A CORRELATION OF VARIOUS SMOOTHNESS MEASURING SYSTEMS FOR ASPHALTIC CONCRETE SURFACES

FINAL REPORT

BY

S. C. SHAH
DATA ANALYSIS ENGINEER

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IMPLEMENTATION

Before total implementation can be made, the Department should verify the guideline specifications suggested in Table 5 of this report. The Mays roadmeter is readily available in five of the nine districts and should present minimum of problem to put them on the newly constructed pavements. Initially, the Department should purchase two 12-foot rolling straightedges and assign them to two of the districts having Mays roadmeter.

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INTRODUCTION

The current requirements for acceptance of asphaltic concrete projects are based on smoothness criteria in addition to Marshall stability and roadway density (1)* This smoothness is determined by means of a 10-foot rolling straightedge. This method has been a vital tool for assessment of roughness of the surface in that the data are easily interpretable and indicative of the surface characteristics of the pavement in a longitudinal direction. However, it is not possible to translate these data to the riding quality of the pavement, per se, as is possible with the various roadmeters such as the BPR roughometer, and the Mays and the PCA roadmeters. On the other hand, while the latter devices may be employed as a basis for final project acceptance, they are not well suited for control of roughness during construction. If a correlation between roughness index and rolling straightedge (RSE) output can be determined, it would be possible to formulate roughness control procedures, based on the RSE during construction and on the roadmeters for final project acceptance.

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*Underlined numbers in parentheses refer to list of references.

PURPOSE AND SCOPE

The primary purpose of this research effort was to assess the presently specified smoothness criteria for new construction of asphaltic concrete surfaces using various rolling straightedges and roadmeters. This assessment was to be based on the correlation between the various systems of smoothness (or roughness) measuring devices and the precision of each of the devices. Furthermore, if the findings indicated that a revision in smoothness criteria is necessary, then an attempt would be made to formulate such smoothness criteria in relation to the rideability of the pavement surface as assessed by the roadmeters.

While the primary aim reflects evaluation of new construction only, measurements were also included on older pavement surfaces. This was considered desirable for definition of surfaces that should be considered unacceptable. The current specifications for surface smoothness define any segment exceeding 2.5 percent of total length, at 1/8 inch (3.175 mm) tolerance, as unacceptable and subject to 50 percent penalty (1).

ROUGHNESS MEASUREMENTS

I. MEASURING SYSTEMS

A. Rolling Straightedges (RSE)

Briefly, the rolling straightedge device consists of 2 in. x 4 in. (5.08 cm x 10.16 cm) rectangular tubing mounted on four 10 in. x 2.5 in. (25.4 cm x 6.35 cm) solid rubber tired wheels (two front wheels and two rear wheels). A center steel wheel 1 in. x 4 in. (2.54 cm x 10.16 cm) mounted on a castor senses any surface irregularities. These irregularities are marked by a jet of colored fluid stored in tanks. The liquid release is controlled by solenoid valves which are actuated by two micro switches which in turn are controlled by two cams. Power is supplied by a dry cell battery. Two dial type indicators (front and rear) each have a pointer which traverses a dial which is graduated in units of 1/16 inch (1.588 mm). Tolerances can be preset, and any location exceeding these tolerances would be marked with the colored fluid for the entire length of the irregularity. The device which is pulled at walking speed is shown in Figure 1.

For this study, three rolling straightedges were used, a 10-foot (3.05 m), a 12-foot (3.66 m) and a 15-foot one (4.57 m). The only difference between the three was the length of the rectangular tubing. Thus, theoretically, the 12-foot straightedge should be able to sense a greater number of irregularities than the 10-foot straightedge, and the 15-foot a greater number than the corresponding 12-foot one.

B. Mays Roadmeter, PCA Roadmeter and BPR Roughometer

The operational features of the various devices falling into this system of pavement surface evaluation have been well documented in a number of publications(2)(3) and need not be discussed here. It suffices to say that the devices provide a rapid and quantitative means of evaluating surface roughness in a manner closely related to highway user opinion.

