Roughness Progression on Superpave Pavements

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ABSTRACT

Pavement smoothness is a major factor affecting performance. It is believed that the service life of a pavement is directly related to its as-constructed smoothness. Since the introduction of the Superpave system in Kansas, bonus payment has increased significantly, indicating that these pavements are smoother initially. However, whether the roughness progression has slowed down is not known yet. This paper presents the analysis results of short-term roughness progression on Superpave sections in Kansas. Seventeen test sections built between 1999 and 2001 were selected for the study. These pavement sections were constructed over different subgrade and base types, and different PG binders were used in the asphalt layers. Annual roughness data was collected from the Kansas Department of Transportation's Pavement Management Information System database. International Roughness Index (IRI) was used as the roughness statistic. Statistical analysis results show that the type of project—reconstruction or rehabilitation—has a significant effect on short-term roughness. It was found that the short-term roughness of the Superpave sections with aggregate base was significantly lower than those with other base types. The analysis results also show that future roughness is a function of initial roughness. This indicates that a smooth Superpave pavement will remain smoother over time.

Key words: pavement—smoothness—superpave

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INTRODUCTION

Pavement smoothness is probably the single most important factor of performance from the standpoint of traveling public. Road user surveys identify pavement smoothness as the most important measure of pavement quality (NQI 1996; Keever et al. 2001). Studies at the road test performed by the American Association of State Highway Officials (AASHO) showed that the subjective evaluation of pavement, based on mean panel ratings, was also primarily influenced by roughness (Hass et al. 1994). Smoothness plays a significant role in the construction, functionality, and performance of roadways (Wolters and Grogg 2002). Many state agencies have adopted specifications that require minimum levels of smoothness for newly built pavements, with some specifications incorporating significant incentive/disincentives as additional encouragement for attaining specified smoothness levels. There are many factors that contribute to the roughness (or lack of smoothness) of a pavement surface. The most common cause of roughness is pavement distress. Common hot-mix asphalt pavement distresses that contribute to the roughness are fatigue cracking, deteriorated transverse cracks, corrugations, and shoving. Over time, swelling soils or frost heave can also contribute to the pavement roughness. Roughness can also be “built in” during construction because of several factors, such as, excessive mixture segregation, variability in the base and subgrade, poor grade control, inconsistency in paving operations, construction joints, and random construction deviations (Wolters and Grogg 2002).

PROBLEM STATEMENT

In 1985, the Kansas Department of Transportation (KDOT) selected a 25 ft California-type profilograph and 0.2 in blanking band for evaluation of profilograms for determining as-constructed smoothness of Portland cement concrete pavements (Hossain and Parcells 1994). By 1990, KDOT was successful in controlling concrete pavement smoothness. This success led to the development of profilograph-based specifications for asphalt concrete (AC) pavements in 1990. Profilograph results for ensuring smoothness of bituminous pavement with higher than four-inch paving depth was implemented through Special Provision 90P-39 (Hossain and Parcells 1994). In 2000, 38 percent of the sections were in bonus range of 0 to 10 inch/mile limit, which was better than any previous year. During 1990 to 1999, 98 to 99 percent of asphalt pavement sections were in the bonus or full pay range of smoothness (Parcells 2001).

Many in the asphalt pavement industry believe that initial pavement smoothness is directly related to the pavement service life. Janoff (1985) studied the relationship between initial roughness and roughness after 10 years of service. The results indicated that approximately 110 percent of initial roughness was present after 10 years of service. Raymond (2000) examined the effect of initial smoothness on long-term roughness progression on asphalt overlays placed over existing asphalt pavements using roughness data from SPS-5, GPS-6, and Canadian Long Term Pavement Performance (C-LTPP) sites. For the C-LTPP sites, 68 percent of the initial roughness remained after eight years of service. These values were 57, 85, and 84 percent for the Long Term Pavement Performance (LTPP), SPS-5, GPS-6, and combination of these three sites, respectively. Perera and Kohn (2001) examined the smoothness of the LTTP SPS-1 (strategic study of structural factors for flexible pavements) test sections in Kansas constructed in 1993. They found that the average as-built IRI of 12 test sections in Kansas was 51 in/mile. However, with time significant smoothness loss occurred for most of these sections. The roughness of some sections increased by 100 in/mile over 5-year time period.

