (> 50mm) and shoving*

### C.4.3 Functional assessment

The functional requirements of a road reflect the service it provides to the road user. They are predominantly those that govern to comfort, safety and speed of travel.

The various functional features to be assessed are: riding quality, skid resistance, surface drainage and the condition of the shoulders.

#### C.4.3.1 *Ride Quality/Roughness*

The roughness of the pavement is defined as the general extent to which road users, through the medium of their vehicles, experience a ride that is smooth and comfortable. Roughness is rated as:

- *Degree 1: Ride very smooth and very comfortable, no unevenness of the road profile, no undulations or uneven patching.*
- *Degree 2: Ride smooth and comfortable, slight unevenness of the road profile, slight rutting, undulation or uneven patching*
- *Degree 3: Ride fairly smooth and slightly uncomfortable, intermittent moderate unevenness of the road profile, moderate rutting, undulation or uneven patching.*
- *Degree 4: Ride poor and uncomfortable, frequent moderate unevenness of the road profile, frequent rutting, undulation or even patching. Comfortable driving speed below speed limit.*
- *Degree 5: Ride very poor and very uncomfortable, extensive severe unevenness of the road profile, extensive rutting, undulation, shoving or uneven patching, comfortable driving speed much lower than the speed limit. Road unsafe owing to severe unevenness.*

Problems resulting in high roughness are to be noted: Loose blocks, Undulations, potholes and failures.

#### C.4.3.2 *Skid Resistance*

Skid resistance reflects the general ability of the road surface to prevent skidding when wet and as rated on a scale of 1 to 5, where:

- *Degree 1: Skid resistance adequate, surface texture coarse, good chamfers. Blocks have rough texture*
- *Degree 3: Skid resistance intermittently inadequate. Blocks have smooth surface texture and chamfer not pronounced*
- *Degree 5: Skid resistance inadequate. Blocks with very smooth texture and chamfers not defined.*

#### C.4.3.3 *Surface Drainage*

The surface drainage of the road is a general measure of the general ability of the road to keep the riding surface clear of water.

The degree of surface drainage is rated on a scale of 1 to 5, where:

- *Degree 1: No visible problem that could retard the run-off of water from the road and shoulders*
- *Degree 3: Problems exist that could lead to general slight ponding or severe localised ponding*
- *Degree 5: Problems that could lead to widespread severe ponding in the wheel paths*

Problems leading to inadequate surface drainage are to be noted: Side drains, shoulders, rutting, profile and failures.

#### C.4.3.4 *Unpaved Shoulders*

The unpaved shoulder is rated in terms of providing a safe recovery area and is assessed as:

- *Degree 0: The edge of the road is defined by a kerb or there are no shoulders*
- *Degree 1: Shoulder can be safely used as a stopping area at the posted speed limit*
- *Degree 3: Problems may be expected if the shoulder is used as a stopping area at the posted speed limit (routine maintenance required)*
- *Degree 5: Shoulder is unsafe to be used as a stopping area at the posted speed limit*

Problems rendering the unpaved shoulder unsafe are to be noted: overgrown by vegetation, slope too steep, shoulder too narrow, differences in level between edge of carriageway and shoulder, erosion of the shoulder by water, and wearing out by traffic.

### C.4.4 Overall Pavement Condition

A general rating for the condition of the pavement is useful for data verification. The following scale can be used for this purpose:

- *Very good: Very few or no defects. Degree of defects less than 2*
- *Good: Few defects. Degree of structural defects mostly less than 3*
- *Moderate: A few defects of degree 3 occur locally or seldom*
- *Poor: General occurrence of defects with degree 3*
- *Very Poor: Many defects. The degree of the majority of structural defects is above 3 and the extent is predominantly general to extensive.*

Other problems are also to be noted:

- *Service crossings*
- *Trees*
- *Moles*
- *Mechanical damage.*

## C.5. Unpaved Roads (TMH9, Part E)

### C.5.1 General

This Section deals with the degree of defects observed on unpaved road (tracks, earth and gravel roads). The extent of the defects is as per the descriptions provided in Section 1. Appendix C provides a typical form for the visual assessment of unpaved roads (Form 4).

For unpaved roads, the visual assessment is divided into three categories:

1. Engineering assessment (material properties)
2. Engineering assessment (surface distress), and
3. Functional assessment

Visual assessments on unpaved roads should preferably be carried out in the dry season, as many of the important defects are not easily identified when the road is wet. The dry season is also longer than the wet season over most of South Africa allowing a longer window for this data collection. If detailed assessments are made throughout the year, then cognisance should be taken of the recent weather conditions. Surveys should, however, be completed as quickly as possible to ensure repeatability and to exclude seasonal influences.

During network level assessments, the assessors should drive at a speed not exceeding 40 km/h when gathering data and should include at least one stop on each segment for a closer assessment of the material quality, layer thickness and general performance.

Evaluations for project level analyses are normally done by highlighting relevant information, problems and needs along the road on a strip chart. Information collected at this level includes:

- *Existing wearing course thickness along the road*
- *Material quality along the road (through sampling and testing)*
- *Structural capacity along suspect areas (using Dynamic Cone Penetrometer)*
- *Positions of frequent drainage problems/ wash-aways*
- *Accident red spots*
- *Unsafe geometric situations*
- *Illegal services and access roads*

The table below can be used as a guideline to estimate the daily traffic volume on unpaved roads.

**Table B.5: Daily Traffic Volume**

| Category | Traffic range per day | Traffic range per hour |
|---|---|---|
| Very low | 0 – 20 veh/day | 0 – 2 veh/hr |
| Low | 20 – 50 veh/day | 2 – 9 veh/hr |
| Medium | 50 – 100 veh/day | 9 – 21 veh/hr |
| Heavy | 100 – 200 veh/day | 21 – 46 veh/hr |
| Very Heavy | > 200 veh/day | > 46 veh/hr |

### C.5.2 Engineering Assessment: Material Information

In this section, the gravel wearing course and subgrade material properties are assessed in terms of their quality and quantity.

#### C.5.2.1 *Gravel Quality*

The performance of an unpaved road depends primarily on the quality of the gravel used to construct the wearing course. The properties contributing to good gravel are particle size distribution and cohesion. The gravel should have a range of particle sizes ranging from very fine up to about 40 mm in order to provide a strong framework of stones interlocked by a tight matrix of fines. An excessive number of large stones results in poor riding quality and difficulties with maintenance. The fines need to have some plasticity to provide cohesion when dry. However, plasticity should not be so high that the road becomes slippery and impassable when wet.

The gravel quality is assessed on a scale from 1 to 5 as follows:

- *Very good: Evenly distributed range of particle sizes and sufficient plasticity that the material will leave a shiny streak when scratched with a pick. No significant cracking, ravelling and/or excessive oversize.*
- *Good: Minor ravelling or cracking and/or minimal oversize material*
- *Moderate: Cracking, loose material or stones clearly visible*
- *Poor: Poor particle size distribution with excess oversize. Plasticity high enough to cause slipperiness. Ravelling is sufficient to cause loss of traction.*
- *Very poor: Poorly distributed range of particle sizes and/or zero or excessive plasticity. Cracking and/or quantity of loose material/stones are significant and affect safety of the road user. Excessive oversize.*

Factors that affect the rating of gravel quality are to be noted:

- *Excessive oversize stones and/or loose gravel*
- *Excessive clay and/or silt (i.e. plasticity too high)*
- *Excessive loose gravel (plasticity too low)*

- *Excessive sand (plasticity too low)*

#### C.5.2.2 *Maximum Size and Grading*

The maximum size of the gravel is to be estimated. The following material size categories could be used: < 13mm, 13-25mm, 25-50mm, >50mm.

The grading of the gravel is to be assessed as coarse, medium or fine graded material.

#### C.5.2.3 *Plasticity*

Plasticity is an indication of the amount of clay in the gravel and is to be rated as:

- *Low: Non-cohesive (sandy)*
- *Medium: Intermediate cohesion*
- *High: Cohesive (clayey)*

#### C.5.2.4 *Wearing Course Layer Thickness*

The wearing course layer thickness can be measured by making small holes in the wheel tracks. Adequate cover of material over pipe drains and culverts can be a good indicator of gravel thickness. The layer thickness is to be assessed as follows:

- *> 125mm: Good shape and no stone protrusion*
- *100-125mm: No exposures of subgrade, but some stone protrusion*
- *50-100mm: Significant stone protrusion, loose coarse material and/or isolated subgrade exposure*
- *25-50mm: More than isolated exposure of the subgrade*
- *0mm: Extensive exposure of the subgrade*

#### C.5.2.5 *Exposed Subgrade*

The in-situ sub-grade material is often unsuitable as a wearing course and results in accessibility problems and shear failures. The exposed sub-grade is to be assessed as follows:

- *None: No exposure of the sub-grade to traffic*
- *Isolated: Exposure only occasionally e.g. steep grades, rock outcrops in cuttings*
- *Frequent: More than isolated but < 20% of the road has exposure of sub-grade*
- *Continuous: Extensive sub-grade exposed to traffic*

#### C.5.2.6 *Subgrade Quality*

The subgrade quality refers to the strength of the sub-grade or additional layers supporting the wearing course. The quality of the subgrade is assessed as below:

- *Good: Adequate strength under all conditions*
- *Moderate: Material that will deform to some extent under wet conditions*
- *Poor: Material that is impassable when wet. If assessed as poor, the cause must be indicated*

### C.5.3 Engineering Assessment (Surface Distress)

#### C.5.3.1 *Potholes*

Potholes are round or elongated depressions in the road surface. The potholes, which affect vehicles the most, are those between 250 and 1 500 mm in diameter with a depth of more than 50 to 75 mm.

The degree of potholes is rated on a scale of 1 to 5, where:

- *Degree 1: Depressions just visible. Cannot be felt in the vehicle.*
- *Degree 3: Larger potholes affecting safety (20 to 50mm deep)*
- *Degree 5: Large, dangerous potholes requiring evasive action (> 75mm deep)*

#### C.5.3.2 *Corrugations*

Corrugations are one of the most disturbing defects of unpaved roads causing excessive roughness and poor vehicle directional stability. Corrugations can be either “loose” or “fixed”. Loose corrugations consist of parallel alternating crests of loose, fine-sandy material and troughs of compacted material at right angles to the direction of travel. Fixed corrugations on the other hand consist of compacted crests and troughs of hard, fine sandy-gravel material.

Corrugations are rated as follows:-

- *Degree 1: Visible, but not felt or heard in a light vehicle*
- *Degree 2: Can be felt and heard, no speed reduction is necessary*
- *Degree 3: Can be felt and heard, speed reduction is necessary*
- *Degree 4: Significant speed reduction necessary*
- *Degree 5: Drivers select a different path and drive very slowly. Safety is affected.*

#### C.5.3.3 *Rutting*

Ruts are parallel depressions of the surface in the wheel paths. They generally form as a result of loss of gravel from the wearing course by traffic abrasion and less commonly by deformation (compaction) of the subgrade and compaction of the wearing course. Ruts are assessed in terms of their capacity to retain water using a visual estimate of their average depth.

Rutting is rated as follows:

- *Degree 1: Rutting is just visible*
- *Degree 2: Less than 20mm deep*
- *Degree 3: Rutting between 20 and 40mm deep*
- *Degree 4: Rutting between 40 and 60mm deep*
- *Degree 5: Rutting is more than 60 mm deep affecting directional stability of a vehicle*

#### C.5.3.4 *Loose Material*

Loose material (finer than 26mm) is formed by the ravelling of the wearing course gravel under traffic. This may be distributed over the full width of the road but more frequently, it is concentrated in windrows between the wheel tracks, or alongside the travelled portion of the road. It is mainly caused by a deficiency of fine material (because of lack of cohesion), a poor particle size distribution (e.g. gap grading) in the wearing course gravel and inadequate compaction. Ravelling is generally worse in the dry season than in the wet season when capillary suction results in apparent cohesion.

Loose material is assessed by estimating or measuring its thickness. This is achieved by scraping "paths" through the material to the hard surface with a geological pick and estimating the thickness or measuring it with a straightedge and wedge.