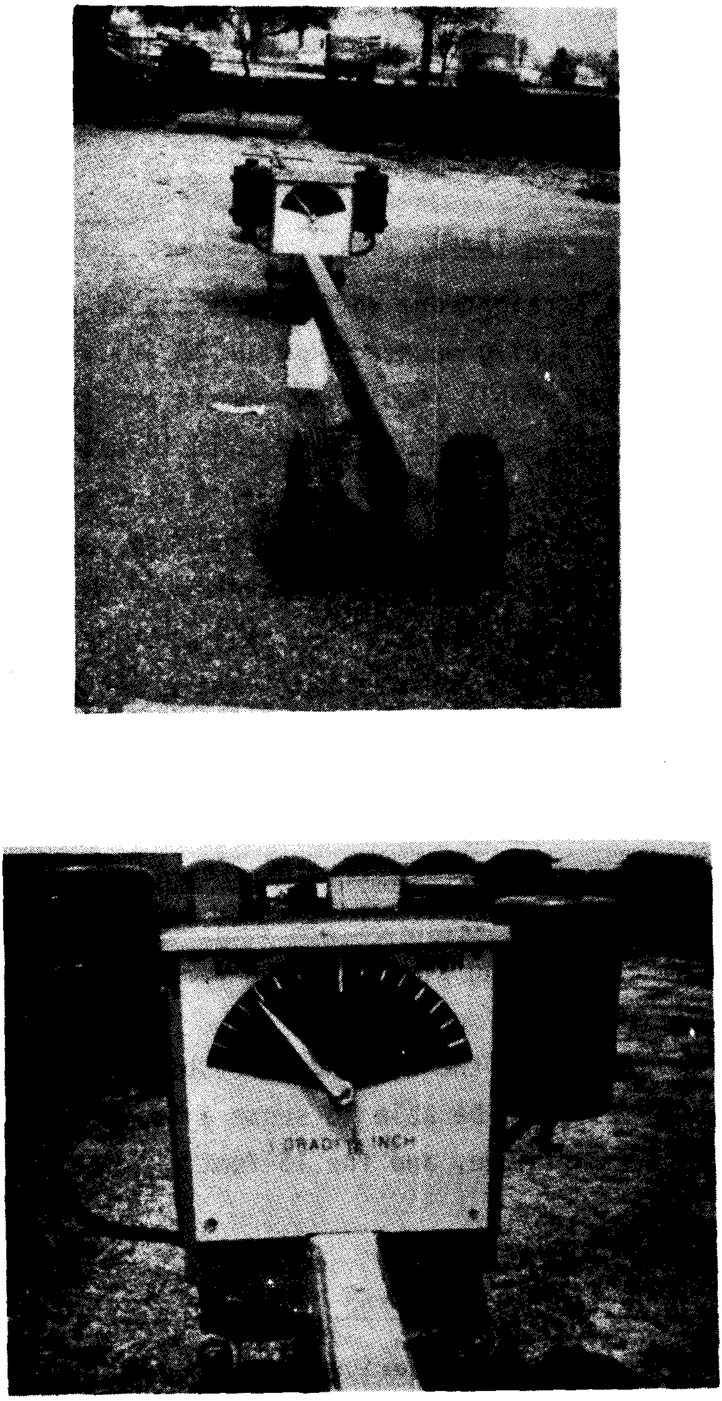

Figure 1
Rolling Straightedge (RSE)

II. TEST SECTIONS

Nineteen hot mix projects were selected for the evaluation. From each project, a 1000-foot (304.8 m) section was selected for the measurement program. Ten of these sections represented new construction with the remaining distributed in age to reflect medium to rough surfaces.

III. TEST PROCEDURE

Testing with the RSE consisted of calibrating each of the devices to 1/8 inch (3.175 mm) tolerance and pulling them the entire length of each test section in both wheel paths of each lane. The same procedure was followed with the tolerance set at 3/16 inch (4.763 mm). The tolerance settings were frequently checked during the test run using a standard calibration test procedure(4).

The three RSE devices were hooked to each other and pulled by one man. This procedure minimized the effects of extraneous variables such as speed and test path alignment. The straightedges were run in each wheel path and the lengths of the ejected fluid markings were totaled over the four wheel paths and reported as an average percent of linear feet outside the given tolerance. The repeatability of the rolling straightedges was determined by running 10 repeat measurements on a 500-foot (152.4 m) test section.

For testing with each roadmeter, three replicates were made over each section at the recommended speed. The results were reported as an average of the replicates.

DATA PROCESSING AND ANALYSIS

Table 1 is a listing of the roughness data for various devices. The data, as mentioned before, represent average measurements for the sections. In order to relate quantitatively the various measuring devices, linear regression analysis techniques were used(5). Preliminary analysis of data indicated a data element (Section 8, 15-foot RSE at 1/8 inch tolerance) too far removed from the rest of data to have occurred by chance and hence was deleted from that observation in subsequent analysis. Examination of other data elements showed a discrepancy for section 5 where the 1/8 inch tolerance reading for 15-foot device is lower than the corresponding 12-foot readings. A similar trend is indicated by the 12-foot device for sections 6, 14 and 18 as compared with the corresponding 10-foot device. Such discrepancies, however, were attributed to random experimental errors and therefore retained in the analysis. The repeatability data for the various devices are summarized in Table 2.

Tables 3 and 4 show listings of the various equations derived through regression analysis for the two tolerance settings. Figures 1 through 4 show plots of the relationships indicated in Table 3. The scatter of data is for the 10-foot device only. For the 12- and 15-foot devices only the regression equations are shown. Furthermore, the curves do not show the upper range of values, specifically the last three sections. However, the plots adequately cover the range of roughness values generally encountered on new construction.

Generally, in correlation analysis, the decision to designate any one of the variables as the independent or X variable is arbitrary, although it is ordinarily recognized that if an assocation between the variables is indicated, then the variable that is easy to measure will be designated as the X variable. However, in this analysis, availability of smoothness criteria had some bearing on the selection of the rolling straightedge as the independent variable.

