VIRGINIA TECH

GUIDELINES FOR THE COLLECTION OF NETWORK-LEVEL STRUCTURAL CONDITION DATA WITH TRAFFIC SPEED DEFLECTOMETER

TPF-5(385) Pavement Structural Evaluation with Traffic Speed Deflection Devices

TASK 2: DEVELOPMENT OF SPECIFICATIONS AND DATA COLLECTION GUIDELINES

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CHAPTER 1. INTRODUCTION

1.1. Purpose and Scope

The purpose of this document is to provide guidelines for the collection of Traffic Speed Deflectometer (TSD) pavement deflection velocity data. The guide describes how to perform data collection with the TSD (Chapter 2) and how to implement a data quality management plan to ensure that the collected data gives a sufficiently accurate representation of the pavement structural condition (Chapter 3). This guide synthesizes information from four main data sources: Austroads, ARRB Group, Inc. user manuals, the Second Strategic Highway Research Program R06(F) proejct, and experiences presented at Deflection at Road Traffic Speed (DaRTS) workshops.

Chapter 2 describes the procedure for measuring the deflection velocity of road pavements using a TSD device. Included are technical assessment protocols for automated structural condition-related data collection/analysis systems and/or services for use in agency vendor selection contracting documents. Chapter 3 specifies methods for the validation of TSD surveys, verification of the TSD device, and calibration of the TSD device. Validation of surveys involves performing a repeated test on a section of a tested network to make sure that the device is repeatable. Verification involves comparing measurements from the TSD with another set of independent measurements obtained from devices such as the Falling Weight Deflectometer (FWD). Calibration of the TSD involves verifying the laser Doppler vibrometer (LDV) angles. Three levels of calibration are specified, with level 1 being the most accurate calibration, where the device is compared with instrumented pavement measurements, and level 3 being the least accurate.

These guidelines do not address all occupational health and safety issues associated with the use of the TSD. It is the responsibility of the TSD operator to run the device safely in accordance with the device manufacturer and appropriate legislation.

1.2. Audience

The audience for these guidelines includes agencies that conduct or contract TSD data collection devices as well as TSD operators.

CHAPTER 2. NETWORK-LEVEL STRUCTURAL CONDITION DATA COLLECTION

2.1. Introduction

The TSD is a relatively new deflection-measurement device, manufactured by Greenwood Engineering. At the time of this writing, four versions of the TSD exist: first-, second-, third-, and fourth-generation devices. Regular system upgrades and modifications are being made by the TSD manufacturer and device owners. The TSD provides continuous deflection velocity measurements, which are averaged at short intervals. Testing with the TSD can be conducted at speeds up to 100 km/hr (60 mph). The device uses LDVs to measure the pavement deflection velocity, which is then used to calculate the pavement deflection slope and subsequently the pavement deflection.

2.1.1. Pavement Loading

The axles are loaded with a maximum weight (load) of 10 metric tons (35,000 lb), nominally 5 tons (17,500 lb) per wheelset. The system applies approximately 50 kN (11,240 lbf) load to the pavement. This is achieved using a main ballast weight of 3,275 kg (7,220 lb) situated under the body of the trailer, and a small ballast weight of 1,050 kg (475 lb) situated underneath the rear axle of the trailer. These weights are balanced to provide a suitable center of gravity for the trailer load handling, as well as the nominal equal load over each wheelset.

Note: For operations in some US states, the rear ballast weight can be removed to comply with heavy vehicle axle weight regulations, which will impart a reduced load of 10,000 lb for each wheel set.

Strain gauges are mounted to the rear axle to measure the bending moment on the loaded axle on both the left and right sides. The load data is collected continuously and averaged over the selected report interval, and converted into a mass measurement for both left and right-side axles. The measured mass is obtained from a load vs. signal equation derived from strain gauge outputs and it is not a direct load cell weight or force measurement. The tolerance between actual and measured strain (*weight*) in a static setting is ± 200 kg (440 lbs), which is acceptable considering the weight of the trailer, air pressure, and suspension balancing, valving, and engineering tolerance in the TSD chassis/suspension body. The loading on the pavement is calculated using Newton's equation for force: N = kg × 9.81.