Loose material is rated as follows:

- *Degree 1: Just visible*
- *Degree 2: Loose material is less than 20mm thick*
- *Degree 3: Loose material is between 20 and 40mm thick*
- *Degree 4: Loose material is between 40 and 60mm thick*
- *Degree 5: Loose material is more than 60mm thick*

#### C.5.3.5 *Stoniness*

Stoniness is the relative percentage of material embedded in the road that is larger than a recommended maximum size (usually 37.5mm). Excessively stony roads result in the following problems:

- *Unnecessarily rough roads*
- *Difficulty with grader maintenance*
- *Poor compaction of areas adjacent to stones (leading to potholes and ravelling)*
- *The development of corrugations*
- *Thick, loose material is necessary to cover the stones*
- *Loose stones left after blading are likely to cause vehicle damage and potentially unsafe conditions.*

Stoniness can either be fixed (embedded) or loose. Fixed (embedded) stoniness is rated as follows:

- *Degree 1: Seen, but not felt or heard in a light vehicle*
- *Degree 2: Protruding stones can be felt and heard, but speed reduction not necessary*
- *Degree 3: Speed reduction necessary. Stone protrusion approximately 40mm*
- *Degree 4: Protruding stones require evasive action (40 - 60 mm)*
- *Degree 5: Vehicles avoid protruding stones or drive slowly (> 60mm)*

The degree of loose stoniness can be rated as follows:

- *Degree 1: Few loose stones 25 to 50mm. Driver can change lanes safely*
- *Degree 3: Many loose stones 25 to 50mm or few loose stones greater than 50mm. Stones influence drivers actions when changing lanes*
- *Degree 5: Windrows of loose stones 25 to 50mm or many loose stones greater than 50mm. Any lateral movement of the vehicles poses a significant safety hazard.*

#### C.5.3.6 *Erosion*

Erosion or scour is the loss of surfacing material caused by the flow of water over the road. Erosion can either be transvers or longitudinal. The result of erosion is run-off channels which, when occurring transversely, result in extreme roughness and dangerous driving conditions, and when occurring longitudinally (on grades), form deep "ruts". Associated with this road defect is a significant loss of gravel.

Transverse or diagonal erosion channels can be quantified by their depth and width. However, they are best assessed in terms of their effect on riding quality. The degree of transverse erosion is rated as follows:

- *Degree 1: Minor evidence of water damage*
- *Degree 2: Seen, but not felt or heard (channels 10 mm deep x 50 mm wide)*
- *Degree 3: Can be felt and heard, speed reduction necessary (channels 30mm deep x 75mm wide)*
- *Degree 4: Significant speed reduction necessary (channels 50 mm deep x 150 mm wide)*
- *Degree 5: Vehicles drive very slowly and attempt to avoid them (channels 60mm deep x 250mm wide)*

Longitudinal erosion is assessed in a similar way to ruts by visual estimation or measuring depth with a 2.0m straight edge and wedge. The degree of longitudinal erosion is rated as follows:

- *Degree 1: Evidence of water damage*
- *Degree 2: Channels less than 20mm deep*
- *Degree 3: Channels between 20 and 40mm deep*
- *Degree 4: Channels between 40 and 60mm deep*
- *Degree 5: Channels more than 60mm deep*

### C.5.4 Functional Assessment

#### C.5.4.1 *Roughness (Ride Quality)*

The roughness of the road is probably the major performance parameter affecting driver and passenger comfort and safety. It also has a significant impact on the overall vehicle operating cost associated with the road. These defects influencing riding quality are: deformation, potholes, stoniness, rock outcrops, corrugation, ruts and erosion.

Road roughness is assessed by the estimated comfortable/safe speed:

- *Degree 1: Speed in excess of 100 km/h*
- *Degree 2: Speed between 80 and 100 km/h*
- *Degree 3: Speed between 60 and 80 km/h*
- *Degree 4: Speed between 40 and 60 km/h*
- *Degree 5: Speed less than 40 km/h*

#### C.5.4.2 *Trafficability/Passability*

Trafficability (or passability) is the capacity of a normal saloon car to negotiate the road without losing traction or without excessive use of low gears.

The degree of trafficability is rated using the following scale:

- *Degree 1: Easy access at constant speed*
- *Degree 3: Speed reduction required at isolated positions to prevent damage to vehicle*
- *Degree 5: Impossible to access with normal saloon car*

Problems relating to poor trafficability are to be noted:

- *Loose material*
- *Clayey material*
- *Rocky terrain*
- *Vegetation encroachment*
- *Steep grades*
- *Insufficient cross drainage*

#### C.5.4.3 *Safety*

Apart from providing access to the road user, safety to the travelling public is considered one of the most important goals of a road authority. Even though the level of service provided on different categories of roads might not be the same, identification of hazardous situations are considered essential for proper management of a road network.

The degree of safety is rated as follows:

- *Degree 1: no obvious risk situations*
- *Degree 2: Minor risk situations*
- *Degree 3: Risk situations causing discomfort*
- *Degree 4: Significant speed reduction required to avoid serious consequences*
- *Degree 5: Dangerous situations that could lead to severe consequences regardless of speed*

Problems that have a negative impact on safety are to be noted:

- *Dust*
- *Skid resistance (dry conditions)*
- *Slipperiness*
- *Drainage*

Notes are to be made on the following safety conditions:

- *Dust: Dust is to be rated in the rear view mirror travelling at 60 km/h. A rating of very good (no loss of visibility) or poor (significant loss of visibility) is to be noted.*
- *Skid resistance: Is to be rated very good, moderate or poor based on the potential unsafe situations. Presence of fine gravel and loss of control when braking are factors.*

- *Slipperiness: To be rated from very good to very poor based on smooth clayey surface, cracking, tyre impressions, evidence of compaction and shearing.*
- *Drainage: To be rated from very good to very poor based on safety problems. Problems can include erosion/wash-away in roadway; drainage and geometry; and erosion/wash-away on side of roadway.*

### C.5.4.4 *Drainage on the Road (Profile/Shape)*

The profile (shape) of a road has a major impact on the performance of that road. Roads with good profile tend to shed water rapidly, avoiding the development of potholes and potentially impassable conditions. Where the profile is flat, water tends to pond in localised depressions resulting in softening of the wearing course and the development of potholes and other defects. Failure to timeously repair a flat road will usually result in the development of ruts under traffic. These may become preferential water paths resulting in erosion, accelerated gravel loss and significant deterioration in riding quality. On grades, the impact of the transverse profile becomes less dominant than the actual grade.

The degree of drainage on the road is rated as follows:

- *Degree 1: Very good shape, well-formed camber (about 3 to 5%)*
- *Degree 2: Good shape, good camber (about 3%)*
- *Degree 3: Flat, some unevenness with camber mostly less than 2%*
- *Degree 4: Uneven, obvious development irregularities that will impeded drainage and form depressions*
- *Degree 5: Very uneven, development of severe irregularities impeding drainage and likely to cause extensive localised ponding. Water tends to flow to the centre of the road or individual lanes*

Problems relating to poor drainage on the road are to be noted:

- *Windrows*
- *Rutting*
- *Road Shape*
- *Road Level*

### C.5.4.5 *Drainage from the Road*

Drainage from the road relates more directly to the capacity of the road to shed water without causing erosion, while drainage from the road relates more closely to the impact of standing water on both the wearing course and underlying road structure. The descriptors are essentially applicable to roads in flat or slightly sloping terrain. Where grades are steep, roads assessed as degrees 4 and 5 will act as drainage courses during periods of intensive rainfall leading to severe erosion.

The degree of drainage from the road is rated as follows:

- *Degree 1: Well above ground level. Edges of the road are at least 300mm above natural ground level with effective side drains.*

- *Degree 2: Slightly above ground level. Road is between 50 and 300mm above natural ground level. Side drains are present. Stormwater could cross in isolated places.*
- *Degree 3: Level with ground. Road is generally at ground level with ineffective side drains. Stormwater could cross in most places.*
- *Degree 4: Slightly beneath ground level. Isolated areas of the road are below natural ground level. No side drains are present and localised ponding of water will occur.*
- *Degree 5: Canal. Road is the lowest point and serves to drain the entire area.*

Problems that could result in poor drainage from the road are to be noted:

- *Culvert Inlets*
- *Side drains*
- *Mitre drains*
- *Road level*

### C.5.5 Overall Condition of the Pavement

A general rating for the condition of the pavement is useful for data verification. The following scale can be used for this purpose:

- *Very good: Very few or no defects. Degree of defects less than 2*
- *Good: Few defects. Degree of engineering defects mostly less than 3*
- *Moderate: A few defects of degree 3 occur locally or seldom*
- *Poor: General occurrence of defects with degree 3*
- *Very Poor: Many defects. The degree of the majority of structural defects is above 3 and the extent is predominantly general to extensive.*

# APPENDIX C: Standard Visual Assessment Field Forms

## VISUAL ASSESSMENT : FLEXIBLE PAVEMENTS

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ROAD AUTHORITY : ..........
REGION / SUBURB : ..........
ROAD NO / STREET NAME : ..........
SEGMENT (FROM - TO) : ..........
SEGMENT DIMENSIONS : LENGTH .......... m WIDTH .......... m

| | | | | | |
|---|---|---|---|---|---|
| ROUTE CLASS : | 1 | 2 | 3 | 4 | 5 |
| TRAFFIC : | VL | L | M | H | VH |
| GRADIENT : | Flat | | Med | | Steep |
| TERRAIN : | Flat | | Rolling | | Mount |

### ENGINEERING ASSESSMENT

**SURFACING**

CURRENT SURFACING :

| | | | | |
|---|---|---|---|---|
| TEXTURE | COARSE | MEDIUM | FINE | VARYING |
| VOIDS | MANY | FEW | NONE | VARYING |

| | DEGREE | | | | | | EXTENT | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MINOR | WARNING | | SEVERE | | ISOLATED | | | | EXTENSIVE |
| | 0 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| SURFACING FAILURES | | | | | | | | | | | |
| SURFACING PATCHING | | | | | | | | | | | |
| SURFACING CRACKS | | | | | | | | | | | |
| BINDER CONDITION (DRY / BRITTLE) | | | | | | | | | | | |
| AGGREGATE LOSS (A / N) | | | | | | | | | | | |
| BLEEDING / FLUSHING | | | | | | | | | | | |
| SURFACING DEFORMATION / SHOVING | | | | | | | | | | | |

**STRUCTURAL**

| | DEGREE | | | | | | EXTENT | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MINOR | WARNING | | SEVERE | | ISOLATED | | | | EXTENSIVE |
| | 0 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| BLOCK CRACKS | | | | | | | | | | | |
| TRANSVERSE CRACKS | | | | | | | | | | | |
| LONGITUDINAL CRACKS | | | | | | | | | | | |
| CROCODILE CRACKS | | | | | | | | | | | |
| PUMPING | | | | | | | | | | | |
| RUTTING | | | | | | | | | | | |
| UNDULATIONS / SETTLEMENT | | | | | | | | | | | |
| PATCHING | | | | | | | | | | | |
| FAILURES / POTHOLES | | | | | | | | | | | |

### FUNCTIONAL ASSESSMENT

| | | | | | | |
|---|---|---|---|---|---|---|
| ROUGHNESS | | Very Good | Good | Moderate | Poor | Very Poor |
| | Problem | | | ndulations | moles | orrugations |
| SKID RESISTANCE | | Very Good | Good | Moderate | Poor | Very Poor |
| | Problem | | | | bleeding | polished |
| SURFACE DRAINAGE | | | Adequate | Inconsistent | | Inadequate |
| | Problem | rutting | shoulders | ndulations | failures | side drains |
| SHOULDERS (unpaved) | | None | Safe | Inconsistent | | Unsafe |
| | Problem | eroded | overgrown | inclined | too high | oo narrow |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| EDGE DEFECTS | 0 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| Problem | | | | | | edge break | | drop off | | dge cracks | |

### SUMMARY

| | | | | | |
|---|---|---|---|---|---|
| OVERALL PAVEMENT CONDITION | Very Good | Good | Moderate | Poor | Very Poor |

(COMMENTS:

| | | | | | |
|---|---|---|---|---|---|
| OTHER PROBLEMS | service crossings | trees | moles | | mechanic al damage |

ASSESSOR : .......... DATE : ..........

# VISUAL ASSESSMENT : CONCRETE PAVEMENTS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ROAD AUTHORITY : ........ | ROUTE CLASS : | 1 | 2 | 3 | 4 | 5 |
| REGION / SUBURB : ........ | TRAFFIC : | VL | L | M | H | VH |
| ROAD NO / STREET NAME : ........ | GRADIENT : | Flat | | Med | | Steep |
| ........ | TERRAIN : | Flat | | Rolling | | Mount |

SEGMENT (FROM - TO) : ........