TABLE 1
AVERAGE DATA FOR VARIOUS ROLLING STRAIGHTEDGES & ROADMETERS

SECT_NO	TOL1	RSE_10FT	RSE_12FT	RSE_15FT	TOL2	SE_10FT	SE_12FT	SE_15FT	MAYS_IPM	BPR_IPM	PCA_PSI
01	1/8	0.11	0.16	0.29	3/16	0.00	0.00	0.00	39	90	3.97
02	1/8	0.00	0.24	0.32	3/16	0.00	0.04	0.06	43	116	3.92
03	1/8	0.23	0.25	0.30	3/16	0.00	0.00	0.00	56	90	3.41
04	1/8	0.14	2.22	4.40	3/16	0.12	0.19	0.72	57	106	3.26
05	1/8	0.00	0.89	0.36	3/16	0.00	0.00	0.00	35	87	4.13
06	1/8	2.93	1.07	9.00	3/16	0.57	1.73	2.64	93	132	2.91
07	1/8	0.22	0.24	1.72	3/16	0.00	0.00	0.00	65	114	3.31
08	1/8	0.53	2.52	18.16	3/16	0.00	0.29	1.41	77	122	3.24
09	1/8	0.46	4.24	9.86	3/16	0.00	0.16	1.95	72	119	3.28
10	1/8	1.67	4.61	9.97	3/16	0.39	0.87	1.38	78	106	3.05
11	1/8	3.01	4.74	7.33	3/16	0.20	0.69	1.04	87	143	2.75
12	1/8	3.63	7.41	8.40	3/16	0.83	1.09	1.96	112	132	2.56
13	1/8	4.50	7.06	11.71	3/16	2.93	4.20	5.45	91	127	2.82
14	1/8	5.33	3.94	5.51	3/16	1.33	0.58	1.63	83	132	2.89
15	1/8	7.45	13.02	22.64	3/16	3.11	3.79	6.61	125	195	2.20
16	1/8	9.54	19.12	23.00	3/16	3.87	6.07	10.26	173	153	2.04
17	1/8	25.33	31.96	37.53	3/16	16.33	21.82	24.61	231	211	1.87
18	1/8	41.47	36.02	44.08	3/16	26.06	23.05	26.50	225	222	1.94
19	1/8	28.97	28.93	35.81	3/16	13.07	13.64	17.37	206	169	2.04

COMMENT NOTE THE FOLLOWING
RSE=SE=ROLLING STRAIGHTEDGE.
THE VALUES LISTED UNDER RSE & SE REPRESENT % LINEAR FEET
OUTSIDE INDICATED TOLERANCES (COL 2 & COL 6)

The analysis also provided concomitant information relative to the relationships between various roadmeters. In addition, the last piece of information extracted from the data pertained to the relationships between the two tolerance settings for each rolling straightedge.

The regression equations represent those that best define the trend for the system evaluated and are likely to change for other roadmeter systems. For these equations, all coefficients are significant at the .05 level as determined by the t-test. An examination of the residuals for the various models did not show any abnormalities.

For these regression equations no test was made for the lack of fit. This was because the basic assumption of no error in the independent variables was not met. In fact, the independent variables (straightedges) were more prone to errors than the dependent variables. The data in Table 2 bears this out. In this table the precision, expressed as coefficient of variation, gets poorer at the higher tolerance setting of the rolling devices. Furthermore, the precision also decreases with increasing length of the rolling straightedges. The roadmeters, however, project better precision than the rolling devices. Such errors in measurements are reflected in regression analysis which is discussed in the next section.

TABLE 2

REPEATABILITY OF VARIOUS SMOOTHNESS MEARURING SYSTEMS

INSTRUMENT		COEFFICIENT OF VARIATION, %			
	SURFACE CONDITION	......SMOOTH		ROUGH	
	TOLERANCE,IN.....	..1/8	3/16	1/8	3/16
10FTRSE		17	16	19	21
12FTRSE		22	26	23	30
15FTRSE		26	30	26	33
MAYS50		6.5		5.9	
PCA 50		5.3		5.8	
BPR 20		1.0		1.8	

TABLE 3

RELATIONSHIPS BETWEEN RSE & ROADMETERS FOR 1/8INCH TOLERANCE

YVAR	XVAR	N	REG_EQNS	RSQ	SE	EQ_NO
MAYS50	10FTRSE	19	54.9+11.0*X-.17*X*X	.94	15.90	1
MAYS50	12FTRSE	19	50.5+ 7.3*X-.06*X*X	.96	13.45	2
MAYS50	15FTRSE	18	46.8+ 4.4*X	.94	15.48	3
***********	**********	**	********************	***	*****	*****
BPR20	10FTRSE	19	108.1+6.0*X-.09*X*X	.78	19.56	4
BPR20	12FTRSE	19	108.2+3.0*X	.79	18.66	5
BPR20	15FTRSE	18	101.3+2.7*X	.84	16.50	6
***********	**********	**	********************	***	*****	*****
PCA50	10FTRSE	19	3.46-.15*X-.003*X*X	.78	.35	7
PCA50	12FTRSE	19	3.63-.15*X-.003*X*X	.85	.29	8
PCA50	15FTRSE	18	3.75-.11*X-.002*X*X	.87	.27	9
***********	**********	**	********************	***	*****	*****
15FTRSE	10FTRSE	18	4.60+1.10*X	.89	4.84	...10
12FTRSE	10FTRSE	19	2.14+ .94*X	.92	3.36	...11
15FTRSE	12FTRSE	18	2.19+1.16*X	.97	2.64	...12
***********	**********	**	********************	***	*****	*****
3/16TOL10FT	1/8TOL10FT	19	.57*X	.97	1.36	...13
3/16TOL12FT	1/8TOL12FT	19	.55*X	.93	2.35	...14
3/16TOL15FT	1/8TOL15FT	18	.52*X	.94	2.32	...15
***********	**********	**	********************	***	*****	*****
PCA50	MAYS50	19	3.98-.01*X	.84	.28	...16
PCA50	BPR20	19	5.02-.02*X	.78	.34	...17
BPR20	MAYS50	19	75.90+.58*X	.82	17.22	...18
***********	**********	**	********************	***	*****	*****