2.1.2. Laser Doppler Vibrometers (LDVs)

LDVs are mounted on a stiff beam inside the trailer to ensure that the relative position and angle between the sensors remain unchanged. The beam and internal trailer temperatures are kept constant with an air-conditioning system and circulation fans. This is to ensure that there is no thermal expansion or contraction of the beam and mounting components that may introduce torsional movement or bending of the beam, thus ensuring the LDV alignment angles remain constant.

The LDVs measure the pavement deflection velocity by sensing the frequency shift of back-scattered light from a moving surface. The basic principle of operation is to split a beam of light from a helium-neon laser by an initial beam splitter into a reference beam and a measurement beam. As the light path length of the reference beam is constant over time, the movement of the pavement generates a dark and bright (fringe) pattern on the detector. This reflected light is captured by a photodiode and the electrical signal is digitally processed to determine the frequency. The frequency shift between the emitted (reference) and reflected light is the Doppler effect, and is directly proportional to the velocity of the object. The advantage of this method is that the deflection velocities are collected in real time at the speed of the vehicle.

The beam is suspended by a servo system. Using laser height sensors, motorized rams, and air struts, the servo system keeps the distance between the LDV sensors and the road surface constant throughout the survey, with the trailer chassis body roll and tilt negated to keep the sensors in focus. A gyroscope, accelerometer, and inclinometer are mounted in the center of the LDV beam assembly to provide the necessary data to compensate for any movement of the beam.

2.1.3. Measurement of Deflection Velocity and Calculation of Deflection Slope and Pavement Deflection

The TSD measures the velocity at which the pavement deflects under loading. As the LDVs are mounted at a nominal 2-degree angle, they are able to measure two deflection velocity components: a vertical deflection velocity due to pavement loading as well as a horizontal velocity component directly related to the sensor's horizontal velocity (driving speed). To remove this dependence, the deflection velocity (V_v) is divided by the instantaneous survey speed (V_h), which results in the measure of a *defection slope*. From deflection velocity measurements and resultant slope, other traditional deflection measurements can be mathematically established through beam curve fits and numerical modeling.

2.1.3.1. *Sensor Location.*

The TSD was built to collect deflection data in the outer wheel path. It uses up to 10 LDVs to make measurements at locations between 100 mm and 1,500 mm from the center of the wheel load. An additional LDV—the reference laser—is positioned 3,500 mm (~138") from the load. The reference laser is presumed to remain relatively unaffected by the load applied and it is expected to measure low vertical pavement deflection velocity. Hence its response is used to remove unwanted vertical velocity inputs (arising from driving velocity and vehicle movement) from the other measurement lasers.

2.1.3.2. *Data Rate*

The data rate is the rate of response in the samples of received light, and not a direct data recording measurement. The maximum data rate is the frequency of the outputted light at 1 kHz for the first three generations of the TSD and 250 kHz for the fourth-generation TSD. The 1 kHz LDV sensors typically operate on the TSD in the 900 Hz range and rates can go as low as 500 Hz before the confidence level in the velocity reading diminishes. Various factors affect data rate, including surface reflectivity, trailer speed, and focus.

Surface Reflectivity. Dark surfaces absorb more light and slick surfaces also scatter more light. Therefore, dark-flushed asphalt surfaces would have a lower data rate compared to light-colored chip seals. In areas of low data rate due to surfaces, survey speed can be reduced to give more opportunity for light to be reflected back to the detector.

Focus. Focusing of the laser beam's convergence is critical in maintaining good data rates. The LDV mounting beam is suspended by a servo system. The servo system keeps the distance between the LDV sensors and the road constant to ensure the sensors remain in focus. At the optimum distance, the laser spot is small and the most amount of light is reflected. When the distance deviates from the optimum, the spot size increases and less light is reflected because of the lower intensity and increased scatter. This can cause a drop in data rate from the lasers. The TSD has a static ride height at axle kingpin of 1260 mm (50") +/-15 mm (0.5"). Due to suspension traveling over road geometry, body roll, and other factors, the ride height fluctuates throughout the survey. The purpose of the servo system is to keep the distance between the LDVs and the road surface as close to optimum as possible. The servo system consists of two electrical servo motors connected to each end of the mounting beam, suspended on an air dampening system. The servo actuators are constantly lowering or raising the beam while the TSD is in motion, based on input from the distance measuring lasers, which measure the height of the front and rear of the beam from the ground. The servo system can compensate for changes in stand-off distance, for example, caused by driving in a curve, but will not react to sudden height changes caused by potholes in the road surface. However, sudden changes in surface profile are in most cases still within the depth of field distance (+/- 100 mm [~ 4"]).

