**ROAD ROUGHNESS MEASUREMENTS
ON
INDIANA PAVEMENTS**

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**Joint
Highway
Research
Project**

**PURDUE UNIVERSITY
LAFAYETTE INDIANA**

by

F.M. Holloway

ROAD ROUGHNESS MEASUREMENTS ON INDIANA PAVEMENTS

TO: K. B. Woods, Director
Joint Highway Research Project

FROM: Harold L. Michael, Assistant Director

April 19, 1956

File: 9-3-3-1
G-36-53I

Attached is a report entitled "Road Roughness Measurements on Indiana Pavements" by F. M. Holloway, Research Engineer. This paper outlines the road roughness study of new Portland Cement Concrete pavements and all Portland Cement Concrete pavements constructed on base courses. The paper was presented at the 42nd Annual Purdue Road School on April 2, 1956.

The paper also includes suggested acceptance standards for new concrete pavements and roughness criteria for resurfacing.

The paper will be submitted for inclusion in the Road School Proceedings.

Respectfully submitted,

Harold L. Michael

Harold L. Michael, Assistant Director
Joint Highway Research Project

HLM:cjg

Attachment

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Purdue University

Lafayette, Indiana

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ROAD ROUGHNESS MEASUREMENTS ON INDIANA PAVEMENTS

INTRODUCTION

The riding public is probably as much aware of road smoothness as any other single quality of a modern pavement. The driver often thinks of a smooth riding pavement as a good pavement and a rough riding pavement as a poor pavement.

Since safety and comfort depends to a great extent upon a smooth riding surface, highway engineers have for many years made an all-out effort to construct and to maintain pavements that are as smooth riding as possible. Considerable progress has been made in this direction. Road equipment manufacturers have spent large amounts of time and money in the development of road building equipment to eliminate some of the irregularities inherent with hand construction methods.

The roughness of a pavement was estimated by eye or with a straight-edge in the early years of highway building. These visual measurements could not be recorded and were always subject to the variations of opinions of observers. Straight-edge measurements were satisfactory for short sections of road, but were slow and not adapted to use in measuring considerable mileage of pavements. With the rapidly increasing mileage in the highway system, it soon became apparent to highway engineers that there was a need for a more accurate and rapid method for measuring and recording road roughness.

Because of this need, engineers concerned with highway construction and maintenance sought to develop equipment with which to measure and compare pavement smoothness or "roughness". As a result many methods and devices were developed and used. One of the early pioneers in the development of these machines was the U. S. Bureau of Public Roads.

In the 1930's, the U. S. Bureau of Public Roads, recognizing the need for a machine to compare riding qualities of roads and that would be capable of standardization in all of its parts, developed the "Relative Road Roughness Indicator". This machine, which was first described as a paper presented to the Highway Research Board in 1940 (4)* and later published in Public Roads (5), removed the uncertainties of vehicle operation that were present in earlier equipment when an automobile was a component part of the measuring apparatus.

The Relative Road Roughness Indicator design is based upon the fundamental principle that the vertical motion imparted to a vehicle spring by the irregularities in a road surface bears a direct relation to the degree of roughness. By maintaining constant the speed, the amount and distribution of the loading, and the type and condition of the springs and tire equipment, the deflection of the springs of the Relative Roughness Indicator is taken as a measure of the "relative" roughness of the road surfaces being tested.

DEVELOPMENT OF ROUGHNESS MEASURING EQUIPMENT AT PURDUE

The Joint Highway Research Project became interested in road roughness measurements when, through the courtesy of Mr. E. F. Kelley, Chief of the Division of Tests, Mr. A. L. Catudal brought the Bureau of Public Roads' Road Roughness Indicator to Indiana in September, 1941, and made roughness measurements on some 300 miles of Indiana pavements.

In his report to the Joint Highway Research Project Advisory Board on January 2, 1942, Mr. Tilton E. Shelburne listed the following among the results of this study:

"These tentative results indicated the desirability of measuring road

* Numbers in parenthesis refer to the references in the Bibliography.