Studies on roughness progression of Superpave pavements are almost nonexistent. After the introduction of Superpave pavements in Kansas, smoothness bonus payment has increased significantly, indicating that Superpave pavements are smoother initially. But the rate of roughness progression is yet to be determined.

OBJECTIVE

The objective of this study was to evaluate the roughness progression of Superpave pavements in Kansas.

TEST SECTIONS

Seventeen sections, built between 1998 and 2002, were selected in this study. These projects are all major modification projects—they were reconstructed or rehabilitated with intensive surface preparation. There were eleven reconstruction and six rehabilitation projects. Tables 1 and 2 show the locations and layer thickness data of these projects, respectively. The project lengths are variable and so are the layer thicknesses. Some of these projects had aggregate base and some had asphalt concrete base. Eleven projects were built over lime-treated subgrade, two over compacted soil, and the rest were over cold-in-place-recycled (CIPR) asphalt base. Most sections are two-lane undivided highways with 8 to10 ft wide shoulders. The K-254 sections are 4-lane divided highways.

Table 1. Features of study sections

KDOT project no.	Route	County	Project length (mile)	Work performed	Construction year
169-1-K-4419-02	US-169	Allen	8.41	Reconstruction	1999
169-2-K-4420-02	US-169	Anderson	4.24	Reconstruction	1999
57-2-K-4421-02	K-57	Anderson	2.19	Reconstruction	1999
254-08-K-5060-02	K-254 (NB)	Butler	4.65	Reconstruction	1998
	K-254 (SB)		4.65	Rehabilitation	1998
70-27-K-5982-01	I-70	Ellsworth	16.9	Reconstruction	2000
50-38-K-5743-01	US-50	Hamilton	12.40	Reconstruction	2001
50-47-K-5744-01	US-47	Kearney	14.96	Rehabilitation	2000
83-55-K-5388-01	US-83	Logan	14.92	Reconstruction	1999
61-59-K-5386-01	K-61	McPherson	2.22	Reconstruction	1999
81B-59-5386-02	US-81B	McPherson	2.50	Reconstruction	1999
27-65-K-5382-01	K-27	Morton	14.39	Rehabilitation	1999
169-67-K-5387-02	US-169	Neosho	6.81	Reconstruction	1999
283-68-K-5391-01	US-283	Ness	16.54	Rehabilitation	1999
281-76-K-5390-01	US-169	Pratt	6.43	Rehabilitation	1998
254-87-K-5060-02	K-254 (NB)	Sedgwick	7.31	Reconstruction	1998
	K-254 (SB)		7.31	Rehabilitation	1998
183-82-K-5751-01	US-183	Rooks	2.78	Rehabilitation	2000
36-101-K-5383-01	US-36	Washington	9.18	Rehabilitation	1999