2.1.4. Data Collected

2.1.4.1. *Raw Data.*

The TSD collects a large amount of raw data, including the following:

a) Continuous data streams of vertical velocity (V_v) and horizontal velocity (V_h) provided from each sensor location.
b) A minimum of 1,000 data samples, recorded per second, per sensor.
c) GPS coordinates.

2.1.4.2. *Processed Data*

The deflection velocity data can be processed to determine and report the following:

a) Deflection slope calculated from the measured deflection velocity and the testing speed.
b) Calculated deflection from the deflection slope at the following locations.
    i) Structural curvature index (SCI) for $SCI_{200} = D_0 - D_8$
    ii) $SCI_{300} = D_0 - D_{12}$, and
    iii) $SCI_{SUB} = D_{36} - D_{60}$.
c) Surface and air temperature to the nearest degree Fahrenheit.
d) Applied axle load left and right in kg or lbs.
e) Estimated load applied to outer wheel in kN or lbf.

2.1.5. Data Processing

2.1.5.1. *Conversion of Deflection Velocity Data into Deflection Basin/Bowl*

The standard output from the LDV is expressed in terms of deflection velocity, which is the vertical deflection velocity of the pavement. The deflection slope is obtained by dividing the vertical deflection velocity by the horizontal travel velocity (i.e., V_v/V_x). The pavement deflection slope is the derivative of the pavement deflection vertical displacement, and therefore can be obtained by integrating the pavement deflection slope. This can be performed numerically, or by modeling the pavement response to obtain a functional form, which can be integrated analytically.

2.1.5.2. *Data Validity*

Valid data will consist of measurements that report less than 50% laser drop-off (sensor drop-off occurs where the resolution of the measurement exceeds the limits of measurability; i.e., a very low deflection becomes a zero deflection). Negative deflection velocity measurements can occur on very strong pavement sections where the deflection is close to zero. These are acceptable if the negative measurements are within agreeable limits based on the standard error of the device measurements. In some cases, such as near the joints in a concrete pavement, it is possible to obtain true negative measurements. We note that for the fourth generation TSD, the sensors placed behind the wheel load, by convention, record deflection velocities that are negative. In this case, positive measurements should be treated in the same way that the negative measurements are treated in the sensors in front of the wheel load.

CHAPTER 3. SPECIFICATIONS & QUALITY MANAGEMENT

3.1. Specifications

3.1.1. Equipment Specifications

A TSD must include the following:

a) A single rear axle trailer with dual wheels towed by a prime mover with a minimum of seven LDV sensors located in the outer wheelpath. The trailer must be fitted with 275/70R 22.5 profile tires operated at a pressure of 760 ± 20 kPa (110 psi). The pressure of each tire must be monitored in real time during data acquisition using wireless tire pressure gauges.
b) Sufficient ballast to allow up to a 10.0 ± 0.10-ton load to be applied to the pavement through the rear axle (equivalent to an approximately 50 kN load in the outer wheel path). Other loads may be chosen if the effect of a different loading is to be assessed.
c) The ability to collect data at varying speeds.
d) A high-resolution distance transducer fitted to a measuring wheel to allow the precise measurement of the vehicle speed and the distance traveled during testing to an accuracy of ±0.1%.
e) A GPS to provide spatial coordinates with real time differential correction and an inertial measurement unit to fill in when the satellite signal is lost.
f) A servo system to ensure that the LDV heights are maintained at their optimum operational height.
g) A suitable cooling/heating system to maintain a consistent temperature within ± 2 °C of the designated operating temperature within the trailer (typically 24 °C for milder climatic regions).
h) Temperature gauges with a minimum range of –5 °C to +100 °C and accuracy of ±1 °C, capable of determining ambient (air) and pavement surface temperatures outside the trailer as well as the ambient air temperature within the trailer and at specific positions on the LDV housing.
i) Suitable instrumentation, signal conditioning, and a data acquisition system capable of capturing and recording deflection velocity values for each LDV up to a 1 kHz sampling frequency. The components of the system should conform to the manufacturer's specifications and be suitable for continuous use.
j) Suitable warning devices as necessary for appropriate traffic control (e.g., lights, and signage).
k) Additional data collection systems for measuring functional pavement condition parameters such as cracking, digital imaging, roughness, rutting, texture, etc. (optional). However, care must be taken to ensure that the systems are operationally compatible (e.g., they collect valid data over the same speed range).