TABLE 4

RELATIONSHIPS BETWEEN RSE & ROADMETERS FOR 3/16INCH TOLERANCE

YVAR	XVAR	N	REG_EQNS	RSQ	SE	EQ_NO
MAYS50	10FTRSE	19	65.3+18.2*X-.47*X*X	.90	21.10	1
MAYS50	12FTRSE	19	60.3+17.7*X-.46*X*X	.93	17.82	2
MAYS50	15FTRSE	19	53.0+13.3*X-.25*X*X	.95	14.68	3
***********	**********	**	********************	***	*****	*****
BPR20	10FTRSE	19	114.6+8.8*X-.19*X*X	.74	21.42	4
BPR20	12FTRSE	19	116.0+4.6*X	.73	21.05	5
BPR20	15FTRSE	19	112.3+4.2*X	.77	19.39	6
***********	**********	**	********************	***	*****	*****
PCA50	10FTRSE	19	3.29-.20*X-.006*X*X	.64	.44	7
PCA50	12FTRSE	19	3.38-.24*X-.008*X*X	.72	.39	8
PCA50	15FTRSE	19	3.50-.20*X-.006*X*X	.78	.34	9
***********	**********	**	********************	***	*****	*****
15FTRSE	10FTRSE	19	1.22*X	.94	2.44	...10
12FTRSE	10FTRSE	19	1.03*X	.96	1.63	...11
15FTRSE	12FTRSE	19	1.19*X	.97	1.17	...12

COMMENT: THE NUMBERS AFTER EACH ROADMETER REPRESENT TEST SPEED.