SEGMENT DIMENSIONS : LENGTH ........ m WIDTH ........ m

## ENGINEERING ASSESSMENT

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TEXTURE | | COARSE | | MEDIUM | | FINE | | VARYING | |
| | | DEGREE | | | | | EXTENT | | | | |
| | | MINOR | | WARNING | | SEVERE | ISOLATED | | | | EXTENSIVE |
| | 0 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| RANDOM CRACKS | | | | | | | | | | | |
| TRANSVERSE CRACKS | | | | | | | | | | | |
| LONGITUDINAL CRACKS | | | | | | | | | | | |
| CORNER CRACKING | | | | | | | | | | | |
| CLUSTER CRACKING | | | | | | | | | | | |
| PUMPING | | | | | | | | | | | |
| JOINT SEAL CONDITION | | | | | | | | | | | |
| FAULTING | | | | | | | | | | | |
| UNDULATIONS / SETTLEMENT | | | | | | | | | | | |
| PUNCH OUTS | | | | | | | | | | | |
| SHATTERED SLABS | | | | | | | | | | | |
| PATCHING | | | | | | | | | | | |

## FUNCTIONAL ASSESSMENT

| | | | | | | |
|---|---|---|---|---|---|---|
| ROUGHNESS | | Very Good | Good | Moderate | Poor | Very Poor |
| | Problem | punch outs | shattered slabs | patching | undulations | faulting |
| SKID RESISTANCE | | | Good | Moderate | Poor | |
| SURFACE DRAINAGE | | Adequate | | Inconsistent | | Inadequate |
| | Problem | rutting | shoulders | undulations | failures | side drains |
| SHOULDERS (unpaved) | | Safe | | Inconsistent | | Unsafe |
| | Problem | eroded | overgrown | inclined | too high | too narrow |
| EDGE DEFECTS | 0 | 1 2 | 3 4 | 5 1 | 2 3 | 4 5 |
| | Problem | | | edge break | drop off | edge cracks |

## SUMMARY

| | | | | | |
|---|---|---|---|---|---|
| GENERAL NOTES | Crushing | | Blow-up | | Alkali-silica |
| OVERALL PAVEMENT CONDITION | Very Good | Good | Moderate | Poor | Very Poor |

COMMENTS:

| | | | | |
|---|---|---|---|---|
| OTHER PROBLEMS | service crossings | trees | moles | mechanical damage |

ASSESSOR : ........ DATE : ........

# VISUAL ASSESSMENT : BLOCK PAVEMENTS

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| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ROAD AUTHORITY | : | ........ | ROUTE CLASS : | 1 | 2 | 3 | 4 | 5 |
| REGION / SUBURB | : | ........ | TRAFFIC : | VL | L | M | H | VH |
| ROAD NO / STREET NAME | : | ........ | GRADIENT : | Flat | | Med | | Steep |
| | | ........ | TERRAIN : | Flat | | Rolling | | Mount |
| SEGMENT (FROM - TO) | : | ........ | | | | | | |
| SEGMENT DIMENSIONS | : | LENGTH ........ m | WIDTH | ........ m | | | | |
| BLOCK SHAPE | : | S-A S-B S-C ........ | LAY PATTERN : | ........ | HB | SB | BW | OT |
| BLOCK THICKNESS (mm) | : | ........ | CHAMFER : | ........ | | 45 | R | 90 |

## ENGINEERING ASSESSMENT

| | DEGREE | | | | | | EXTENT | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MINOR | | WARNING | | SEVERE | ISOLATED | | | | EXTENSIVE |
| | 0 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| SPALLED / CRACKED / BROKEN BLOCKS | | | | | | | | | | | |
| BLOCK SURFACE INTEGRITY (DURABILITY) | | | | | | | | | | | |
| LOSS OF JOINTING SAND | | | | | | | | | | | |
| EDGE RESTRAINT / ANCHOR BEAM DAMAGE | | | | | | | | | | | |
| RUTTING | | | | | | | | | | | |
| POTHOLES / PATCHING / REINSTATEMENTS | | | | | | | | | | | |
| UNDULATIONS / SHOVING | | | | | | | | | | | |

## FUNCTIONAL ASSESSMENT

| | | | | | | |
|---|---|---|---|---|---|---|
| ROUGHNESS | | Very Good | Good | Moderate | Poor | Very Poor |
| | Problem | | | undulations | moles | corrugations |
| SKID RESISTANCE | | Very Good | Good | Moderate | Poor | Very Poor |
| | Problem | | | | | polished |
| SURFACE DRAINAGE | | Adequate | | Inconsistent | | Inadequate |
| | Problem | rutting | shoulders | undulations | failures | side drains |
| SHOULDERS (unpaved) | | Safe | | Inconsistent | | Unsafe |
| | Problem | eroded | overgrown | inclined | too high | too narrow |

## SUMMARY

| | | | | | |
|---|---|---|---|---|---|
| OVERALL PAVEMENT CONDITION | Very Good | Good | Moderate | Poor | Very Poor |
| COMMENTS: | | | | | |
| OTHER PROBLEMS | service crossings | trees | moles | mechanical damage | |

ASSESSOR : ........ DATE : ........

# VISUAL ASSESSMENT : UNPAVED ROADS

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Africa Community Access Partnership

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ROAD AUTHORITY | : | ROUTE CLASS : | 1 | 2 | 3 | 4 | 5 |
| REGION / SUBURB | : | TRAFFIC : | VL | L | M | H | VH |
| ROAD NO / STREET NAME | : | GRADIENT : | Flat | | Med | | Steep |
| SEGMENT (FROM) | : | TERRAIN : | Flat | | Rolling | | Mount |
| SEGMENT (TO) | : | ROAD TYPE : | Gravel | | Earth | | Track |
| SEGMENT DIMENSIONS | : | LENGTH m | WIDTH m | | | | |

## MATERIAL INFORMATION / GRAVEL PROPERTIES

| | | | | | |
|---|---|---|---|---|---|
| MATERIAL TYPE | Ferricrete | Calcrete | Quartzite | Chert | Dolomite |
| | Sandstone | Granite | Shale | Dolorite | Varies |
| MATERIAL QUALITY | Very Good | Good | Moderate | Poor | Very Poor |
| | | Problem | oversize | clay/silt / loose gravel | loose sand |
| MAXIMUM SIZE | | < 13 mm | 13 - 25 mm | 25 - 50 mm | > 50 mm |
| GRADING | | Coarse | Medium | Fine | |
| ESTIMATED 'PI' | | < 6 | 6 - 12 | > 12 | |
| LAYER THICKNESS | 0 mm | 25 - 50 mm | 50 - 100 mm | 100 - 125mm | > 125mm |
| EXPOSURED SUBGRADE | | none | isolated | frequent | continious |
| SUBGRADE QUALITY | Very Good | Good | Moderate | Poor | Very Poor |
| | | Problem | | wet / clay/mud | sand |

## SURFACE DISTRESS / ENGINEERING ASSESSMENT

| | DEGREE | | | | | | EXTENT | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MINOR | WARNING | | | SEVERE | ISOLATED | | | | EXTENSIVE |
| | 0 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| POTHOLES | | | | | | | | | | | |
| CORRUGATIONS | | | | | | | | | | | |
| RUTTING | | | | | | | | | | | |
| LOOSE MATERIAL | | | | | | | | | | | |
| STONINESS : FIXED | | | | | | | | | | | |
| STONINESS : LOOSE | | | | | | | | | | | |
| EROSION : LONGITUDINAL | | | | | | | | | | | |
| EROSION : TRANSVERSE | | | | | | | | | | | |

## FUNCTIONAL ASSESSMENT

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ROUGHNESS | | | Very Good | Good | Moderate | Poor | Very Poor |
| | Problem | formation | potholes | stoniness | rock outcrop | corrugations | loose mat | rut/erosion |
| TRAFFICIBILITY | | | Very Good | Good | Moderate | Poor | Very Poor |
| | Problem | loose mat | clay | rocky | vegetation | steep | drainage |
| SAFETY | | | Very Good | Good | Moderate | Poor | Very Poor |
| | Problem | | | | | | |
| DRAINAGE : ON THE ROAD | | | Very Good | Good | Moderate | Poor | Very Poor |
| | Problem | | | windrows | rutting | road shape | road level |
| DRAINAGE : SIDE OF THE ROAD | | | Very Good | Good | Moderate | Poor | Very Poor |
| | Problem | | | culvert inlets | side drains | mitre drains | road level |

## SUMMARY

| | | | | | |
|---|---|---|---|---|---|
| OVERALL PAVEMENT CONDITION | Very Good | Good | Moderate | Poor | Very Poor |

COMMENTS:

ASSESSOR : ________________ DATE : ________________

## APPENDIX D: Roughness Measurement

The standard measure of road roughness is the International Roughness Index (IRI) which was developed during The International Road Roughness Experiment in Brazil in the 1980s. It is a mathematical quarter car simulation of the motion of a vehicle at a speed of 80 kph over the measured profile and can be calculated directly from road levels measured at frequent intervals. Devices for measuring levels are usually either slow and labour intensive or fast, automatic and expensive. Hence, the roughness of low volume roads is best measured using a Response Type Road Roughness Measuring System (RTRRMS) that must be periodically calibrated to allow the values of roughness to be reported in terms of IRI. Methods of calibration include a rod and level survey or a standard instrument, such as the TRL Profile Beam, the MERLIN (Machine for Evaluating Roughness using Low-cost Instrumentation), the Face Dipstick and the ARRB Walking Profiler.

### OPERATION OF THE MERLIN

The MERLIN is available in Mozambique and is thus discussed in detail below.

A diagram of the equipment is shown in Figure D.1. It has two feet, 1.8 metres apart which rest on the road surface along the wheel path. A moveable probe is placed on the road surface mid-way between the two feet and measures the vertical distance (y) between the road surface under the probe and the centre point of an imaginary line joining the two feet.

The result is recorded on a data chart mounted on the machine. By recording measurements along the wheel path, a histogram of y can be built up on the chart. The width of this histogram can then be used to determine the IRI.

To determine the IRI, 200 measurements are usually made at regular intervals. For each measurement, the position of the pointer on the chart, shown in Figure D.2, is marked by a cross in the box in line with the pointer and, to keep a count of the total number of measurements made, a cross is also put in the tally box on the chart. When the 200 measurements have been made the position mid-way between the 10th and 11th crosses, counting in from one end of the distribution is marked on the chart. The procedure is repeated for the other end of the distribution. The spacing between the two marks, D, is then measured in millimetres.

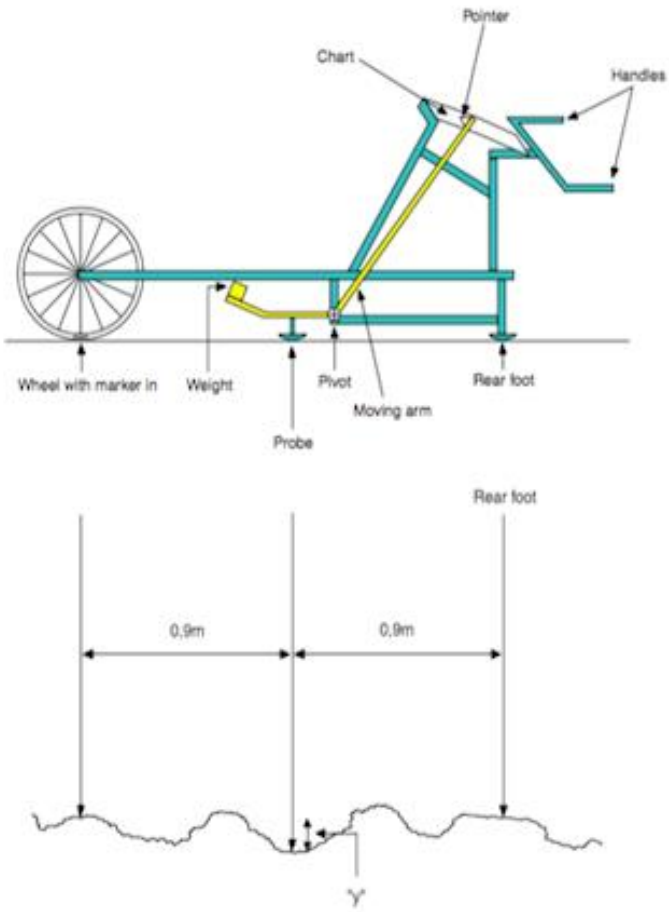


**Figure D-1: MERLIN equipment**

For earth, gravel, surfaced dressed and asphaltic concrete roads, the IRI can be determined using the following equation.

