DRAFT

Accreditation and Quality Assurance of Devices for measurement of ride quality of newly laid surfaces

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|  |  |  |  |

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Introduction to this Draft

Currently, the performance requirements for ride quality of newly laid surfaces (series 700 of the MCHW) are specified in relation to the measurements provided using the Rolling Straight Edge (RSE). Due to the known limitations of this method, in terms of safety, practicality and its ability to robustly identify poor ride quality, research has been carried out to identify an alternative approach to testing ride quality.

This research has recommended that:

* The RSE is replaced by a non-contact measurement system that is able to measure the shape (Longitudinal Profile) of the newly laid surface more robustly.
* The measurement of ride quality is expanded to better assess the ride quality achieved over the full width of laying, through the use of multiple measurement lines. This will further improve the robustness of the performance assessment of new surfaces.
* The measured shape is used to obtain a parameter that better reflects the ride quality experienced by road users – namely the Roughness Index, RI that is applied in National Highways Ride Quality Metric. This will align the assessment of new surfaces with assessments carried out during the in-service lifetime of the pavement.
* The delivery of ride quality information from newly laid sites becomes a digital process, with data being delivered to National Highways in a format such that it can be loaded directly into their management databases. This will provide the ability to track ride quality performance throughout the lifetime of the pavement, using a common approach.
* The tools and contractors that undertake the measurements are subject to tests and checks to ensure that there is a high level of quality in the measured data. This will reflect similar quality standards applied to the measurements undertaken during the in-service lifetime of the pavement.
* And that this requirement be built into a revised version of the MCHW to optimise the delivery of newly laid surfaces that meet the expectations of road users.

The draft specification presented in this document presents the requirements for measurement of ride quality of newly laid surfaces using non-contact methods, which has been developed in the light of the above recommendations.

This draft specification is being published to provide information on the anticipated requirements for the:

* Collection of measurements using non-contact methods
* Processing of these measurements into the required parameters
* Fitting and delivering the data to customers (e.g. National Highways)

This draft specification is being provided alongside a stakeholder engagement programmed being led by National Highways in the summer of 2023 to enable feedback on the approach and how it might best be implemented. Asphalt and measurement industry stakeholder participants in this programme will have opportunity to obtain a better understanding of the implications of the new approach, both for the delivery of new surfaces that meet the performance requirements, and for the measurement of the performance of these new surfaces.

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Definitions of terms used in this document

Note that in this Draft version some criteria are highlighted yellow, where work is ongoing to determine firm values for these criteria.

This document uses the following terms:

**Accreditation Certificate;** documentary evidence of the performance achieved during Accreditation/Re-accreditation. It also sets out the limitations and validity period of the accreditation and the version number of the specification against which the assessment was made. It shall be retained by the Owner and produced upon request.

**Accreditation Period;** normally 24 months from the date of attending an Accreditation/Re-accreditation Assessment.

**Accredited Surveys;** surveys undertaken using Equipment which is adhering to the required QA and has a valid Accreditation Certificate.

**Accreditation Assessment;** an event where accreditation tests are performed to demonstrate that the Equipment can meet the requirements under controlled test conditions.

**Auditor;** any organisation overseeing the Accreditation and QA programmes outlined in this specification. Specific requirements imposed on the Auditor are given in Appendix A. The Auditor is determined by the Network Authority.

**Bias;** bias is a measure of the average offset between the Survey Data and the Reference Data. It is calculated by calculating the differences between the Survey Data and the Reference Data and taking the average of these values.

**Base Condition Data (BCD);** the data file provided by MSP, which contains parameters such as eLPV and information to enable them to be fitted to the network.

**Calibration;** laboratory (or baseline) calibration of a System (or one of its Components) of the Equipment.

**Closed Test Site;** refers to a test site which can be closed to traffic to ensure testing can be completed in a controlled environment and/or for the collection of detailed Reference Data.

**Component;** refers to a part of one of the Systems fitted to the Equipment.

**Contractor;** the organisation carrying out the Accredited Survey. The Contractor may be a third party organisation commissioned to carry out the surveys, but could also be the body undertaking the surfacing works.

**Derived Values;** Parameters derived from the Raw Condition Data (e.g. by the Machine Survey Pre-processor). Includes enhanced Longitudinal Profile Variance.

**Developer;** the manufacturer of an existing Equipment or System, or the organisation or individual who is introducing a new model or variant of Equipment or System. The Developer could also be the Contractor.

**eLPV;** Enhanced Longitudinal Profile Variance, a parameter that is calculated from the Longitudinal Profile to assess the smoothness (ride quality) of the road surface

**Employer;** the organisation that commissions the Contractor to provide Survey Data.

**Equipment;** the overall machine carrying out the survey to collect the Survey Data, incorporating the Systems and, where applicable, the survey vehicle.

**Equivalent Measurement System;** Equipment that is comparable with existing Accredited Equipment from the same Developer, to an extent that enables it to seek initial Accreditation via the Re-Accreditation process rather than full Accreditation.

**Enhanced Longitudinal Profile Variance (eLPV);** a parameter quantifying ride quality in terms of a specific wavelength range (e.g. 3m and 10m), obtained by applying an algorithm to Longitudinal Profile measurements.

**GNSS;** Global Navigation Satellite System e.g. GPS

**HARRIS**; Highways Assessment Road Research Information System – Equipment used for the purposes of reference measurements, Accreditation and Quality Assurance

**Improvement Notice;** a notice issued if the Auditor finds the Equipment is not meeting the requirements of the Accreditation or Quality Assurance processes. The notice shall detail the timescale within which the improvement is required and any restrictions to the use of the equipment prior to satisfactory completion of the improvement.

**Live Test Site;** a test site which is open to live traffic.

**Location Referencing;** the techniques and conventions that are used to locate items on the road Network.

**Location Referencing/Reference Point;** A known physical or abstract point somewhere on a section having an accurate locational reference.

**Longitudinal Profile;** The variation of level along the length of a carriageway, excluding wavelengths less than 0.5m or greater than 100m. Used to calculate enhanced Longitudinal Profile Variance.

**MSP;** Machine Survey Pre-processor. Software provided by the Network Authority for the processing of Surface Profile RCD into Base Condition Data for loading into P-AMS. The MSP will fit the Survey to the Route and calculate eLPV values.

**Network;** roads in a given area or of a given classification for which the Network Authority has responsibility.

**Network Authority;** the organisation ultimately responsible for maintenance of any given road network. Unless stated otherwise in this document the Network Authority is National Highways.

**Newly Laid Surface(s);** for the purposes of accreditation a Newly Laid Surface is defined as one that is on a site that has been open to traffic for <=5 days (inclusive). Although the MCHW allows measurements to be undertaken between 3 and 28 of completion of the surfacing, the limited time range specified for accreditation tests ensures that the Equipment demonstrates its ability to carry out measurements over the full range of conditions allowed by the MCHW (as surveys closer to the date of laying are considered to present the most demanding measurement conditions).

**Owner;** the organisation or individual to whom the Equipment belongs and to whom Accreditation Certificates are awarded. The Owner could also be the Contractor.

**P-AMS;** Pavement Asset Management System operated by the National Highways for the management and assessment of the network.