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surface roughness of Indiana pavements on a large scale."

As a result of this first study, Mr. Shelburne presented to the Advisory Board on February 19, 1942, a working plan covering an exhaustive study of road surface roughness in Indiana, but because of the war the Joint Highway Research Project could neither get materials to build a Road Roughness Indicator nor get the Bureau of Public Roads to bring their machine to Indiana on a co-operative project.

After the war, the Joint Highway Research Project again was interested in road roughness measurements. The development of a three-wheel type of roughometer was initiated and a pilot machine constructed. The machine, however, did not prove stable and the idea was eventually abandoned.

On December 8, 1953, the Advisory Board recommended the construction of a Relative Road Roughness Indicator of the Bureau of Public Roads type. Finally, on October 7, 1954, a requisition for the construction of a Road Roughness Indicator was placed with the Purdue University Central Machine Shop through the University Service Enterprises.

Although the official name given to this equipment by the Bureau of Public Roads is "Relative Road Roughness Indicator," for simplicity it will be referred to as the "Purdue Roughometer" throughout the remainder of this report. The machine which was built and used for this study is essentially an exact copy of the machine built and used by the Bureau of Public Roads for measuring relative road roughness.

PURPOSE AND SCOPE

The purpose of this project was four-fold: first, to develop and to calibrate the new Purdue Roughometer of the Bureau of Public Roads type; second, to test and compare the riding qualities of certain pavement types

FIGURE 1 ELEMENTS OF ROAD ROUGHNESS INDICATOR

COURTESY OF B.P.R.

Figure 2. Close-Up View of Pumpwater Attached To
the Tally Machine

FIGURE 3 SCHEMATIC SECTION OF INTEGRATOR

for each revolution of the wheel.

On the instrument board (shown in Figure 4) that is carried in the towing vehicle are mounted the magnetic counter that records the road roughness units, the second magnetic counter that records wheel revolutions of the trailer as a measure of distance traveled, a switch controlling both counters, and a stop watch. When used with the wheel revolution counter, the stop watch provides a check on the speed of the towing vehicle. The instrument board also provides a place for data sheets. The magnetic counters operate on the storage battery of the towing vehicle.

A 1955 Chevrolet Carry-All was purchased by the Joint Highway Research Project to be used as the towing vehicle for the roughometer. Although the principal function of this vehicle is to provide the means for towing the Roughometer along the road at a constant speed, it is also used for hauling the Roughometer when traveling from one location to another. In order to load the Roughometer into the carry-all, a set of wheels is fastened at the front of the frame to permit the machine to stand alone like a tricycle. The Roughometer can then be pushed into the body of the towing vehicle by means of three ramps made from six-inch steel channels. After the Roughometer is loaded it is fastened so that it will not roll about when being transported. A general view of the Roughometer and towing vehicle making a road roughness test is shown in Figure 5.

PROCEDURE

Calibration Tests

The Purdue Roughometer used in the road roughness tests described herein was constructed by the Purdue University Central Machine Shop from plans and specifications furnished by the Bureau of Public Roads

Figure 4. Close-Up View of Instrument Panel
With Data Sheet

Figure 5. Conducting A Road Roughness Test.

and each component part was carefully checked by a staff member of the Joint Highway Research Project before assembly. Loading deflection tests were made on each of the special leaf-springs before assembly to assure that they had matching load characteristics. After assembly, the trailer was tested to determine the weight necessary to place the axle at the center of percussion.

As a final step before the Purdue Roughometer was road tested, the integrator was calibrated. Since the accuracy of the measurements with the Roughometer depends largely on the accuracy of the integrator, a calibrating device for the integrator which met the general recommendations of the Bureau of Public Roads was constructed by the Central Machine Shop.

