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THE DEVELOPMENT OF FLORIDA SMOOTHNESS SPECIFICATIONS FOR FLEXIBLE PAVEMENTS

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EXECUTIVE SUMMARY

Initial pavement smoothness has been shown to improve the overall pavement performance. This combined with the importance of providing a comfortable ride for the driving public justifies the importance of achieving high initial pavement smoothness. FDOT has recently developed smoothness specifications for asphalt pavements. These smoothness specifications will be used on high-speed facilities and they will be based on measurements obtained with laser road profilers. The ultimate goal is to include incentive/disincentive specifications aimed at rewarding the contractor for a high quality ride and simultaneously providing a financial deterrent to providing a poor quality ride.

INTRODUCTION

Road roughness is an important factor in evaluating the condition of a pavement section because of its effects on ride quality and vehicle operating costs. In its broadest sense, road roughness has been defined as "the deviations of a surface from a true planar 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, which cause vibrations in road-using vehicles.

In general, road roughness can be caused by any of the following factors [2]:

a. Construction Techniques that allow some variation from the design profile;

b. Repeated loads, particularly in channelized areas, that cause pavement distortion by plastic deformation in one or more of the pavement components;

c. Frost heave and volume changes due to shrinkage and swell of the subgrade; and

d. Non-uniform initial compaction.

In the last three decades, several studies pointed out the major penalties of roughness to the user. In 1960, Carey and Irick [3] showed that the driver's opinion of the quality of serviceability provided by a pavement surface is primarily influenced by roughness. Between 1971 and 1982, the World Bank supported several research activities in Brazil, Kenya, the Caribbean, and India. The main purpose of these studies was to investigate the relationship between road roughness and user costs. In 1980, Rizenbergs [4] pointed to the following penalties associated with roughness: rider non-acceptance and discomfort, less safety, increased energy consumption, road-tire loading and damage, and vehicle deterioration. It has been widely suspected that the initial roughness of a pavement section will affect its long-term performance. Recently, a study conducted by the State Materials Office of Florida DOT determined that initial pavement roughness measurements are highly correlated with roughness measurements made 6 years after construction [5].

BACKGROUND

Because of the importance of pavement roughness, most State Highway Agencies (SHAs) collect roughness data on their pavement sections on yearly basis. These roughness measurements are sometimes utilized by highway agencies to establish smoothness specifications for new pavement constructions. Some SHAs require that a specific limit 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 FDOT State Materials Office recently completed a study to evaluate the feasibility of using laser profilers for accepting the ride quality of new asphalt wearing surfaces. The Ride Number (RN) was used in calculating the smoothness of the sections included in the experiment. It is the objective of this paper to describe the testing done with the laser profiler and the resulting smoothness specifications for asphalt pavements.

DATA COLLECTION

In 1997, the FDOT's laser profiler was used to test seventeen new asphalt-wearing surfaces located in various districts in the state of Florida. Ten different contractors were involved in the construction of the seventeen projects. The laser profiler was run at a rate 2 (six inch averages) and the data was processed as ride number (RN) filtered to 300-foot wavelengths (RN_{2F}). This method of analysis is described as a revision to ASTM E1489, "Standard Practice for Computing Ride Number of Roads from Longitudinal Profile Measurements". Ride number is a mathematical processing of the profile to produce an estimate of subjective ride quality [6].

All pavement sections exhibiting areas not typical of rural construction (traffic lights, intersections, etc.) were not included in this study. This was done to eliminate the effect of accelerating, decelerating, stopping, as well as intersection geometry and manhole covers on road profile measurements. Table 1 shows a list of the newly constructed asphalt projects included in the evaluation. The total length of all sections included in the experiment was 373.1 miles. The Florida DOT laser profiler was used to collect the necessary profile data on all new construction projects included in this evaluation. Two passes were made in the driving lane of each section. In addition, four passes were made in each lane of two selected projects to determine the repeatability of the measurements. The laser sensors collected the data at a rate of 32,000 times per second. The profiler was programmed for data storage at a rate 2, which means the data was averaged every six inches and the values were stored for use in the ride number equation. Once the longitudinal profile data were collected, they were processed through a computer program that produces an estimate of subjective ride quality for highway pavements. The intent of Ride Number (RN) is to provide users with a standard practice for reporting ride quality. This practice is based on an algorithm developed in National Cooperative Highway Research Project (NCHRP) 1-23 [6]. Once field-testing was completed, all projects were divided into tenth mile segments. Ride numbers of all of these segments were then summarized in a computerized database and prepared for the analyses.

