METHOD OF TEST FOR CALIBRATING, CORRELATING AND CONDUCTING SURFACE SMOOTHNESS MEASUREMENTS USING A CALIFORNIA PROFILOGRAPH

1. SCOPE

This procedure covers the method used for approving California profilographs and for conducting surface smoothness measurements on ministry contracts with these devices.

2. RELEVANT DOCUMENTS

2.1 MTO's Field Guide for the Acceptance of Hot Mix and Bridge Deck Waterproofing

2.2 ASTM E1274 Standard Test Method for Measuring Pavement Roughness Using a Profilograph.

3. DEFINITIONS

3.1 **Blanking Band:** a band of uniform height "B" in mm (0 mm for asphaltic concrete and 5 mm for concrete pavements) with a length equal to the sublot length, which is optimally positioned between the highs and the lows of the profile trace to "blank out" as much of the profile trace as possible.

3.2 **Correlation Site:** A location established by the ministry to conduct California profilograph correlations.

3.3 **Data Filter Factor:** An input parameter which is used to electronically modify the surface trace. For California profilographs, a "*Butterworth*" Filter of *2.0* (i.e. feet) or *0.61 m* and a "Gain" setting of *1.000* where "Gain" has been provided as an option on newer Surface Systems Instruments (i.e. SSI) software for profilographs, shall be used for ministry work.

3.4 **Profile Index**: The rate of smoothness averaged over both wheelpaths for any given sublot of surface course or section of pavement.

3.5 **Odometer:** A device for measuring the longitudinal distance along a profile being measured by a California profilograph.

3.6 **Rate of Smoothness:** Is calculated by adding up all of the amplitudes for the individual bumps and depressions on a profile trace outside of a blanking band which are greater than *0.8 mm* and which also extend at least *0.6 m*, as measured by the California profilograph along the profile length and then dividing that number by the sublot length; expressed in mm/km.

3.7 **Reduction Length:** An input parameter equal to the sublot length (normally set at 100 m).

3.8 **Scallop:** A bump or depression in the pavement surface at a location which is automatically determined by the SMD's computer as either a line through the profile trace for McCracken or SSI profilographs or a shaded mark above the profile trace for Cox profilographs, which is at least "S" mm (i.e. "S" **=** *10 mm* shall be the upper limit for acceptability for asphaltic concrete and concrete surface and "S" = *15 mm* shall be the upper limit for acceptability for concrete base) above or below

a *7.5 m long baseline* (i.e. bump width) or 7.62 m long baseline for older Cox Brothers profilographs, where the setting cannot be changed which is constantly changing in elevation due to the surrounding pavement.

3.9 **Smoothness Measuring Device (SMD):** A California profilograph used for measuring the surface smoothness of a pavement.

3.10 **Sublot:** A continuous traffic lane of pavement; excluding the shoulder; which has been measured by SMD for purposes of repairs/price adjustments and normally having a length of 100 m, measured horizontally, for highway survey purposes.

3.11 **Wheelpaths**: Means 1.0 m on each side of the centreline of the actual trafficked lane. The trafficked lane does not include adjacent paved areas such as paved shoulders or tapers.

4. APPARATUS

4.1 California Profilographs

4.1.1 Hardware

All California profilographs shall conform to the requirements of ASTM E1274 for devices "With Non-Uniformly Spaced Wheels". A schematic diagram for a typical profilograph, which was manufactured by the McCracken Concrete Pipe Machinery Company**,** is shown in Figure 1. Although similar devices were also made by Cox Bros., most new profilographs are now being made by Surface Systems Instruments (SSI).

4.1.2 Software

The on-board computer for all California profilographs must be programmed to read in metric units with all "bumps" used to determine profile index rounded to the nearest 0.2 mm (i.e. the rate of smoothness must be measured to the nearest 2 mm/km) or better.