After initial road tests showed that the equipment apparently functioned properly, the next step in this project was the calibration of the Roughometer by means of correlation tests between the new Purdue Roughometer and the Bureau of Public Roads' machine. Because the Bureau of Public Roads was unable to bring their machine to Indiana at this time, it was felt that the next best method of comparing the two machines would be by comparing the results of road roughness tests made by the Purdue machine with the results obtained recently by the Bureau of Public Roads for the same Indiana road sections.

Figure 6 shows graphically a comparison of the Bureau of Public Roads and Purdue roughness measurements for one of the road sections. This section is the U. S. 31 test road located near Columbus where the rigid sections in 1953 and 1954 had overall indices of 87 and 88 inches per mile respectively as measured by the Bureau of Public Roads, compared with the Purdue 1955 value of 88 inches per mile. The flexible pavement on this same test road had overall indices of 69 and 65 inches per mile in 1953 and 1954 respectively, compared with 66 inches per mile for 1955.

FIGURE 6

A COMPARISON OF THE ROAD ROUGHNESS MEASUREMENTS MADE BY THE BUREAU OF PUBLIC ROADS WITH THOSE MADE BY PURDUE UNIVERSITY ON THE U.S. 31 TEST SECTIONS BUILT IN 1953

Selection of Test Sections

During the field portion of this project, a total of 79 road sections were tested. Of these, 14 sections were new portland cement concrete pavements (completed during 1954) and 65 sections were older portland cement concrete pavements constructed on granular base courses (referred to as "subgrade treatments" in the Indiana Standard Specifications For Road and Bridge Construction and Maintenance, 1952). The term "road section" in this paper will be used to define a section of pavement that is as far as known identical in age, traffic volume, and construction over its entire length. These road sections were generally between 1 and 10 miles in length with most being between 4 and 6 miles long.

Roughness measurements for all new projects were made for the purpose of establishing a basis for suggesting specification limits. It was also felt that these measurements would stimulate interest among contractors and might create rivalry for the smoothest riding pavements on future paving contracts. These original roughness readings on all new concrete pavements should be valuable for determining pavement performance at later dates. Thus, the change in riding qualities can be studied for these pavements with age and other factors such as traffic. This information might also be used advantageously for improvement of present design and construction practices.

The older concrete pavement sections which were tested for roughness are the same sections which are included in a performance study by the Joint Highway Research Project of rigid pavements constructed on granular base courses. It was felt that an evaluation of the roughness data for these sections might give a better understanding of the factors affecting pavement performance.

Road Testing Procedures.

All roughness tests were made at $20 \frac{1}{2}$ m.p.h. in the direction of traffic movement with the trailer wheel in the center of the traffic lane. This is the normal procedure employed by the Bureau of Public Roads. The tire inflation pressure was checked both before and after each run to make certain that it remained at $30 \frac{1}{2}$ p.s.i.

The unit of measurement used in this study is "inches of roughness per mile" and is actually an accumulation of the vertical movements of the trailer wheel within the frame for a mile stretch of road. The roughness values given for each road section represents the average of two test runs in each lane. In the case of dual pavements, each pavement was considered separately. The "average roughness" (or Roughness Index) for any particular road section is the total inches of accumulated roughness divided by the number of miles in that section.

Complete instructions for operating the Roughometer are given in the Manual of Information Regarding the Operation and Maintenance of the Public Roads Relative Road Roughness Indicator, prepared by the Physical Research Branch, Bureau of Public Roads, U. S. Department of Commerce, May 1941 (Revised June, 1951) (6).

RESULTS OF FIELD STUDY

The results of the roughness tests for each pavement type are discussed in the following sections:

New Portland Cement Concrete Pavements

The 14 new concrete pavement sections tested ranged in length from 1.008 to 7.482 miles with the average length being 4.706 miles.