3.1.2. Survey Testing Procedure

3.1.2.1. *Pre-test Setup*

Daily and other Periodic System Checks

The daily pre-survey and other relevant periodic system checks listed in the manufacturer's User Manual must be followed prior to commencing survey work. The procedures have to be submitted to, and approved by, the agency.

Temperature

Switch on the air conditioning system and all TSD components, including any additional data acquisition systems, and allow sufficient time for the ambient air temperature within the trailer to reach ± 2 °C of the designated operating temperature before commencing any data collection or calibration activities

3.1.2.2. *Deflection Velocity Survey*

The operator shall follow the manufacturer's instructions for use of the equipment (refer to the manufacturer's User Manual).

a) Ensure that the laser shutters are open, and the measuring wheel is lowered. The lane to be surveyed is called the "test lane." For routine network surveys, unless otherwise directed, the test lane shall be the lane that is used by most of the traffic. For most roads, this coincides with the outer/slow/curb lane. The median lane shall be tested if parked vehicles obstruct the outer lane; this must be noted and reported.
b) The vehicle must be driven in the usually trafficked wheelpaths such that the measurements are made in the outer wheelpath.
c) Throughout the survey, the vehicle must be driven in a smooth manner, and care must be taken to ensure that the speed of travel is within the manufacturer's operating range wherever possible.
d) Data must be collected with reference to the pre-specified referencing system, and the location of any reference points measured during the survey noted in the data reporting. The start point of the survey must be defined prior to commencing the survey.
e) The data rate from the LDVs, defined as the number of valid readings recorded per second, can be affected by vehicle speed, color of the pavement, and the height of the LDV from the pavement. If the data rate for a laser falls below a specified value, typically 650 Hz, for significant periods of time and is notably lower than the other lasers, then it is possible that the laser spot needs to be refocused. This requires a special piece of hardware from the equipment manufacturer. If refocusing the laser spot fails to improve the data rate, the LDV will need to be replaced and the malfunctioning unit returned to the manufacturer for maintenance and recalibration.
f) Testing must be terminated if conditions are such that difficulty is encountered maintaining the required test lane and/or minimum test speed, resulting in the collection of invalid data.
g) No attempt should be made to avoid pavement defects unless they are likely to damage the vehicle and/or jeopardize safety.

h) Testing must not be performed during periods of rain or where the road surface is wet. If a localized section of wet road is encountered, it must be noted and/or flagged. Arrangements shall be made to test the section when weather conditions are more favorable, if required.
i) Long stops during acquisition should be avoided. Terminate testing and re-test later, if required.
j) Testing shall be terminated if continuation is likely to cause damage to the equipment, or if heavy vehicle weight and dimensional limitations are exceeded.

3.1.3. Data Reporting (Minimum Data Reporting Requirements)

For each test run, the following data must be recorded:

a) Survey title/contract number
b) Date and time
c) Survey device identification
d) Operator
e) Driver
f) Road number/reference
g) Road name, if applicable
h) Test direction
i) Test lane
j) Start and end references
k) Intermediate features and/or reference points, if applicable
l) Any unusual occurrences (e.g., lane changes, bridge abutments, end of seal)

