IMPLEMENTATION OF BEST PRACTICES FOR CONCRETE PAVEMENTS

GUIDE SPECIFICATION FOR CONCRETE PAVEMENT SMOOTHNESS – AASHTO R 54-14 (2018) COMMENTARY

January 2020

The current AASHTO R 54-14 specification (2018), *Standard Practice for Accepting Pavement Ride Quality When Measured Using Inertial Profiling Systems*, is a consensus-based document that was developed with input from owner-agency and pavement industry stakeholders. It is a template for incentives and disincentives for IRI-based ride quality specifications that can be used in part or in whole by owner-agencies in developing their own specifications.

The commentary provided herein is intended to supplement AASHTO R 54-14 (2018) by presenting recommendations for revised language in the existing specification and additional guidance for application of the specification for concrete pavements specifically. This commentary is based upon the current state of the practice for pavement smoothness and current understanding of the specific issues related to smoothness measurement on concrete pavements.

The commentary is organized based on the structure of R 54, with references to the various sections of the current version of R 54-14 (2018). For example, §3.1.2 refers to Section 3.1.2 of R 54-14 (2018). The commentary may be used by owner-agencies to revise the language found in R 54-14 (2018) when developing their own specifications based on the R 54 template or may be used to guide the usage and implementation of the specification.

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§3.1.2 IRI is a more objective measure of ride quality, or vehicle response to a pavement surface profile, than the profilograph index or straightedge measurements. For additional background on IRI, see references 9.5 and 9.6.

§3.1.4 Note that this definition may be misleading, and the following alternative is proposed:

> *Area of Localized Roughness (ALR)—any segment of roadway where the roughness contributes disproportionately to the overall roughness index value. The most common method for identifying ALR within an IRI-based specification is using a report of continuous IRI with a base length of 25 feet. This yields the IRI of every possible 25-foot segment. Any segment of pavement that causes the continuous report to exceed a threshold IRI value is considered a defective segment requiring correction.*
>
> *Note–The boundaries of an ALR typically do not precisely align with the boundaries of the*

feature(s) causing the roughness. Inspection of the measured profile and/or the pavement is required to identify the feature(s) causing the roughness and the area where corrective action would be most beneficial.

As of 2019, 15 states currently use a continuous IRI report (25-foot base length) for identifying ALR. For mainline paving on higher-speed facilities (greater than 45 mph), threshold values range from 80 to 200 inches/mile, with an average of approximately 148 inches/mile. For additional information on typical threshold values for localized roughness, see the annotations in §6.4.4.

§4.1 Note 2 is highly relevant for portland cement concrete (PCC) pavement and was included in R 54 at the request of the concrete pavement industry. At minimum, measurement using multiple-point height sensors or a continuous line over a width of 76.2 mm or more is recommended. Using a line laser with a 4-inch (100 mm) line, as Note 2 recommends, has produced satisfactory results. However, sensor hardware and processing algorithms change frequently, and each IPS unit must be verified for the texture type(s) built under a pay adjustment schedule.

Certification in accordance with R 56 is specified in §5.2 below. If certification is performed on a jointed PCC test section, care is required to avoid the confounding effects of short-term (e.g., diurnal) changes in profile caused by curl and warp.

§5.2 Currently, M 328 (§4.2.3) specifies a recording interval of 2.0 inches or less for a measured profile. To support the identification of specific features within the profile (e.g., locating joints), a recording interval of 0.75 inches or less is recommended, per R 36-13.

M 328 (§4.4) requires a profiler to alert the operator when a sensor signal is out of range. Although it is not in the specification, encourage the procurement of a profiler for quality control (QC) that automatically registers the following in its stored profile: (1) areas where sensors exceeded their range, (2) areas where the profiler operating speed was outside of the valid range, (3) areas where the profiler acceleration or deceleration was above a set threshold, and (4) areas where filter initialization was incomplete. (Note that NCHRP Report 914 by Karamihas et al. [2019] recommends these additions to M 328.)

§6.1 The optimal approach to nondirected QC testing is a business decision and depends on the specific circumstances of the job and the contractor's approach to management of risk/reward. It is expected that contractors who build up robust experience with nondirected QC testing will have a competitive advantage and deliver smoother pavement at a lower cost. To the extent possible, encourage nondirected QC testing and showcase success stories.