4.1.3 Profile Traces

All California profilographs must be capable of printing out a continuous or semi-continuous (i.e. automatically printed out at 100 m intervals)) trace at the end of each 100 m sublot while measuring and recording data (i.e. while the profilograph is in motion). All profile traces must be printed on a continuous spool of paper (single sheets are not acceptable) with a 1:1 vertical scale and 1:300 longitudinal scale. Each profile trace shall begin with an automatically-printed header (i.e. stick-on labels or similar methods are not acceptable) listing all of the input parameters that were used for that run. The list of parameters must include, but not be limited to, the data filter factor settings, blanking band height/length, the bump height/width, date/time, lane, direction, and wheelpath. Stations must be automatically marked every 10 m. The trace must also show the calculated rate of smoothness for each 100 m sublot in mm/km and clearly identify the locations of any scallop where the bump height (or depth) and/or width has been exceeded. At the end of each profile run, the computer must print a summary, which lists of all of the measured sublots with their corresponding start/end stations, rates of smoothness, and the locations of all scallops.

4.2 **Tire Pressure Gauge:** For checking the tire pressure of the measuring wheel of a California profilograph.

4.3 **Air Pump:** For maintaining acceptable air pressure of a California profilograph's measuring wheel.

4.4 **Calibration Blocks:** For California profilographs, two finished steel blocks, usually 12.7mm (1/2") and 38.1 mm (1.5") in height, are required for checking the vertical calibration of the measuring wheel. The height (or thickness) of the calibration blocks (or plates) from an average of three measurements, taken to the nearest 0.01 mm, shall be clearly engraved on at least one of its sides and will be subject to verification by the ministry's representative.

4.5 **Smooth Rigid Base Plate:** A steel or aluminium plate, approximately 0.3 x 0.3 m square and 6.35 mm (1/4") thick, for use with the calibration blocks.

4.6 **Offset Bar:** A rigid metal bar, at least 2.5 m long, with a suitable weighted chain hanging from the end. The chain is dragged along a reference line, in order to ensure that the California profilograph is following a proper offset.

4.7 **Small Tape Measure:** A metal tape, at least 5 m long, used to measure and establish offset distances from a reference line.

4.8 **Large Tape Measure:** A metal or teflon-coated woven tape, at least 50 m long, used to establish and measure distances from fixed stations.

4.9 **Chalk and Spray Paint:** For temporary and permanent marking.

5. PROCEDURES

5.1 CALIBRATION AND CORRELATION OF SMOOTHNESS MEASURING DEVICES

5.1.1 Visual Check

A ministry representative will check the California profilograph (and the equipment for power assist, if the operator intends to use power assist on ministry contracts), in order to ensure that all mechanical parts and the associated electronics appear to be in suitable condition and that all appropriate accessories and peripherals are included with the device.

5.1.2 Checking Tire Pressure of the Measuring Wheel

The operator must demonstrate to the ministry representative that the tire pressure of the measuring wheel of a California profilograph, in its cold state, meets ASTM requirements [i.e. 25 p.s.i. $\pm$ 1 p.s.i. (or 170 kPa)]. If the tire pressure is too low, then it must be slightly inflated using the air pump (i.e. with caution, since over-inflation can permanently cause the measuring wheel to become out-of-round). However, if the tire pressure is too high, then the tire can be deflated slightly by pushing a small object such as a key into the tire valve.

5.1.3 Checking Height Sensor Calibration

The operator of the California profilograph must demonstrate to the ministry representative that the height sensor is properly calibrated.

5.1.3.1 The profilograph is moved to a relatively flat area and the measuring wheel is lowered onto a smooth rigid base plate sitting on the pavement surface.

5.1.3.2 The height measurement, M1, shown on the profilograph's screen is then recorded (see Figure 2).

5.1.3.3 One of the metal calibration blocks of known height, H, is then placed on top of the smooth rigid base plate and under the measuring wheel, and the second height measurement, M2 shown on the profilograph's screen, is recorded.