DATA ANALYSIS

The purpose of the analysis was to evaluate ride numbers collected with the laser profiler to determine if they can be used to accept the smoothness of newly constructed asphalt surfaces. The ride number data were reviewed with wheel path as a consideration. If ride number was to be used for acceptance specifications, the following question should be answered: should each wheel path be considered independently or should ride numbers from both wheel paths be averaged?

As shown in Table 2, ride numbers were divided into fourteen ranges. The percentages of sections falling in each range were then determined for the left, right, and average wheel paths. It is clear from Table 2 that there are slight differences in the ranges due to wheel path selection. It is also clear from Table 2 that averaging results from the two wheel paths will result in having a smaller number of sections in the exceptionally smooth ranges. This indicates that pavement smoothness cannot be fully determined from only one wheel path. Therefore, consideration should be given to using the average of both wheel paths for smoothness acceptance.

Table 3 shows the accumulated frequency distribution of the average ride numbers from both wheel paths. It is clear from that table that 24.95 percent were below 4.31 and 0.83 percent above 4.50. The rest of the sections (about 75 percent) were between 4.31 and 4.5. Table 3 also shows that about 71 percent of the left and right wheel path ride numbers were between 4.31 and 4.50.

Repeatability testing was accomplished on two of the seventeen projects. Table 4 summarizes the results of the repeatability testing accomplished in the passing and driving lanes of SR 8 and SR 30. The four passes made with the laser profiler in each lane of SR 8 showed a mean range of 0.05. The four passes in each lane of SR 30 were more scattered than SR 8. The ranges of the ride numbers based on four passes were as high as 0.1.

The laser road profiler was also utilized to make two runs per lane per direction on each one of the seventeen test sections included in the experiment. Ride numbers were calculated for all runs. The mean difference between every two runs was 0.03 with a standard deviation on the differences between passes of 0.03.

FDOT SMOOTHNESS SPECIFICATIONS

A panel of pavement experts from the Florida Department of Transportation established the first version of the smoothness specifications for asphalt pavements. The following factors were considered in developing the new specifications:

a. The main objective is reducing the scatter of the initial roughness by encouraging contractors to build smoother pavements.

b. Any smoothness policy developed should have enough incentives to make it worthwhile for the contractors to go the extra mile to achieve better smoothness.

c. The high speed FDOT laser road profiler should be utilized in the smoothness acceptance testing. The elimination of the manual straight edging of high-speed facilities for smoothness acceptance will significantly reduce the potential safety risks.

d. The data obtained in the repeatability study of road profiler measurements should be utilized to establish smoothness limits.

The expert's panel developed new smoothness specifications where the use of the rolling straight edge during construction for quality control will be maintained. The laser profiler measurements will be used for quality acceptance. Only incentives will be paid in this first phase of implementation. These incentives are applicable on projects with a posted speed limit equal or greater than 50 miles per hour and to all lanes longer than 5000 feet. The smoothness of each lane will be tested by a single pass of the FDOT laser road profiler. Each lane will be divided into 0.1 mile lots. The smoothness will be determined and the price adjustment will be made in accordance to the criteria shown in Table 5.

SPECIFICATION IMPLEMENTATION

As part of the implementation of the new specifications, the would be incentives were calculated on all test sections included in this study. Table 6 shows the percentages of lots in each payment category for each test section. It is clear from this Table that 5 percent of the lots were in each one of the \$600 and \$300 payment categories. In addition, 8 percent of the sections were in the lowest incentive category of \$100. The ranges of values were very wide. For example, in the smoothest category, the best section had 24% of the lots receiving the \$600 incentives while the worst section had no lots in this category. Table 6 also indicates that some sections may receive incentives on as much as 49 percent of the lots while others may end up with no incentives whatsoever.

Table 7 shows a summary of the calculated incentives on all test sections. It is clear from Table 7 that the highest incentive value was \$64,300 while the lowest was \$0. It was felt that those dollar values should be related to the overall size of the project and the bid values. Table 8 shows the average incentive payment per lot for each test section. The highest value was \$196 while the lowest value was \$0. The bid values were obtained on almost all sections included in the experiment. These values are summarized in Table 8. When considering the incentive as a percentage of total bid values, the highest percentage was 1.43 but most values were around or below the one percent.

The State Materials Office of the Florida DOT has used the laser road profiler to test two newly completed construction projects. The smoothness specifications did not apply initially to these sections. However, they were supplemented later without objections from the contractors. The testing resulted in no lots eligible for incentives in the first project and only one lot eligible for \$100 in the second project. Several projects in various districts will include the new smoothness specifications in the near future.