IRI = 0.593 + 0.0471 D

This equation assumes that the MERLIN has a mechanical amplification factor of 10. In practice this may not be true because of small errors in manufacturing. Therefore, before the MERLIN is used the amplification must be checked and the value of D corrected. To do this the instrument is rested with the probe on a smooth surface and the position of the pointer carefully marked on the chart. The probe is then raised and a calibration block approximately 6mm thick placed under the probe. The new position of the pointer is marked. If the distance between the marks on the chart is S and the thickness of the block T then measurements made on the chart should be multiplied by the scaling factor:

Scaling factor = 10 T S

### Length of test section used in calibration

If 200 measurements (one at each wheel revolution) are taken using a MERLIN with a 26-inch (415 mm) diameter wheel, the length of the section surveyed will be 415 metres. For shorter or longer sections, a different procedure will be required. The guiding principles are:

i. The test section should be a minimum of 200 metres long
ii. Take approximately 200 readings per chart. With less than 200 readings the accuracy will decrease and with more the chart becomes cluttered. If the number of readings differs from 200, then the number of crosses counted in from each end of the distribution, to determine D, will also need to be changed. It should be 9 crosses for 180 readings, 11 for 220 readings etc.
iii. Always take measurements with the marker on the wheel in contact with the road. This not only prevents errors due to any variation in radius of the wheel but also avoids operator bias.
iv. Take regularly-spaced measurements over the full length of the test section. This gives the most representative result.
v. If taking repeat measurements along a section, try to avoid taking readings at the same points on different passes, .e.g. start the second series of measurements half a metre from where the first series was started.

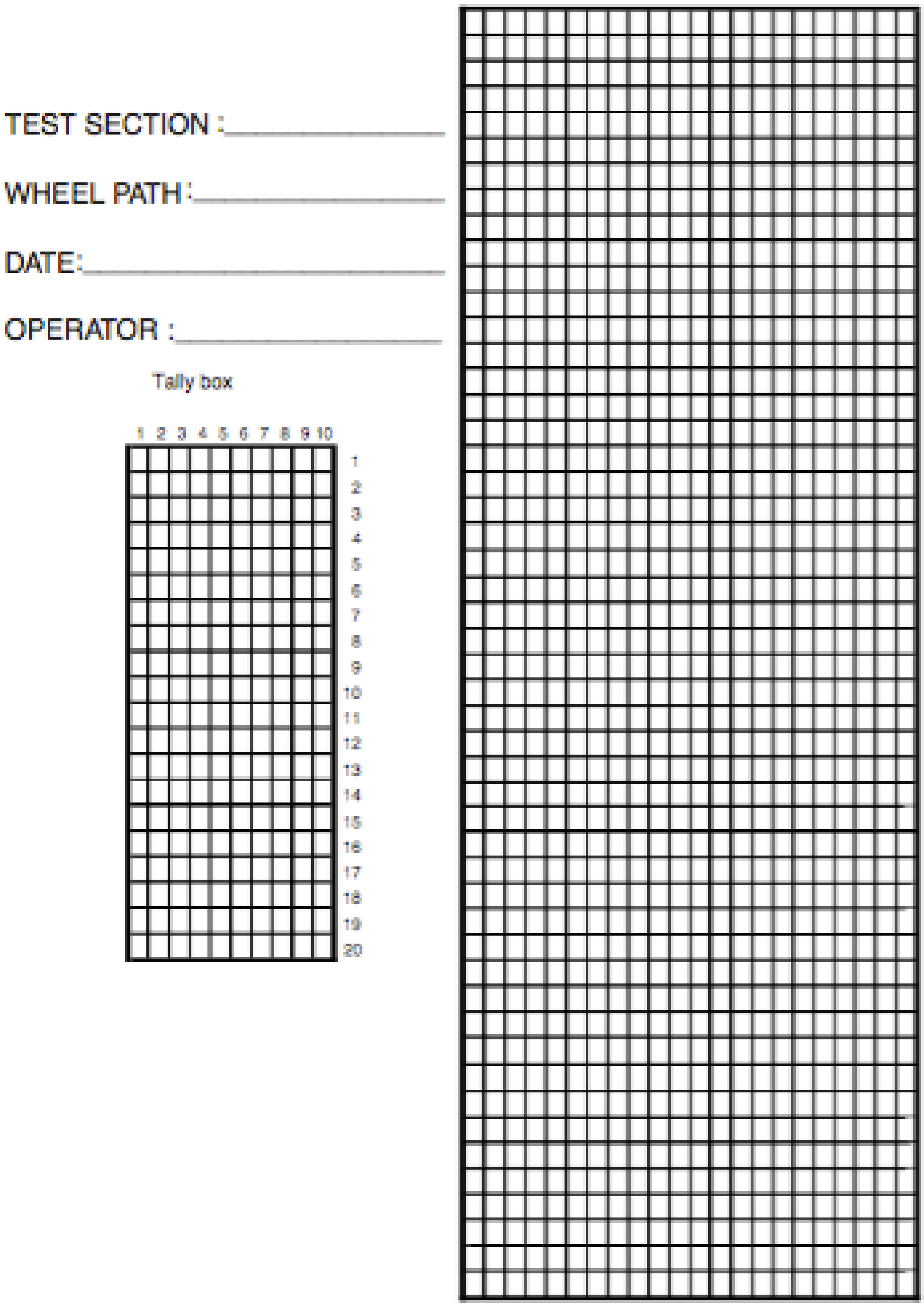


Figure D-2: MERLIN Data collection form

For a 210-metre test section take the measurements in two passes, taking one reading every revolution of the wheel, and offsetting the second pass by half a metre.

For a 280-metre test section take the measurements in two off-set passes, taking one reading every wheel revolution on the first pass and one reading every two revolutions on the second.

For a 500-metre test section take the measurements in one pass, taking one measurement every wheel revolution and omitting every fifth measurement. Or, rather than omitting readings, enlarge the tally box and take all 240 measurements. Measure the limits on the chart by counting in 12 crosses rather than 10.

### ROUGHNESS SURVEYS USING A RTRRMS

When roughness measurements are needed on more than a few short sections of road, a RTRRMS is recommended. The main advantages of these types of systems are their relative low cost and the high speed of data collection. The systems are capable of surveys at speeds up to 80 km/h, so many hundreds of kilometres of road can be measured in a day.

The TRL Bump Integrator (BI) Unit is a response-type road roughness-measuring device that is mounted in a vehicle. The instrument measures the roughness in terms of the cumulative unidirectional movement between the rear axle and the chassis of a vehicle in motion. The BI system comprises a bump integrator unit and a counter unit and is powered by the 12-volt battery of the vehicle. The NAASRA meter, Linear Displacement Integrator (LDI) and the Mays meter are similar response-type road roughness measuring devices and the survey and calibration procedures will be like that used with the TRL BI Unit, described below.

### FITTING THE TRL BI UNIT

The BI unit is mounted in a rear-wheel drive vehicle as shown in Figure D-3. The unit is bolted to the rear floor-pan of the vehicle directly above the centre of the rear axle. A 25mm hole needs to be cut in the floor-pan and a bracket or hook fixed to the centre of the differential housing of the rear axle

Before each survey, the flexible metal cord from the cylindrical drum of the BI unit is passed through the hole in the floor and hooked onto the bracket on the rear axle. This cord must not touch the sides of the hole. Tension in the cord is maintained by a return spring inside the drum of the BI unit. The BI unit measures the unidirectional movement, in centimetres, between the vehicle chassis and the axle as the vehicle is driven along the road. This is displayed on a counter box, usually fixed to the front passenger fascia.

### SURVEY PROCEDURE

A safe working environment should always be maintained. As the vehicle may be moving slower than the majority of other traffic, it should be clearly signed and fitted with flashing lights.

The vehicle should be well maintained and in good working order. The wheels should be properly balanced the steering geometry correctly aligned and the shock absorbers in good condition. The tyres should not have flat spots or be unduly worn. Tyre pressures should be maintained precisely to the manufacturers specifications and always checked cold. The load in the vehicle must be constant. Ideally the vehicle should contain only the driver and observer, and no other load should be carried.

The engine and suspension system should be fully warmed-up before measurements commence. This can be achieved by driving the vehicle for at least 5 km before measurements start.

The tension cord from the BI unit to the axle should only be connected during the survey. At all other times, the cord should be disconnected to stop unnecessary wear of the BI unit. When attaching the cord to the rear axle, the cord should be pre-tensioned by turning the BI pulley 2.5 turns anti-clockwise. The wire is then wound around the pulley 2 turns in the same direction as the arrow. Note: the pulley must NOT be turned clockwise or suddenly released after being tensioned as the internal spring mechanism could be damaged.

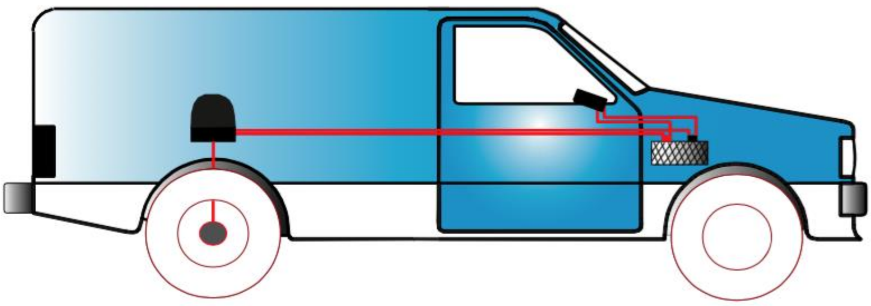

**Figure D-3: Diagrammatical representation of Bump Integrator unite fitted to a vehicle**

When measurements are being taken the vehicle should be driven at constant speed, avoiding acceleration, deceleration and gear changes. This is necessary because the vehicle s response to a given profile varies with speed. To improve reproducibility, it is best to operate the RTRRMS at a standard speed of 80 km/h. However, if this speed is unsafe for reasons of traffic, pedestrians or restrictive road geometry, a lower speed of 50 or 32 km/h can be used. Calibration must be carried out for each operating speed used in the survey.

Readings are recorded at half kilometre intervals. This distance should be measured with a precision odometer fitted to the vehicle. The use of the vehicle odometer or kilometre posts is not recommended for survey purposes.

There are two counters in the recording unit, connected by a changeover switch. This allows the observer to throw the switch at the end of each measurement interval so that the reading can be manually recorded while the other counter is working. The first counter can then be re-set to zero ready for the next changeover.

The type of road surfacing and any landmarks should be recorded to aid future analysis of the data. On completion of the survey, the wire cord should be disconnected from the rear axle.

After the survey, the results should be converted into vehicle response roughness values (VR). The counts measured by the BI are in units of cumulative centimetres of uni-directional movement of the rear axle. These should be converted to vehicle response roughness values using the following equation.

VR = BI count x 10 Section length

Where

VR= Vehicle Response (mm/km)

BI = No of counts per section (cm)

Section length (kms)

These vehicle response roughness values should then be converted to units of estimated IRI, E[IRI], using a calibration that is unique to the RTRRMS at that time.

## CALIBRATION OF A RTRRMS

The RTRRMS must be regularly calibrated against an instrument such as the MERLIN or Rod and Level surveys. Calibration should preferably be carried out before the survey and checked on control sites during the survey period to ensure that the RTRRMS remains within calibration. The calibration of the RTRRMS will need to be re-checked before any subsequent surveys or after any part of the suspension of the vehicle is replaced.

