Review of Industry Developed Smoothness Specifications

Introduction
Since 2009, the concrete industry has been actively engaged in developing guidelines and evaluating specifications at the agency level. The following sections document the details of those efforts.

2009 – 2010 ACPA Relative Cost Task Force Efforts
In 2009, industry decided to update the ACPA 1995 Relative Cost survey as the results were almost 15 years old at that time (1). One aspect of the updated report included a smoothness survey. The purpose of the smoothness survey was twofold: First, to determine the cost, if any, to achieve various ranges of specified smoothness levels; and, second, to determine what additional effort is needed to meet a given level of smoothness and what that effort may consist of (2). To accomplish this, a smoothness level of 7 in./mi. on a 0.2” blanking band was selected as the “Control” roughness by which all improvements would be compared. At this time, most state agencies were using the profilograph profile index for smoothness acceptance.

Too few responses were received in this survey to provide a comprehensive evaluation, however, Figure 1 indicates the IRI results. The blue line represents contractor costs, and, as evident, the cost to achieve lower and lower levels increases at an ever-increasing rate and is essentially an exponential curve. The contractor costs indicated (blue line) in Figure 1 are a result of diamond grinding the surface to achieve the lower IRI values. Contractors assumed diamond grinding was necessary for values below an IRI of 70 to 90 with the cost associated with the percent of surface ground. For low IRI values blanket grinding was indicated, and an additional cost of approximately $2.25 incurred to achieve an IRI of 35 or less. At the time of this survey (2009) real time smoothness and stringless paving were not mainstream.

![]()
Review of Industry Developed Smoothness Specifications

Figure 1  IRI Level Versus Additional Cost to Obtain Smoothness Values Less than 7 inches per mile (0.2’ blanking band) When Using a 0 Blanking Band Specification (2)

Profile Index (PI) Incentive Levels in Use in 2013

Figure 2 indicates the additional costs necessary to get below 7 inches per mile with a 0.2 inch blanking band specification. As mentioned, these results were developed by the ACPA 2010 survey (2). In addition, a 2013 survey conducted by the National Concrete Consortium (NCC), and augmented by the ACPA/IGGA, evaluated maximum incentive values for different smoothness levels (3). These survey results have been overlaid onto the plot enabling a comparison of the incentives versus costs. The round points indicate incentive values and the square points and line represent contractor estimated costs.

Figure 2  Additional Cost to Obtain Smoothness Values Less than 7 inches per mile

The square yard cost of smoothness has remained similar across the different roughness statistics, even though the states differ considerably among themselves at times. If the average in-place cost of concrete pavement were assumed as $35 sq yd, a 5% incentive would be $1.75 which is typically the upper range on smoothness incentives.

2013 ACPA Smoothness Guidelines

In 2013 the ACPA smoothness task force developed smoothness guidelines to assist in specification development (4,5). Table 1 below indicates the recommended lot-based smoothness and incentive/disincentive levels. Lots represent 528 ft long section of a lane. The Table is divided into speeds ranges; above and below 45 mph. In addition, there is also a separate ACPA specification for
Review of Industry Developed Smoothness Specifications

industrial facilities which is not discussed in this document. It should also be noted that the specification does not currently provide additional incentives for smoothness levels below and MRI of 40.

Table 2 pertains to Areas of Localized Roughness (ASR). For ALR there is no associated incentive/disincentive, only a minimum threshold that needs to be met. As with lot-based smoothness requirements, two speed ranges are provided. Since IRI is a simulation of a vehicle traveling at 50 mph, extension to lower speed facilities should require different specifications than higher speed facilities.

<table>
<thead>
<tr>
<th>TABLE 1 PRICE ADJUSTMENT SCHEDULE**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed Less Than 45 MPH</td>
</tr>
<tr>
<td>MRI</td>
</tr>
<tr>
<td>&lt;55</td>
</tr>
<tr>
<td>55 to 74</td>
</tr>
<tr>
<td>75 to 90</td>
</tr>
<tr>
<td>91 to 110</td>
</tr>
<tr>
<td>&gt;110</td>
</tr>
</tbody>
</table>

**It is important to note that incentive/disincentives can vary based upon the particular roadway conditions, construction practices, and agency requirements. Each project should be specified based on its own merits and requirements.

<table>
<thead>
<tr>
<th>TABLE 2 SHORT-INTERVAL ROUGHNESS REQUIREMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed Less Than 45 MPH</td>
</tr>
<tr>
<td>IRI ≤ 190</td>
</tr>
</tbody>
</table>

2014 IGGA Diamond Grinding Specifications

In 2014, the IGGA updated its smoothness specifications for diamond grinding. Specifications were developed for three categories of roadway; Next Generation Concrete Surfaces, City Streets, and Preservation Grinding. Preservation grinding is conducted on existing roadways and does not include bump grinding on new construction. As with the ACPA specifications, two roadway speeds are considered; above and below 45 mph.