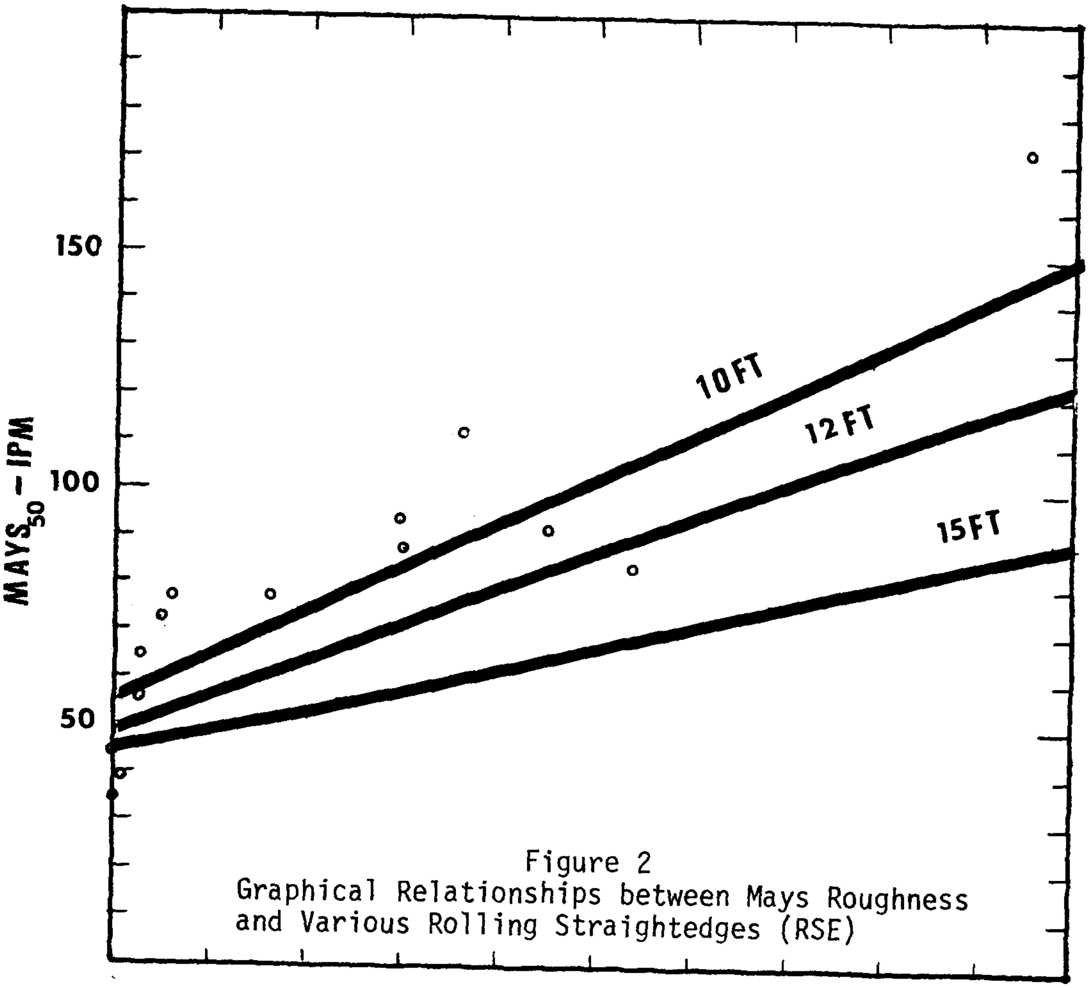

Figure 2
Graphical Relationships between Mays Roughness
and Various Rolling Straightedges (RSE)

