Pavement Construction Smoothness Specifications in the United States

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In research conducted jointly by the University of Wyoming and the Wyoming Department of Transportation, current pavement construction smoothness specifications throughout the United States were collected and analyzed. A survey consisting of 13 questions dealing with pavement smoothness specifications, devices used for these specifications, and incentive and disincentive policies was sent out to all 50 state departments of transportation. Forty-five of the agencies responded to the survey. The responses were summarized in a computerized data base and analyzed for trends.

Road roughness is a major factor in evaluating the condition of highway pavement sections because of its effects on ride quality for road users and vehicle operating costs. In its broadest sense, road roughness has been defined as "the deviations of a surface from a true planer surface with characteristic dimensions that affect vehicle dynamics, ride quality, dynamics loads, and drainage" (*1*). Despite this broad description, the practice today is to limit the measurement of roughness qualities to those related to the longitudinal profile of the road surface that cause vibrations in vehicles using the road. Road roughness can also be defined as "the distortion of the road surface that imparts undesirable vertical accelerations and forces to the vehicle or to the riders and thus contributes to an undesirable, uneconomical, unsafe, or uncomfortable ride" (*2*). In general, road roughness can be caused by any of the following factors (*3*):

- Construction techniques that allow some variation from the design profile;
- Repeated loads, particularly in channelized areas, that cause pavement distortion by plastic deformation in one or more of the pavement components;
- Frost heave and volume changes due to shrinkage and swell of the subgrade; and
- Nonuniform initial compaction.

During the past three decades, several studies pointed out the major penalties of roughness to the user. In 1960 Carey and Irick showed that a driver's opinion of the quality of serviceability provided by a pavement surface is influenced primarily by roughness (*4*). Between 1971 and 1982, the World Bank supported several research activities in Brazil, Kenya, the Caribbean, and India, the main purpose of which was to investigate the relationship between road roughness and user costs. In 1980 Rizenbergs pointed to the following penalties associated with roughness: rider nonacceptance and discomfort, less safety, increased energy consumption, road-tire loading and damage, and vehicle deterioration (*5*).

Gillespie and Sayers examined the relationship between road roughness and vehicle ride to illustrate the mechanisms involved and to reveal those aspects of road roughness that play the major role in determining the public's perception of road serviceability (*6*). It is believed that the initial roughness of a pavement section will affect its long-term performance. Recently, a study conducted by Janoff suggested that initial pavement roughness measurements are highly correlated with roughness measurements made 8 to 10 years after construction.

Because of the importance of pavement roughness, most state highway agencies (SHAs) have established smoothness specifications for new pavement construction. Some SHAs require that a specific limit of smoothness be met, whereas others use a variable scale with price adjustment factors related to the degree of smoothness achieved. These price adjustments are based on the assumption that lower initial pavement roughness will result in better long-term pavement performance.

The University of Wyoming and the Wyoming Department of Transportation (DOT) are performing a joint research project to evaluate the effectiveness of smoothness specifications in Wyoming. As part of this evaluation, a nationwide survey was performed in spring 1994. The survey contained questions related to pavement smoothness specifications used by different SHAs. Most SHAs responding to the survey indicated their interest in learning about the findings of the survey. This paper summarizes the responses to the survey and shows the need for more uniform standards across the nation to accept pavement smoothness.

OBJECTIVES OF SURVEY

Copies of the smoothness specifications survey were mailed to all 50 SHAs in February 1994. The objectives of the survey were to

1. Identify the different roughness measurement devices used by SHAs to accept pavement smoothness for new construction,
2. Determine the acceptance limits for the various roughness measurement devices,
3. Identify SHAs that have incentive and disincentive policies for initial pavement smoothness,
4. Determine how SHAs developed their incentive and disincentive policies,
5. Estimate the percentage of pavement sections that qualified for incentives or disincentives in recent years, and
6. Evaluate the effectiveness of the various smoothness specifications.

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RESULTS FROM SURVEY

The construction smoothness survey included 13 questions aimed at satisfying the objectives stated. All states except California, Delaware, Missouri, Nevada, and Utah responded to the survey. The responses have been reduced and summarized in the sections that follow.

SHAs with Smoothness Specifications

Of the 45 SHAs that responded to the survey, only Massachusetts, Rhode Island, and Vermont indicated that they do not have any type of smoothness specifications. This rate implies that most highway agencies perceive initial pavement smoothness as being important.