<table>
<thead>
<tr>
<th>TABLE 3 SMOOTHNESS REQUIREMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posted Speed Limit (mph)</td>
</tr>
<tr>
<td>Existing Segment MRI</td>
</tr>
<tr>
<td>Required Post Grind MRI</td>
</tr>
</tbody>
</table>

Note: the 0.35 multipliers will probably be adjusted to conform to the AASHTO diamond grinding specification once it is developed and approved possibly during 2018.

<table>
<thead>
<tr>
<th>TABLE 4 RECOMMENDED PRICE ADJUSTMENTS</th>
</tr>
</thead>
</table>


IGGA specification development involved reviewing existing specifications and contractor experience. At the time, actual pre and post grind data was not available for evaluation. It should be noted that the preservation grinding specification is based upon a percent improvement concept. Since existing roads can be very rough, the only way to get them smooth is by reducing thickness. The use of a percent improvement allows the roads to achieve a significant improvement without a significant reduction in the thickness to achieve an arbitrary new construction standard.

In a perfect world, it would be desirable for an owner to conduct a pre-evaluation profile assessment to determine the specification limits based upon the amount of removal they will accept for the existing conditions. This allowable thickness removal would then establish the project smoothness requirements. Currently, this is not done by any agency.

Figure 3 indicates a plot used by the IGGA Tech Committee to see how the incentive/disincentive strategies varied among different roadway categories and construction types. These plots are developed from IGGA specifications.

It should be noted that preservation grinding incentives/disincentives are less than typically used on new construction where the value of the product is much larger. However, if a 5% cap was placed on the item cost, incentives/disincentives would not accurately reflect the cost of achieving smooth roads and as such, it is more difficult to establishing appropriate values without the attendant increase in pavement performance resulting from increased smoothness known.
2017 AASHTO TSP2 Concrete Task Force Diamond Grinding Specification Development

In 2016, AASHTO established a concrete task force under the Transportation System Preservation Technical Services Program (TSP-2) umbrella. This task force was established to develop concrete preservation specifications for submission to the AASHTO TSSb for consideration as an AASHTO specification. The first spec considered for development was the diamond grinding specification. Although the IGGA preservation spec was the basis for much of the proposed specification, a need existed to acquire actual pre and post grind data from state projects. This turned out to be more difficult than anticipated as actual construction profile data was difficult to retrieve.

Each of seven states eventually provided data for analysis. Two of the states had actual construction data, while five of the states provided PMS data. The difficulty with PMS data is that the before and after measurement times vary considerably from actual construction data and the sensors used for PMS data are sometimes not appropriate for diamond ground surfaces.
As noted in Figure 4, the average percent improvement (i.e. 50%) differs considerably among states. When all the data is combined, the average percent improvement is 50%. Figure 5 indicates that the percent improvement decreases as initial roughness decreases to a limiting value at which it appears to not decrease any further.
The concrete task force developed the proposed smoothness requirements indicated in TABLE 5. As with the other industry developed specifications, there are two roadway speed categories. In addition, there are two existing roughness levels. For smoother existing roughness levels (i.e. $\leq 130$) a single specified smoothness value is required. This is to prevent reducing thickness too much to achieve a percent improvement.

<table>
<thead>
<tr>
<th>Posted Speed Limit (MPH)</th>
<th>Existing MRI</th>
<th>Required Post Grind MRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\leq 45$</td>
<td>$\leq 230$</td>
<td>$&lt; 138$</td>
</tr>
<tr>
<td>$&gt;$ 45</td>
<td>$&gt; 230$</td>
<td>$\leq 0.4^* \text{ (Existing Segment MRI)}$</td>
</tr>
<tr>
<td></td>
<td>$\leq 130$</td>
<td>$&lt; 78$</td>
</tr>
<tr>
<td></td>
<td>$&gt; 130$</td>
<td>$\leq 0.4^* \text{ (Existing Segment MRI)}$</td>
</tr>
</tbody>
</table>

**TABLE 5—Proposed AASHTO Smoothness Requirements**
Review of Industry Developed Smoothness Specifications

2018 Southwest Concrete Pavement Association Smoothness Specification Development

For several years, industry and Caltrans has been working on improving smoothness specifications. The Southwest Concrete Pavement Association and its members have put together actual pre and post grind construction data to evaluate the percent improvement for five construction projects. They have also collected a small sample of new construction profile data. Figure 6 below indicates a scatter plot of the corrected roughness as a function of the existing roughness.

![Profile Grinding Improvement (Existing MRI vs Corrected MRI) (Courtesy SSI)](image)

The IGGA/ACPA requested the raw data from this plot, with the new construction data flagged so that cumulative distribution plots could be developed. Figure 7 represents the new construction data for the corrected roughness levels. As indicated, 50% of the lots achieved a corrected MRI of 58 or less.