Table 2. Layer type and thickness of the study sections

Project no.	Subgrade		Base		Binder course		Surface course	
	Type	Thick-ness (in)	Type	Thick-ness (in)	Binder	Thick-ness (in)	Binder	Thick-ness (in)
169-1-K-4419-02	LT	6	AC	6	SM-2C (PG64-28)	4	SM-1T (PG64-28)	1
169-2-K-4420-02	LT	6	AC	6	SM-2C (PG64-28)	4	SM-1T (PG64-28)	1
57-2-K-4421-02	LT	6			SM-2C (PG64-28)	5.5	SM-1T (PG64-28)	1
254-08-K-5060-02	LT	6	AB+UDB	7 + 6	SM-2C (PG58-28)	6.5	SM-1T (PG70-28)	1
254-08-K-5060-02	LT	6	CIPR	4	SM-2C (PG58-28)	8	SM-1T (PG70-28)	1
70-27-K-5982-01	COM	18	AC	4	SR-2C (PG58-34)	2	SM-1T (PG64-28)	1
50-38-K-5743-01	FA	6	AC	6	SM-19B (PG70-28)	2.5	SM-9.5T (PG70-28)	1.5
50-47-K-5744-01	COM	18	AC	10	SM-19B (PG70-28)	2.5	SM-9.5T (PG70-28)	1.5
83-55-K-5388-01	COM	18	CIPR	4	SM-2C (PG58-28)	9	SM-1T (PG58-28)	1
61-59-K-5386-01	LT	6	AB+UDB	11 + 6.5	SR-2C (PG58-28)	5.5	SM-1T (PG64-28)	1
81B-59-5386-02	LT	6	AB+UDB	11 + 6.5	SR-2C (PG58-34)	5.5	SM-1T (PG64-28)	1
27-65-K-5382-01	COM	18	CIPR	3	SM-2C (PG58-28)	6.5	SM-1T (PG70-28)	1.5
169-67-K-5387-02	LT	6	AC	8	SM-2C (PG58-28)	4	SM-1T (PG64-28)	1
283-68-K-5391-01	COM	18	CIPR	4.5	SR-2C (PG58-34)	6.5	SM-2A (PG58-28)	1.5
281-76-K-5390-01	COM	18	CIPR	4	SM-2C (PG58-28)	5	SM-1T (PG64-28)	1
254-87-K-5060-02	LT	6	AB+UDB	7 + 6	SM-2C (PG58-28)	4	SM-1T (PG70-28)	1
254-87-K-5060-02	LT	6	CIPR	4	SM-2C (PG58-28)	7	SM-1T (PG70-28)	1
183-82-K-5751-01	COM	18	CIPR	4	SR-2C (PG-64-28)	4	SM-1T (PG64-28)	1
36-101-K-5383-01	LT	6	AB	13	SR-2C (PG58-28)	-	SM-1T (PG58-28)	1

LT: Lime-treated
COM: Compaction type - 95% of standard density and moisture range: optimum ± 5%
FA: Fly-ash
CIPR: Cold-in-place-recycled asphalt
AC: Asphalt concrete
AB: Aggregate base
UDB: Unbound-drainable-base

DATA COLLECTION

Data collected for this study can be divided into two categories: layer property data and profile or roughness data.

Layer Property Data

This category includes properties of subgrade soil, as well as characteristics of the Superpave mixtures for the surface and binder layers.

Subgrade Data

Subgrade data was collected from the design files. Table 3 shows subgrade soil properties of the study sections. These properties include optimum moisture content, dry density, plasticity index, and percent of soil passing No. 200 sieve. Subgrade soils on most sections were modified with lime. On other sections, subgarde soils were either modified with fly ash or just compacted. According to the Unified Soil Classification system, soil type for most sections is CL or CL-ML. More than 81 percent subgrade materials passed through No. 200 sieve. Plasticity index values varied from 8 to 35 percent. The range of optimum moisture content was 13 to 23 percent. Dry density of the subgrade soil exceeded 90 lb/ft^3 for all sections.

Table 3. Subgrade soil properties

Project No.	Unified Soil Classification	Dry Density (lb/ft^3)	Optimum Moisture Content (%)	Liquid Limit (%)	Plasticity Index (%)	Subgrade Materials Passing US No. 200 Sieve (%)
169-1-K-4419-02	ML-CL	99	21	45	24	91
169-2-K-4420-02	ML-CL	97	18	36	10	93
57-2-K-4421-02	ML-CL	97	18	38	10	93
254-08-K-5060-02	CH	92	23	55	31	99
70-27-K-5982-01	CL	100	19	49	25	88
50-38-K-5743-01	ML-CL	100	21	36	13	96
50-47-K-5744-01	CL-CL	103	21	42	18	89
83-55-K-5388-01	ML-CL	101	19	39	17	99
61-59-K-5386-01	CL	97	18	35	11	98
81B-59-5386-02	CL	103	22	38	18	95
27-65-K-5382-01	CL	102	20	35	13	91
169-67-K-5387-02	CL	99	22	44	19	89
283-68-K-5391-01	CL	103	19	45	24	85
281-76-K-5390-01	SC	115	13	23	8	85
254-87-K-5060-02	CL	99	19	38	17	96
183-82-K-5751-01	CL	N/A	N/A	36	16	81
36-101-K-5383-01	MH	N/A	N/A	60	35	88

Superpave Mixture Data

Table 4 shows the mixture properties of the binder and surface courses for the study sections. Asphalt content of the mixtures varied from 4.8 to 6.0 percent. Air voids for all projects met KDOT specification of 4±2 percent. However, the VMA values are different due to varying nominal maximum aggregate size of the mixtures. The VMA values ranged from 12 to 16.4 percent. VFA's were very close to 70 percent required for most projects. Fine aggregate angularity and sand equivalent values were similar for all mixtures.