**Parameter;** specific data fields that form part of the Survey Data supplied by the Contractor to the Employer (and may be calculated by the Contractor or by MSP, for example eLPV).

**Primary Check Site;** a site established by the Contractor to check the medium term consistency of the Survey Data.

**Quality Assurance (QA);** a process to give the Employer confidence that the data and results being provided are reliably consistent and suitable for purpose.

**Reference Data;** data against which the Equipment shall be compared for the purposes of Accreditation or Quality Assurance.

**Reference Device;** device that is used to collect Reference Data. The Reference Device (e.g. HARRIS) is typically operated by the Auditor.

**Reference Profile**: Reference Values for use in the Accreditation and Quality Assurance procedures.

**Re-accreditation Assessment;** an event where performance tests are carried out on Equipment which has previously met the mandatory requirements of an Accreditation Assessment.

**Repeatability;** assessment of the consistency of the Equipment/System with previous measurements obtained with the same Equipment/System.

**Reproducibility;** assessment of the consistency of the Equipment or System with the Reference Data.

**Roughness Index;** a parameter quantifying ride quality, obtained by applying an algorithm to 3m and 10m enhanced Longitudinal Profile Variance values.

**Route File;** An ASCII formatted file that contains the definition of a Survey Route (including the sections contained within the survey).

**Routine maintenance;** any maintenance or work done on the Equipment which may affect, or there is a risk that it may affect, the measurement performance (for example accuracy, reliability, consistency) of the Equipment.

**Section**: A length of the network defined in accordance with section referencing rules, each having fixed start and end positions and road alignment.

**Section Label;** An alphanumeric label that, together with a date, uniquely identifies a Section.

**Sub-section;** A fragment of a Section having a pre-determined length. Typical sub-section lengths are 10m.

**Surface Profile Raw Condition Data (RCD);** The data file format for the delivery of the Survey Data;

**Survey Data;** data collected by the Contractor using the Equipment and supplied to the Employer as Surface Profile RCD,

**Survey Lane;** A Lane, within the limits of a Section along which part of a Survey is to take place. A Survey Lane is identified by a Section Label, Lane Direction Indicator, Lane Name, start Chainage and end Chainage.

**Survey Route**; An ordered list of Survey Lanes, each with a Start Reference Label. A Survey Route also shall have an End Reference Label.

**System;** individual measurement system installed on the Equipment e.g. distance measurement system, profile measurement system.

**Trafficked Surfaces;** surfaces on sites that have been open to traffic for a minimum of one month.

**Valid**; a measured data value or Derived Value that would not meet the requirements for accuracy (Repeatability or Reproducibility)

1. Introduction
   1. Introduction
      1. The Accreditation and Quality Assurance requirements for devices for the measurement of ride quality of Newly Laid Surfaces are defined within this document.
      2. The central principles of the Accreditation and Quality Assurance process are:

* To undertake tests of the Equipment leading to the award of an Accreditation Certificate showing suitable performance levels prior to undertaking Accredited Surveys.
* To undertake Re-accreditation at appropriate intervals.
* To apply an on-going Quality Assurance programme for all Accredited Surveys.
* To confirm that the Accreditation and Quality Assurance programme is implemented.
* To define the role of the Auditor.
  1. Summary
     1. The overall Accreditation and QA process is shown in
     2. Figure 1.
     3. **Pre-approval of Equipment**
        1. Prior to undertaking an Accreditation/Re-accreditation Assessment, it may be necessary to undertake an assessment of the Equipment to check its suitability for undertaking Accredited surveys. The need for this shall be determined by the Auditor.
     4. **Accreditation/Re-accreditation testing**
        1. Any Equipment seeking to undertake Accredited Surveys shall take part in, and provide satisfactory performance in, an Accreditation/Re-accreditation Assessment. Following completion of the Assessment the Auditor shall issue an Accreditation Certificate. The Certificate shall detail the level of performance achieved by the Equipment during the assessment and specify the Accreditation Period.
        2. If the Equipment has met the mandatory requirements, but has poor performance in non-mandatory aspects, then the Auditor may issue an Improvement Notice in addition to the Accreditation Certificate. If the required improvement is not demonstrated to the Auditor in the time specified in the Improvement Notice, then the Auditor may revoke the Accredited status of the Equipment.
        3. Owners/Contractors wishing to continue to undertake Accredited Surveys shall attend a Re-accreditation Assessment prior to the end of the Accreditation period.
     5. **Accredited Surveys and QA**
     6. Owners/Contractors undertake Surveys according to the requirements of the Employer and deliver Survey Data as specified in the document.
        1. Owners/Contractors and the Auditor apply a QA process to Surveys and Survey Data. If the QA or other process identifies an issue that may affect the Equipment or the Survey Data the Auditor may issue an Improvement Notice to the Contractor. If a suitable improvement is not demonstrated to the Auditor in the given time frame then the Accreditation status may be revoked.
  2. Structure of this document
     1. This document is split into the following sections:
* The roles and responsibilities of the involved parties are given in Section B
* The specification for the Equipment and Survey Data is provided in Section C.
* Accreditation Assessments are described in Section D.
* Re-accreditation Assessments are described in Section E.
* The Contractor’s Quality Assurance is described in Section F.
* The Auditor’s Quality Assurance checks are described in Section G.
* Details on Improvement Notices are given in Section H.

Accreditation / Re-accreditation testing

Accreditation certificate

Not meeting specification

Pre-approval of new Equipment

Met mandatory criteria?

Y

N

Improvement shown?

Y

N

Acceptable performance?

Y

N

Accredited surveys

QA programme

Surveys of newly laid surfaces

Improvement action

Issue identified

Figure 1: Outline of the Accreditation and Quality Assurance process

1. Roles of the parties
   1. The Network Authority
      1. The Network Authority shall nominate Auditor(s).

* The Network Authority shall ensure that the Auditor(s) hold the required skills to undertake these checks and understand the results (see Appendix A).
* The Network Authority may conduct some or all of the Auditor’s role internally.
  1. Employer
     1. The Employer shall Require:
* That the Contractor has achieved Accreditation for their Equipment. Employers should request the Contractor to provide a copy of an Accreditation Certificate (or Certificates) that is valid throughout the period over which surveys are to be carried out on the Employer’s Network.
* The Contractor to undertake QA checks. These QA checks shall be as specified in this document unless replaced by alternative or additional checks defined by the Employer.
  1. Owner
     1. Owners shall ensure that their Equipment is compliant with the requirements for Equipment and Survey Data given in Section C.
     2. Owners shall obtain Accreditation via an Accreditation/Re-accreditation Assessment prior to undertaking Accredited Surveys, according to Section D and Section E.
     3. Owners shall renew the Accreditation status of their Equipment by the end of the Accreditation Period if they wish to continue to undertake Accredited Surveys.
     4. The Owner should have their own ISO 9001 process and continue to undertake checks to support this. However, the Owner shall also ensure that they adhere to all QA requirements specified in this document or otherwise specified by the Employer.
     5. Where Equipment is hired by the Owner to a Contractor, the Owner should ensure that the Contractor takes responsibility for conducting the required QA during the period of hire.
     6. The Owner shall report promptly to the Auditor any Routine Maintenance or alterations carried out on the Equipment that could affect the measurement of Survey Data.
  2. Contractor
     1. A Contractor hiring/owing Equipment shall establish the Accreditation status of the Equipment and the QA requirements of the Employer.
     2. The Contractor shall ensure that the required QA is undertaken.
     3. The Contractor shall ensure that the Equipment shall only be operated by competent drivers and operatives (as appropriate). The Contractor is responsible for the training and instruction of all drivers and operatives and for ensuring that they comply with the requirements for surveys.
  3. Auditor
     1. The Auditor will carry out Accreditation and Re-accreditation Assessments and carry out QA checks. These roles may be carried out by the same or by separate bodies. In the main body of this document the role is simply referred to as “the Auditor”. Specific requirements for the bodies undertaking one or both of these roles are given in Appendix A.
     2. If the Auditor identifies an issue with the Equipment, QA or survey process which could affect the quality of the Survey Data the Auditor may issue an Improvement Notice. Copies of these improvement notices may also be supplied to the Employer.