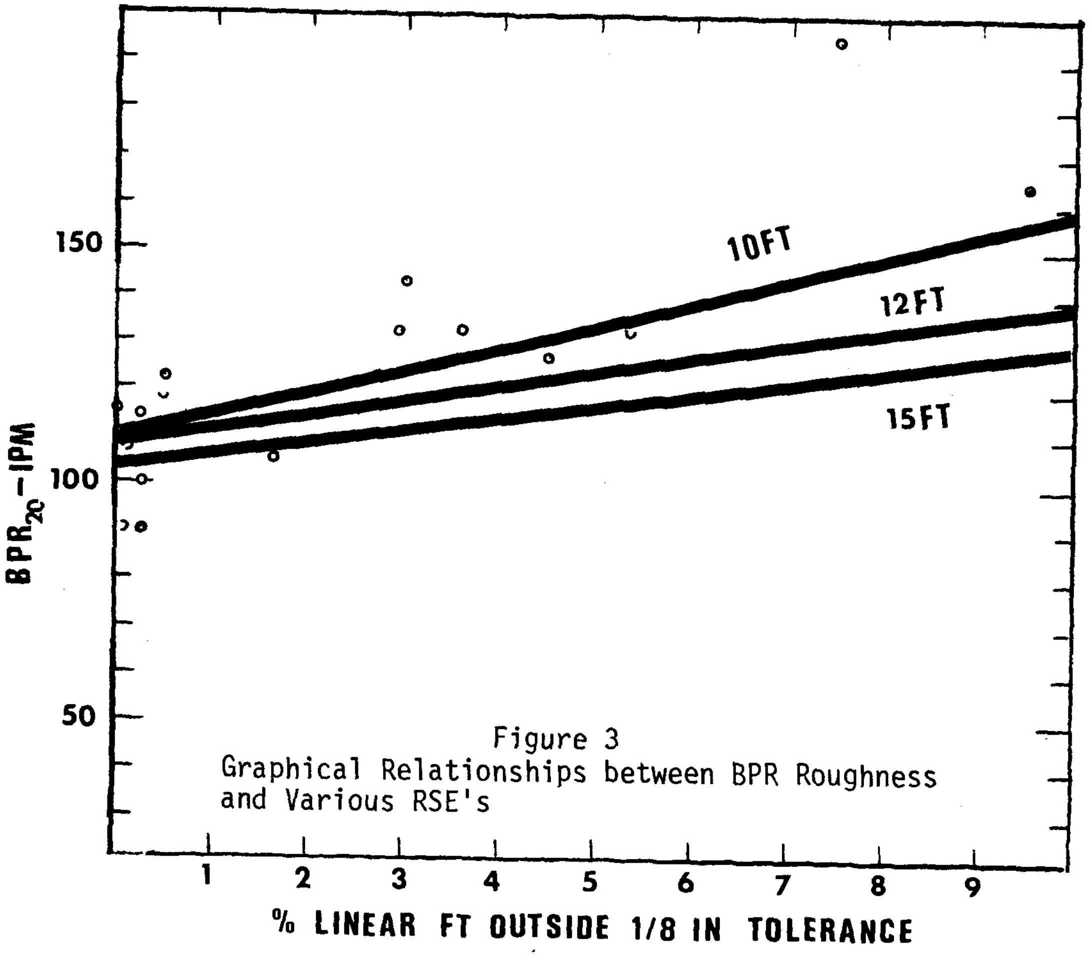

Figure 3
Graphical Relationships between BPR Roughness
and Various RSE's

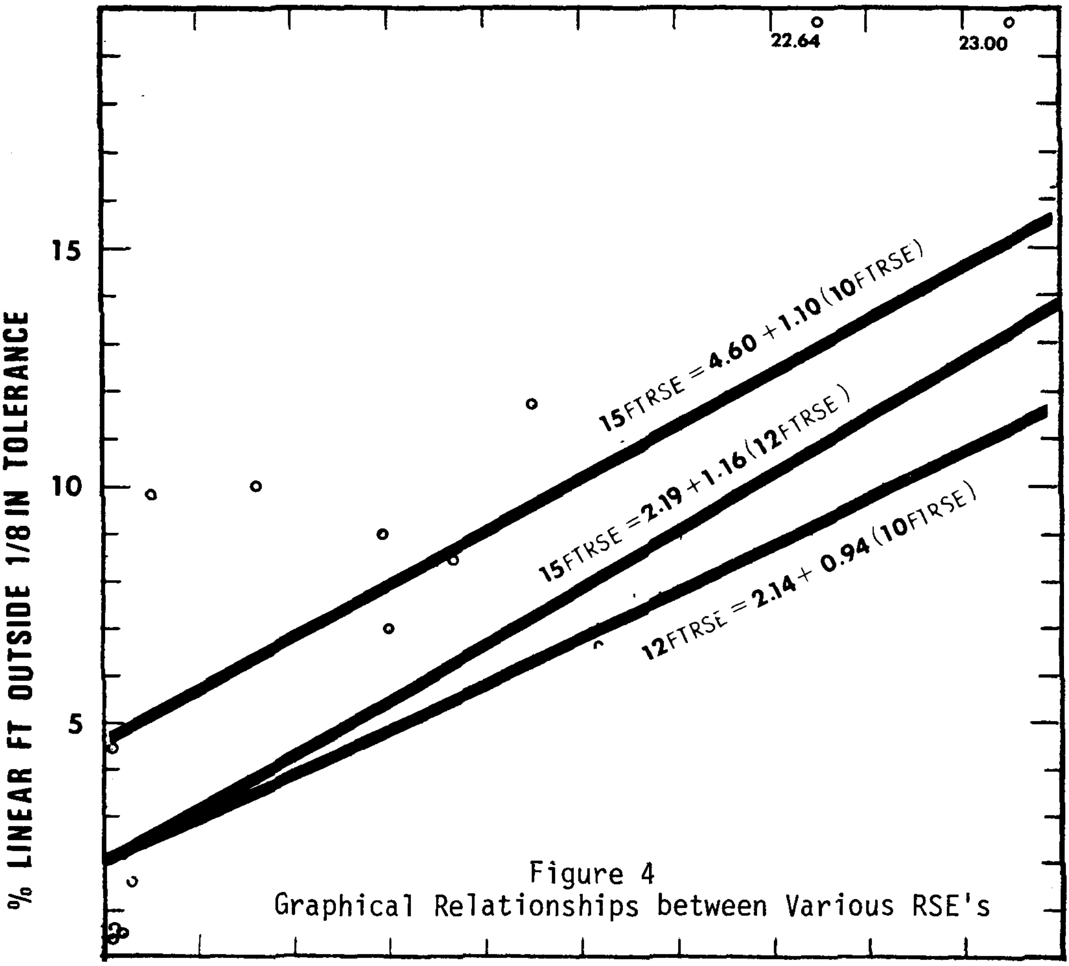

Figure 4
Graphical Relationships between Various RSE's

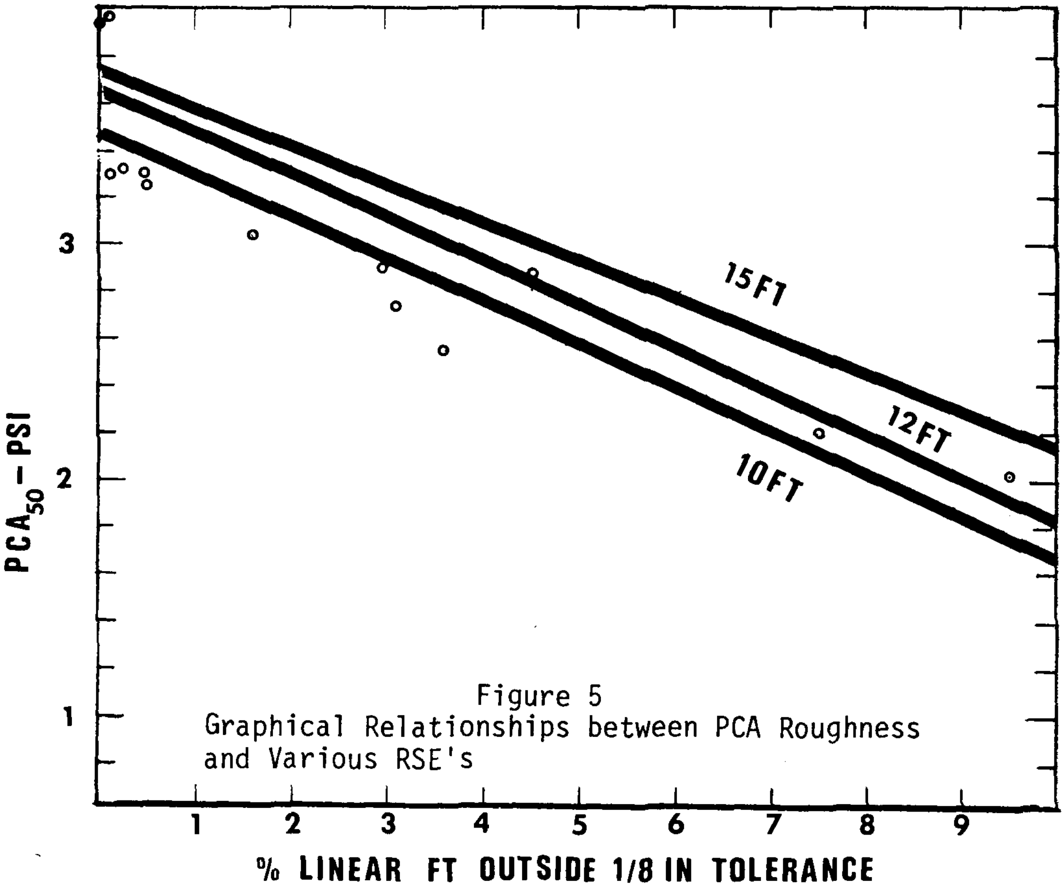

Figure 5
Graphical Relationships between PCA Roughness and Various RSE's

DISCUSSION OF RESULTS

The degree of association between various devices is indicated by the R-Square term in Tables 3 and 4. This term, which lies between 0 and 1, measures the proportion of total variation about the mean explained by the regression. Thus, the closer this value is to unity, the better the variation that is explained by the regression equation. Another measure of the precision of the regression equation is the standard error of estimate and is denoted by SE in the tables. This is a measure of the variation of the actual Y values from the computed Y values and is analogous to the standard deviation of a frequency distribution. The smaller this value, the better the predictive equation. This standard error can be used to set confidence limits on the regression line. The following paragraphs are devoted to discussion of each group of equations:

I. Relationship between Straightedges versus Roadmeters

The correlations shown in the tables and figures demonstrate that each of the smoothness measuring devices responds to many of the same properties associated with smoothness of the surface, although not necessarily in the same dimensional units. The Mays roadmeter indicates a much stronger association with the various straightedges than the other two roadmeters. Likewise, the standard error (SE) for the Mays group is less than the corresponding BPR group. The standard error of 15.9 or 16 for 10-foot data (equation 1) could be used to calculate the confidence range on the average calculated values of Mays roughness for any value of X. Thus, for X = 0 in equation 1, the Mays prediction is 55 inches/mile and for X = 1 this prediction is 66 inches/mile. The 95 percent confidence range on the average estimated value of these predictions, for the same fixed values of X, would be 46 to 64 for the first prediction and 57 - 75 for the second prediction(5). Therefore, if it is assumed that the present RSE requirements are able to provide the desired surface smoothness as presently specified, then the roughness of 75 inches/mile with the Mays roadmeter should be considered acceptable for 100 percent pay. The development of such limits is covered towards the end of this section.

The differences in constant terms for given roadmeter equations can be attributed to random errors and should be taken in light of the precision of the various rolling devices indicated in Table

II. Relationship between Rolling Straightedges (RSE)