Table 4. Superpave mixture properties

Section	Asphalt content (%)		Air voids (%)		VMA (%)		VFA (%)		Aggregate passing #200 sieve (%)		Fine aggregate angularity		Sand equivalent		Gmm	
	Surf*	**Base**	**Surf**	**Base**	**Surf**	**Base**	**Surf**	**Base**	**Surf**	**Base**	**Surf**	**Base**	**Surf**	**Base**	**Surf**	**Base**
US-169 (1)	4.6	4.6	3.4	3.8	13.8	13.8	75.4	72.5	4.7	5.1	44	44	80	79	2.466	2.448
US-169 (2)	5	4.8	3.8	3.9	13.6	13.4	72.1	70.9	4.8	5.5	44	44	80	78	2.449	2.392
K-57	5.6	5	4.0	4	14.7	13.6	72.8	70.6	4.5	4.9	44	44	78	78	2.433	2.457
K-254 (1)	6	5.2	4.7	4.2	15.3	13.7	69.3	69.3	3.5	4.2	44	43	83	75	2.409	2.434
I-70	6.3	5.3	4.3	4.4	15.0	13.6	70.6	67.6	4.8	4.9	46	44	79	78		2.374
US-50 (1)	5.1	4.9	3.9	3.5	15.1	13.2	74.2	73.5	4.1	3.6	47	44	88	86	2.432	2.442
US-50 (2)	5	4.8	4.2	4.3	15.1	12.8	72.2	66.4	4.2	3.4	46	44	78	86	2.426	2.401
US-83	6.1	4.7	4	3.7	16.2	13.9	75	73.4	4.2	4	42	48	92	80	2.489	2.437
K-61	5.9	5	5.9	4.2	15.8	13.3	62.7	68.4	4.1	4.7	42	43	77	88	2.388	2.403
US-81B	6.1	5	5.2	4	15.6	13.1	66.7	69.5	3.8	5.3	41	44	65	89	2.397	2.415
K-27	5.9	5.8	5	3.3	15.3	14.2	68.7	76.7	4.8	4.9	48	46	67	69	2.535	2.397
US-169 (3)	6.2	3.7	3.9	4.3	15.6	13.5	75	68.1	3.6	3.6	45	47	93	95	2.41	2.429
US-283	5.4	4.4	4.6	4.3	15.8	13.7	70.9	68.6	3.4	3.3	43	42	92	90	2.442	2.481
US-281	5.4	4.9	4.6	4.4	15.8	13.9	70.9	68.3	4.6	3	43	43	87	88	2.376	2.404
K-254 (2)	5.6	5.3	4.5	4.3	14.9	14.1	69.8	69.5	4.3	4.5	44	44	79	78	2.394	2.405
US-183	5.48	5.1	4.45	3.7	15.08	13.4	70.5	72.2	5.8	4.1	43	43	99	84	2.471	2.464
US-136	5.29	5.4	4.81	4.2	15.72	13.3	69.4	68.4	4.6	4.9	42	42	76	76	2.367	2.364

* Surface layer

Roughness Data

Annual roughness data in terms of International Roughness Index (IRI) were collected from the KDOT Network Optimization System (NOS) survey results stored in the Pavement Management Information System (PMIS) database (KDOT 2003). For each section, three to five years of roughness data was available from the PMIS database. Profile data in the NOS survey is collected with a South-Dakota-type high-speed inertial profiler equipped with laser sensors. Profile measurements were done once on both left and right wheel paths.

As-constructed IRI value represents the average IRI of the left and right wheel path measurements. Most sections in this study were built with low initial roughness. The range of the as-constructed IRI was 32 to 76 in/mi with an average of 44 in/mi. All sections fell under Roughness Level I of KDOT NOS. US-254 section in Butler County, a reconstruction project, had the lowest IRI value. On the other hand, US-281 section in Republic County, which was built over compacted natural subgrade, had the highest IRI value.

Figure 1 presents the typical pattern of roughness progression. A definite pattern of roughness progression is evident—roughness increased with time.