1. Equipment and Survey Data
   1. The Equipment
      1. The Equipment comprises

* A distance measurement System and a spatial referencing System (usually based on a GNSS method or equivalent) for the measurement of location and speed.
* A contactless measurement System for the measurement of Longitudinal Profile.
* Processing tools/software for the delivery of the Survey Data in the required formats.
  1. Survey Data
     1. **Location and Speed**
        1. Location and speed data shall be reported at points separated by 10m of longitudinal distance travelled as:
* The OSGB36 National Grid Co-ordinates of the position of the measurements (at the end of each 10m length).
* The average operating speed of the measurement system over the 10m length.
  + 1. The measurement of location (distance and National Grid Co-ordinates) should be unaffected by the operating speed (within the accredited operating range of the Measurement System, see below) or by the road geometry and shall be consistent and stable throughout any period of data collection, being unaffected by changes in the measurement system (for example resulting from “warming up” of tyres)
    2. All National Grid Co-ordinates shall be reported at the location at which the Longitudinal Profile measurements were collected. Hence any offset or difference in position between the location of the Longitudinal Profile sensors and the location measurement sensors (e.g. location of the GNSS receiver) will be removed before delivery of the location data. Where the Measurement System includes multiple Longitudinal Profile sensors mounted transversally the location data shall be reported at the central position of the Longitudinal Profile sensors.
       1. Equipment that travels at greater than walking speed shall be fitted with a System to automatically identify location reference points physically marking the changes of sections (e.g. using automatic detection of retro reflective markers); these allow for more accurate calibration of the distance measurement System of the Equipment and will be a requirement for accreditation testing.
    3. **Longitudinal profile**
       1. The Equipment shall measure Longitudinal Profile in at least four longitudinal measurement lines (parallel with the edge of the road). Two of these measurements should fall within the locations of the wheelpaths for the lane being surveyed.
* The preferred wheelpath measurement area lies between 0.9m and 1.05m from the centreline of the vehicle.
  + - 1. The longitudinal separation of measured points shall not exceed 20mm.
      2. The measurement of Longitudinal Profile shall be such that the frequency response is essentially flat in the bandwidth 0.5m to 100m (i.e. the ratio of measured Longitudinal Profile amplitude to True Longitudinal Profile amplitude shall be 1.0 ±0.1 for profile components with wavelengths between 0.5m and 100m).
      3. A filter should be applied to the measured Longitudinal Profile to attenuate wavelengths in excess of 100m. The filter shall be such that the amplitude of wavelengths greater than 150m is attenuated by at least 50%. The filter shall not distort the phase of any profile features with wavelengths shorter than 100m.
      4. The Longitudinal Profile is processed to calculate the parameters 3m and 10m eLPV, which are subsequently combined to calculate the Roughness Index parameter (RI, see Appendix C). The performance in the Accreditation tests is therefore assessed in terms of the measurement of raw Longitudinal Profile, 3m eLPV and 10m eLPV.
      5. Note that when measuring Longitudinal Profile a run-in/run-out is required so that the eLPVs can be calculated for the entire Survey length of interest,, which must include any transition to/from the existing surface to the newly laid surface (where present). . This run in is necessary to fully satisfy the requirements of the filters applied in the calculation of eLPV (see Appendix C). It is recommended that 100m of Longitudinal Profile measurements are provided for this run-in/run-out.
  1. Data Format
     1. The Survey Data will be provided as a single data file for each survey, in the current version of the Surface Profile Raw Condition Data (RCD) format.
     2. Surface Profile RCD files should span a length that encompasses the whole of the site under test. This should include, unless impractical, a length of “run in” and “run out” of at least 100m.
     3. Surface Profile RCD Files should be named such that they can be referred to the site, contractor and survey date e.g. “M4\_Acme\_20190604.rcd”
     4. A specification for the current format of the Surface Profile RCD file can be obtained from the Network Authority.
     5. Any value (e.g. Longitudinal Profile point) that is not considered Valid by the Contractor (e.g. because of adverse surface condition) should be reported as invalid using the mechanism provided by the Surface Profile RCD file format. The presence of invalid Longitudinal Profile points may lead to some eLPV values being classified as invalid.
  2. Survey routes, fitting and data delivery
     1. A Survey Route file should be provided alongside each Surface Profile Raw Condition Data (RCD), file to facilitate fitting of the survey to the network.
     2. A specification for the current Survey Route File format can be obtained from by the Network Authority.
     3. As required by the Employer, the Contractor will either:
* Create the Surface Profile Raw Condition Data (RCD) file and Survey Route file. Use the MSP software to process the Surface Profile Raw Condition Data (RCD) and Survey Route file to obtain the fitted Base Condition Data (BCD) file, which will be delivered to the Employer,

or

* *In addition to the above*, load the BCD file into the Employer’s database.
  + 1. The MSP software can be obtained from the Network Authority.
    2. Note that the above (delivery of Surface Profile Raw Condition Data (RCD) files, delivery of Survey Route files, Use of MSP and loading into the database) will each be tested during Accreditation, such that Contractors will need to demonstrate their capability in each component to achieve Accreditation for that component (and this will be stated on the Accreditation certificate).