5.1.3.4 The operator must check this with at least two blocks of differing heights [usually 12.7mm (1/2") and 38.1 mm (1.5")].

5.1.3.5 The absolute value of the difference between M1 and M2 must be within 0.5 mm of the heights of both blocks, in order for the height sensor to be properly calibrated.

5.1.3.6 If the height sensor is not properly calibrated, then the correlation procedure will be terminated at that point and the sensor must be recalibrated by the manufacturer.

5.1.4 Checking Odometer Calibration

The operator must demonstrate to the ministry representative that the California profilograph's odometer is properly calibrated.

5.1.4.1 The longitudinal centreline of the profilograph is aligned along a line, 100 m long, which has been established at the correlation site for this purpose.

5.1.4.2 The profilograph's measuring wheel is lowered onto the pavement surface so that its geometric centre is sitting at the beginning of the line.

5.1.4.3 The station reading on the profilograph's screen is set to 0 m and then the profilograph is manually pushed 100 m using its internal odometer.

5.1.4.4 Once the profilograph is about 90 m into the run, the operator should begin to slow it down so that it is completely stopped just at the point where the odometer turns exactly 100 m.

5.1.4.5 The distance between the geometric centre of the California profilograph's measuring wheel and the end of the 100 m section, as measured using a small metal tape measure**,** must be no more than 1.0 m.

5.1.4.6 If the distance between the geometric centre of the California profilograph's measuring wheel and the end of the 100 m section is more than 1.0 m, then the 100 m line must be rerun and the odometer of the profilograph recalibrated using the manufacturer's procedure so that it exactly reads 100 m when the geometric centre of the measuring wheel has reached the end of the run (i.e. $\pm$ 1.0%).

5.1.5 Checking Tracking (Skewness)

While the California profilograph is being pushed during the odometer calibration check, a ministry representative will also check to see if it is tracking properly **(**i.e. that the front and back bogey wheels are following one another in the same path**)**.

5.1.5.1 If the horizontal tracking is deemed to be unacceptable, then the run will be terminated and the operator will be asked to adjust the bogey wheels (usually by loosening a knurled knob on the back wheels) to improve tracking (i.e. to eliminate skewness).

5.1.5.2 Once the California profilograph is tracking properly, the operator may be required to wait until checks of several other profilographs have been made before his profilograph is allowed to have a second calibration check of its odometer.

5.1.6 Conducting Correlation Runs

Once the ministry's representative is satisfied that the California profilograph has been properly calibrated, it will then be required to run along a 300 m line**,** which has been established by the owner at a correlation site for all California profilographs used on ministry contracts for acceptance testing.

5.1.6.1 Each California profilograph must be perfectly aligned with the geometric centre of its measuring wheel sitting on the pavement and at the beginning of a 300 m long correlation line.

5.1.6.2 The operator must set all relevant input parameters related to the blanking band, data filter factor, reduction length, rate of smoothness, and scallops in accordance with the Definitions provided in Section 3. In addition, for older profilographs manufactured by James Cox and Sons Inc., the panel switch must be set to the "Fixed Distance" mode at all times.

5.1.6.3 The California profilograph will then run the measuring wheel a distance of 300 m, using the California profilograph's internal odometer at a speed of 3 to 4 km/hr.

5.1.6.4 Once the California profilograph has reached about 250 m, the operator must begin slowing the profilograph down so that it comes to a complete stop when its odometer reads exactly 300 m.

5.1.6.5 The distance between the centreline of the measuring wheel and the end of the run is then measured using a small metal tape. That distance must be no more than 3.0 m (i.e. $\pm$ 1%).

5.1.6.6 The California profilograph must repeat the 300 m distance two more times for a total of three complete runs.

5.1.6.7 The California profilograph must repeat the 300 m run three times for each combination of mode of operation (manual or power-assist) and measuring wheel that the operator intends to use on ministry contracts during the construction season in which the correlation is being conducted. Also, if the operator intends to measure concrete pavements on ministry contracts, then at least one additional series of three runs must also be carried out while being manually pushed with the computer-generated blanking band set at a height of 5 mm.