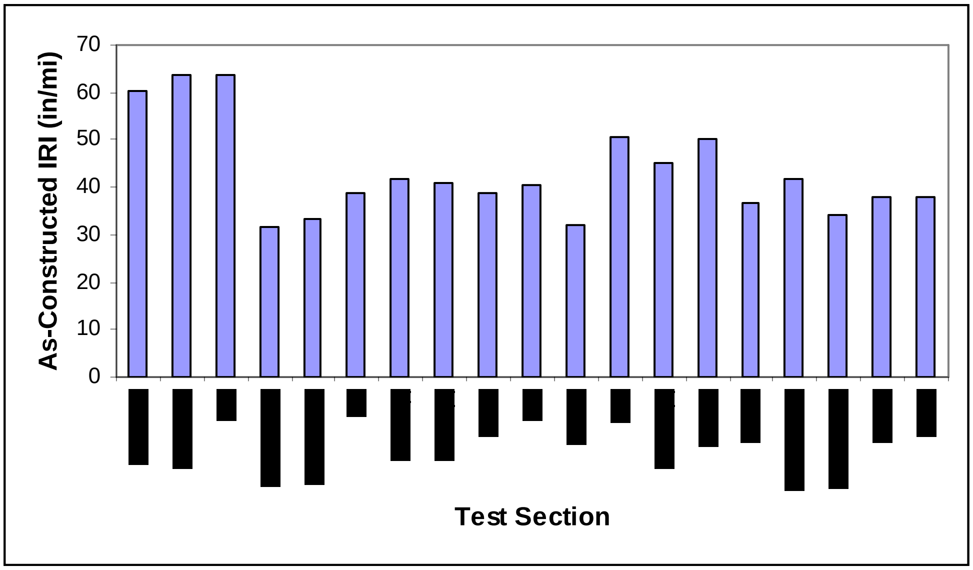

Figure 1. As-constructed IRI values for the study sections

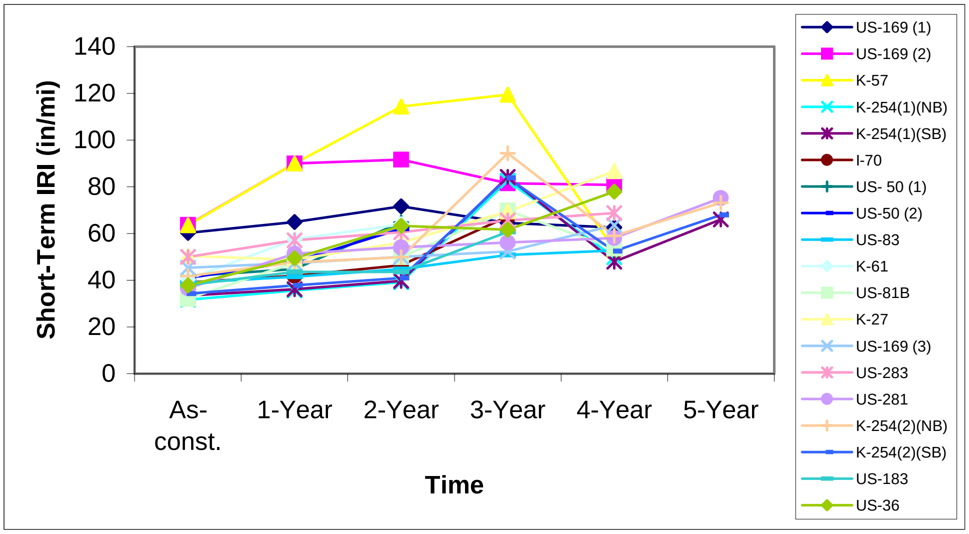

Figure 2. Roughness progression on the study sections

STATISTICAL ANALYSIS

Analysis of Variance (ANOVA)

Analysis of Variance (ANOVA) was performed to examine the effect of different factors on short-term roughness of Superpave pavement sections using the SAS software (SAS 1979). ANOVA tests the difference between two or more groups of population. The process compares the variability that is observed between two conditions to the variability observed within each condition. When the variability that can be predicted (between the two groups) is much greater than the variability that cannot be predicted (within each group), it can be concluded that those groups of population means are significantly different from each other. The response variable for this analysis was IRI. There were several treatment variables: (a) work type (reconstruction or rehabilitation); (b) profile age (as-constructed, 1, 2, 3, 4, and 5 years); (c) base type (aggregate, AB; asphalt, AC; and CIPR); (d) base thickness (A = thickness < 4 in; B= 4 in ≤ thickness≤ 6 in; and C = thickness >6 in); (e) subgrade type (Lime-treated and others); and (d) PG binder type (PG 58-28, PG 64-28, and PG 70-28).