1. Accreditation
   1. Introduction
      1. Any Equipment shall require Accreditation if Equipment of this specific design has not previously been Accredited to this specification and it is not identified as an Equivalent Measurement System.
      2. The Accreditation process checks

* That the Equipment delivers Survey Data which meets the performance, requirements.
* That the Equipment is capable of measuring and reporting this Survey Data consistently under both controlled and network conditions on trafficked and newly surfaced pavements.
* That the Contractor’s approach to operating the Equipment produces consistent and reliable Survey Data.
* That the Contractor is able to fit the Survey Data to the network and provide the Survey Data in the correct formats.
  + 1. **Pre-approval and preparation**
       1. Pre-approval is required prior to Accreditation. The Contractor shall provide details of their Equipment to the Auditor so that the Auditor can confirm it is eligible for assessment based on the specification given in Section C. This information shall include:
* The make and model of all sensors used (profile laser, location, distance, data acquisition), how many profile sensors are present (i.e. how many measurement positions, and their location). If required, the Auditor will adapt the tests to be appropriate for the measurement system presented.
* The operational procedures that the Contractor will implement when using the Equipment. For example, operational speeds, system installation, warm-up procedures, calibration, training of staff, procedures to process data etc.
* Any limitations on the road surface types for which the Equipment is to be Accredited (the Equipment should meet the criteria on all surface types for which it is to be Accredited).
* Note: If seeking accreditation as an Equivalent Measurement System this description will support any decision by the Auditor on whether the Equipment is suitable for consideration as an Equivalent Measurement System.
  + 1. The Contractor should provide any other information that may be required for the auditor to prepare the tests. This may include any requirements for the test conditions. For example, contactless profile measurements made on damp/wet surfaces can be subject to undesirable deviations from the required accuracy. Therefore, it is assumed that Accreditation shall be tested, and awarded, for dry pavements only. Contractors requiring Accreditation on damp pavements should request the Auditor to include such tests. If assessment of surveying of wet/damp conditions is undertaken for Accreditation, then Re-accreditation assessments may also incorporate reassessment of this capability.
    2. **Equivalent Measurement systems**
       1. Equipment shall be considered as an Equivalent Measurement System if there is another Accredited Equipment which (meets all of):
* Is made by the same Manufacturer
* Is made to the same design
  + - 1. Equipment shall only be considered as an Equivalent Measurement System if both the Network Authority and the Auditor agree that it should be.
      2. Equipment considered to be an Equivalent Measurement System will be tested according to Re-accreditation Assessment requirements described in Section E .
      3. Following any updates to this specification, at least one Equipment from the set of Equivalent Measurement Systems may need to undertake an Accreditation Assessment.
    1. **Stages of Accreditation**
       1. Accreditation will be carried out in two stages. The first stage will assess the capability in the measurement of Longitudinal Profile on Trafficked Surfaces. If this is deemed acceptable the Equipment will be tested on Newly Laid Surfaces. Both stages shall be passed to achieve Accreditation for the assessment of Newly Laid Surfaces.
    2. For all stages of the Accreditation tests there is a requirement for the Contractor to undertake repeat surveys with the Equipment over different test sites. For every survey run delivered to the Auditor the Contractor should provide:
* The Surface Profile RCD
* The Route File
* The BCD file provided by MSP
  + 1. For the closed test sites the Auditor will provide network information to enable the Contractor to produce route files. For sites located on the network of the Network Authority there may be a requirement for the Contractor to access the network definition of the Network Authority. This will be established during the pre-approval and preparation phase.
    2. **Completion of Accreditation**
       1. Following completion of an Accreditation Assessment the Auditor shall issue an Accreditation Certificate, which shall show:
* The performance achieved by the Equipment.
* The Accreditation Period.
* The range of conditions for which the Equipment is Accredited (e.g. if it can test in wet/damp conditions).
* The version of this specification the Equipment was assessed against. Accreditation or Re-Accreditation may be required in the event of this specification being updated. In these situations, an Improvement Notice shall be issued (see Section H).
  + - 1. In addition to testing the Equipment, the Auditor may assess and provide feedback on the competence of drivers and operatives as part of the Accreditation.
      2. If the Equipment has met the mandatory criteria of the Accreditation Assessment, but the Auditor notes that the performance of the Equipment or the Contractor is not suitable in other aspects, then the Auditor may issue an Improvement Notice as detailed in Section H.
  1. Accreditation Stage 1 – Trafficked Surfaces
     1. Stage 1 testing will confirm the performance of the Equipment on trafficked surfaces. One or more Closed and/or Live test sites shall be selected by the Auditor. Details of the sites and Reference Data are given in Appendix B.
     2. **Mandatory Requirements – Location Referencing**
        1. Note that that there are three methods for recording the location of selected physical positions (Location Reference Points) in the survey data, which may be required for the assessment of location referencing:
* “Push button” entry relies on the survey operator pushing a button to enter the location of each Location Reference Point manually.
* “Automatic marker” uses a system which automatically detects markers placed at each Location Reference Point. These will take the form of retroreflective posts placed at the roadside.
* “OSGR fitted markers” utilises the coordinate data to identify the elapsed chainage of each Location Reference Point within the survey data.
  + - 1. Automatic markers shall be used for the assessment of location referencing on some test sites. OSGR fitted markers shall be used for the assessment of location referencing on sites where no retroreflective markers are in place.
      2. **Distance**
      3. The Accreditation of distance measurement shall be carried out using at least 6 test sections, surveyed over a range of speeds (as appropriate to the Equipment design and agreed with the Auditor prior to the tests).
      4. The accreditation criteria are given in Table 1.

Table 1 – Criteria for measurement of distance travelled

|  |  |
| --- | --- |
| **Parameter** | **Acceptability Limit** |
| Distance measured between LRPa - automatic markers | ≥95% within 1m or 0.1% of the length (whichever greater) |
| Distance measured between LRPa – OSGR or push button fitted | ≥95% within 3m or 0.2% of the length (whichever greater) |

Notes:

1. These will be obtained using the Surface Profile RCD or BCD (as appropriate) and compared with the Reference
   * + 1. **OSGR Coordinates**

The Accreditation of OSGR Coordinates shall be carried out using at least 6 test sections, surveyed over a range of speeds (as appropriate to the Equipment design and agreed with the Auditor prior to the tests). The criteria are given in Table 2.

Table 2 – Criteria for measurement of OSGR coordinates

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Parameter** | **Average within** | **90% within** | **95% within** | **All within** |
| OSGR - site with automatic markers | 1.5m | 2m | 4m | 10m |
| OSGR – other sites | n/a | n/a | 4m | 10m |

* + 1. **Mandatory requirements – Longitudinal Profile**
       1. **Longitudinal Profile of artificial profiles**
       2. A set of artificial profiles will be laid on a Closed Site. A range of measurement speeds shall be identified (as appropriate to the Equipment design and agreed with the Auditor prior to the tests) and at least 3 surveys shall be carried out at each speed. Depending on the size of the plates and the positions of the measurement lines, this may require repeat runs.
       3. The accuracy of the Longitudinal Profile shall be assessed for each measurement position independently, according to Table 3.

Table 3 – Criteria for artificial profiles assessment

|  |  |
| --- | --- |
| **Parameter** | **Acceptability Limit** |
| Measured heights of steps in the artificial profile | ≥95% within ±2.0mm |

* + - 1. **Longitudinal profile of pavement surface – closed site**
      2. A test site of at least 300m length shall be defined on a Closed Site. A range of measurement speeds shall be identified (as appropriate to the Equipment design and agreed with the Auditor prior to the tests) and at least 3 surveys shall be carried out at each speed.
      3. At least 95% of the differences in corresponding amplitude between the measured Longitudinal Profile and the Longitudinal Profile measured by a Reference Device shall fall within the ranges given in Table 4 for the wavebands 3m and 10m (calculated from datums derived using a bandpass finite impulse response filter (see Appendix D) using the wavebands [0.3333/m, 2/m] and [0.1/m, 2/m].
      4. Each measurement line will be assessed independently.

|  |  |
| --- | --- |
| **Waveband (m)** | **Differences** |
| **Acceptable Range (mm)**  **[95% of differences within this range]** |
| 3 | ±2.00 |
| 10 | ±4.00 |