For each test result (minimum of 10 m) the following data must be reportable:

a) Location of the test section with regard to the client-specified location reference system, whether it be linear or spatial
b) Pavement surface temperature (°C)
c) Ambient air temperature at the time of testing (°C)
d) Strain gauge left axle load (kg)
e) Strain gauge right axle load (kg)
f) Gradient slope measurement at the sensor location
g) Curvature (µm)
h) Deflection calculation at agreed-upon locations
i) Vehicle speed during the test
j) Error or event flags
k) Operator comments where applicable

3.2. Quality Management

Quality management of the TSD devices includes device verification, device validation, and device calibration. Device verification involves verifying the repeatability of the measurements on a regular basis, taking into account the number of miles of data collected or based on a length of time. Device validation involves comparing the device measurements to approved methods of pavement deflection measurements such as FWD and/or instrumented pavement sections. Device calibration involves determining the angle of the LDVs.

3.2.1. Device Validation (Benchmarking)

The LDVs are mounted at an angle of approximately 2° from the vertical to allow obtaining input from the TSD horizontal travel speed from the collected measurements, without distorting the pavement vertical deflection speed component. Consequently, this measurement system is highly sensitive to the sensors' angle-values, and therefore these values need to be precisely documented. Validation of the TSD needs to be performed regularly to ensure the angles have remained unchanged despite climate fluctuations or extended operation of the device. Validation involves verifying the repeatability of the TSD. This needs to be performed every 2,000 miles of collected data or monthly, whichever comes first. To test the device repeatability, a pavement section (benchmarking site), at least 10 miles in length, within the 2,000 miles of collected data (or within the monthly data collection) is selected and tested again to verify that the device measurements are repeatable. Two quantities are measured to assess the device's repeatability: the standard deviation (or coefficient of variation if divided by the measurement) of the difference between the two measurements and the mean difference (bias) between the two measurements. These two quantities must be within agreed-upon limits between the agency and the service provider prior to data collection and will depend on the data averaging interval used to obtain the measurements.

Desired characteristics of a benchmarking site are as follows:

a) Is 10 miles long—must be long enough to allow the collection of sufficient consistent and repeatable data required to perform statistical analysis, and also enable at least three repeat runs pre- and post-laser geometric calibration, within the same day and to minimize time between runs (temperature changes) and provide more flexibility to do extra runs, trials, research, etc.

b) Is ideally of varying and moderate speed (up to 50 mph) with suitable turnaround locations that can safely surveyed at less than 30 mph if needed to minimize potential data loss.

   Is unaffected by traffic (i.e., peak hour traffic, parking restrictions, traffic lights, urban areas).

c) Is within 15 minutes of existing distance/laser angle calibration sites.

3.2.1.1. *Startup Validation*

Prior to the commencement of the field survey, processed data from the nominated accreditation sites will be formatted in the primary database format.

3.2.1.2. *Close out Validation*

Within 14 days after the survey completion date, conduct close-out loops by retesting the site with a minimum of three consecutive runs.

Determine the repeatability between the close-out survey with the accreditation survey. The acceptance standard for repeatability shall be set by the agency.

3.2.2. Device Verification

Device validation does not guarantee that the measurements are accurate. To ensure accuracy, the measurements of the device need to be verified with a different set of measurements. This can be performed in two different ways:

a) Comparing the measurements of the device with FWD measurements obtained on the same pavement sections during the same day.
b) Comparing the measurements of the device with sensors embedded in pavement sections. An effective approach would be to compare the deflection velocity measurements from the LDVs to pavement deflection velocity obtained from embedded geophones near the pavement surface.

The recommended frequency of device verification is once every 15,000 miles of collected data but no more than three times a year (spring, summer, fall) and no less than twice a year. (Level 1 or level 2 calibrations are discussed in the next section. When these are performed, can be counted as device verification procedures as well as calibration procedures.) For the device verification, the standard deviation of the difference, the average difference between the device measurements, and the verifying sensor measurements should be calculated to be within acceptable limits.

3.2.3. Device Calibration

Device calibration is an operation that, in a first step, creates a relationship between quantity values and measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties under specified conditions and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication.

Three levels of calibration are recommended. Level 1 calibration involves calibrating the device on an instrumented pavement section where the results of the calibration can be verified with embedded sensors or geophones. Level 2 calibration involves calibrating the device and verifying the calibration with another calibrated deflection measuring device such as the FWD or another level 1 calibrated TSD. Level 3 calibration involves calibrating the LDV angles without verifying the results of the calibration with other independent measurements.