5.1.6.8 Acceptance of the California profilograph will be based on the results of the correlation calculations described in Section 6.1.

5.2 SURFACE SMOOTHNESS MEASUREMENTS ON MINISTRY CONTRACTS

5.2.1 Taking Surface Smoothness Measurements

5.2.1.1 For California-type profilographs smoothness testing must be carried out as stated in this Subsection.

5.2.1.2 For all California profilographs, the height sensor, the odometer, and the tire pressures of all pneumatic tires must always be within acceptable tolerances and checked using the methods described in section 5.1.

5.2.1.3 For all measurements, the operator must set all relevant input parameters, in accordance with the requirements given in Section 5.1 and the definitions given in Section 3.

5.2.1.4 All surface smoothness testing must be carried out in the direction of traffic.

5.2.1.5 All individual profile runs must be less than or equal to 500 m in length. However, a profilograph will be allowed to increase the length of its runs, if it can be demonstrated to the satisfaction of the ministry that the longitudinal stations can be consistently maintained within 1% of the actual stations that are marked out in the field (i.e. that the pavement is essentially horizontal).

5.2.1.6 Stations, areas that will not be measured, areas that will be measured but not price-reduced, and all distances from such areas must be referenced from the centreline of the measuring wheel.

5.2.1.7 The operator of a California profilograph must measure the heights of all scallops recorded on the profile trace. For McCracken and SSI profilographs, this is done by measuring the maximum height above and perpendicular to the “excessive height” lines printed on profile traces using a millimetre scale and adding 10 mm. For traces produced by Cox Brothers profilographs, the SMD operator must measure the heights of all scallops by measuring the maximum height above and perpendicular to the lines shown on excessive height templates or so-called “bump” templates and by adding 10 mm (see Figure 3).

5.2.1.8 The amplitudes of all scallops identified by a California profilograph’s computer must be rounded to the nearest 0.5 mm.

5.2.2 Measuring Existing Pavements, Binder or Base Courses

Where either an existing pavement surface or an asphalt binder course must be measured, then the pavement sections of the existing surface or the binder course, whichever is being measured, must have exactly the same stations and numbers as the sublots of the overlying asphalt surface course. Similarly**,** where an existing pavement surface or concrete base must be measured, then the pavement sections of the existing pavement surface or concrete base, whichever is being measured, must have exactly the same stations and numbers as the sublots of the overlying concrete surface. However, if the stations for any sublot of asphalt surface course or concrete surface do not to match the stations of the underlying measured existing surface, asphalt binder coarse or concrete base, then the contractor will be required to either re-measure the asphalt surface course (or concrete surface) or to recalculate the profile indices for the affected sublot so that the stations for the asphalt surface course (or concrete surface) match the measured existing pavement surface, asphalt binder course or concrete base exactly.

6. CORRELATION CALCULATIONS AND ANALYSES FOR ACCEPTANCE

6.1 Means and Standard Deviations for Individual 100 m Sections

For each set of three runs of the 300 m correlation line, the operator of the candidate California profilograph must calculate the mean, standard deviation, and the coefficient of variation (i.e. ratio of standard deviation to the mean as a percentage) of the rate of smoothness measurements for each 100 m section of pavement measured as follows:

(1) $$\overline{X} = \frac{\sum x_i}{n}$$

(2) $$s = \sqrt{\frac{\sum \left(x_i - \overline{X}\right)^2}{n-1}}$$

(3) Coefficient of Variation (%) = $$s/\overline{X} \times 100$$

Where: $\overline{X}$ = the mean rate of smoothness for each 100 m section

s = the sample standard deviation for each 100 m section

x_i = the individual rate of smoothness for each 100 m section

n = 3

6.2 Individual Average Rate of Smoothness for Entire 300 m Section

The profilograph operator must calculate the average rate of smoothness for all three runs of the 300 m correlation line measured by the candidate California profilograph.