The calibration exercise involves comparing the results from the RTRRMS and the MERLIN over several short road sections. The relationship obtained by this comparison can then be used to convert RTRRMS survey results into units of E[IRI]. The recommended practice for roughness calibration is described below.

i) A minimum of eight sections on the road under evaluation should be selected with roughness levels that span the range of roughness of the road. The sections should have a minimum length of 200 m and should be of uniform roughness over their length. In practice, it may be difficult to find long homogeneous sections on very rough roads. In this case, it is better to include a shorter section than to omit high roughness sites from the calibration. The sections should be straight and flat, with adequate run-up and slow-down lengths and should have no hazards, such as junctions, which may prevent the vehicle travelling in a straight course at constant speed along the whole section.

ii) The roughness of each section should be measured by the RTRRMS at the same vehicle speed that is to be used for the survey. The value of VR (mm/km) should be the mean value of at least three test runs.

iii) The MERLIN should be used to measure the IRI in both wheel paths. The average of these IRI values is then plotted against the vehicle response for each of the test sections. The calibration equation for the RTRRMS is then derived by calculating the best-fit line for the points. This relationship generally has a quadratic form but, depending on the characteristics of the vehicles suspension and the levels of roughness over which the RTRRMS has been calibrated, has also been found to be logarithmic.

$$E[IRI] = a + b\ VR + c\ VR^2$$

Where

E[IRI] = Estimated IRI (m/km)

VR = Vehicle Response (mm/km)

a, b and c = constants

The calibration equation can then be used to convert data from the RTRRMS (VR) into units of E[IRI].

## INTERPRETATION OF RESULTS

To divide the road into homogeneous sections, such as to minimise the variation in roughness within each section, it is recommended that the cumulative sum method be used.

## APPENDIX E: Gravel Loss Measurement

The loss of gravel from unpaved roads is an essential part of investigation of innovative materials or construction techniques. Numerous techniques ranging from the incorporation of metallic sensors, Ground Penetrating Radar (GPR), the excavation of holes, etc. have been used in attempting to quantify gravel loss. However, only precise levelling surveys have been found to be sufficiently accurate for research and monitoring purposes. The process for this is described below.

The process involves comparing the average height of a section of road over time with the height of fixed benchmarks. These benchmarks must be positioned at the start and end of the monitoring section, preferably in the road and placed so that they are unlikely to be affected by subgrade movements.

The setting of 500 mm steel roads (10 - 15 mm in diameter) in concrete blocks at subgrade level has been found to be satisfactory (Figure E-1).

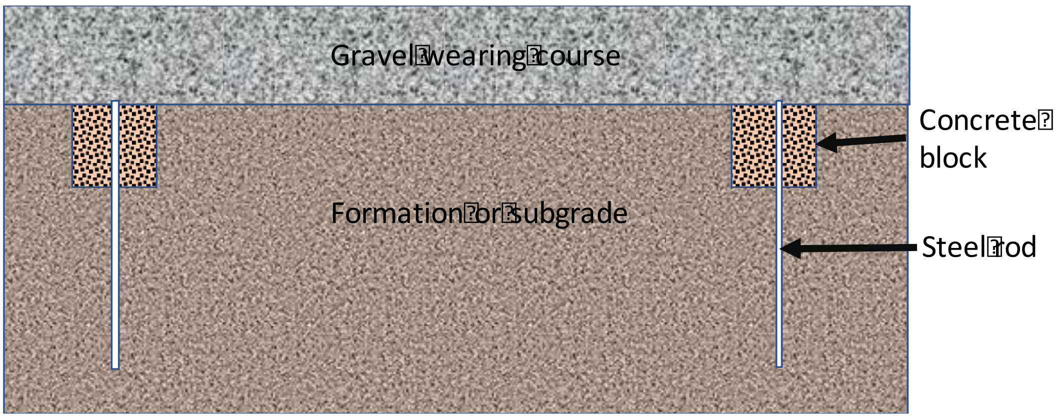


**Figure E-1: Placement of stable benchmarks**

A gravel loss monitoring section will normally be 50 m long, on a flat and level section of road with no culverts or cross-drainage structures and should fit within the trafficked portion of the carriageway.  The bench marks should be placed at each end of the section and at least 3 (preferably 4) should be installed as shown in Figure E-2.

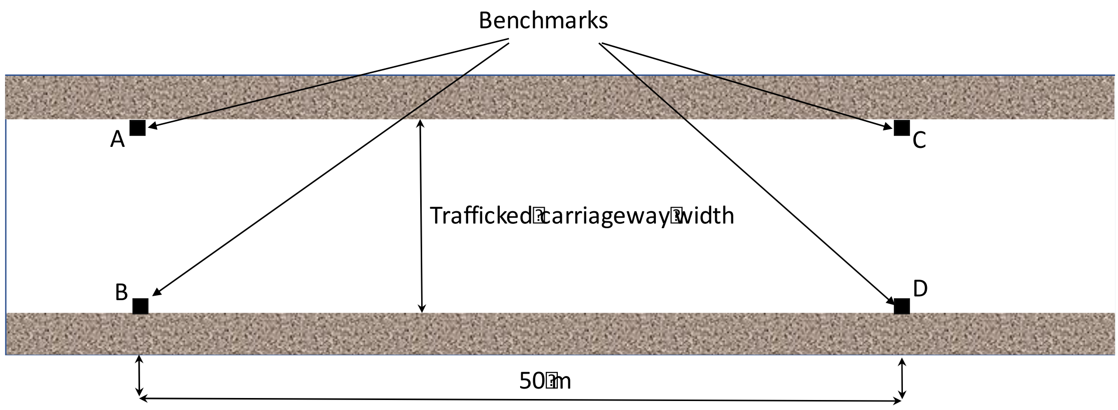


**Figure E-2: Location of stable benchmarks**

The width of the monitored section (trafficked carriageway width) is usually between 5 and 8 or 9 metres and should be fixed at metre lengths.

During monitoring, the heights of each of the bench marks should be determined and checked against the previous heights to ensure that there has been no movement relative to each other. Two tape measures should then be laid out, one longitudinally along the 50 m length between the bench marks on one side (B and D) and the second transversely between the first two benchmarks (A and B).

A level should be taken at each 1-metre interval along the tape between benchmarks A and B. The transverse tape should then be moved to the point at 5 m along the longitudinal tape and measurements taken across the road again. This will continue at 5 m intervals until the final transverse measurement at 50 m giving 11 sets of readings, each numbering between 6 and 9 or 10 across the road. The objective is to try and take the level readings as close as possible to fixed points during each survey.

If there has been no differential movement between the benchmarks, any one of them can be used as a datum. The average height of all the readings is then calculated and the difference between this and the bench mark height determined. This is done at about 3 month intervals and a progressive change (decrease) in the height of the road relative to the benchmarks will be determined.

This can be plotted as the gravel loss with time.

# APPENDIX F: Deflection Measurement

## INTRODUCTION

The structural integrity of a pavement can be quickly and efficiently assessed by applying a load to the pavement surface and measuring the resulting deflections. Numerous pavement deflection measurement techniques are currently in use and these can be categorised according to the applied load characteristics. Measuring the pavement surface deflection under a static or slow moving load (Benkelman Beam) represents the first-generation approach. The next generation involved the application of a dynamic vibratory load (Road Rater and Dynaflect). The third-generation deflection equipment (Falling Weight Deflectometer) simulates the effect of a moving wheel load by applying a dynamic impulse load. Recent (but large and expensive) equipment measures deflections caused by an actual wheel load moving at highway speeds.

This Appendix gives descriptions, procedures for use, and factors influencing the application of the two most common measurement methods, the Benkelman beam and the Falling Weight Deflectometer.

### BACKGROUND TO DEFLECTION MEASUREMENTS

Early use of deflection data implied the analysis of maximum deflection relative to empirical (experience and/or experiment based) standards. Generally, some statistical measure of the maximum deflection was compared with a permissible deflection level. Should the measured value have exceeded the permissible one, an empirical rehabilitation procedure (e.g. an overlay) would have been applied to adequately reduce the measured deflections.

As the understanding of pavement behaviour progressed, the mechanistic approach developed. This approach involves the application of laws of physics to understand how the traffic loads are being distributed through the pavement layers. Certain fundamental properties of materials must be known together with the layer thicknesses and load characteristics.

The current mechanistic-empirical design approach incorporates elements of both individual approaches. The mechanistic component involves the computation of pavement structural responses (deflections, stresses, strains) within the layers using physical models. The correlation between these responses and the pavement performance is given by the empirical component.

The simplest physical model of a pavement structure consists of a succession of layers, each of them characterised by an elastic modulus, Poisson’s ratio and thickness (see Figure F-1). The elastic modulus (E-modulus) is mathematically defined as the constant ratio of stress and strain for that pavement layer’s material. The elastic modulus is expressed in MPa and can typically vary between 30,000 MPa for Portland Cement Concrete and 35 MPa for subgrade soils.

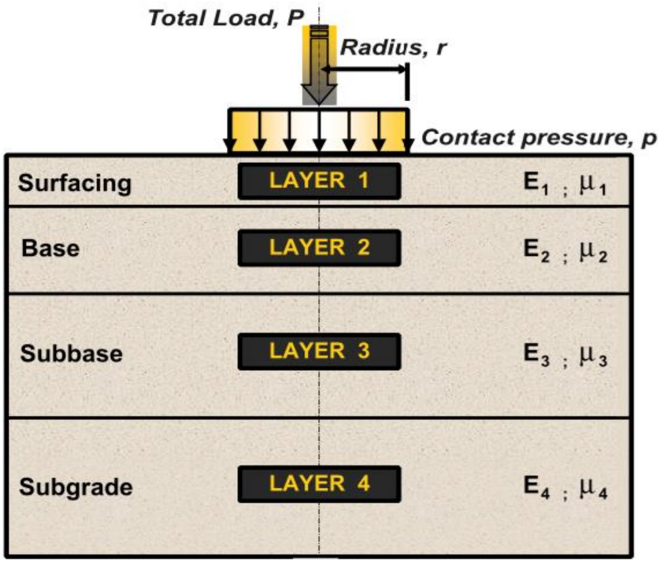


**Figure F-1 Simplified pavement structure model.**

The pavement material is also physically characterised by Poisson's ratio, mathematically defined as the ratio of transverse to longitudinal strain of a loaded specimen. Poisson's ratio is dimensionless and can theoretically vary from 0 to 0.5. Generally, stiffer materials will have lower Poisson's ratios than softer materials (e.g. from 0.15 for Portland Cement Concrete to 0.45 for subgrade soils).

## DEFLECTION BEAM (BENKELMAN BEAM)

### General

This is the least expensive instrument for measuring deflections, and was originally devised by A C Benkelman. It is a mechanical device that measures the maximum deflection of a road pavement under the dual rear wheels of a slowly moving loaded lorry. The beam consists of a slender pivoted beam, approximately 3.7 m long, supported in a low frame that rests on the road. The frame is fitted with a dial gauge for registering the movement at one end of the pivoted beam, the other end of which rests on the surface of the road. It is shown in Figure F-2.

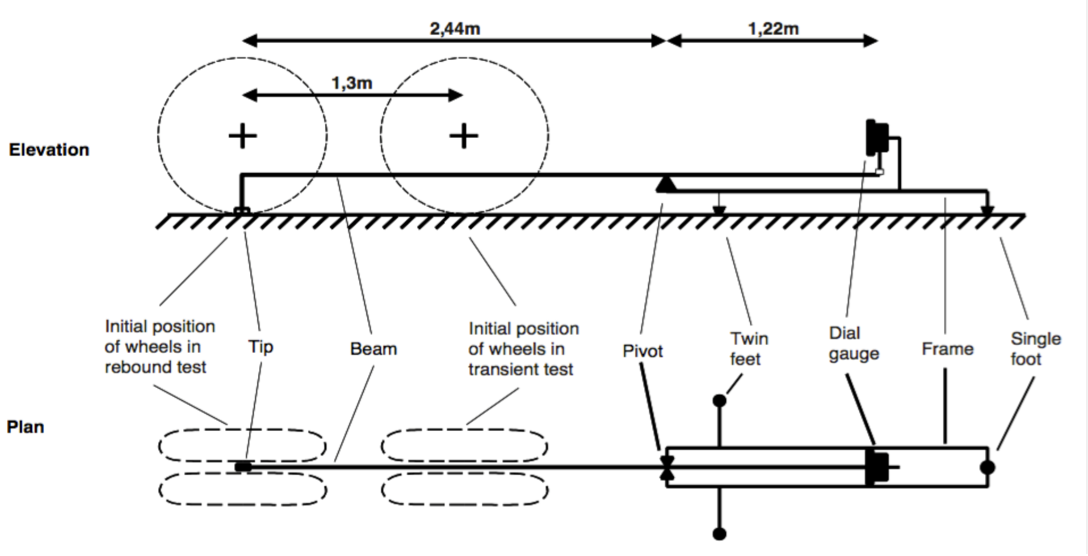


**Figure F-2 Diagrammatic representation of the Benkelman beam.**

## Deflection beam survey procedure

A safe working environment should always be maintained. Many organisations will have on-site safety procedures that should be followed.