Table 4: Accuracy requirements between the measured and Reference Enhanced Longitudinal Profile amplitude

* + - 1. **eLPV of pavement surface – closed site**
      2. The Auditor will calculate (using MSP or equivalent) the 3m and 10m eLPV values from the measured and the reference Longitudinal Profile recorded in the above tests over each 10m length
* Each measurement line will be assessed independently.
* The Bias between the eLPVs calculated from the measured Longitudinal Profile and those calculated from the Reference Device at the same position shall fall within the ranges given in Table 5.
* The Reproducibility of the measured the eLPVs (assessed using the differences between measured eLPVs and reference eLPVs) shall fall within the ranges given in Table 5.
* The Repeatability of the measured the eLPVs (assessed using the differences between eLPVs measured in repeat Survey runs) shall fall within the ranges given in Table 5.
* For Reproducibility and Repeatability, the differences between the measured and Reference eLPVs shall be calculated as either differences or the Fractional Differences. This shall be determined by the value of the reference eLPV, as defined in Table 6.

|  |  |  |  |
| --- | --- | --- | --- |
| Waveband (m) | Bias | Difference/Fractional Difference | |
| Reproducibility | Repeatability |
| 95% within this range | 95% within this range |
| 3 | 0.10mm2 | ±0.30 | ±0.20 |
| 10 | 0.55mm2 | ±0.70 | ±0.55 |

Table 5: Accuracy requirements for differences and fractional differences between the measured and Reference eLPV

|  |  |  |
| --- | --- | --- |
| Waveband (m) | eLPV (mm2) | Calculation method |
| 3 | 0 to 0.5 | Difference |
| 3 | > 0.5 | Fractional Difference |
| 10 | 0 to 1.0 | Difference |
| 10 | > 1.0 | Fractional Difference |

Table 6: Application of error type according to the value of the Reference eLPV

* + - 1. For the assessment of eLPV the validity flags (provided in the Surface Profile RCD) will be used to determine whether a valid value of eLPV has been obtained. Valid 3m and 10m eLPV values shall obtained over at least 80% of each 300m subsection length (subsection lengths at the end of each section/site that are less than 300m long will assessed with the previous 300m subsection length). In the event this is not achieved for a subsection, the data from a separate survey run shall be assessed. Where there is strong/ongoing evidence of the Equipment being unable to provide valid datasets on sites (where valid datasets can be obtained by the Reference device), the Equipment may be deemed unable to undertake the assessment and to have failed the criteria.
      2. The tests shall determine the minimum speed, and the limits of acceleration and deceleration within which the Equipment is considered able to provide accurate measurements of eLPV. This shall be achieved by repeating the tests at a range of speeds, and also whilst the Equipment is accelerating and/or decelerating over the test site.
      3. If it cannot be shown that the eLPV measurements are unaffected by survey speed over a range of speeds then a single speed shall be used for the Assessment (and become an operational requirement for that Equipment).
      4. The reduction in repeatability when under conditions of slow/high speed or high/low acceleration/ deceleration will be used to specify speed and acceleration/ deceleration. Such limits must be applied within the MSP in all processing of the Surface Profile RCD provided by the Equipment.
      5. **eLPV of pavement surface – Live site(s)**
      6. The Auditor will select a number of test lengths located on live sites on the network. At least three survey runs will be carried out on each site using the Equipment at a range of speeds (as appropriate to the traffic conditions, Equipment design and agreed with the Auditor prior to the tests).
      7. The 3m and 10m eLPV reported over 10m reporting lengths at each survey speed shall meet the requirements of Table 7.
* Each measurement line will be assessed independently.
* For both Reproducibility and Repeatability the differences shall be calculated as either the differences or the Fractional Differences between the measured and Reference eLPVs. This shall be determined by the value of the reference eLPV, as defined in Table 6. The Bias is the absolute mean of the differences.
* The validity criteria of D2.3.10 will be applied when testing the performance on Live Sites.

Table 7 – Criteria for eLPV on Live sites (network)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Reproducibility | | Repeatability | |
| 95% of differences within | Bias | 95% of differences within | Bias |
| 3m eLPV (in each measurement line) | ±0.65 | 0.10mm2 | ±0.50 | 0.10mm2 |
| 10m eLPV (in each measurement line) | ±0.95 | 0.55mm2 | ±0.60 | 0.55mm2 |

* 1. Accreditation Stage 2 – Newly Laid Surfaces
     1. If the requirements of trafficked surfaces tests are met the Equipment will be deemed capable of providing measurements of ride quality on trafficked surfaces. The Equipment can then proceed to Stage 2, which will assess the performance in the measurement of ride quality on Newly Laid Surfaces
     2. The Auditor shall identify suitable site(s) for the assessment, communicate the location and range of valid survey dates to the contractor and arrange for surveys with a Reference Device. Details of the Newly Laid Surface test sites and Reference Data are given in Appendix B.
     3. A minimum of three runs of each of the Newly Laid Surface sites shall be carried out using the Equipment within the time frame given.
     4. **Mandatory Requirements – Location referencing**
     5. The location referencing requirements on the Newly Laid Surface test sites are the same as those defined in D2.2 above. The method of recording location reference points shall be OSGR fitting.
     6. **Mandatory Requirements – Longitudinal Profile**

The requirements for the measurement of Longitudinal Profile on Newly Laid Surface test sites are the same as those defined in D2.3 above (measurement on Live Sites). The validity criteria of D2.3.10 will also be applied when testing the performance on Newly Laid Surfaces.

1. Re-accreditation
   1. Re-accreditation Tests
      1. Once the Equipment has been accredited it shall require Re-accreditation on expiry of the Accreditation Period. This can be obtained by successfully completing a Re-accreditation Assessment.
      2. Re-accreditation will be undertaken using a sub-set of the tests applied for Accreditation, with the same performance criteria.

* Equipment will be assessed on at least one Closed Test Site, and Equipment that will operate at traffic speed will also be assessed on at least one Live Site.
* Re-accreditation of Equipment (including Equipment that has met the requirements for Newly Laid Surfaces) will normally only include tests on trafficked sites. The Auditor may require tests to be carried out on Newly Laid Surfaces where there is evidence to support this (e.g., if there have been Improvement Action Notices, or if there have been significant changes to the Equipment or the specification).
* If the Accreditation assessment identified that the Equipment can measure in wet/damp conditions then the Re-accreditation may include tests to confirm this continues to be the case.
  + 1. Following completion of a Re-accreditation Assessment the Auditor shall issue Accreditation Certificates showing the performance achieved by the Equipment and the Accreditation Period.
    2. If the Equipment has met the mandatory criteria of the Re-accreditation Trial, but the performance of the Equipment is not suitable in other aspects then the Auditor shall also issue an Improvement Notice as detailed in Section H.

1. Contractor’s Quality Assurance
   1. Introduction
      1. An on-going Quality Assurance regime shall be applied to ensure that the data provided by the Equipment remains valid throughout the Accreditation Period. In addition to the specific processes described below, the Contractor’s documented Quality Assurance regime shall cover all aspects of the surveys including, but not limited to:

* Equipment operation and maintenance, including inspection of the Equipment to check for defects and that the Equipment and all of its Systems are operating correctly
* Calibration and servicing of the Equipment.
* Driver and operator training and instruction – the Equipment shall only be driven and operated by competent personnel
* Survey operation and record keeping
* Data recording, processing, and analysis
* Fitting and delivery of Survey Data

Undertaking Primary Checks, as described in F.2.