Do not permit measurements to be made by vehicle-mounted inertial profilers until the concrete has gained sufficient strength to support the vehicle's weight. However, encourage measurement of the finished surface as soon after paving as possible within this restriction. (The fewer days of production that pass without identifying a potential problem that causes roughness, the better.) For example, set the earliest timing for vehicle-mounted profilers based on material strength (e.g., 1,000 psi for lightweight profilers and 2,000 psi or more for high-speed profilers). As a general rule, pavement that is strong enough to support joint sawcut equipment should be strong enough to support lightweight profilers, at minimum.

Walking-speed profilers provide a means to obtain profiles and roughness values on PCC pavement in situations where insufficient material strength or insufficient space is available to accommodate inertial profilers.

Straightedges and profilographs are not sensitive to the same set of features as IRI. However, if a straightedge or profilograph is the only available QC tool due to cost, timing, or physical constraints, its use is encouraged. IRI is sensitive to roughness features that may not be registered by a straightedge or profilograph. However, most features that register on a straightedge or profilograph increase IRI. This includes virtually all features that would register as a defect or violate a bump template.

Use of real-time smoothness (RTS) measurement for QC should be encouraged but not required. RTS provides live quantitative feedback for evaluating the effects of changes in the paving process on the roughness of the paved surface. Some of those effects correlate to the roughness of the hardened surface. Note that RTS measurements should never be used for acceptance purposes because these measurements are typically made prior to finishing, texturing, curing, and joint sawing operations, each of which will have some impact on the final surface profile. See Rasmussen et al. (2013) and Fick et al. (2018) for additional information on RTS measurement.

§6.2 Timing affects the roughness of jointed PCC pavement because of (1) cyclic changes in (temperature) curling and (moisture) warping, (2) early, non-cyclic changes in (moisture) warping, (3) slow development of material strength in the days (and weeks) after placement, and (4) early changes in the structural status of sawcut joints. The optimal timing for roughness measurement depends on several factors, and very few data are available to serve as a guide.

Once the concrete has set and the joints are functioning, the extremes in the daily cycling of roughness typically occur just before sunrise and in the late afternoon. This is particularly the case over a daily cycle with clear skies. Some agreement is needed between the Owner-Agency and the contractor that defines the timing of the measurements. (Options include [1] attempting to capture the extremes, [2] attempting to capture the worst case, or [3] allowing the contractor to select and report the time of day of the measurements.) In any case, the time and date of the measurements should be included among the metadata captured with each profiler pass.

§6.2.1 The requirements described in R 57 reflect the extensive experience of several profiler operators. However, as with any specification, much of the background information is omitted. For construction QC on PCC pavement, the following practices should be emphasized:

R 57, §5.3.2.2.2 requires verification of longitudinal distance accuracy to within 0.15 percent on a test section of 528 feet or longer. This accuracy level (when considering the effects of tire warming) is not sufficient to pinpoint specific features within QC measurements that cover a much longer distance. In particular, reference landmarks may be needed to find the specific locations of features that cause localized roughness and/or require correction. Collection of auto-triggered event markers at landmarks no more than 0.5 miles apart on tangent sections is recommended. For sections with horizontal curvature, more frequent landmarks may be required.

R 57, §5.3.2.4.1 specifies the measurement of IRI on a control section to within 5 percent of the established value. This may be problematic on jointed PCC, because the IRI value may vary *by more than 5 percent, either due to changes in the profile as the material sets or cyclic changes in curl. However, comparison of filtered profiles and roughness profiles can still reveal whether equipment problems have occurred. To mitigate this potential problem, measure the control section under the same conditions (e.g., at the same time of day) when the IRI value was first established.*

R 57, §5.3.2.4.3 requires a calibration log. This is an important requirement for any measurements used for acceptance or pay adjustments. The following should be preserved and produced upon request: (1) distance measuring instrument (DMI) checks and the results (e.g., reference and measured distance and calibration factor change), (2) block test raw measurements and calibration factor changes, and (3) bounce test results (and raw data files). To the extent possible, these items should be saved in data files. (In the bounce test, for example, the logbook can show that a bounce test was performed and passed, but the raw data and results can reside within the data file.)