3.2.3.1. *Laser Doppler Vibrometer Angle*

The LDVs are mounted at an angle of approximately 2° from vertical to allow a constant velocity input from the horizontal vehicle speed, while having little effect on the vertical speed component. As the measurement system is highly sensitive to the relative angle differences, the precise angles need to be documented. To ensure the angles have remained unchanged during transit, climate fluctuations, or extended use, the geometric calibration process must be undertaken regularly. The LDV angle calibration or check will be done whenever a laser or mounting beam is changed or moved. The trailer tire pressure should be verified and recorded.

The ideal criteria for an LDV geometric calibration site are as follows:

a) 0.5 mile (1 km) long minimum – to provide enough consistent data to perform offset calculation
b) Homogeneous pavement: same construction and surface type throughout, no bridges or culverts

- Repeatable consistent data on surface and structure underneath

c) Smooth consistent surface: no dips, bumps, potholes, patches, raveling, etc
   - Repeatable consistent data and trailer rides smoothly with no dynamic loading on pavement

d) Dead straight and dead flat
   - So gyros, laser servo height, and other data compensations are minimized and do not impact LDV reading/calibration

e) Ideally of moderate speed (up to 50 mph) with suitable turnaround locations
   - So calibration time between runs is minimized (minimizes temperature changes) and LDV can safely survey below 50 mph to minimize potential data loss

f) Light-colored surfac
   - LDVs work better on light colored surfaces with lower data loss (darker surface absorbs more laser light)

g) Near existing distance calibration site

Level 1 calibrations should be done at least once a year or every 45,000 miles of collected data, ensuring that calibration of the LDV angles are performed no more than 30 days before the testing. Level 2 calibration can be done if Level 1 calibration was performed within the year but additional calibration is needed.

All results will be recorded on a *Laser Doppler Vibrometer Calibration Form* as referenced in **Appendix A1.1**.

3.2.3.2. *Distance*

Distance calibration is to be completed prior to an LDV calibration. Ideally, the distance calibration site will be near or the same as the LDV calibration site. Distance calibrations will be completed monthly or every 3,000 miles, over a surveyor-certified distance calibration site with a minimum length of 0.5 miles. Start and end points will be triggered by automated optical triggers.

Note: Replace tires prior to calibration if damaged or excessively worn.

All results are recorded on a *Distance Calibration Form* as referenced in **Appendix A1.2**.

Distance calibration is verified by surveying a known accurate length and comparing the result of the surveyed measured length against the actual length. The measured length must be within + / - 0.1% (1 m/1,000 m) of the specified length to be considered acceptable (i.e., to pass).

All results are recorded on a *Distance Validation Form* as referenced in **Appendix A1.3**.

3.2.3.3. *Strain Gauges*

The strain gauge system is calibrated by the dynamic offset weight method. The strain gauge calibration or calibration check is done on a monthly basis, or whenever a significant weight is changed or moved.

The dynamic offset calibration determines scaling and offset factors for each strain gauge so that their readings can be converted to a load. This is achieved by placing the trailer wheel on reference scales for each side and varying the mass by removing/adding the various combinations of ballast weight. Taking simultaneous readings from the reference scales and also the strain gauge system at each of these mass combinations, a plot of actual vs. measured readings can be made. From this plot, the calibrated offset and scale factor can be determined and re-entered into the system.

Results are recorded on *Strain Gauge Calibration Form* as referenced in **Appendix A1.4.**

3.2.3.4. *Laser Profiler*

All profiling lasers and accelerometers are calibrated for offset distance and linearity during the initial system setup. Laser calibration is repeated at a minimum of once every 3 months and/or whenever a laser is changed or moved. Accelerometer calibrations are repeated annually, with the accelerometers' offset calibration performed only as required.

All results are recorded on a *Laser Calibration Form* as referenced in **Appendix A1.5** and an *Accelerometer Calibration Form* as referenced in **Appendix A1.6**

A Bounce Test is conducted daily prior to collection of data for the day. All parameters must pass before surveying commences.