* 1. Contractor’s Primary Check
     1. **General**
        1. The Contractor’s Primary Check provides long term monitoring of the Equipment and checks the performance of the Equipment since the last Accreditation/Re-accreditation Assessment. The Check can also incorporate calibration of the location referencing (distance) System, when required.
        2. Contractor’s Primary Checks shall be carried out at least every 28 days for any period in which the Equipment is in use.
     2. **Check Site**
     3. The Contractor shall establish at least one test site as a Contractor’s Primary Check site. The site provides a reference site for monitoring the performance of the Equipment since the last successful Accreditation or Re-accreditation of the Equipment.
     4. Typically, the site would be close to the Contractor’s base where measurements can be taken safely and without unreasonable disruption to other users of the site. The site shall contain:
* A length of at least 400m of straight and level pavement for the assessment and calibration of distance measurements.
* Ideally, a range of ride quality (i.e. to provide a range of eLPVs)
  + 1. To accommodate testing carried out across the network (which may make it impractical to return to the Contractor’s base to carry out a Contractor’s Primary Check), it may be necessary to have more than one Contractor’s Primary Check site. Furthermore, if the condition of a Check site is affected by maintenance or other external factors the Contractor may need to re-establish the Reference Data, or establish another site. Having a second Contractor’s Primary Check site would reduce the risks presented as a result of changes to a single site.
    2. The site(s) chosen by the Contractor should be reported to the Auditor. The sites may be subject to monitoring by the Auditor.
    3. **Check Site Reference Data**
    4. Reference data should be obtained by carrying out a survey on the site within 14 days of successfully carrying out an Accreditation/Re-accreditation Assessment, or successfully carrying out a Contractor’s Primary Check on an existing site. More than one survey should be undertaken when collecting the Reference Data as a measure of consistency and repeatability.
    5. The Survey Data should be processed (using MSP or equivalent) to provide Location Reference (OSGR co-ordinates) and 3m and 10m eLPV values for each 10m length of the site.
    6. On at least one Primary Check Site locational reference (Distance) data should be obtained by measuring and marking a selected length of the site to an accuracy of ±0.5m, using steel tape or other reliable device (to support calibration of the distance measurement system). The marking deployed should be such that the locations of the start and end points of the length can be identified when carrying out a survey of the site. The Contractor should consult the highway authority responsible for the test site location and obtain its agreement before making any marking on or modification of the site.
    7. **Test process – Distance measurement**
       1. A check of the distance measurement System shall be carried out by measuring the site length with the Equipment and comparing the results to the Reference Data. The distance measurement System shall meet the requirements given in Table 8. If the measurements are not within these requirements then the Equipment shall be re-calibrated and the Check repeated.
    8. **Test process – Longitudinal Profile and OSGR** 
       1. The Contractor shall compare the Survey Data with the Reference Data. The performance shall meet the requirements stated in Table 8.

Table 8 – Performance requirements for the Primary Check

| Parameter | Measure | Reporting Interval | Tolerance | Bias |
| --- | --- | --- | --- | --- |
| Distance | Distance measured between location reference points | Distance measured between location reference points | ±3 m or ±0.1%a  ±1 m or ±0.1%b | n/a |
| Coordinates | Horizontal offset at location reference point | At each location reference point | 95% within 3m | n/a |
| Coordinates | Horizontal offset for each reported coordinate | 10m | 95% within 3m | n/a |
| Longitudinal Profile:  3m eLPV | Fractional Error in each measurement line | 10m | 95% within ± 0.60 | 0.1mm2 |
| Longitudinal Profile:  10m eLPV | Fractional Error in each measurement line | 10m | 95% within ± 0.70 | 0.8mm2 |

Notes: a) If using OSGR fitting; b) if using reflective markers

* + 1. **Failure of a Test**
       1. If the required performance is not achieved then the survey of the site shall be repeated. If after three repeat runs, the differences still exist then the Contractor shall undertake an investigation to identify the source of error.
       2. No further Surveys should be carried out until a resolution of the issue has been demonstrated through a successful Primary Check.
       3. If the investigation identifies a problem with the Equipment indicative of a long term issue (that may have affected the performance of surveys carried out for Employers) the results of surveys undertaken with the Equipment since the previous successful Primary Check should be considered suspect, and the Auditor shall be informed.
    2. **Reporting**
       1. The Survey Data and performance achieved in all Contractor’s Calibration Checks shall be retained by the Contractor for examination by the Auditor as required. Any Contractor’s Calibration Check Survey Data requested by the Auditor shall be provided within 14 days of receipt of the request.
  1. Equipment Checks Following Routine Maintenance or alterations
     + 1. It is expected that between re-accreditations of the Equipment, some Routine Maintenance or alterations may be required. The success of the maintenance shall be verified with suitable QA checks ***before******recommencing*****surveys.** In most cases a successful Primary Check would provide a suitable level of QA. If the Contractor is uncertain on the suitable level of QA then they should contact the Auditor for advice.
       2. The records of the maintenance carried out and the checks undertaken following maintenance shall be maintained by the Contractor for examination by the Auditor if required. Any QA records requested shall be provided to the Auditor within 14 days of receipt of the request.

1. Quality Assurance checks by the Auditor
   1. Checks on Contractor’s QA
      1. The Auditor may require the Contractor to demonstrate any aspect of their Quality Assurance regime at any time, through review of their documentation, or their data and records. The scope includes but is not limited to:

* Equipment operation and maintenance
* Calibration of the measurement Systems
* Driver and operative training and instruction
* Survey operation and record keeping
* Data recording, processing, and analysis
* Delivery of Survey Data
  + 1. If there are any doubts as to the performance of the Equipment or the test procedure following the checks on the Contractor’s QA or from other reports, then the Auditor may undertake additional investigations. Additional investigations may also be conducted if requested by the Employer.
    2. If during checks on the Contractor’s QA the Auditor identifies a lack of competence which may affect the ability of the Contractor to record and deliver good quality Survey Data then the Auditor may issue an Improvement Notice to the Owner and/or Contractor as discussed in Section H.

1. Improvement Notices
   1. Procedure
      1. The Improvement Notice shall detail the nature of the improvement required and a timescale over which it shall be completed. It allows the Contractor to correct problems with their Equipment or Quality Assurance procedures.
      2. Being served with an Improvement Notice will not necessarily lead to withdrawal of Accreditation. However, failure to comply with the Improvement Notice within the given time frame will likely lead to withdrawal of Accreditation.
      3. If the Improvement Notice results in the withdrawal of Accreditation the Auditor shall review the data and the circumstances to determine if the Equipment would be required to carry out a full Accreditation Assessment or a Re-accreditation Assessment to demonstrate the improvement. However, the Auditor may identify a different route to demonstrate the improvement if a suitable one exists.
      4. The Improvement Notice shall detail any restrictions to the use of the Equipment prior to satisfactory completion of the improvement.
      5. The Auditor shall inform the Employer of any Improvement Notices issued and changes of Accreditation status.
         * 1. Requirements on the Auditor

Roles of the Auditor

The role of the Auditor is split into two main roles:

* Conducting and reporting the Accreditation/Re-accreditation process
* Monitoring the QA performed by the Contractor.