The statistical model for the experiment is given by the following equation:

$$IRI_{ijklmn} = WORK_i + AGE_j + SG_k + BASE_l + BCTHIK_m + PG_n + Interactions + \varepsilon_{ijklmn} \tag{1}$$

Where IRI_{ijklmn} is the International Roughness Index (in/mile);
$WORK_i$ is the ith work type effect;
AGE_j is the jth profile age effect;
SG_k is the kth subgrade type effect;
$BASE_l$ is the lth base type effect;
$BCTHIK_m$ is the mth base course thickness effect; and
PG_n is the nth PG binder type effect.

All conclusions were made at 95% confidence level. The means of the response variable (IRI) at different levels of a factor were compared by the least square means (LSMean) approach (Milliken and Johnson 1984). This technique weighs the estimates of each treatment or treatment combination effect equally, but not each observation. The LSMean model deals with the average of individual treatment measurements and treatment combination; it gives unequal weight to each observation.

ANOVA Results

ANOVA results show that the project type (reconstruction or rehabilitation), profile age, base type, and base thickness have significant effects on the mean IRI values at 95% confidence level. Table 5 shows the pair wise comparison of LSMean IRI values for different factors. On average, the reconstruction projects showed higher IRI values than the rehabilitation projects. Deep milling and/or cold-in-placing recycling appear to be beneficial in achieving smoother Superpave pavements.

The age of the pavement has a significant effect on the mean IRI values. The change in mean IRI is most significant during the first year. There is no significant difference in mean IRI values between the first and the second years. It is to be noted that for a number of projects, the mean IRI value decreased after four years. This happened due to some preventive maintenance activities, such as slurry sealing, etc., on those projects.

The lime-treated subgrade results in smoother pavements; although, the difference in mean IRI values for the lime-treated subgrade and other subgrade types (compacted natural and fly ash treated) is not statistically significant.

As mentioned earlier, the effect of base type on Superpave pavement smoothness is significant. The projects with aggregate base showed much lower IRI than those on asphalt bases. The projects with CIPR base also showed the same trend. Projects with thinner base appeared to outperform those with thicker base in terms of smoothness.

Table 5. Comparisons of IRI values for different factors

Levels of Factor	LSMean of IRI (in/mi)	Pair-wise Comparison
Factor: Work Type***		
Reconstruction	60	> Rehabilitation
Rehabilitation	54.1	
Factor: Time***		
As-constructed	40.6	< All other time periods
1-year	50.1	> As-constructed; < 3, 4, 5-year
2-year	52.8	> As-constructed; < 3, 5-year
3-year	67.0	> As-constructed, 1, 2-year
4-year	60.9	> As-constructed, 1-year
5-year	71.0	> As-constructed, 1, 2-year
Factor: Subgrade		
Lime-treated	54.0	
Others	60.1	
Factor: Base Type***		
Aggregate (AB)	51.0	< AC
Asphalt (AC)	68.9	> AB; > CIPR
CIPR	51.3	> AC
Factor: Base Thickness***		
A (< 4 in)	44.7	< B; < C
B (4 –6 in.)	64.8	>A
C (> 6 in.)	61.6	> A
Factor: PG Grade		
PG 70-28	59.5	
PG 64-28	53.5	
PG 58-28	58.1	

* Significant at 95% confidence level

CONCLUSIONS

Analysis of as-constructed and short-term roughness of the Superpave sections in Kansas is presented. Some of the key findings of this study are as follows:

- Superpave sections built over asphalt bases have significantly higher IRI values than those over aggregate or CIPR bases.
- As-constructed roughness significantly affects the short-term roughness of a pavement section. The smoother the Superpave pavement is built, the smoother it will remain over time.
- Rehabilitation projects tend to be smoother than reconstruction projects.
- Overall, the lime-treated subgrade results in smoother pavements.

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