Roughness Measurement Devices Used in Accepting Pavements

Many roughness measurement devices are on the market today. The accuracy and repeatability of measurements obtained with various devices vary from poor to excellent. A point of interest in this research project was to determine which measurement devices are being used for accepting new pavements. As indicated in Table 1, 30 out of 42 SHAs with smoothness specifications indicated that they use the California-type profilograph in accepting portland cement concrete (PCC) pavements. Five SHAs use the Rainhart profilograph, one uses the Mays meter, and four use other devices. The Michigan and Minnesota DOTs indicated that they use the GM profilometer (Michigan also uses the California-type profilograph). The New Jersey and Florida DOTs use a rolling straight edge for accepting concrete pavements. Alaska, Maine, and New Hampshire indicated that they do not build PCC pavements.

For the acceptance of new asphalt cement (AC) pavements, 15 SHAs indicated using the California-type profilograph and 16 use some form of a straight edge that varies in length between 3.05 and 7.62 m (10 and 25 ft). As presented in Table 1, five states used the Mays meter and four states use another type. Florida and New Jersey use rolling straight edges. Arizona uses the K.J. Law 690 DNC, and Michigan uses the GM profilometer and the California-type profilograph.

Minnesota, North Carolina, and Pennsylvania did not indicate the devices used for accepting asphalt sections. It should be mentioned that all SHAs using straight edges to accept asphalt pavements do not have any incentive and disincentive policies.

Acceptance Limits for Concrete Pavement

As presented in Table 2, most SHAs using the California profilograph specify a maximum smoothness acceptance limit of 110 or 158 mm/km (7 or 10 in./mi) for concrete pavement. An acceptance limit of 789 mm/km (50 in./mi) is used by Kansas DOT because of the elimination of the blanking band when reducing the pavement profile. Kansas does this to reduce the possibility of a long and low-amplitude wave being missed. Five states indicated using the Rainhart profilometer with various acceptance limits ranging from 63 to 189 mm/km (4 to 12 in./mi). Michigan and Minnesota indicated using the GM profilometer with acceptance limits of 49.8 ride quality index and 24 root mean square acceleration, respectively. Florida and New Jersey have an acceptance limit of 1 mm/m (1/8 in. in 10 ft) using a rolling straight edge. West Virginia uses the Mays ride meter with an acceptance limit of 1579 mm/km (100 in./mi).

Acceptance Limits for Asphalt Pavements

Most SHAs that pay pavement incentives or disincentives on asphalt pavements use the California-type profilograph. As indicated in Table 3, the consensus for an acceptance limit was 110 or 158 mm/km (7 or 10 in./mi). The rest of the SHAs indicated using a range of 47 to 189 mm/km (3 to 12 in./mi) except for Kansas, where a value of 631 mm/km (40 in./mi) is used for accepting

TABLE 1 Roughness Measurement Devices Used by SHAs To Accept Pavements

		Device Type				
		California Type Profilograph	Rainhart Profilograph	Straight Edge	Mays Meter	Others
Pavement Type	PCC*	AL, AZ, AR, CO, CT, HI, ID, IL, IN, IA, KS, LA, MD, MI, MS, MT, NE, NM, NY, ND, OH, OK, OR, PA, SD, TX, VA, WA, WI, WY	GA, KY, NC, SC, TN	0	WV	FL, MI, MN, NJ
	AC**	AL, ID, IL, IN, IA, KS, LA, MD, MI, NE, OH, OK, TX, VI, WI	0	AL, AR, CO, CT, HI, ME, MS, MT, NH, NM, NY, ND, OR, SD, WA, WY	GA, KY, SC, TN, WV	AZ, FL, MI, NJ

* PCC: Portland Cement Concrete

** AC: Asphalt Cement

TABLE 2 Acceptance Limits for PCC Pavements

	Acceptance Limits						
	63 mm/km 4 in/mile	79 mm/km 5 in/mile	95 mm/km 6 in/mile	110 mm/km 7 in/mile	158 mm/km 10 in/mile	189 mm/km 12 in/mile	789 mm/km 50 in/mile
California Type Profilograph	0	ID, ND	AL, CO, LA	AZ, AR, IA, MD, MS, NM, OH, OK, OR, WA, WY	HI, IL, MI, NE, PA, SD, TX, VA, WI	CT, IN, MT, NY	KS
Rainhart Profilograph	NC	0	0	GA	TN	KY, SC	0