These roles can be carried out by the same or by separate bodies. The requirements that these bodies shall meet for these two roles are given in the sections below.

The Auditor for Accreditation and Re-accreditation Assessments shall:

* Organise Accreditation and Re-accreditation Assessments, including designing and developing the methodology for the testing, arranging surveys with the Reference Device, arranging and maintaining suitable sites for Accreditation/Re-accreditation, together with the processing, interpretation and reporting of results.
* Periodically assess the performance of the Trafficked Surfaces site(s) chosen for Accreditation/Re-accreditation so that the longer-term behaviour of the site(s) can be monitored.
* Issue Accreditation Certificates showing the performance achieved by Equipment at the Accreditation/Re-accreditation Assessment in a timely fashion. This should be within 2-3 weeks of the corresponding Assessment.
* Maintain a publicly available list of Accredited Equipment.

The QA Auditor shall:

* Conduct checks on the QA conducted by the Contractor (offering advice where necessary).
* Where required, act as a technical advisor and intermediary to aid discussions between Contractor and Employer with regards to the quality of Survey Data.

The Auditor shall issue improvement notices to the Contractor/Owner if the Auditor identifies an issue with the Equipment, QA or survey process which could affect the quality of the Survey Data.

Capabilities of the Auditor

The Accreditation Auditor shall:

* Have experience with the Survey Data produced by the Equipment and be knowledgeable on how to process and interpret it.
* Understand the implications of any differences in the Survey Data and how this is likely to affect the Employer.
* Demonstrate independence for their Auditor role.
* Have access to suitable test sites to undertake the Accreditation/Re-accreditation testing and capability to identify Newly Laid Sites. In addition, they shall also have access to suitable supporting tools to provide the Reference Data and support the accreditation testing. The requirements for the test site and the Reference Data are given in Appendix B.

The QA Auditor shall:

* Have experience with the Survey Data produced by the Equipment and be knowledgeable on how to process and interpret it.
* Understand the implications of any differences in the Survey Data and how this is likely to affect the Employer.
  + - * 1. Site and Reference Data requirements for Accreditation/Re-accreditation

Accreditation/Re-accreditation – Trafficked Surfaces

The sites selected for tests on Trafficked Surfaces will have a total length of at least 10km and may be located on the local or strategic road networks (Live Sites), or on a test track (Closed sites).

Selected lengths of the Closed Sites will be equipped with reflective posts that can be identified by sensors installed on the Equipment to record location referencing points. The Auditor will provide technical details on the posts.

**Location referencing**

The Closed Site shall contain one or more sections of straight and level pavement (minimum 500m) for the assessment of Distance. The start and end points of this section(s) shall be clearly marked (e.g. with reflective posts).

The sites may contain test sections which include curves, and tree coverage in which the availability of signal for GNSS may be low.

At least one of the test sites will have Reference data for location that has been obtained using a calibrated measurement wheel (for distance) and survey grade RTK GPS (for National Grid Co-ordinates. All sites will have further Reference data for location referencing obtained using the National Highways HARRIS survey vehicle, or a comparable device.

**Longitudinal Profile**

These tests shall be carried out on Closed Site and Live Sites.

The Artificial profiles will be located in Closed Sites, and have surfaces (profile mats) of dimensions approximately 1m by 1m, each containing a step that bisects the mat. Surveys will be undertaken such that the Equipment measures the step height as the Equipment drive over the mat. Step heights will be between 10mm and 25mm.

The reference data for the Artificial Profiles is the set of heights to which the steps profiles have been machined (and which can be manually measured using a micrometre).

At least one of the Closed Test sites will have Reference Data collected using an appropriate reference profilometer to provide the true profile over the length of the site

All test sites (Closed and Live Sites) will have Reference Data collected using the HARRIS Equipment.

Accreditation/Re-accreditation – Newly Laid Surfaces

Identification of Newly Laid Surfaces for accreditation testing will require liaison with asphalt installers. It is anticipated that:

* The Contractor would commence the accreditation programme and complete stage 1 of the tests (trafficked sites)
* The Contractor would liaise with the Auditor to establish the Newly Laid Surface test sites. The Contractor may work with a surfacing provider to propose suitable sites, or the Auditor could undertake this activity, or there may be a combination of these approaches applied (as agreed between the Contractor and the Auditor).
* The Newly Laid Surfaces assessment shall be held on at least two Sites, containing different types of asphalt surfacing material.

Having identified and agreed a set of sites the Auditor and the Contractor shall carry out surveys on the sites with the reference and test Equipment.

* Reference data on the Newly Laid Surface sites will be obtained using the National Highways HARRIS survey vehicle or an alternative, comparable, device. This data will be collected between 3 and 5 days after completion of the surfacing.
* The Contractor shall use the Equipment to survey the sites within 5 days of the site being laid.
  + - * 1. Calculation of RI and eLPV

Calculation of Roughness Index

Diagram

Description automatically generatedRoughness Index (RI) is calculated from 3m and 10m Enhanced Longitudinal Profile Variance (eLPV) as:

eLPV is calculated in MSP. However, a definition of eLPV is provided here for information. Note that this definition may change, as a result of enhancements to the procedures.

Note that a run-in/run-out is required so that the eLPVs can be calculated for the entire Survey length of interest. This run in is necessary to fully satisfy the requirements of the filters applied in the calculation of eLPV. It is recommended that 100m of Longitudinal Profile measurements are provided for this run-in/run-out.

Calculation of eLPV

Two values of eLPV shall be reported for each reporting length, 3m and 10m eLPV. The calculation of each value of eLPV can be summarised as follows:

* The raw Longitudinal Profile is filtered using a high pass filter that attenuates frequencies below a predetermined cut-off.
* The eLPV is calculated from the filtered profile over the reporting length.

Filtering

The Longitudinal Profile measurements shall be filtered using the Filter described in Appendix D.

The filter frequencies required to obtain the filtered Longitudinal Profile from which the eLPV may be calculated are given in Table 9. The definitions given in Table 9 are considered as the default values, and will be parameterised within the MSP (i.e. configurable by the user with default values defined within the MSP parameter file).

Table 9 – Specification for filters applied in the calculation of eLPV

|  |  |  |
| --- | --- | --- |
|  | **3m eLPV** | **10m eLPV** |
| **Frequency** | fL= 0.3333 m-1 | fL=0.1000 m-1 |
| **Filter Type** | High Pass | High Pass |

Obtaining eLPV

eLPV is calculated as:

Where:

* N is the number of filtered profile points within each reporting length (10m default, but will be parameterised in the MSP, i.e. configurable by the user with default values defined within the MSP parameter file)
* zj is the height of filtered profile point j **in mm**

Invalid values and Validity of eLPV

Invalid values of Longitudinal Profile are reported in the Surface Profile RCD using the invalid flag. These will be accommodated in the filtering process via the sample and hold approach in which the last valid Longitudinal Profile value is used to replace the invalid value.