In general, these new rural concrete pavements were relatively smooth. They ranged from a low of 67 inches of roughness per mile for the smoothest section to a high of 85 inches of roughness per mile. The over-all weighted average for all sections was 75 inches per mile. (See Figure 7)

The results of tests on the new portland cement concrete pavement sections are shown in Table 1. The values for roughness measurements are shown in inches per mile and are given as overall average, low mile, and high mile.

It is interesting to note the general agreement in the results of these tests with the results of other states for new concrete pavements. Mr. Swanberg, Engineer of Materials and Research, Minnesota Department of Highways reports (7) that their measurements indicate that concrete pavements can be built with a roughness index as low as 52 inches per mile and most of their pavements, both bituminous and concrete, recently built are in the range of 65 to 80 inches per mile.

Prof. Ralph Moyer of the Institute of Transportation and Traffic Engineering, University of California, also reports (7) that for 93 miles of new rural concrete pavements in California, the average roughness value was 52 inches per mile with a range of 38 to 75 inches per mile. He gives credit for the smooth concrete pavements in California primarily to the

FIGURE 7 ROAD ROUGHNESS INDICES FOR CONCRETE PAVEMENTS

TABLE 1
ROAD ROUGHNESS TESTS
(NEW PORTLAND CEMENT CONCRETE PAVEMENTS (COMPLETED IN 1954))

Route	Project No.	Length Tested	County	Inches of Roughness/mi.		
				Avg.	Low mi.	High mi.
S.R. 324	U724(5)	3.040 mi.	Allen	85	73	92
U.S. 41	F169(28)	5.184 mi. (dual-lane)	Newton	78	68	80
S.R. 39	S417(4)	7.153 mi.	Boone	84	76	99
S.R. 39	S417(5)	7.236 mi.	Clinton	87	61	73
S.R. 135	S124(3)	6.673 mi.	Harrison	69	62	75
S.R. 64	S88(9)	4.987 mi.	Dubois	70	64	76
S.R. 64	S88(8)	7.482 mi.	Dubois	73	62	79
U.S. 41	F35(6)	2.699 mi.	Sullivan	83	67	89
S.R. 19	S422(6)	3.881 mi.	Lake	74	73	76
S.R. 26	S106(2)	4.715 mi.	Jay	72	66	78
S.R. 109	F791(4)	1.008 mi.	Madison	78	-	-
S.R. 109	F791(5)	1.121 mi.	Madison	82	-	-
U.S. 41	F65(8)	4.298 mi.	Gibson	80	73	90
S.R. 62	F16(23)	1.707 mi.	Spencer	72	-	-

"skillful use of the Johnson Finisher developed in California in 1936."

On the basis of their experience in checking the roughness of new pavements since 1946 with a Bureau of Public Roads Roughometer, the Minnesota Department of Highways has tentatively adopted the following standards:

<u>Roughness Index</u> <u>(in. per mile)</u>	<u>Riding Qualities</u>
Below 75	Good
75 - 100	Fair
Above 100	Poor

The tests of new pavements in this study have shown, as have Minnesota and California tests, that pavements can be built to meet the Minnesota roughness standards and it seems entirely proper and reasonable to expect that new pavements in Indiana should be built to meet these standards. In fact, it appears that a roughness index between 90 and 100 inches per mile should also be considered for inclusion in the "poor" riding classification.

Workmanship during construction appears to be one of the factors for the difference in roughness between any two new road sections. As an example, S. R. 39 between Frankfort and Lebanon was built as two construction sections by two different contractors. Each section is approximately seven miles long, each completed in 1954, and each of the same design. One of the sections had an overall average roughness of 72 inches per mile while the other was 84 inches per mile.

If adopted by all states, roughness standards for new construction should result in improvement in the design and operation of mechanical finishing equipment and finishing methods for the construction of both

portland cement concrete and bituminous pavements. Roughness measurements would give a common denomination for comparing the workmanship of various contractors and would tend to create a competitive spirit among contractors which would result in smoother riding pavements.