Testing can be minimised by only taking measurements in the outer wheel path, as this is usually the most heavily trafficked wheel path (and the most moisture sensitive) and therefore gives the poorest results. If it is not evident, however, that deflections measured in the outer wheel path are consistently higher than in the inner wheel path, deflection beam measurements should be made in both lanes of a single carriageway road.

Tests can be made at any frequency, but when measurements are taken at closely spaced regular intervals (say 25 or 50 metres) the additional time and cost implications for the Benkelman beam survey will not normally be merited by gains in data quality. In this respect the automated deflection beam measurements using a Deflectograph can provide a cost-effective alternative, while providing far more comprehensive coverage and detail.

Consequently, when using manual deflection beam measurements, it is recommended that the following strategy be adopted.

i. Tests are carried out on a basic pattern of 100 or 200-metre spacing.
ii. Additional tests should be undertaken on any areas showing atypical surface distress.
iii. When a deflection value indicates the need for a significantly thicker overlay than is required for the adjacent section, the length of road involved should be determined by additional tests.

### Timing of deflection surveys

In some cases, the moisture content of the road pavement, especially the subgrade, changes seasonally. In these circumstances the tests should be carried out after the rainy season, when the road is at its weakest.

### Details of test truck

The truck must have dual rear wheels and should be loaded to a standard rear axle load if possible. The axle load must in any case be recorded as load-related corrections to readings may be required. The traditional standard axle load recommended 80 kN.  The important factor is that the test method and test conditions must be compatible with the deflection criteria and design procedures adopted. The effect of any differences from the original procedures adopted in the deflection design criteria must be established for the roads under investigation.

### Test method

There are two basic methods which are commonly used for operating the deflection beam. These are the transient deflection test and the rebound test.

*Transient deflection test*

In this test, the tip of the beam is inserted between the dual rear-wheel assembly of the loaded truck. The dial gauge is set to zero and the truck then drives slowly forward. As the wheels approach the tip of the beam, the road surface deflects downwards (loading deflection) and the movement is registered by the dial gauge. As the wheels move away from the tip of the beam, the road surface recovers (recovery deflection) and the dial gauge reading returns to approximately zero. The test procedure is summarised below.

i. Mark the point, in the verge-side wheelpath, at which the deflection is to be measured and position the truck so that the rear wheels are 1.3 m behind the marked point.
ii. Insert the deflection beam between the twin rear wheels until its measuring tip rests on the marked point. Insert a second beam between the offside wheels, if deflections are to be measured in both wheelpaths. It is helpful in positioning the truck and aligning the beams if a pointer is fixed to the truck 1.3 m in front of each pair of rear wheels.
iii. Adjust the footscrews on the frame of the beam to ensure that the frame is level transversely and that the pivoted arm is free to move. Adjust the dial gauge to zero and turn the buzzer on. Record the dial gauge reading which should be zero or some small positive or negative number.
iv. The maximum and final reading of the dial gauge should be recorded while the truck is driven slowly forward to a point at least 5 m in front of the marked point. The buzzer should remain on until the final reading is taken. Care must be taken to ensure that a wheel does not touch the beam. If it does the test should be repeated.

v. The transient deflection is the average of the loading and recovery deflections. Because of the 2:1 ratio of the beam geometry over the pivot point (see Figure F-2) the transient deflection is calculated by either:
   a. Adding the difference between initial and maximum dial gauge readings to the difference between maximum and final dial gauge readings, or,
   b. Calculating the loading deflection, as double the difference between the initial and maximum values, and the recovery deflection, as double the difference between the maximum and final readings and then calculating the mean of the two deflections.

vi. At least two tests should be carried out at each chainage and the mean value is used to represent the transient test result. If the results of the two tests do not fall within the repeatability limits described in Table F-1 then a third test should be carried out.

**Table F-1 Repeatability of duplicate transient deflection tests.**

| Mean deflection (mm) | Max. permissible difference between the two tests (mm) |
|---|---|
| < 0.10 | 0.02 |
| 0.10 – 0.30 | 0.03 |
| 0.31 – 0.50 | 0.04 |
| 0.51 – 1.00 | 0.05 |
| > 1.00 | 0.06 |

*Rebound deflection test*

This is probably the most commonly used method which, while not as comprehensive as the transient method, allows a greater production rate with less need for repeat measurements (e.g. due to the tyre touching the beam when guide pointers are not used on the truck). Because the rebound deflection can be influenced by the length of time during which the loading wheels are stationary over the test point care must be taken over the exact procedure used. The rebound test is not recommended for use on roads that may creep under the effect of the stationary wheels.

For the rebound deflection test the dual wheels are positioned immediately above the test point and the measuring tip of the beam is placed on the test point and between the dual wheels. The beam is adjusted in the same way as for the transient test and when the initial reading has been noted, the truck is driven forward at creep speed until the wheels are far enough away to have no influence upon the deflection beam. The final dial gauge reading is recorded and the rebound deflection is twice the difference between the initial and final dial gauge readings.

Whichever method is adopted for the deflection beam measurements, the possible effect of plastic flow upon the results should be noted, although this is only likely to be significant for thicker or relatively fresh asphalts. When an asphalt surfacing material flows plastically, it squeezes upwards between the dual loading wheels of the deflection truck which, in the transient deflection test, reduces the transient loading deflection because the upward movement of the material counteracts the downward movement of the pavement. The transient recovery deflection that is measured may be correct but further plastic movement of the raised surfacing material can occur during the time taken for the wheels to move from the test point to the final position, thereby causing an error in the recovery deflection reading. It is usually very clear from the test results when plastic flow occurs and testing should be stopped to avoid recording erroneous data.

In the rebound test, greater plastic flow will be induced in susceptible materials because of the time the wheels remain stationary over the test point. When the truck is driven forward the road surface rebounds but an indeterminate amount of recovery of the displaced surfacing material can occur. There is thus no clear indication from the simple rebound test when plastic flow occurs.

### Analysis of deflection survey data

Deflection readings can be affected by several factors that should be considered before the results can be interpreted. These are the temperature of the road, plastic flow of the surfacing between the loading wheels, seasonal effects and the size of the deflection bowl.

*Road temperature*

The stiffness of asphalt surfacings will change with temperature and therefore the magnitude of deflection can also change. The temperature of the bituminous surfacing is recorded when the deflection measurement is taken, thus allowing the value of deflection to be corrected to a standard temperature. It is recommended that 35°C, measured at a depth of 40 mm in the surfacing, is a suitable standard temperature. Fortunately, it is often found that little or no correction is required when the road surfacing is either old and age hardened or relatively thin.

If, however, there is a need to adjust for temperature (thicker, newer asphalt surfaces) the following should be noted. The relation between temperature and deflection for any pavement is obtained by studying the change in deflection on a number of test points as the temperature rises from early morning to midday. As it is not possible to produce general correction curves to cover all roads, it is therefore necessary to establish the deflection/temperature relationship for each project.

*Seasonal effects*

In areas where the moisture content of the subgrade changes seasonally, the deflection will also change. This is usually one of the parameters that is investigated in experimental sections.

*Size of deflection bowl*

The size of the deflection bowl can occasionally be so large that the front feet of the deflection beam lie within the bowl at the beginning of the transient deflection test. If this happens, the loading and recovery deflection will differ. The simplest way to check whether the differences in loading and recovery deflection are caused by the size of the bowl is to place the tip of another beam close to the front feet of the measurement beam at the beginning of the transient test. This second beam can be used to measure any subsequent movement of the feet of the first beam as the truck moves forward. If feet movements larger than 0.06mm are observed only the recovery part of the deflection cycle should be used for estimating the value of transient deflection.

### Data processing

After all measurements have been made, and any corrections applied to the raw data, it is then convenient to plot the deflection profile of the road for each lane. When measurements in both wheel paths have been made, only the larger deflection of either wheel path at each chainage is used. Any areas showing exceptionally high deflections that may need reconstruction or special treatment can then be identified.

The deflection profile is then used to divide the road into homogeneous sections, in such a way as to minimise variations in deflections within each section. The minimum length of these sections should be compatible with the frequency of thickness adjustments that can sensibly be made by the paving machine, whilst still maintaining satisfactory finished levels. When selecting the sections the topography, subgrade type, pavement construction and maintenance history should all be considered.

A number of statistical techniques can be used to divide deflection data into homogeneous sections. The recommended technique is the cumulative sum method, where plots of the cumulative sums of deviations from the mean deflection against chainage can be used to discern the sections.

## FALLING WEIGHT DEFLECTOMETER (FWD)

### General

The Falling Weight Deflectometer (FWD) simulates the effect of actual traffic-induced loads by dropping onto the pavement surface a constant weight from variable heights. A diagram is shown in Figure F-3. The FWD is generally built onto a semi- trailer and equipped with its own power source (generator/batteries). It weighs about 1 tonne and can comfortably travel, on surfaced roads, at 100 km/h. A distance-measuring device is also attached to the semi-trailer, for relative and global distance measurements.

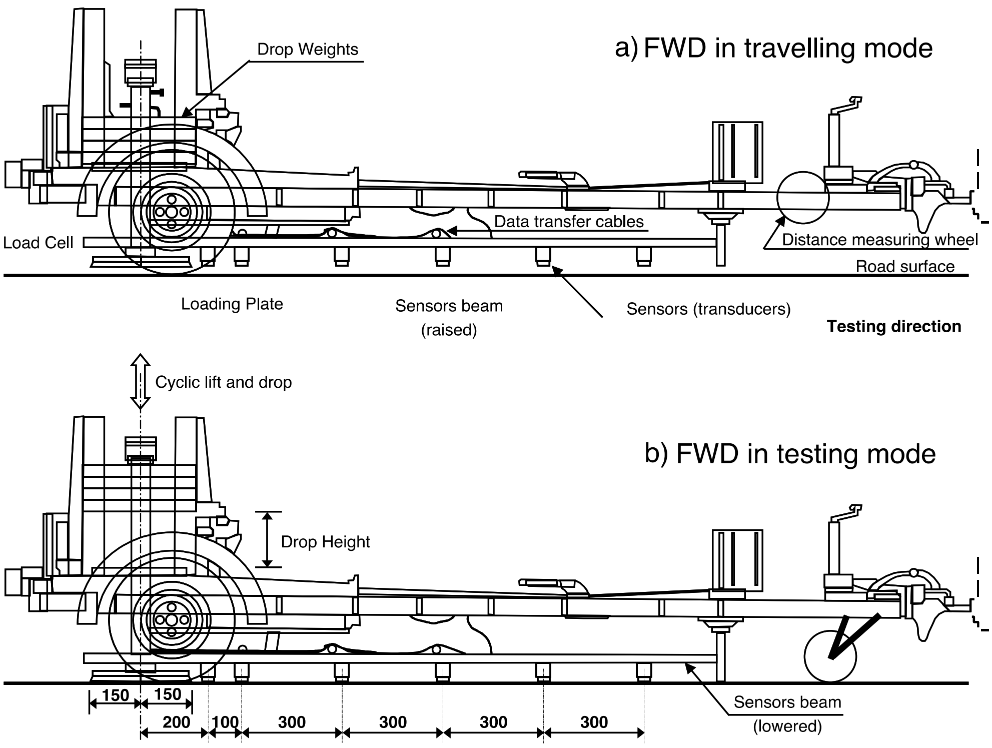


**Figure F-3 Diagrammatic representation of the FWD**

A number of detachable weights are locked on a hydraulic piston that facilitates their quick and precise lift. The weights are thereafter dropped from a predetermined height. A circular, flexible, loading plate (150 mm radius) ensures the smooth load transfer between the dropping weights and the potentially uneven pavement surface. A load cell, placed directly under the dropping weight, accurately measures the loading level. The resultant pavement surface deflections are measured by 9 sensors/transducers placed under a sensors beam at the following offsets (from the loading plate's centre): 0 / 150 / 200 / 300 / 600 / 900 / 1200 / 1500 /1800 mm. Multiple data transfer cables, also attached to the sensors beam, ensure the communication between the load cell / sensors / FWD engines and the central computer.

## Measurement procedure

All the relevant safety measures apply.