CONCLUSIONS

Initial pavement smoothness has been shown to improve the overall pavement performance. This combined with the importance of providing a comfortable ride for the driving public justifies the importance of achieving high initial pavement smoothness. FDOT has recently developed smoothness specifications for asphalt pavements. These smoothness specifications will be used on high-speed facilities and they will be based on measurements obtained with laser road profilers. The following conclusions are made from the data contained in this report:

1) Ride Numbers measured with a laser profiler can be used to rank the level of rideability on rural projects with some limitations. The sections evaluated should be at least 0.100 mile in length.

2) The use of the laser profiler for rural sections of roadway will enhance the ability to monitor the public's perception of ride quality and the safety of the personnel doing acceptance testing.

3) Roadway sections at bridges, railroad crossings, intersections, etc. will need to be tested using a rolling straightedge. Acceleration and deceleration lanes will also need to be tested with a rolling straightedge.

4) Establishing ride specification based on road profiler measurements for urban areas would be very difficult considering the variety of items affecting profiles such as manhole covers, intersecting profiles from side streets, other utility lines, etc. The limitations of the type of construction are a factor as well as the reduced speed that desensitizes the perception of the riders.

5) Limitations that affect the use of the laser profiler for collecting ride data are stop and go driving due to traffic lights, traffic flow, etc. The laser profiler must operate at fairly constant speeds above 15 miles per hour. The laser profiler also must be operated at constant speed when it enters and leaves the test section.

6) About twenty five percent of the new sections tested will have ride numbers less than 4.30. These sections are targeted for improvement with the newly developed specifications.

RECOMMENDATIONS

The following recommendations are made based on this study:

1) The ride number based on average of both wheel paths should be used as the criteria for smoothness acceptance.

2) The smoothness specifications as shown in Table 5 should be implemented on a limited bases on several experimental projects. Each section should be divided into one tenth of a mile segments. Incentives should be determined based on one run on each individual lot.

3) The specification limits should be refined after considering the results from the experimental projects. The refined version of the specifications should incorporate incentives as well as disincentives to improve the initial smoothness of roadways. A minimum acceptance level also needs to be selected.

4) A maximum incentive limit should be set based on the percentage of asphalt mix cost.

It is anticipated that these smoothness specification for asphalt pavements will result in less than 1 percent increase in the total contract cost.

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Table 1. Newly Constructed Test Sections Included in The Experiment.

TEST SECTION NUMBER	STATE ROAD	COUNTY	BEGINNING MILE POST	ENDING MILE POST
1	44	Citrus	11.646	15.753
2	90	Collier	33.504	44.161
3	91	Lake	0.930	23.793
4	600	Polk	4.278	10.756
5	44	Sumter	0.000	7.854
6	91	Sumter	6.498	10.638
7	91	Sumter	0.000	6.267
8	8	Columbia	10.058	20.690
9	53	Madison	0.570	6.465
10	399	Escambia	0.000	10.000
11	61	Leon	0.000	3.430
12	10	Santa Rosa	13.400	18.785
13	30	Walton	0.000	3.041
14	9	Brevard	22.550	31.190
15	100	Flagler	0.000	16.487
16	91	Orange	0.000	5.841
17	100	Putnam	0.000	19.381

Table 2. Percent of Sections in Each Range of Ride Numbers.

RIDE NUMBER RANGE	LEFT WHEEL PATH	RIGHT WHEEL PATH	AVERAGE WHEEL PATHS
0.00-3.40	0	0	0
3.41-3.50	0	0.03	0
3.51-3.60	0	0	0
3.61-3.70	0.05	0.08	0.05
3.71-3.80	0.29	0.16	0.16
3.81-3.90	0.43	0.11	0.24
3.91-4.00	0.91	0.86	0.51
4.01-4.10	2.01	1.77	2.22
4.11-4.20	6.35	5.66	5.28
4.21-4.30	16.62	17.18	16.48
4.31-4.40	42.16	40.98	46.64
4.41-4.50	29.56	30.39	27.58
4.51-4.60	1.61	2.79	0.83
4.61-5.00	0	0	0

Table 3. Accumulated Percentages of Sections in Various Wheel Path Combinations.