Older Portland Cement Concrete Pavements Built on Granular Base Course

Table 2 shows the results of roughness tests on 65 older concrete pavements constructed on granular base course materials (sometimes referred to as subgrade treatments). The purpose of these measurements was to determine if there existed any measurable relationship between roughness and the performance of rigid pavements built on granular base courses. This part of the study received supporting data from a pavement performance study that was in progress. It includes roughness measurements of every known concrete pavement in Indiana that has been constructed on a granular base course except those which have been resurfaced and short sections located within urban areas.

Three types of granular base course material have been used under rigid pavements in Indiana, namely, gravel, crushed stone, and sand. Of the three types tested, pavements with crushed stone base courses were the smoothest with an average of 84 inches per mile. The roughness averages for the sand and gravel types were rather close behind with averages of 86 and 88, respectively. It is concluded that there appears to be very little relationship between road roughness and type of granular base course used when that is the only factor considered.

Although in general the road sections which are older tend to be rougher than those built in recent years, it was found that it is not necessarily true that just because a road is older it is rougher than a newer road. A good example of this is shown by the average roughness for

TABLE 2

ROAD ROUGHNESS TESTS

OLDER PORTLAND CEMENT CONCRETE PAVEMENTS BUILT ON GRANULAR BASE COURSES

Route	Within Sec.	Length Tested	County	Inches of Roughness/mi.		
				Avg.	Low mi.	High mi.
U.S. 41	J	4.0 mi.	Vigo	98	89	108
U.S. 41	J	4.0 mi.	Vigo	91	82	100
U.S. 41	J	2.0 mi.	Vigo	74	74	74
U.S. 41	J	2.0 mi.	Vigo	84	84	84
S.R. 39	K	1.0 mi.	Morgan	79	-	-
U.S. 31	H, I	5.0 mi.	Johnson	76	71	80
U.S. 31	H, I	12.0 mi.	Johnson	85	76	92
S.R. 46	K	1.8 mi.	Bartholomew	78	72	84
S.R. 107	A	2.6 mi.	Jefferson	78	74	81
S.R. 37	J, K	7.0 mi.	Morgan and Monroe	87	74	98
S.R. 37	J	6.0 mi.	Monroe	93	88	98
S.R. 135	B	3.4 mi.	Harrison	88	78	97
S.R. 135	B	3.0 mi.	Harrison	85	76	96
S.R. 135	B	6.7 mi.	Harrison	69	62	75
U.S. 52	P-2	6.0 mi.	Tippecanoe	85	75	97
U.S. 52	P-2	6.0 mi.	Tippecanoe	81	73	94
U.S. 52	N	1.0 mi.	Clinton	76	-	-
U.S. 52	N, O	11.0 mi.	Tippecanoe and Clinton	84	79	90

(Continued next page)

TABLE 2 (Continued)

Route	Within Sec.	Length Tested	County	Inches of Roughness/mi.		
				Avg.	Low mi.	High mi.
U.S. 52	L, M	2.0 mi.	Boone	95	78	120
U.S. 40	A	4.0 mi.	Vigo	88	84	92
U.S. 40	A	4.0 mi.	Vigo	91	82	97
U.S. 52	P-2, Q	8.0 mi.	Tippecanoe and Benton	68	64	74
U.S. 52	P-3, Q	4.5 mi.	Tippecanoe and Benton	71	68	78
U.S. 41	J	4.0 mi.	Vigo	106	84	123
U.S. 41	J	4.0 mi.	Vigo	103	92	118
S.R. 25		1.0 mi.	Tippecanoe	118	-	-
U.S. 52	M	1.0 mi.	Boone	95	-	-
U.S. 40	P	4.0 mi.	Henry	105	94	113
U.S. 40	P	1.6 mi.	Henry	101	100	102
S.R. 100	H	3.0 mi.	Marion	117	125	112
U.S. 40	Q-2	5.2 mi.	Henry	98	87	103
U.S. 40	Q-1, Q-2	6.6 mi.	Henry	91	76	107
U.S. 40	T	1.8 mi.	Wayne	100	86	114
U.S. 40	T	1.8 mi.	Wayne	107	104	110
U.S. 31	P	1.0 mi.	Howard	88	81	96
S.R. 100	H	3.0 mi.	Marion	80	78	82
U.S. 31	P	6.9 mi.	Howard	102	92	107
S.R. 32	D	1.6 mi.	Hamilton	98	89	105