Establishing a concise but clear and consistent testing reference system prior to the commencement of testing is critical. The reference system should include the following:

a) General information

Date, operator(s), FWD serial number, road ID (for network testing), measurement units (metric/imperial), test start and end chainages, test spacing (distance between adjacent test points); sensors spacing (depending on the pavement layer thicknesses);

b) Test point information and parameters

Number and sequence of drops (in terms of corresponding load levels); air, surface and in-depth temperatures; pavement cracking type, extent and magnitude; road profile (e.g. fill/cut, to reflect potential water ingress); change(s) in the pavement structure; and underground structures (e.g. culverts, pipes, which can significantly affect the deflection magnitude).

**Testing direction**

The number and sequence of drops can be set up differently in up to five series. The operator can apply any or all of these series at a test point. Generally, one series of two drops (4 tonne each) is usually applied for all test points.

The air, surface and in-depth temperatures are usually determined at the start and end of a testing session. Should any temperature change occur during testing, the operator should repeat FWD measurements. It is usually more beneficial to continuously monitor the temperatures.

All relevant calibrations (see next section) must be undertaken as required. A large amount of deflection data could prove incorrect and, therefore, useless should the system malfunction at any time.

While moving between two adjacent points the sensors beam must be raised, irrespective of travelling speed. Once the FWD has stopped, the sensors beam is lowered together with the loading plate. The operator inputs the test point information and, automatically, the weights are raised and dropped from a test height for an in-built, on-the-spot system check. Once the operator is satisfied with the system pre-test data, the weights are automatically raised and dropped to and from the predetermined height(s) as many times as required. After each drop, the relevant data is sent to the computer, which displays it. The operator can interrupt the automatic testing sequence at any time and restart and /or continue it manually (drop by drop), if so necessary.

### Calibrations

Three types of calibration of the sensors are done, namely absolute, reference and relative. Absolute calibration is done in the factory, at the time of manufacture, while designated agents typically undertake reference calibration annually, also indoors. The absolute and reference calibration results should be recorded by the agents in calibration certificates and should always be available for inspection.

The relative calibration is usually done monthly and/or at the start of every new project, in approximately 4 hours. During this calibration, the sensors are placed one on top of each other and subjected to a standard vertical load. If all the sensors are in good condition, their readings should be sensibly equal.

The load cell should be tested at the start and end of each testing session by plotting, on the computer screen, its output curve, for a standard drop. This plotting option is available on most FWD equipment. If the load cell is in good condition, its output curve shall have a continuous sinusoidal shape.

Generally, no other calibration is required, even when the equipment has to travel on rough roads or pull aside on grass.

### Output

The testing output is stored in specific text files during testing. The general information is stored in the file header. The initial test drop parameters and results follow. Subsequently, all drop loads and their corresponding pavement surface deflections are recorded separately, though grouped per test point. The test point information is generally recorded per point, though it can also be recorded for each drop.

Microsoft Excel can be satisfactorily used to import and process these files. Once the potential user tries to open such a file, the text import procedure is automatically started and a delimited file type is assigned. As this default file type is convenient, the user can subsequently choose the delimiter type for converting the text to columns. For the purposes of FWD data analysis, the most adequate delimiter type is space. The resultant file can be saved as an Excel spreadsheet and used for further processing.

It is, however, recommended that the FWD service provider processes the files according to the Client's requirements. Inherent measurement errors can be easily overlooked if the processing personnel do not have the required expertise.

### Deflection bowl parameters

The deflections recorded at a test point constitute that point's deflection bowl (see Figure F-4a). The maximum deflection, measured directly under the load, can serve as a good indicator of the overall pavement strength. The inner deflections (closer to the loading plate) relate to the upper layers (surfacing, base, subbase) strength whereas the outer ones relate to the lower layers (selected, subgrade). For this reason, several deflection bowl parameters are derived from measured deflections (see Figure F-4b).

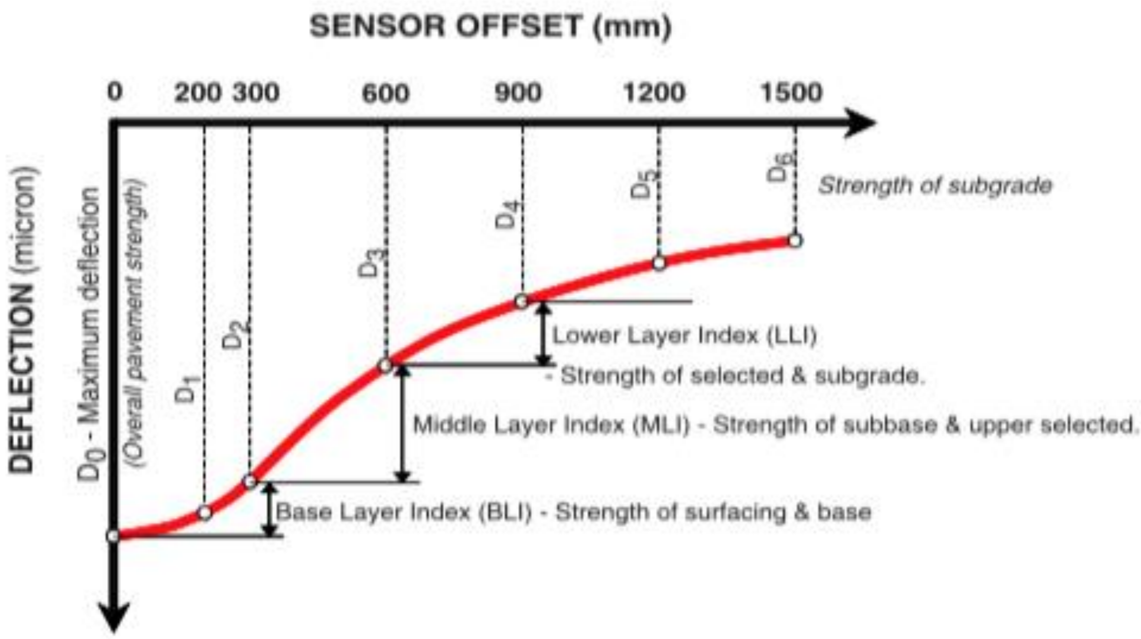


**Figure F-4a: Deflection Bowl Parameters**

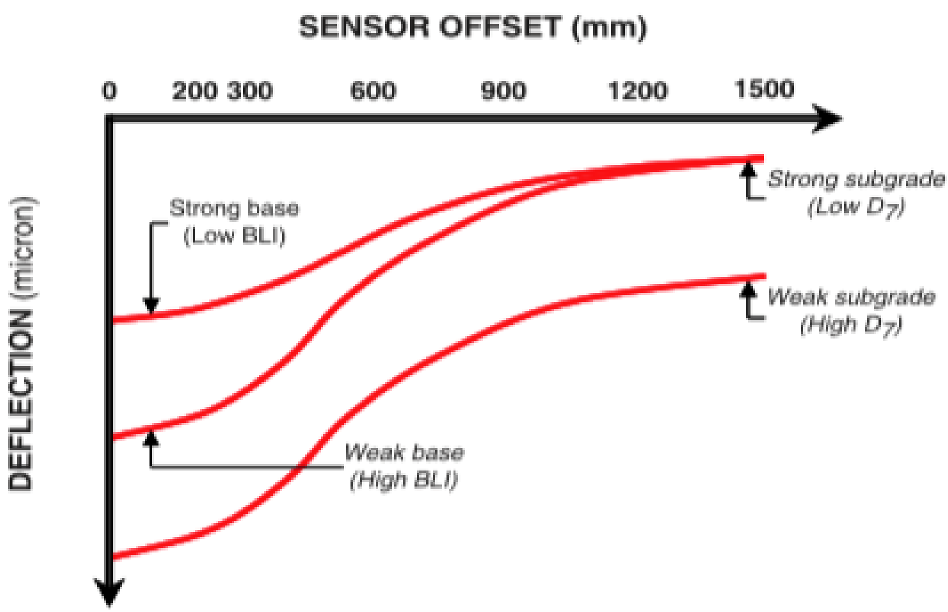


**Figure F-4b: Deflection Bowl Parameters**

A number of software packages have been specifically developed for FWD data conversion and processing. The output includes deflection bowl parameters, allowable traffic, etc.

### Back-calculation

Complete deflection bowls are used in an iterative procedure, known as back-calculation, to estimate the pavement layer E-moduli. The straightforward goal of the back-calculation process is to estimate a set of layer E-moduli that best match the measured and calculated deflections, at all offsets.

A physical model is assumed, with estimated E-moduli and Poisson's ratios. The layer thicknesses are considered known (these can be identified accurately from a DCP test). A set of theoretical deflections is then mathematically derived (at the same offsets as the FWD sensors) based on the estimated E-moduli and the traffic loading. This set of computed deflections is compared with the FWD measured one. Based on the difference between the two sets of deflections, the estimated E-moduli are adjusted and the theoretical deflections re-computed. This process is iterated until the difference between the computed and measured deflections is being reduced to a minimum (that is, 5-10%).

Typical examples of FWD outputs also include different indices for different layers based on comparisons of different sensor deflections. These include the upper, middle and lower layer indices, which indicate the properties of the materials in each of these portions of the pavement.

# APPENDIX G: Traffic Tallying Form

| | | | |
|---|---|---|---|
| Traffic Tallying Form | | Project: | |
| Area/Town: | Road: | Count made by: | Date: |
| Location/Chainage of Count Section | | Day: | Sheet of |

| VEHICLE CLASS \ HOUR | 6 - 7 | 7 - 8 | 8 - 9 | 9 - 10 | 10 - 11 | 11 - 12 | 12 - 13 | 13 - 14 | 14 - 15 | 15 - 16 | 16 - 17 | 17 - 18 | COUNT | FACTOR | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Passenger Cars | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| Light Goods Vehicle (Pick Ups, Small Bus, Vans, Small Trucks) | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| Medium Bus | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| Coach (eg. Salem Bus) | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| Medium Truck (2 Axle) | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| Heavy Truck (2 Axle) | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| Heavy Truck (3 Axle) | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| Heavy Truck (4 Axle) | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| Articulated Trucks | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| Tractor and Agric Vehicles | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| HOUR TOTAL | | | | | | | | | | | | | | | |

| | | | |
|---|---|---|---|
| **Traffic Tallying Form** | | **Project:** | |
| **Area/Town:** | **Road:** | **Count made by:** | **Date:** |
| **Location/Chainage of Count Section** | | **Day:** | **Sheet of** |

| **VEHICLE CLASS \ HOUR** | **18 – 19** | **19 – 20** | **20 – 21** | **21 – 22** | **22 – 23** | **23 – 24** | **0 – 1** | **1 – 2** | **2 – 3** | **3 – 4** | **4 – 5** | **5 – 6** | **COUNT** | **FACTOR** | **TOTAL** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Passenger Cars** | | | | | | | | | | | | | | | |
| **Light Goods Vehicle (Pick Ups, Small Bus, Vans, Small Trucks)** | | | | | | | | | | | | | | | |
| **Medium Bus** | | | | | | | | | | | | | | | |
| **Coach (eg. Salem Bus)** | | | | | | | | | | | | | | | |
| **Medium Truck (2 Axle)** | | | | | | | | | | | | | | | |
| **Heavy Truck (2 Axle)** | | | | | | | | | | | | | | | |
| **Heavy Truck (3 Axle)** | | | | | | | | | | | | | | | |
| **Heavy Truck (4 Axle)** | | | | | | | | | | | | | | | |
| **Articulated Trucks** | | | | | | | | | | | | | | | |
| **Tractor and Agric Vehicles** | | | | | | | | | | | | | | | |
| **HOUR TOTAL** | | | | | | | | | | | | | | | |