Figure 8 indicates the percent improvement achieved on the new construction diamond ground lots. As indicated, 50% of the lots achieved greater than a 30% improvement.

Figure 9 indicates the corrected roughness (i.e. MRI) for preservation grinding. As indicated, the average corrected roughness (i.e. MRI @ 50%) was approximately 60.

Figure 10 indicates the percent improvement for preservation grinding. As indicated, the average percent improvement achieved was 50%.
Review of Industry Developed Smoothness Specifications

Figure 7 New Construction Corrected Levels (i.e. MRI) Achieved

Figure 8 Percent Improvement for New Construction
Review of Industry Developed Smoothness Specifications

Figure 9  Corrected Roughness (i.e. MRI) for Preservation Grinding

Figure 10  Percent Improvement for Preservation Grinding
Review of Industry Developed Smoothness Specifications

References
3. M. Masten, National Concrete Consortium Survey, March 2013, CP Tech Center
4. L. Scofield, “Development of PCCP Ride Measurement Equipment and Specifications”, ACPA Task Force, American Concrete Pavement Association, 4-7-13

Excellent Smoothness References Not Included in this document
1. D. Harris, “Development of Methods and Specifications for the Use of Inertial Profilers and the International Roughness Index for Newly Constructed Pavement”, Joint Transportation Research Program Technical Reports, Purdue University, 2013
Appendix 1: Evaluation and Impact of Initial Pavement Smoothness

Introduction

Initial pavement smoothness has been of interest to pavement designers and the traveling public since the early 1900s. No other pavement quality has as significant impact on the traveling public and perhaps pavement performance as roughness. The concept of pavement serviceability, by which all federal aid projects have been designed by over the past half century, is essentially based on initial pavement smoothness and how roughness changes over time. The new ME Design process also incorporates roughness as one of its design parameters.

Most DOT pavement management systems (PMS) trigger their rehabilitation and preservation activities based, at least, upon the current level of roughness and/or the rate of change in roughness. This essentially establishes when intervention will occur, impacting LCCA analysis and maintenance expenditures. Therefore, capital expenditures are directly related to pavement roughness.

Although it is a widely held belief that initial pavement smoothness ensures extended pavement life, historical data to support this has been tenuous at best. A recent report by the Indiana DOT has established, through evaluation of their PMS data, that such a correlation does exist and that they could establish their incentives and disincentives amounts as well as their initial pavement smoothness requirements based on this. This establishes, for the first time, smoothness specifications, and incentives and disincentives based upon extended pavement performance. Operating costs for traffic on smoother roadways has been evaluated and consistently demonstrates the value of smoothness on the operating vehicle costs (use phase) of the roadway.

The measurement of pavement smoothness has evolved from approximate profiling methods obtained at a walking speed to very accurate measurements obtained at highway speeds. It is now even possible to measure smoothness in real-time during paving. This change has allowed more research and analysis into pavement roughness statistics.

In recent times, the highway community is moving to the International Roughness Index (IRI) with approximately one third of the states currently using it for construction acceptance. Virtually, all states are using IRI as their roughness measurement in their PMS systems and this is one of the measurements that will be reported to the FHWA as part of the each state’s performance requirements.

With the introduction of IRI and the increased ability to accurately and efficiently measure smoothness, new construction specifications have seen a trend towards lower initial smoothness requirements and the use of the same specifications for both asphalt and concrete pavements. Additionally, a short interval roughness component somewhat analogous to the bump detection of old has been incorporated in current specifications. However, currently there is little data to support the relevance of this new statistic to consumer satisfaction and agencies are all over the board in specification values.

During the SHRP II research effort, project R06 evaluated the real-time smoothness measurement capability of current technologies. The SHRP II effort has now moved from the research
Appendix 1: Evaluation and Impact of Initial Pavement Smoothness

phase into the implementation/demonstration phase. Unfortunately, during the research phase the relationship between real-time smoothness measurements, QC, QA data, and acceptance testing was not established for concrete pavements. In addition, the relevance of the real-time smoothness measurements to the short-term roughness levels (i.e. 6 to 12 months after paving) was not obtained.

There is a need to determine if the real-time measurement, obtained before any joint cracking has taken place and hence curling and warping exists, is related to the post paving roughness levels. This is of particular concern if it is possible to reduce the initial real-time smoothness levels through mix changes which could ultimately negatively impact the long-term pavement durability or performance.

Research Needs

There is a need to conduct research into several primary areas.

- Relevance of Short Interval Roughness (i.e. localized roughness)
- Extent and Severity of Curl and Warp Issues Within the Industry
- Causes and Approaches to Mitigating Curl and Warp Issues
- Impact of Curl and Warp on Grinding Operations
- Implementation of Preservation Specifications based on pre-bid analysis of the existing roughness and thickness modification levels required to achieve the desired smoothness specifications.