R 57, §5.3.2.3.2 requires a bounce test with a simulated speed at the midpoint of the manufacturer's recommended range. If QC testing is likely to be performed at a consistent speed throughout a job, select that speed for the bounce test simulation. Note that, in addition to high IRI values, inconsistent values produced by either the bounce or still test signify a potential equipment problem.

R 57 does not specifically require the inspection and cleaning of height sensor lenses. Encourage regular inspection of height sensor lenses for dirt and debris and inspection of the lenses for condensation at the start of a testing day. Do not inspect the lenses when the laser is powered. (Note: Some lasers emit harmful light that is not visible.)

R 57, §6.1, Table 1 specifies clean, dry pavement. Sawcut residue at joints is expected to artificially increase the measured roughness.

§6.3 *In practice, it is typical for Owner-Agencies to require contractor measurements to be within 5 to10 percent of the Owner-Agency's test results. Cyclic changes and early-age changes in the roughness of a jointed PCC's profile may account for a portion on the difference observed in the verification testing. Comparison of filtered profiles may be needed to detect changes in roughness caused by changes in slab curl and warp. To mitigate this potential problem, perform QC testing and verification testing under the same conditions (e.g., at the same time of day, temperature, and cloud cover conditions).*

§6.4 *The Profile Viewer and Analysis (ProVAL) software package contains several tools for examining the sources of roughness, including identification of sources of localized roughness (via the Smoothness Assurance Module) and detection of periodic (i.e., regular) features such as curl and warp (via the Power Spectral Density module). Encourage the use of these tools for QC to the extent possible.*

Evaluation of profiles from both sides of the lane is recommended. E.g., evaluate the left- and right-side profiles independently for pay adjustment factors (§6.4.3) and localized roughness (§6.4.4). An option that reduces processing effort is the use of mean roughness index (MRI) for pay adjustment factors. However, the use of MRI is considered less rigorous than the use of other indices, and roughness thresholds must be adjusted accordingly. Localized roughness should be *evaluated using the left- and right-side profiles independently, regardless of the index selected for pay adjustment factors.*

Establish common landmarks at the start and end of the pavement and at intermediate points along the pavement for the duration of the job. As described in the discussion of R 57, §5.3.2.2.2 above, collection of auto-triggered landmarks is recommended to assist with the evaluation of the profiles for three reasons:

> *First, use of common landmarks helps ensure that profiles are measured over a common pavement segment for verification testing and helps reveal significant differences in longitudinal distance measurement.*
>
> *Second, landmarks provide a way to closely align repeated measurements for a pavement segment. (R 54 does not explicitly recommend using repeated passes. However, using repeated passes to overcome sources of random error that affect the assessed pay adjustment is recommended when it can be financially justified.)*
>
> *Third, landmarks in the measured profile provide a reference for locating areas of localized roughness and implementation of corrective action.*

§6.4.2 Exclude areas from Type A roughness measurement when valid operation of an inertial profiler is not possible. In these instances, application of Type B roughness measurement is highly recommended to ensure that localized defects are not present.

§6.4.3 The pay adjustment calculation shown in Table 3 is based on a continuous report of roughness (see reference 9.7), as opposed to a fixed-interval report. A continuous report is recommended because it removes the difficulties caused by splitting the pavement into discrete segments, that is, cases where particularly high or low roughness values are reported only as a consequence of the starting and ending points of an interval.

Currently, common practice is to use a fixed-interval report and to base pay adjustments on those fixed-interval IRI values. Typically, roughness is reported over 0.1-mile intervals throughout the job. In such cases, pay adjustment factors are still assigned to various roughness ranges and represent a value of pay adjustment per 0.1-mile of pavement. For intervals that include excluded areas, roughness is averaged only over the non-excluded length, and the pay adjustment is weighted in proportion to the non-excluded length. Segments where most of the 0.1-mile range is excluded are often excluded from the evaluation or evaluated using a Type B roughness measurement.