Equations 10 through 12 in Tables 3 and 4 define the relationships between various devices. The 15-foot seems to correlate best with the 12-foot data as evidenced by high R-square and low standard error. Since the slope of each equation is close to unity, the offset provides a measure of the difference that can be expected between the correlated devices. Therefore, under present specifications, the number of non-conforming segments on new construction will increase with increasing straightedge lengths. Thus, comparison of data in Table 1 with the current specifications for 1/8 inch tolerance indicates two sections subject to penalty for 10-foot RSE, five sections for 12-foot RSE and six sections for 15-foot RSE. The data for 3/16 inch tolerance were forced through the origin since such a condition was indicated by sections 1, 3, 5 and 7. Comparison of equation 13, 14 and 15 show relationships between the two tolerance settings. On the average the 3/16 inch tolerance readings would be approximately 1/2 of the 1/8 inch setting.

Although the 12- and 15-foot straightedges are better able to detect surface irregularities that may have gone undetected by the 10-foot straightedge, their precision need to be improved if they are to be used for specification purposes. Furthermore, the 12- and 15-foot devices required frequent adjustments to maintain them at the desired tolerance level. This, in fact, could be considered as one of the primary factors that could be advanced against their use in lieu of the 10-foot device.

The major problem that confronted the data collection phase was maintaining the various straightedges at the calibrated tolerance level. It was determined that the calibrated tolerance level of these various devices was invariably lost during travel to the test location and had to be recalibrated at the test location. Furthermore, frequent checks on calibration during the test runs indicated a need for recalibration of all devices (10-, 12-, and 15-

foot) in general and the last two in particular. The point that is being emphasized is that for the data (as is presently collected with the 10-foot device during acceptance testing) to be free from bias, the calibration should be accomplished at the jobsite and not at the district laboratory as is generally done. Rough handling and the speed at which the device is pulled, both affect final measurements.

III. Relationships between Roadmeters

The relationships between various roadmeters is indicated by equations 16, 17 and 18 in Table 3. The PCA data seems to correlate better with the Mays data than the corresponding BPR data. Equation 18, for BPR - Mays relationship, seems to explain the difference that was indicated in the constant term between the first group of equations (1, 2 and 3) and the second group of equations (4, 5 and 6) in Tables 3 and 4. This can be checked by substituting zero in equation 1 and resubstituting the resulting Mays value in equation 18. The magnitude of this BPR roughness should be approximately the same as that derived by substituting zero in equation 4.