RIDE NUMBER RANGE	LEFT WHEEL PATH	RIGHT WHEEL PATH	AVERAGE WHEEL PATHS
0.00-3.40	0	0	0
3.41-3.50	0	0.03	0
3.51-3.60	0	0.03	0
3.61-3.70	0.05	0.11	0.05
3.71-3.80	0.35	0.27	0.21
3.81-3.90	0.78	0.38	0.46
3.91-4.00	1.69	1.23	0.96
4.01-4.10	3.70	3.00	3.19
4.11-4.20	10.05	8.66	8.47
4.21-4.30	26.67	25.84	24.95
4.31-4.40	68.83	66.82	71.59
4.41-4.50	98.39	97.21	99.17
4.51-4.60	100.00	100.00	100.00
4.61-5.00	100.00	100.00	100.00

Table 4. Ranges of Ride Numbers based on Four Runs on Two Experimental Sections.

STATE ROAD	COUNTY	BEGINNING MILE POST	ENDING MILE POST	LANE TESTED	RANGE OF RN	AVERAGE RN
8	Columbia	10.058	20.690	EBPL	0.05	4.41
8	Columbia	10.058	20.690	EBTL	0.05	4.40
8	Columbia	10.058	20.690	WBPL	0.05	4.41
8	Columbia	10.058	20.690	WBTL	0.05	4.42
30	Walton	0.000	3.041	EBPL	0.09	4.28
30	Walton	0.000	3.041	EBTL	0.06	4.27
30	Walton	0.000	3.041	WBPL	0.10	4.34
30	Walton	0.000	3.041	WBTL	0.07	4.34

EBPL: East Bound Passing Lane.
EBTL: East Bound Travel Lane.
WBPL: West Bound Passing Lane.
WBTL: West Bound Travel Lane.

Table 5. Incentive Criteria for Smoothness of Asphalt Pavements.

RIDE NUMBER	PAY ADJUSTMENT
$4.47 \leq RN$	\$600 PER LOT
$4.45 \leq RN < 4.47$	\$300 PER LOT
$4.43 \leq RN < 4.45$	\$100 PER LOT
$RN < 4.43$	NO INCENTIVE

Table 6. Percentages of Lots In Each Payment Category.

TEST SECTION NUMBER	NO INCENTIVES	INCENTIVES		
		$100	$300	$600
1	86	6	3	5
2	100	0	0	0
3	97	2	1	0
4	89	8	3	0
5	81	10	7	2
6	92	4	3	1
7	86	8	4	2
8	51	19	16	14
9	52	10	14	24
10	72	10	7	11
11	97	3	0	0
12	82	8	4	6
13	91	7	2	0
14	73	13	8	6
15	65	15	10	10
16	71	11	7	11
17	95	3	1	1
Average	82	8	5	5
Minimum	51	0	0	0
Maximum	100	19	16	24

Table 7. Incentives calculations for The Sections Included in The Implementation of The New Specification.

TEST SECTION NUMBER	TOTAL # OF LOTS	# OF LOTS RECEIVING			TOTAL INCENTIVES IN DOLLARS
		$600	$300	$100	
1	159	8	5	10	7,300
2	182	0	0	0	0
3	584	0	3	10	1,900
4	125	0	4	10	2,200
5	154	3	11	16	6,700
6	146	1	4	6	2,400
7	394	6	15	33	11,400
8	422	61	66	79	64,300
9	103	25	14	10	20,200
10	200	22	13	19	19,000
11	68	0	0	2	200
12	106	6	4	8	5,600
13	116	0	2	8	1,400
14	317	20	26	40	23,800
15	311	32	32	48	33,600
16	110	12	8	12	10,800
17	379	2	3	13	3,400

Table 8. Incentives Per Lot and As a Percentage of Total Bid Price.

TEST SECTION NUMBER	TOTAL # OF LOTS	TOTAL INCENTIVES IN DOLLARS	BID PRICE	INCENTIVES PER LOT	INCENTIVE AS A PERCENTAGE OF BID
1	159	7,300	5,463,315	46	.13
2	182	0	2,371,865	0	0
3	584	1,900	2,461,817	3	.08
4	125	2,200	1,620,057	18	.14
5	154	6,700	1,969,404	44	.34
6	146	2,400	1,038,359	16	.23
7	394	11,400	1,055,877	29	1.08
8	422	64,300	4,506,109	152	1.43
9	103	20,200	1,659,653	196	1.22
10	200	19,000	n/a*	95	n/a*
11	68	200	828,963	3	.02
12	106	5,600	1,283,188	53	.44
13	116	1,400	n/a*	12	n/a*
14	317	23,800	2,589,304	75	.92
15	311	33,600	3,020,111	108	1.11
16	110	10,800	971,797	98	1.11
17	379	3,400	4,495,983	9	.08

* These were special contracts and the bid values did not reflect work done on pavements only.