## APPENDIX H: LTPP Density and Moisture Content Assessment

| LTPP DENSITY AND MOISTURE CONTENT ASSESSMENT | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **LTPP Section** | | | | | Date | | | Evaluator | | | | |
| Calibration | | | Prv | Std | Std | Std | | | | | | |
| Standard MC | | | | | | | | | | | | |
| Standard wet density | | | | | | | | | | | | |
| | Probe | Input | Actual | Outer wheel path | | | Inner wheel path | | | Centreline | | |
| | | | | Wet | MC | Dry | Wet | MC | Dry | Wet | MC | Dry |
| **PANEL A** | 24 | 200 | 600 | | | | | | | | | |
| | 22 | 200 | 550 | | | | | | | | | |
| | 20 | 200 | 500 | | | | | | | | | |
| | 18 | 200 | 450 | | | | | | | | | |
| | 16 | 200 | 400 | | | | | | | | | |
| | 14 | 200 | 350 | | | | | | | | | |
| | 12 | 200 | 300 | | | | | | | | | |
| | 10 | 200 | 250 | | | | | | | | | |
| | 8 | 200 | 200 | | | | | | | | | |
| | 6 | 150 | 150 | | | | | | | | | |
| | 4 | 100 | 100 | | | | | | | | | |
| | 2 | 50 | 50 | | | | | | | | | |
| **PANEL B** | 24 | 200 | 600 | | | | | | | | | |
| | 22 | 200 | 550 | | | | | | | | | |
| | 20 | 200 | 500 | | | | | | | | | |
| | 18 | 200 | 450 | | | | | | | | | |
| | 16 | 200 | 400 | | | | | | | | | |
| | 14 | 200 | 350 | | | | | | | | | |
| | 12 | 200 | 300 | | | | | | | | | |
| | 10 | 200 | 250 | | | | | | | | | |
| | 8 | 200 | 200 | | | | | | | | | |
| | 6 | 150 | 150 | | | | | | | | | |
| | 4 | 100 | 100 | | | | | | | | | |
| | 2 | 50 | 50 | | | | | | | | | |
| **PANEL C** | 24 | 200 | 600 | | | | | | | | | |
| | 22 | 200 | 550 | | | | | | | | | |
| | 20 | 200 | 500 | | | | | | | | | |
| | 18 | 200 | 450 | | | | | | | | | |
| | 16 | 200 | 400 | | | | | | | | | |
| | 14 | 200 | 350 | | | | | | | | | |
| | 12 | 200 | 300 | | | | | | | | | |
| | 10 | 200 | 250 | | | | | | | | | |
| | 8 | 200 | 200 | | | | | | | | | |
| | 6 | 150 | 150 | | | | | | | | | |
| | 4 | 100 | 100 | | | | | | | | | |
| | 2 | 50 | 50 | | | | | | | | | |
| **Gravimetric Moisture Content** | | | | | | | | | | | | |
| | **Sample Depth** | | **Tin No** | | **MC** | **Actual Dry** | | **MC** | **Actual Dry** | | **MC** | **Actual Dry** |
| **PANEL A** | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| **PANEL B** | | | | | | | | | | | | |
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| | | | | | | | | | | | | |

# APPENDIX I: Rut Measurement Form

## Appendix C10: Rut Measurement Form

| | | | |
|---|---|---|---|
| Project | | Survey no/Sheet | |
| Province | | Surveyor | |
| Road Name | | Date | |
| Section | | Direction of counting on each | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Chainage | | | | | | |
| Lane | LEFT | | | RIGHT | | |
| Location | Outer Path | Inner Path | Width | Inner Path | Outer Path | Width |
| Reading (mm) | | | | | | |
| | | | | | | |
| Chainage | | | | | | |
| Lane | LEFT | | | RIGHT | | |
| Location | Outer Path | Inner Path | Width | Inner Path | Outer Path | Width |
| Reading (mm) | | | | | | |
| | | | | | | |
| Chainage | | | | | | |
| Lane | LEFT | | | RIGHT | | |
| Location | Outer Path | Inner Path | Width | Inner Path | Outer Path | Width |
| Reading (mm) | | | | | | |
| | | | | | | |
| Chainage | | | | | | |
| Lane | LEFT | | | RIGHT | | |
| Location | Outer Path | Inner Path | Width | Inner Path | Outer Path | Width |
| Reading (mm) | | | | | | |
| | | | | | | |
| Chainage | | | | | | |
| Lane | LEFT | | | RIGHT | | |
| Location | Outer Path | Inner Path | Width | Inner Path | Outer Path | Width |
| Reading (mm) | | | | | | |
| | | | | | | |
| Chainage | | | | | | |
| Lane | LEFT | | | RIGHT | | |
| Location | Outer Path | Inner Path | Width | Inner Path | Outer Path | Width |
| Reading (mm) | | | | | | |
| | | | | | | |
| Chainage | | | | | | |
| Lane | LEFT | | | RIGHT | | |
| Location | Outer Path | Inner Path | Width | Inner Path | Outer Path | Width |
| Reading (mm) | | | | | | |
| | | | | | | |

| |
|---|
| Average rut depth: |
| Maximum rut depth: |
| 90$^{th}$ percentile rut depth: |
| Average pond width: |
| Average pond depth: |

# APPENDIX J: Profiling Assessment Form

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **LTPP Profile Assessment Form** | | | | | | | | | | | | | | | | | | | | |
| | **Section:** | | | | | | **Panels:** | | | | | | **Date:** | | | | | | **Evaluator:** | | |
| **TRANSVERSE PROFILING** | **Panel** | Lane Centre | 1.9 | 1.8 | 1.7 | 1.6 | 1.5 | 1.4 | 1.3 | 1.2 | 1.1 | 1.0 | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | RE |
| | Max Rut: | | | | | | | | | | | | | | | | | | | | | |
| | Width: | | | | | | | | | | | | | | | | | | | | | |
| | | | 2.1 | 2.2 | 2.3 | 2.4 | 2.5 | 2.6 | 2.7 | 2.8 | 2.9 | 3.0 | 3.1 | 3.2 | 3.3 | 3.4 | 3.5 | 3.6 | 3.7 | 3.8 | 3.9 | CL |
| | **Panel** | Lane Centre | 1.9 | 1.8 | 1.7 | 1.6 | 1.5 | 1.4 | 1.3 | 1.2 | 1.1 | 1.0 | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | RE |
| | Max Rut: | | | | | | | | | | | | | | | | | | | | | |
| | Width: | | | | | | | | | | | | | | | | | | | | | |
| | | | 2.1 | 2.2 | 2.3 | 2.4 | 2.5 | 2.6 | 2.7 | 2.8 | 2.9 | 3.0 | 3.1 | 3.2 | 3.3 | 3.4 | 3.5 | 3.6 | 3.7 | 3.8 | 3.9 | CL |
| | **Panel** | Lane Centre | 1.9 | 1.8 | 1.7 | 1.6 | 1.5 | 1.4 | 1.3 | 1.2 | 1.1 | 1.0 | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | RE |
| | Max Rut: | | | | | | | | | | | | | | | | | | | | | |
| | Width: | | | | | | | | | | | | | | | | | | | | | |
| | | | 2.1 | 2.2 | 2.3 | 2.4 | 2.5 | 2.6 | 2.7 | 2.8 | 2.9 | 3.0 | 3.1 | 3.2 | 3.3 | 3.4 | 3.5 | 3.6 | 3.7 | 3.8 | 3.9 | CL |
| | **Panel** | Lane Centre | 1.9 | 1.8 | 1.7 | 1.6 | 1.5 | 1.4 | 1.3 | 1.2 | 1.1 | 1.0 | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | RE |
| | Max Rut: | | | | | | | | | | | | | | | | | | | | | |
| | Width: | | | | | | | | | | | | | | | | | | | | | |
| | | | 2.1 | 2.2 | 2.3 | 2.4 | 2.5 | 2.6 | 2.7 | 2.8 | 2.9 | 3.0 | 3.1 | 3.2 | 3.3 | 3.4 | 3.5 | 3.6 | 3.7 | 3.8 | 3.9 | CL |
| | **Panel** | Lane Centre | 1.9 | 1.8 | 1.7 | 1.6 | 1.5 | 1.4 | 1.3 | 1.2 | 1.1 | 1.0 | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | RE |
| | Max Rut: | | | | | | | | | | | | | | | | | | | | | |
| | Width: | | | | | | | | | | | | | | | | | | | | | |
| | | | 2.1 | 2.2 | 2.3 | 2.4 | 2.5 | 2.6 | 2.7 | 2.8 | 2.9 | 3.0 | 3.1 | 3.2 | 3.3 | 3.4 | 3.5 | 3.6 | 3.7 | 3.8 | 3.9 | CL |
| | **Panel** | Lane Centre | 1.9 | 1.8 | 1.7 | 1.6 | 1.5 | 1.4 | 1.3 | 1.2 | 1.1 | 1.0 | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | RE |
| | Max Rut: | | | | | | | | | | | | | | | | | | | | | |
| | Width: | | | | | | | | | | | | | | | | | | | | | |
| | | | 2.1 | 2.2 | 2.3 | 2.4 | 2.5 | 2.6 | 2.7 | 2.8 | 2.9 | 3.0 | 3.1 | 3.2 | 3.3 | 3.4 | 3.5 | 3.6 | 3.7 | 3.8 | 3.9 | CL |
| **LONGITUDINAL** | Position (m) | | 0 | 20 | 40 | 60 | 80 | 100 | 120 | 140 | 160 | 180 | 200 | 220 | 240 | 260 | 280 | 300 | 320 | 340 | 360 | 380 |
| | Outer | | | | | | | | | | | | | | | | | | | | | |
| | Inner | | | | | | | | | | | | | | | | | | | | | |
| | Lane Centre | | | | | | | | | | | | | | | | | | | | | |

## APPENDIX K: Benkelman Beam Deflection form

| | |
|---|---|
| **Project:** | **Chainage from/to:** |
| **Direction:** | **Lane (L/R):** |
| **Tested by:** | **Date:** |

| **Chainage** | **Deflection Reading, X $10^{-2}$** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Inside wheel track** | | | | **Outside wheel track** | | | |
| | **Initial Reading** | **Max Reading** | **Final Reading** | **Deflect. mm$^{-2}$** | **Initial Reading** | **Max Reading** | **Final Reading** | **Deflect. mm$^{-2}$** |
| | | | | | | | | |
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# APPENDIX L: DCP Measurement Form

## APPENDIX C6: DCP Measurement Form

| | | | | | |
|---|---|---|---|---|---|
| Project Title | | | Survey Number | | |
| Province | | | Road Name | | |
| Section | | | Chainages | | |
| Length | | Date | | Zero Error (mm) | |
| Test Position | | Cone | | Surveyor | |

| Blows | Reading (mm) | Penetration Depth (mm) | Blows | Reading (mm) | Penetration Depth (mm) |
|---|---|---|---|---|---|
| 0 | | | | | |
| 5 | | | 205 | | |
| 10 | | | 210 | | |
| 15 | | | 215 | | |
| 20 | | | 220 | | |
| 25 | | | 225 | | |
| 30 | | | 230 | | |
| 35 | | | 235 | | |
| 40 | | | 240 | | |
| 45 | | | 245 | | |
| 50 | | | 250 | | |
| 55 | | | 255 | | |
| 60 | | | 260 | | |
| 65 | | | 265 | | |
| 70 | | | 270 | | |
| 75 | | | 275 | | |
| 80 | | | 280 | | |
| 85 | | | 285 | | |
| 90 | | | 290 | | |
| 95 | | | 295 | | |
| 100 | | | 300 | | |
| 105 | | | 305 | | |
| 110 | | | 310 | | |
| 115 | | | 315 | | |
| 120 | | | 320 | | |
| 125 | | | 325 | | |
| 130 | | | 330 | | |
| 135 | | | 335 | | |
| 140 | | | 340 | | |
| 145 | | | 345 | | |
| 150 | | | 350 | | |
| 155 | | | 355 | | |
| 160 | | | 360 | | |
| 165 | | | 365 | | |
| 170 | | | 370 | | |
| 175 | | | 375 | | |
| 180 | | | 380 | | |
| 185 | | | 385 | | |
| 190 | | | 390 | | |
| 195 | | | 395 | | |
| 200 | | | 400 | | |

**Notes:** Ruttting, Pumping, Longitudinal Cracks, Crocodile Cracks, Block Cracks, Other

## APPENDIX M: LTPP Test Pit Form

| LTPP Test Pit Form | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **LTPP Section** | | **Panel** | | **Position** | | **Date** | | **Profiled by** | |
| **Surface/layer bond** | | | | | | | | | |
| **Depth (mm)** | **Moisture** | **Colour** | **Consistency** | **Structure** | **Soil Type** | **Origin** | **Disturbed Sample** | **Undisturbed Sample** | **Comments** |
| | | | | | | | | | |
| to | | | | | | | | | |
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| **Checklist** | **Cracks** | | **Description** | | | | | | |
| | **Rutting** | | **Heaving** | | **Interference Bond** | | **Moisture at Interference** | | **Layer Definition** |
| | **Carbonation** | | | | | | | | |