Because all instruments seem to measure substantially the same parameter, the choice as to which one should be adopted for roughness (or smoothness) measurement for acceptance of hot mix asphaltic concrete needs to be answered. If precision of each instrument is used as the criteria for the choice, then, according to Table 2, the BPR roughometer would take precedence over the other two. However, if additional factors such as initial cost, operating and maintenance cost, speed of operation and correlation with the presently used device for smoothness measurement is considered, then the Mays roadmeter warrants careful consideration as a means of evaluating new hot mix construction for acceptance.

IV. Revision in Smoothness Criteria

From the preceding discussion, it appears that the present method of smoothness assessment of new asphaltic concrete pavement surfaces is adequate. Unless improvement can be made in the precision, the 12- and 15-foot devices do not seem to offer any alternative to the presently used 10-foot device.

On the other hand, if they are to be recommended for acceptance measurements, then the 12-foot RSE deserves further consideration because of better correlation with the 10-foot RSE and better precision than the 15-foot one. However, the specifications will have to be according to the relationship that was presented in equation 10, or else the number of non-conforming segments of the pavement will increase at the present level of tolerance.

Table 5 presents guideline specifications for 10-foot and 12-foot straightedges. The Mays roughness criteria is based on equation 1 of Table 3. The criteria for 12-foot straightedge were developed from equation 11 and engineering judgment.

TABLE 5

RECOMMENDED SMOOTHNESS CRITERIA FOR RSE & MAYS ROADMETER

INSTRUMENT..........	10FTRSE		12FTRSE		MAYS
TOL,IN.........	1/8	3/16	1/8	3/16	ROUGHNESS
% PAYMENT	% LINEAR FT EXCEEDING TOL		% LINEAR FT EXCEEDING TOL		IN/MI
100% PAY	0.50 OR LESS	0.20 OR LESS	1.25 OR LESS	0.60 OR LESS	70 OR LESS
95% PAY	0.51 - 1.25	0.21 - 0.65	1.26 - 2.20	0.61 - 1.10	71 - 83
80% PAY	1.26 - 2.54	0.66 - 1.25	2.21 - 3.54	1.11 - 1.75	84 -100
50% OR RMV	2.55 OR MORE	1.26 OR MORE	3.55 OR MORE	1.76 OR MORE	100 OR MORE

NOTE... THE 3/16 INCH TOL IS FOR PAVER WITHOUT AUTOMATIC SCREED CONTROL

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

SUMMARY:

In the preceding section an attempt was made to discuss the correlations between various devices generally available in Louisiana for assessment of roughness (or smoothness) of asphaltic concrete surfaces with emphasis on new construction. The analysis of data on nineteen hot mix sections, ranging from new to old pavement surfaces, provided equations relating the three rolling straightedges (10-, 12- and 15-foot) to various roadmeters such as the PCA and the Mays roadmeters and the BPR roughometer. On the basis of the data presented and the field experience gained in the use of these devices, the following conclusions and recommendations seem warranted:

CONCLUSIONS:

1. There is a strong relationship between the various instruments (or devices) generally used for assessment of asphaltic concrete surface smoothness (Tables 3 and 4).
2. The Mays roadmeter seems to correlate the best with the three rolling straightedges (RSE) (Table 3).
3. The precision of the roadmeters is far superior to the three straightedges evaluated in this study (Table 2).
4. Amongst the roadmeters, the BPR indicated better repeatability then the other two. However, if additional factors such as cost, ease and speed of operation and the magnitude of correlation with the RSE are considered, then the Mays roadmeter offers an excellent alternative for evaluation of new hot mix surfaces (Table 2).
5. The measure of precision of the three rolling straightedges gets worse with an increase in the longer dimensions of the device (from 10-foot to 15-foot). Likewise, for a given straightedge, the precision also diminishes with increasing tolerance settings (Table 2).
6. Although the 12- and 15-foot RSE are better able to detect surface irregularities that may go undetected by the 10-foot RSE at a specified tolerance level, their poor precision, frequent recalibration and, to a lesser degree, the difficulty they present in transportation may make their use prohibitive.

7. Finally, for project acceptance, the calibration of the straightedges should be checked at the jobsite prior to test runs and, also frequently, between the test runs. If this is not done, then the validity of the data may be questioned.

RECOMMENDATIONS:

As with any empirical findings, the relationships presented in Tables 3 and 4 should be verified with additional data. Such data collection could be a part of verification of the suggested specifications presented in Table 5. The Department could accomplish this with minimum of effort since the Mays roadmeters are readily available in five of the nine districts. If evaluation of the 12-foot device is to be explored further, then consideration should be given to purchasing two of them and assigning them to two of the districts with the Mays roadmeters. The cost of the latter would be less than $2,500.

The decision as to which of the devices (straightedges or Mays roadmeter) should be specified for control and which one for project acceptance can be arbitrary since all devices were shown to measure essentially the same surface characteristics. However, if the specifications are to be truly "end-result" oriented, then the Mays roadmeter should be seriously considered for project acceptance. The Mays roadmeter provides a summary statistic that relates the roadway roughness to features that directly induce forces on the rider.

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