6.3 Average Coefficient of Variation

The operator of the candidate California profilograph must calculate the average coefficient of variation for the individual coefficients of variation representing all three runs of each 100 m pavement section measured by the profilograph.

6.4 Correlation Benchmark Mean

6.4.1 A ministry representative will calculate a “Correlation Benchmark Mean” for the 300 m correlation Line by averaging the individual average rates of smoothness measurements for all candidate California profilographs that meet the ministry’s acceptance criteria on the first attempt during the first round of the season.

6.4.2 The individual average rate of smoothness for any candidate California profilograph that does not meet the ministry’s acceptance requirements (based on the individual averages established by all the other acceptable candidate California profilographs) on the first attempt, during the first round of the season, will not be included in the calculation of the Correlation Benchmark Mean for that season.

6.4.3 Ratio of the Individual Average to the Correlation Benchmark Mean

Once the Correlation Benchmark Mean has been established for the season, a ministry representative will calculate the ratio of the individual average rate of smoothness measurements to the Correlation Benchmark Mean, for each candidate California profilograph.

7. REPORTING OF RESULTS

7.1 CORRELATION SITE

7.1.1 All calculations carried out during the correlation of the candidate California profilograph must be entered on a California Profilograph Correlation Sheet, such as the one shown in Figure 4.

7.1.2 Separate forms must be filled out for each set of three runs taken of the 300 m correlation line**,** for each combination of blanking band, mode of operation, and measuring wheel.

7.1.3 All correlation forms should be handed to a ministry representative on site, along with the applicable profile traces. Once the Correlation Benchmark for the site has been established, the ministry representative will complete the sheet.

7.2 MINISTRY CONTRACTS

7.2.1 Surface Smoothness Reporting Forms

7.2.1.1 All rate of smoothness measurements and profile index calculations measured by California profilographs on ministry contracts shall be entered into an ®Excel 2003 template, which has a form similar to the Summary Sheet for Measurements by a California Profilograph shown in Figure 5.

7.2.1.2 For measurements taken on asphalt surface course and concrete surface, the location and height of any scallop with an “S” value greater than 10 mm must also be shown.

7.2.1.3 For measurements taken on concrete base, the location and height of any scallop with an “S” value greater than 15 mm must also be shown.

7.2.1.4 Areas of special conditions, such as superelevations or curves, any additional information such as joints or major intersections, and any areas which are being measured but will be exempt from surface smoothness-related price reductions/repairs**,** must be clearly marked on all summary sheets**.**

7.2.2 Continuous Daily Profile Record

One original, unbroken, continuous profile record**,** representing all of the sublots and other pavement surfaces which were measured on a particular day**,** must be produced at the end of that day or prior to the California profilograph leaving the site.

7.2.2.1 Before Each Individual Run

At the beginning of each different profile run, the contract number, mix type, pavement surface that was measured, the lane direction and wheelpath that was measured, the reference point that was used during measuring, the side of the lane that the reference point was on and the offset that was used, as well as any other relevant information must be automatically recorded.

7.2.2.2 Within Each Individual Run

Areas of special conditions, such as superelevations, curves, joints or major intersections, and any areas that are being measured but will be exempt from surface smoothness-related price reductions/ repairs within an individual profile run, must be automatically printed or manually marked on the profile trace.

7.2.2.3 Documentation on Outside of Profile Record

The contract number, mix types, and pavement surfaces that were measured, the lanes, directions and stations covered, and whether the individual traces are the initial, subsequent, or the final ones must be clearly shown.

8. CRITERIA FOR GAINING AND MAINTAINING SMD ACCEPTANCE

8.1 YEARLY CORRELATION ACCEPTANCE

8.1.1 The individual average rate of smoothness, for the three sets of measurements taken of the 300 m correlation line by a candidate California profilograph, must be within 4% of the Correlation Benchmark Mean for that line.