IRI ranges and pay adjustment factors vary widely among Owner-Agencies because thresholds are typically set based on local experience and the extent to which an Owner-Agency is willing to incentivize smoothness. Merritt et al. (2015) summarizes IRI thresholds used for pay adjustments in states with IRI-based specifications for PCC pavement. Tables C1 and C2 below, which summarize IRI-based specification thresholds and pay adjustments for concrete pavements, are updated versions of Tables 2 and 5 from Merritt et al. (2015).

Table C1 provides the range and average IRI/MRI values for incentive, full pay, disincentive, and corrective action found in current concrete pavement specifications. Note that not all states with IRI/MRI-based specifications provide both incentives and disincentives, and therefore the values *for incentives and disincentives may represent less than 28 states.*

Table C1. Summary of IRI/MRI thresholds for incentive, full pay, disincentive, and corrective action found in current specifications for concrete pavement.

		Incentive Upper Limit	***Full Pay Lower Limit***	***Full Pay Upper Limit***	***Disincentive Lower Limit***	***Disincentive Upper Limit***	***Threshold for Correction***
MRI & IRI (28 states)	*min*	*39.9*	*40.0*	*54.0*	*54.1*	*67.5*	*67.5*
	max	*68.0*	*68.1*	*93.0*	*93.1*	*140.0*	*140.0*
	avg	*56.8*	*57.1*	*72.3*	*71.8*	*94.2*	*93.9*

Table C2 provides the maximum, minimum, and average incentive and disincentive pay adjustments for states with IRI/MRI-based specifications for concrete pavement. Note that pay adjustments are applied either as dollars per lot (for different lot sizes) or as an increase or decrease in the percent contract unit price for the concrete pavement. As with the IRI/MRI thresholds, not all states provide both incentives and disincentives, and therefore the values for payment of incentives and disincentives may represent less than 28 states.

Table C2. Summary ride quality pay adjustments found in current specifications for concrete pavement.

Pay Adjustment Basis		***Maximum Incentive***	***Maximum Disincentive***
$ per lot (0.1 mi) 14 states	*min*	*$200*	*-$250*
	max	*$1,700*	*-$2,250*
	avg	*$1,087*	*-$1,088*
$ per lot (SY) 3 states	*min*	*$0.50*	*-$1.12*
	max	*$2.80*	*-$1.12*
	avg	*$1.65*	*-$1.12*
$ per lot (1.0 mi) 1 state		*$7,350*	*-$7,350*
$ per lot (0.01 mi) 1 state		*$50*	*-$500*
$ per lot (500 ft) 1 state		*$250*	*-$250*
Percent Contract Price 8 states	*min*	*101%*	*97%*
	max	*108%*	*50%*
	avg	*105%*	*80%*

In some cases, portions of the finished surface exist where the roughness is beyond the contractor's control. Examples include bridge decks, bridge approach slabs, railroad crossings, utility covers, gutter pans, and crowned intersection crossings. If the contractor has no control over the design or installation of these items, exclude at least 25 feet of pavement on either side of them from roughness calculations. In some cases, such as a slope break that occurs at the end of a bridge approach slab, exclusion of a longer distance past the end may be needed.

If the contractor is responsible for installing a built-in structure or has some opportunity to modify it (e.g., the elevation of a utility cover), a localized roughness provision may be appropriate.

Constraints on the paving process compromise the ability of the contractor to provide a smooth surface. Examples include excessive grade (e.g., more than 4.5 percent) or excessive curvature (e.g., a radius less than 1,000 feet) and the associated superelevation transitions, the paving of an overlay, the paving of one lane at a time, or requirements to match the profile of a curb or an adjacent lane. In these cases, the use of a secondary pay adjustment schedule with higher roughness values associated with each pay adjustment range may be appropriate. At minimum, application of a localized roughness provision is recommended.

Note that experience may be needed to determine the smoothness level that can be achieved in these instances. When paving an overlay or matching the profile of an adjacent pavement, the lowest roughness that can be achieved may depend on the roughness of the underlying or adjacent surface(s). In practical terms, limits on the roughness of the newly paved surface may be set based on the IRI of the underlying or adjacent surface using some form of a percent-improvement specification. In the case of paving next to an adjacent lane, different types of roughness affect paving differently (e.g., long-wavelength roughness is more difficult to correct than short-wavelength roughness). If the expense is justified by the pay adjustment schedule, an Owner-Agency may consider allowing the contractor to modify (e.g., diamond grind) the underlying or adjacent surface as part of the plan to provide a smooth final surface. These factors should all be carefully considered by the project designer prior to project letting with a smoothness specification.