TABLE 3 Acceptance Limits for AC Pavements, California Profilograph

	Acceptance Limits					
	47 mm/km 3 in/mile	95 mm/km 6 in/mile	110 mm/km 7 in/mile	158 mm/km 10 in/mile	189 mm/km 12 in/mile	631 mm/km 40 in/mile
California Type Profilograph	LA	AL, TX	ID, IA, MD, NE, OH, OK,	IL, MI, VA, WI	IN	KS

asphalt pavements with the same data reduction policy as described earlier for concrete pavements. Georgia, Kentucky, South Carolina, Tennessee, and West Virginia use the Mays meter with varying acceptance values, as indicated in Table 4. Four SHAs indicated using nonprofilograph devices for accepting asphalt pavements. Michigan uses both the California type profilograph and the GM profilometer; acceptance limits are 158 mm/km (10 in./mi) for the California profilograph and 49.8 ride quality index for the GM profilometer. Arizona has an acceptance limit of 1 mm/m (1/8 in. in 10 ft) using the K.J. Law 690 DNC. The rolling straight edge is used with acceptance limits of 2 mm (3/16 in.) for a 4.57-m (15-ft) length and 3 mm (1/8 in.) for a 3.05-m (10-ft) length by the Florida

TABLE 4 Acceptance Limits for AC Pavements, Mays Meter

Acceptance Limits			
Mays Meter Number			Rideability Index
35	40	100	3.6
GA, TN	SC	WV	KY

and New Jersey DOTs, respectively. A straight edge was the device of choice for all states without incentive and disincentive policies.

Incentive and Disincentive Policies

Incentive and disincentive policies used by different SHAs are of great interest to this research project. Table 5 gives the number of SHAs that have some sort of incentive or disincentive policy. Seventeen SHAs had incentive as well as disincentive policies for concrete pavements, but only 10 SHAs had both incentives and disincentives for asphalt pavements. Some SHAs had only incentive policies; others had only disincentive policies.

The information received on the actual incentive and disincentive policies varied greatly, with no more than two SHAs having similar policies. However, most SHAs had a similar upper-range adjustment price factor of 105 percent for incentives and a lower range of 90 percent for disincentives. Several SHAs would reduce the incentive percentage by 1 percent and increase disincentive percentages by 2 percent for every increase of 16 mm/km (1 in./mi). Examples of two incentive and disincentive policies are presented in Table 6. The immense variance of incentive and disincentive policies among SHAs indicates the variability of opinion on what profilograph index (PI) values indicate smooth or rough roads. More research is needed to determine the effect of PI values on the short- and long-term ridability of roads.

Development of Incentive and Disincentive Policies

As presented in Table 7, 22 SHAs indicated using engineering judgment in developing their current incentive and disincentive policies. Five SHAs based their specifications on research. However, states did not identify the type of research, length of study, or number of projects analyzed. Only three states indicated following AASHTO guidelines in the development of their specifications.

As indicated in Table 8, a majority of states indicated performing smoothness testing the same day or the day after pavement was laid for both asphalt and concrete pavements. Others responses indicated testing within 30 days or before the section is opened to traffic.

Performance and Percentages of Sections Qualifying for Incentive or Disincentive

Most SHAs said that they do not keep track of the percentages of pavement sections receiving incentives or disincentives. Those SHAs with good records showed significant differences in the percentages of sections receiving incentives or disincentives. The range of concrete sections that received incentives was 10 to 98 percent, whereas that incurring disincentives was 0 to 100 percent. New Jersey, the SHA reporting 100 percent disincentive on concrete pavements, requires less than 5 percent of the total lot to have surface variations greater than 1 mm/m (1/8 in. in 10 ft).

The variations among SHAs when considering asphalt pavements were as much as concrete pavements. The range of asphalt sections that received incentives was 15 to 95 percent; that incurring disincentives was 1 to 100 percent. Wisconsin, the SHA reporting 100 percent disincentive, assesses disincentives to any pavement that has a PI higher than 158 mm/km (10 in./mi) using a California-type profilograph.

Fourteen SHAs indicated observing roughness-related problems on sections that had received incentives. Some of these problems are due to the specifications, which do not always eliminate wheel chatter, or long wavelengths that create a roller coaster effect.

Effectiveness of Acceptance Specifications

The satisfaction of different SHAs with their current smoothness specifications was determined in this survey. Most SHAs rate their smoothness specifications as good or very good (Table 9). Only two states indicated poor satisfaction with their smoothness specifications.

CONCLUSIONS AND RECOMMENDATIONS

In this paper the responses of SHAs to a comprehensive pavement smoothness survey were summarized. These responses lead to the following conclusions:

- There is a great interest among SHAs in the subject of pavement smoothness specifications.