8.1.2 The average coefficient of variation for any three sets of three individual 100 m pavement sections measured by a candidate California profilograph must be no more than 5%.

8.2 MAINTAINING ACCEPTANCE THROUGHOUT THE YEAR

8.2.1 The operator of the California profilograph must carry out regular inspections of the security of all bolts, wearing and roundness of any bogey wheels and pneumatic tires, tracking of the profilograph, electronics etc. to ensure that the profilograph is in suitable condition at all times.

8.2.2 Each California profilograph must be equipped with all necessary peripherals (e.g. printer etc.) in good working condition and all accessories such as suitable calibration blocks, a tire pressure gauge, air pump, tape measures, chalk, paint, wooden stakes, etc.

8.2.3 The tire pressure of the pneumatic measuring wheel must be maintained at 25 p.s.i. $\pm$ 1 p.s.i. (or 170 kPa $\pm$ 7 kPa)] at all times.

8.2.4 The height calibration of the sensor attached to the measuring wheel must be within acceptable limits at all times. The height calibration must be checked daily and each time the California profilograph is assembled, in accordance with the procedures stated in Section 5.1.3.

8.2.5 The California profilograph's odometer must measure within acceptable limits at all times (i.e. 1% of the true distance) and must be checked at least once a month, in accordance with the procedures stated in Section 5.1.4.

8.2.6 Any changes to the equipment (e.g. mode of operation, or measuring wheel, etc.) and/or software from those that were demonstrated at the Correlation Site, during the initial yearly approval, must be discussed with either the ministry's Bituminous Section (for asphalt) or Concrete Section (for concrete) prior taking further measurements, respectively, on any of the owner's contracts.

Depending upon the nature of such changes, the contractor's California profilograph may be required to repeat the correlation procedure at the owner's correlation site, at the discretion of the ministry.