§6.4.4 Avoiding localized roughness is important because areas of localized roughness can reduce ride comfort, increase vehicle wear, and/or accelerate pavement deterioration, even when they appear on an otherwise smooth pavement. When no explicit specification for localized roughness is applied, some incentive still exists to avoid it because of the detrimental effect on overall roughness. In particular, Owner-Agencies should encourage contractors to diagnose areas of localized roughness as a means to maximize their performance under §6.4.3.

Graduated pay adjustment for localized roughness, as shown in Table 4, is not common in practice. Most existing specifications require corrective action to remove all ALR or the assessment of a negative pay adjustment in lieu of corrective action. Pay adjustments for ALR vary from $10 to $30 per foot of length of ALR or $1,200 to $4,000 per 0.1-mile lot containing ALR (see Merritt et al. 2015).

A graduated scale with a format similar to that shown in Table 4 provides a way to avoid a large pay adjustment in cases where an ALR appears that is just barely above the roughness threshold or is only above the threshold for a short length. Engineering judgment should be applied to avoid requiring correction of ALR with a low peak roughness or a short length. Another alternative is to include a specification provision for a minimum length of ALR (as determined from the report of continuous IRI with a 25-foot base length) before corrective action is required. A minimum length of 15 feet has been specified for this purpose by at least one Owner-Agency.

§6.4.5 This section specifies corrective work for areas of localized roughness. Note that some Owner-Agencies also require corrective action or removal and replacement of areas where the

prevailing roughness is above a given threshold (i.e., corresponding to the uppermost row of values in Table 3 or the roughness of a 0.1-mile segment above a specified limit). The effectiveness (and cost-effectiveness) of corrective action depends on the cause of the roughness and the options available. Owner-Agencies often do not permit contractors to grind to obtain a positive pay adjustment because this restriction encourages good paving practice as the preferred method to achieve a smooth surface. When grinding is used, some provision may be needed to avoid excessive loss of pavement thickness, such as performing final thickness acceptance testing after all corrective action is complete.

As discussed in §6.4 the ProVAL software package contains several tools for identifying localized roughness requiring corrective work. It also contains a grinding simulation tool (via the Smoothness Assurance Module) for use in evaluating the effectiveness of diamond grinding for smoothness correction. Note that this is a simulation tool, and the results obtained will only be as good as the information input into the simulation. Owner-Agencies should encourage the use of this tool for developing a corrective action plan but should not require that it be used because contractors may have their own preferred methods for developing a corrective action plan. Owner-Agencies should also not use this tool to prescribe corrective action but should use it as a tool for general assessment of the amount of corrective action required.

§7.1 Final measurement for acceptance is typically based on the final 0.1-mile-interval IRI/MRI values after any corrective action to remove ALR. The basis of payment is typically one of the following (as shown in the table in §6.4.3 above): a fixed dollar amount for the 0.1-mile (or other) interval, a fixed dollar amount per square yard of pavement placed in the 0.1-mile interval, or a percent increase/decrease in the contract unit price for the concrete pavement placed in the 0.1-mile interval.

§9 Additional References

Fick, G., D. Merritt, P. Taylor, T. Hanke, N. Torres, and R. Rasmussen. 2018. Implementation Support for Second Strategic Highway Research Program (SHRP2) Renewal R06E: Real-Time Smoothness Measurements on Portland Cement Concrete Pavements During Construction. National Concrete Pavement Technology Center, Iowa State University, Ames, IA.

Karamihas, S. M., M. E. Gilbert, M. A. Barnes, and R. W. Perera. 2019. NCHRP Research Report 914: Measuring, Characterizing, and Reporting Pavement Roughness of Low-Speed and Urban Roads. National Cooperative Highway Research Program, Washington, DC.

Merritt, D. K., G. K. Chang, and J. L. Rutledge. 2015. Best Practices for Achieving and Measuring Pavement Smoothness, A Synthesis of State-of-Practice. Louisiana Transportation Research Center, Baton Rouge, LA.

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