All results are recorded on a *Still and Bounce Test Record Form* as referenced in **Appendix A1.7**.

3.2.3.5. *Imaging System*

The field of view (FOV) is set for all cameras, and positional references are checked for Device Synchronization location.

This calibration method is used for asset view cameras. The purpose is to provide a calibration for the distance and direction of objects with respect to the vehicle. The addition of vehicle location data by GPS acquisition allows asset location.

Cameras are calibrated by locating at least two calibration point markers positioned at an offset along a reference line at accurately measured distances from the camera in the FOV. Within the software, crosshair markers are superimposed on the screen and can be accurately placed into position over the calibration point marker. The distances for each calibration point marker and the crosshair are then displayed on the screen and the measured reference distances from the camera to the calibration point can be entered to correct or confirm the calibration.

The camera's azimuth can also be set by aligning on-screen crosshairs with the reference line.

The calibration is completed during the initial system setup and should be repeated annually and whenever a camera is changed or moved, or the camera's zoom or focus is changed.

3.2.3.6. *Inertial Positioning System*

Prior to project commencement, the Inertial Positioning System and GPS positional references are checked for correct Device Synchronization location

The Inertial Positioning System is calibrated via the 180 offset and 360 method, prior to project initiation. This calibration corrects accelerometer errors caused by vehicle loading and suspension aging and gyroscope errors caused by gyroscope drift.

Before commencing calibration, switch on the system and allow 15 minutes for the sensors to warm up and stabilize. The vehicle should be parked on a flat, level space, and the positions of the wheels accurately marked. The vehicle will have to be re-positioned accurately at, and based on, these marks several times during the tests.

While the System is acquiring stationary data, it is important that the vehicle is not moved in any way. Do not move inside the vehicle or allow the vehicle to be bumped or buffeted by wind.

During the 180 calibration, the vehicle is driven in a loop after a stationary period (without reversing) and parked exactly back on the previous wheel marks but flipped—i.e., the front is now the back, and the left now the right. After a second stationary period, at this “flip” on the same position, the system automatically calculates the offset required X, Y, Z axis tilt.

For the 360 calibration, the vehicle is driven in a looped circle and parked exactly back on the previous wheel marks. From this “full circle” back to the same position, the system automatically calculates the offset required for gyroscopic drift correction.

These calibrations should be repeated monthly throughout the course of the project at a suitable site.

REFERENCES

Austroads AG:AM/T017	Pavement Data Collection with a Traffic Speed Deflectometer (TSD) Device
ARRB Group (2020)	Pavement and Roadway Data Collection Quality Management Plan
ARRB Group (2020)	Comprehensive Structural and Functional Pavement Survey Methodology. iPAVe Survey Methodology
JCGM 200:2013	International vocabulary of metrology: basic and general concepts and associated terms. VIM, 3rd Edition, Joint Committee for Guides in Metrology.
ISO 9000:2005	Quality management systems: fundamentals and vocabulary
Pedersen, L. (2013)	Viscoelastic Modeling of Road Deflections for Use with the Traffic Speed Deflectometer. Ph.D. dissertation.

APPENDIX A. FORMS

1.1 Laser Doppler Vibrometer (LDV) Calibration

Form for recording results of *LDV Calibration*

Vehicle Reg.		Trailer Tire Pressure			The *Description* and *X Position* of all lasers has been checked for correctness							Y/N
Date	Name Calibration File	Completed by	Calibration Angle (rad)									
			Positions Forward of Load					Behind Load				
			1510	910	1210	450	310	210	110	-110	-210	-310

NOTE: as LDV angles are high precision numbers with a large number of significant figures, it is recommended this form be integrated into the system and electronically completed.