The number of invalid Longitudinal Profile values in each 10m length will be counted.

* Any 10m length with greater than 5% invalid Longitudinal Profile values will be considered an invalid 10m length, and hence the values of 3m and 10m eLPV obtained will be considered invalid.
* Any 10m length containing greater than xm of continuous invalid Longitudinal Profile values will be considered an invalid 10m length, and hence the values of 3m and 10m eLPV obtained will be considered invalid.
  + - * 1. Filters

Overview

For the calculation of eLPV it is necessary to carry out filtering of the profile measurements.

Filtering of the data is achieved by firstly calculating the “filter coefficients”. These are then applied to the profile to generate a new data set that represents the filtered profile.

The procedure applied in the filtering of the data varies according to the type of filter required:

* For a high pass filter calculate the width using fL, calculate the high pass coefficients and apply the high pass filter coefficients to the profile data.
* For a low pass filter calculate the width using fH, calculate the low pass coefficients and apply the low pass filter coefficients to the profile data.
* For a band pass filter where both fL and fH are defined in the specification, calculate the width using fL, calculate the low pass coefficients and the high pass coefficients, convolve these to generate the bandpass coefficients and apply the band pass coefficients to the profile data.
* For a band pass filter defined by only the value of fC, calculate fL and fH, calculate the width using fL, calculate the low pass coefficients and the high pass coefficients, convolve these to generate the bandpass coefficients and apply the band pass coefficients to the profile data.

Calculation of filter coefficients

The filter is defined by a set of m + 1 coefficients, which shall be calculated before the filter is applied. The values of the coefficients are determined by the values used to define the filter (as given in this specification) and are not dependent on the profile data to be processed. The filter coefficients for the pass-band filter are calculated in four stages, as described in the following sections.

Filters are defined as either low pass, high pass or band pass. Low pass and high pass filters are assigned values for fH and fL defining the frequency range required. Band pass filters may be defined using only a central frequency fC.

Where only a central frequency, fC, is defined a bioctave passband filter shall be applied, which allows frequencies within a two-octave range to pass without attenuation and attenuates all other frequencies.

For a bi-octave filter the lower frequency limit, fL, is defined by:

And the upper frequency limit, fH, is defined by:

Calculation of the width of the filter

The width of the filter, m, is determined by:

Where:

* Δ is the interval between profile points
* 1/f is expressed in the same units as Δ
* R is the “Filter Order”, which shall have a default value of 3, but which shall be parameterised in software.

The calculated value of m shall be rounded up to the next, even integer. Note:

* For a band pass filter f takes the value of fL
* For a low pass filter f takes the value of fL
* For a high pass filter f takes the value of fH

Calculation of low-pass coefficients

There are m+1 low-pass coefficients, blpi. The values of blpi are initially determined by:

for i = -m/2, -m/2+1, …m/2

Where:

* Hi are the coefficients of a Hamming window, given by:
* Hi = 0.54 – 0.46 \* cos(2 \* pi \* (i + m/2) / m)
* sinc(x) = sin (x) / x if x ≠ 0 OR sinc(x) = 1 if x=0
* pi = 3.14159
* if x≠0 OR if x=0
* f = fH, i.e. equal to the upper frequency limit of the bi-octave filter, expressed in the same units as Δ
* and the trigonometric functions are defined such that the arguments are in radians

The coefficients, blpi, are then be normalised as:

for I = -m/2, -m/2+1, …., m/2

Where:

Calculation of high-pass coefficients

There are m+1 high-pass coefficients, bhpi. To calculate the high-pass coefficients the method described above for calculating the low pass coefficients shall be applied, but where the frequency limit, f, is now equal to the lower frequency limit of the filter, fL.

Transformation of the coefficients

Following the normalisation of the coefficients, the following transformation is performed:

for i = -m/2, -m/2+1, ….1 and for i = 1,…. +m/2 (ie for i  0)

for I = 0

Band-pass coefficients (where required)

The coefficients of a band pass filter are obtained by combining the low pass and high pass coefficients. The high-pass (bhpi) and low-pass (blpi) filter coefficients shall be convoluted to generate a new set of m+1 coefficients describing the band-pass filter, bpi.

The convolution procedure can be visualised as the high-pass and low-passed coefficients being progressively overlapped. At each overlap position, the value of the convoluted coefficient is equal to the product of the corresponding high-pass and low-pass coefficients, summed over the overlap region. This process is illustrated in Figure 2. Consider in the first instance the central position (Figure 2-A). In this simple case, where the overlap of the high-pass and low-pass coefficients is complete, the value of bp0 is calculated by summing the product of the high-pass and low-pass coefficients at each position.

The calculation of other values of bpi can be considered by moving one set of coefficients relative to the other, as shown in Figure 2-B, where the low pass coefficients have been moved to the right by one point in order to obtain bp1. The region of overlap is now reduced at one end, but can be determined from the number of increments by which one set of coefficients has been offset. Within the overlap region the value of bp1 is the sum of the product of the overlapping high-pass and low-pass filter coefficients. This procedure is then repeated to obtain the values of bp2 to bpm/2, by incrementing the movement of one set of coefficients relative to the other and each time calculating the sum of the product of the overlapping high-pass and low-pass filter coefficients, until the situation displayed in Figure 2-C is obtained.

To obtain the values of bp-1 to bp-m/2 the above procedure is repeated, but the low-pass filter coefficients are now shifted in the opposite direction from a shift of –1 points to a shift of –m/2 points. Hence to generate the m+1band-pass filter coefficients required, the final limiting overlap positions will have either increment I = m/2, as illustrated in Figure 2-C, or I = -m/2, which is as Figure 2-C but with the increment applied in the opposite direction.

In the general case it can be considered that the m+1 values of bpi obtained through the convolution of blpi and bhpi are given by:

for I = -m/2, -m/2+1, …., m/2



A

B

Overlap region

bp(i=0) =

Low-pass coefficients

High-pass coefficients

Band-pass coefficients

-m/2

m/2

Overlap region

Low-pass coefficients

High-pass coefficients

Band-pass coefficients

-m/2+i

m/2

bp(0<i£m/2) =

Low-pass coefficients

High-pass coefficients

Band-pass coefficients

Overlap region

C

Figure 2: Illustration of filter process

Application of the coefficients to filter the profile data

The value of the filtered profile height, zi’, at each position, I, is obtained by multiplying the profile heights between z(i-m/2) and z(i+m/2) by the corresponding m+1 filter coefficients and the summing the resulting products. Hence:

For band pass coefficients. Replace with high pass or low pass coefficients as appropriate to the type of filter required.

It can be inferred from the above definition that the calculation of the filtered profile cannot be performed within a distance of m/2 points of the start of the measured profile or m/2 points of the end of the measured profile.

If the filtering method was applied separately over each 10m length there will be an inevitable loss of information. For the range of frequencies to be filtered using texture profile the total length “lost” at the start and end of each 10m length will be less than 1m, which may not have a severe effect on the measurement of noise or fretting (although it would be desirable if this could be avoided by evaluating the filter over the whole of the Survey length). However, for the calculation of enhanced variance the effect will be severe and therefore the filter shall be applied over the whole of the Survey such that the points are only lost at the beginning and end of the Survey.