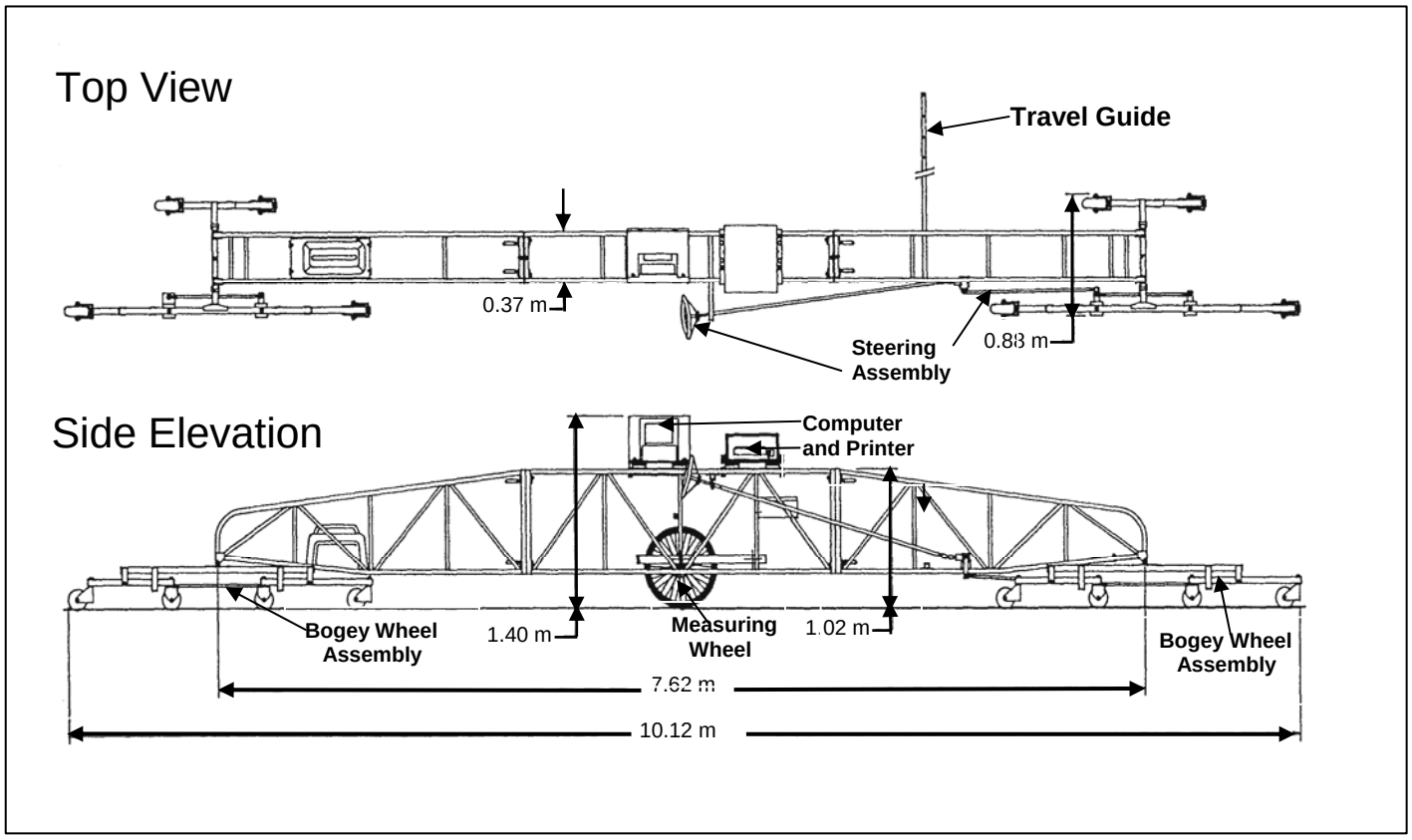

Figure 1 – California Profilograph

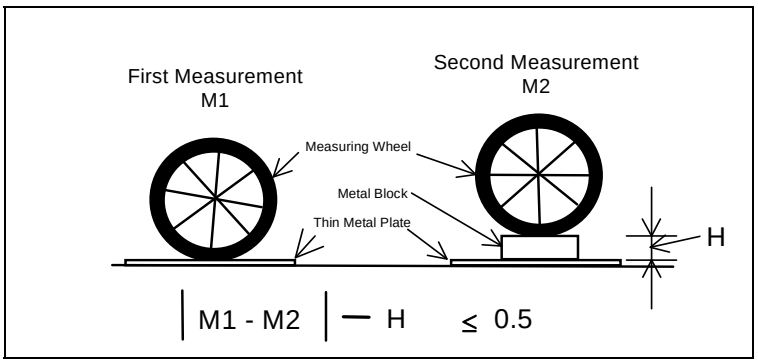

Figure 2 – Checking the Calibration of the Height Sensor for a California Profilograph