1.2 Distance Calibration

Form for recording results of *Distance Calibration* via acquisition or calibration software

Date	Tire Pressure +/- 1 psi				Site	Speed (mph)	Cal. Length (mi)	Old Cal Pulse Rate	New Cal Pulse Rate	Field Work Supervisor (Print Name)
	DF	PF	DR	PR						

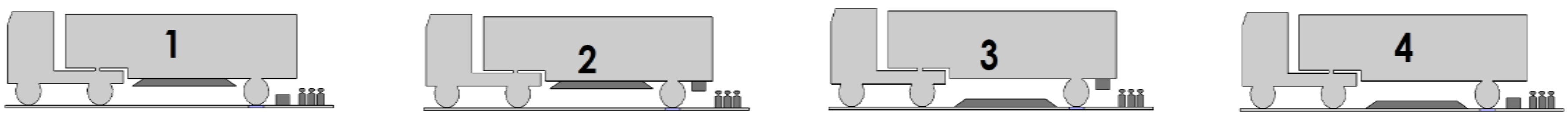
1.3 Distance Validation

Form for recording results of *Distance Validation* via a simulated survey of an accurate known length in acquisition software. Measured length must be within + / - 0.1% (1 m/1,000 m) of specified length to achieve a pass

Date	Odometer Reading	Tire Pressure +/- 1 psi				Site	Speed (mph)	Known Length (mi)	Measured Length (mi)	Difference (%)	Pass/Fail	Field Work Supervisor (Print Name)
		DF	PF	DR	PR							

1.4 Strain Gauge Calibration

Form for recording results of *Strain Gauge Calibration*



Date	Vehicle	Completed by	Strain Gauge Calibration - Weights			
			Load		LSB	
Load config setup	Load config setup	Reading number	Left (kg)	Right (kg)	Left	Right
Small load off - large load on	1	1				
All loads	2	2				
Large load off - small on	3	3				
All load off	4	4				
Small load off - large load on	1	5				
All loads	2	6				
Large load off - small on	3	7				
All load off	4	8				
Calculations		R^2			A0 LEFT OFFSET	A1 RIGHT OFFSET
		SLOPE				

Date	Vehicle	Completed by	Strain Gauge Calibration - Weights			
			Load		LSB	
Load config setup	Load config setup	Reading number	Left (kg)	Right (kg)	Left	Right
		INTERCEPT			A0 LEFT SCALE	A1 RIGHT SCALE
		INTERCEPT				

NOTE: As statistical calculations are required, this form needs to be integrated within system or outlined within Excel.

1.5 Laser Calibration

Form for recording results of *Laser Calibration*

Date:		Calibrated By			Gauge Block nominally measuring 25 x5 0 x 80 mm			
Vehicle Reg.		Quality Manager			Nominal	50 mm	25 mm	80 mm
The *Description* and *X Position* of all lasers has been checked for correctness				Y/N	Actual Size			

Laser Profiler Acceptance Criteria ± 0.5mm of measured height			Driver							Passenger					
			1500	1350	1150	950	750	450	Centre	450	750	950	1150	1350	1500
Calibration Height 50 mm	Old Calibration Factor	SMTD													
		MPD													
		Ro+R													
	New Calibration Factor	SMTD													
		MPD													
		Ro+R													
	Measured Height	SMTD													
		MPD													
		Ro+R													
Linearity Check 25 mm	Measured Height	SMTD													
		MPD													
		Ro+R													
Linearity Check 80 mm	Measured Height	SMTD													
		MPD													
		Ro+R													

1.6 Accelerometer Calibration

Form for recording results of *Accelerometer Calibration*

Date:			Calibrated By	
Vehicle Reg.			Quality Manager	
Calibration Factor (Sensitivity) Measured Accelerometer results to be within specified Tolerances				
Driver		Measured Accel	Target Accel	Allowed Tolerance
	1st Test		2.000g	± 0.1g
	2nd Test		2.000g	± 0.01g
	Old Cal Factor:		New Cal Factor:	
Passenger		Measured Accel	Target Accel	Allowed Tolerance
	1st Test		2.000g	± 0.1g
	2nd Test		2.000g	± 0.01g
	Old Cal Factor:		New Cal Factor:	

1.7 Still and Bounce Test Results

Form for recording results of *Still and Bounce* test results

Bounce Test Results (IRI*) criteria. Enter Values Daily				Vehicle Reg		
Date	Driver			Passenger		
	Still < 0.1 m/km	Bounce < 0.2 m/km	Pass/Fail	Still < 0.1 m/km	Bounce < 0.2 m/km	Pass/Fail

*International Roughness Index