TABLE 5 SHAs with Incentive and Disincentive Policies

	Incentives and Disincentive	Incentives Only	Disincentive Only	None
PCC	AL, AZ, CT, IL, IA, KS, KY, MN, MT, NE, ND, OH, PA, SD, TX, VI, WI	MI, NM, OR, OK, WY	IN, LA, MD, MS, NJ, NY, SC, WV	AK, AR, CO, FL, GA, HI, ID, ME, MA, NH, NC, RI, TN, VT, WA
AC	AL, AR, IL, IA, KS, KY, NE, TN, TX, VA	MI, OK	IN, LA, MD, NJ SC, WI	AK, AR, CO, CT, FL, GA, HI, ID, ME, MA, MN, MI, MT, NH, NM, NY, NC, ND, OH, OR, PA, RI, SD, VT, WA, WV, WY

TABLE 6 Incentive and Disincentive Policies of Texas (*L*) and Alabama (*R*) DOTs

PI* mm/km (inches/mile)	Price Adjustment Factor
<47 (<3)	105%**
49 to 63 (3.1 to 4)	104%
65 to 79 (4.1 to 5)	103%
80 to 95 (5.1 to 6)	102%
96 to 110 (6.1 to 7)	101%
112 to 158 (7.1 to 10)	100%
159 to 174 (10.1 to 11)	98%
175 to 189 (11.1 to 12)	96%
191 to 205 (12.1 to 13)	94%
207 to 221 (13.1 to 14)	92%
223 to 237 (14.1 to 15)	90%
>237 (>15)	Correct

PI* mm/km (inches/mile)	Price Adjustment Factor
<47 (<3)	105%
49 to 95 (3.1 to 6)	100%
96 to 126 (6.1 to 8)	95%
128 to 158 (8.1 to 10)	90%
>158 (>10)	Correct

* Profilograph Index

** Percentage of Contract Unit Price

TABLE 7 Sources for Development of Incentive and Disincentive Policies

Research	AASHTO Guidelines	From Other States	Engineering Judgment Combined With One Other Category	No Specifications
CT, IL, OK, PA, WV	MS, OH, TX	MD, NY	AZ, HI, IN, IA, KS, KY, LA, MI, MN, MT, NE, NJ, NM, ND, OR, SC, SD, TN, TX, VA, WI, WY	AK, AR, CO, FL, GA, ID, MA, ME, NH, NC, RI, VA, VT

- Most SHAs use the California-type profilograph to accept pavement smoothness.
- A few SHAs still use response-type devices to accept pavement smoothness.
- The acceptance limits for pavement smoothness vary greatly among SHAs. Two sections with the same smoothness level may receive disincentives in one state and incentives in another.
- Most SHAs base their specifications on engineering judgment rather than research.
- Most SHAs are highly satisfied with their current smoothness specifications.

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TABLE 8 Timing of Pavement Smoothness Testing

		Time of Testing			
		Same Day	Next Day	End of Construction	Others
Pavement Type	PCC	AR, CO, OR, PA	AL, AR, CT, GA, ID, IL, IN, IA, KS, LA, MS, NM, NY, NC, ND, OH, OK, SD, TX, VA, WA, WI, WY	FL, KY, MN, NJ	HI, MD, MI, MT, NE, SC, TN, WV
	AC	AK, CO, KS, ME, NH, OR, VA, WA, WI	AL, AR, CT, GA, ID, IN, IA, LA, MS, NM, NY, ND, OH, OK, SD, TX, WY	FL, IL, KY, NJ	AZ, HI, MD, MI, MT, NE, SC, TN, WV

TABLE 9 Effectiveness of Smoothness Specifications as Rated by SHAs.

		Pavement Type	
		PCC	AC
Rating	Excellent	AR, KS, PA, VA	KS
	Very Good	AL, GA, ID, IA, LA, MN, MS, MT, NE, NY, OH, SD, TN, WV, WI	AL, AK, GA, ID, IA, KY, LA, MS, MT, NE, NY, OH, SD, TN, VA, WV,
	Good	AR, CT, FL, HI, IL, IN, MD, MI, NC, ND, OK, OR, SC, WY	AR, CT, FL, HI, IL, IN, MD, ME, MI, ND, OK, OR, SC, WI, WY
	Fair	KY, NJ	NJ
	Poor	CO, TX	CO, TX
	No Answer	NM, WA	AZ, NH, NM, WA,
	No Specifications	AL, ME, MA, NH, RI, VT	MA, MN, NC, PA, RI, VT

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