Figure 3 – Measuring Scallop Height Using a Bump Template From a Profile Trace

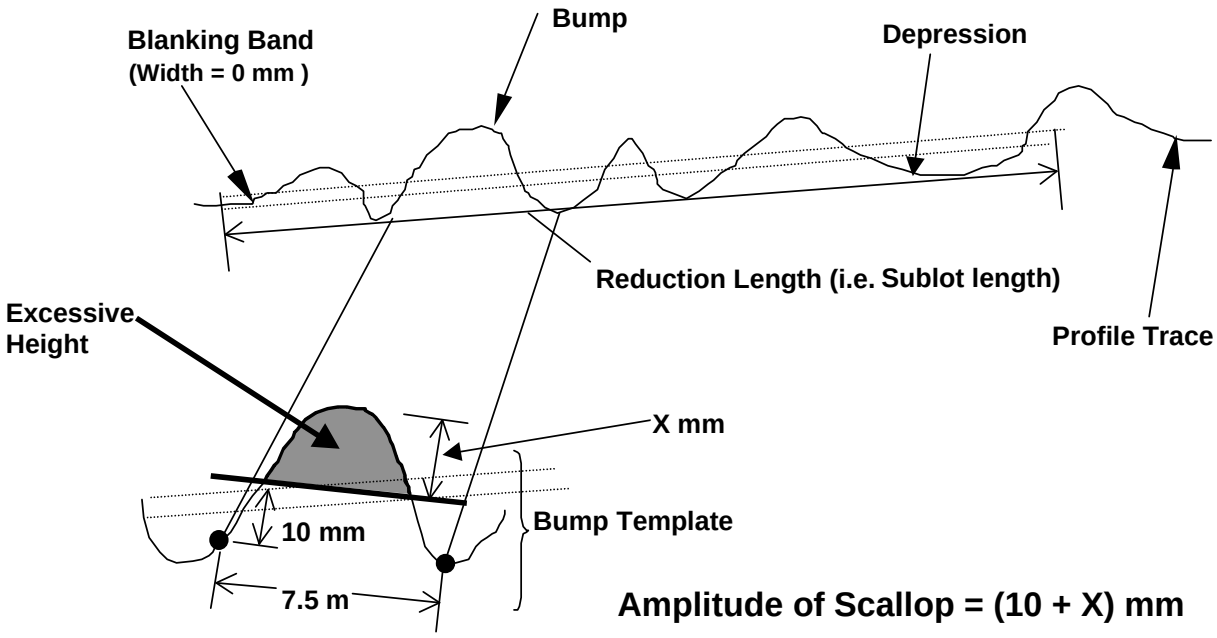

Figure 4 – Sheet For Correlation of California Profilographs

Correlation of California Profilographs

Site: _____ Date:_____

Name of Company: _____

Manufacturer: _____ Serial #:_____

Operator: _____ Measuring Wheel #: _____

Is the Profilograph Being Independently Powered? Yes_____ No_____

If Answer to Above is Yes, How is it Powered? _____

Asphalt Correlation (Blanking Band = 0.0 mm)

Stations	Run #1	Run #2	Run #3	Average	Std. Dev.	Coeff. of Variation (%)
Average						

Correlation Benchmark Mean **= _____ mm/km (Provided)**

Average Coefficient of Variation **= _____ %**

Ratio of Company's Average to Correlation Benchmark **= _____**

Concrete Correlation (Blanking Band = 5.0 mm)

Stations	Run #1	Run #2	Run #3	Average	Std. Dev.	Coeff. of Variation (%)
Average						

Correlation Benchmark Mean **= _____ mm/km (Provided)**

Average Coefficient of Variation **= _____ %**

Ratio of Company's Average to Correlation Benchmark **= _____**

Figure 5 – Summary Sheet for Measurements by California Profilograph

Smoothness Measurements For Asphalt / Concrete Pavements

☐ Daily Working Sheet ☐ Running Summary

Contract No.:____________ Mix Type:__________ Profilometer Type / Serial #:____________ Page __________ of __________

Contractor/Owner-Operator:__________________ Filter Factor / Blanking Band (0 for Asphalt)__________________________________

Highway No.:____________ Lane No. and Description:______________________________________ Sublot _________ to __________

Sublot Information			Scallops / Surface Roughness Measurements												Sublot Payment Factor
			Date	Initial / Subsequent Measurements (Mark With an "X")				Scallops†				Roughness Measurements			
								Left Wheelpath		Right Wheelpath		Wheelpath			
SubLot #	Stations* (Start / End)	Length (m)		Initial	Subsequent #1	#2	#3	Station	Height (mm)	Station	Height (mm)	Left	Right	Mean (PI)	(Based on Final run)

Notes: * Areas that are superelevated or on curves should be designated as "(S)" or "(C)", respectively

† If a scallop is left unrepaired, write "(U)" after its height

Completed by:_________________ on _______________(date)