(Continued next page)

TABLE 2 (Continued)

Route	Within Sec.	Length Tested	County	Inches of Roughness/mi.		
				Avg.	Low mi.	High mi.
S.R. 100	E	4.7 mi.	Marion	65	78	90
S.R. 100	H	1.4 mi.	Marion	101	98	106
S.R. 3	K	1.7 mi.	Henry	109	94	121
S.R. 157	K	7.0 mi.	Greene	69	64	72
S.R. 64	C, D	5.0 mi.	Pike	75	70	78
U.S. 41	B	4.4 mi.	Vanderburg	79	72	83
U.S. 41	B	4.4 mi.	Vanderburg	83	75	88
U.S. 41	C	9.0 mi.	Gibson	74	65	84
U.S. 41	C	9.0 mi.	Gibson	75	74	78
S.R. 37	F	3.0 mi.	Lawrence	80	76	83
U.S. 41	B	4.7 mi.	Vanderburg	87	82	90
U.S. 41	B	2.0 mi.	Vanderburg	87	84	90
S.R. 37	F	5.0 mi.	Lawrence	71	66	79
S.R. 62	D, E	5.6 mi.	Vanderburg	83	78	99
S.R. 662	A, B	5.5 mi.	Vanderburg and Warrick	78	71	89
S.R. 66	G	3.6 mi.	Perry	76	72	84
U.S. 30	L	1.0 mi.	Whitley	95	-	-
U.S. 24	O	11.0 mi.	Huntington	94	88	98

(Concluded next page)

TABLE 2 (Continued)

Route	Within Sec.	Length Tested	County	Inches of Roughness/mi.		
				Avg.	Low mi.	High mi.
U.S. 30	L	16.0 mi.	Kosciusko and Whitley	85	70	106
U.S. 30	W	3.8 mi.	Allen	95	86	108
S.R. 15	B	10.0 mi.	Wabash	99	87	118
U.S. 41	S	9.0 mi.	Newton	96	85	115
U.S. 41	S	5.2 mi.	Newton	87	31	90
U.S. 31	X	6.0 mi.	St. Joseph	102	96	110
U.S. 31	X	6.0 mi.	St. Joseph	99	96	102
U.S. 41	V	8.0 mi.	Marshall	106	95	115
U.S. 41	V	3.8 mi.	Marshall	98	93	106

six miles of pavement constructed in 1938 which was lower than any of the others except the 1953 and 1954 construction years, and here the 1938 construction is only slightly rougher. Of course it must be kept in mind that the roughest of the older pavements are more likely to have been resurfaced than the newer pavements. Relatively new pavements are not normally resurfaced even though they may be rough riding.

This does not necessarily mean that as a particular road grows older it does not get rougher, but rather that it is difficult to predict how much road roughness is due to age alone. There are other factors which must be taken into consideration, probably the most important of which is "How rough was the road when it was new?" From the discussion of new rural concrete pavements it may be noted that there was a spread in roughness of almost 20 inches per mile between the smoothest and the roughest sections. From this it would seem that it is not possible to state how much of the present roughness of a pavement is caused by age and other factors unless the original roughness index for that particular pavement in question is known.

Even though most of the older pavement sections are rougher than the newer ones, this does not necessarily mean that the older ones are rougher because they have grown rough with age. It suggested that a large part of this difference in roughness may be due to improved finishing methods during more recent years, rather than to differences in age. It may even be that a new pavement during its life time may become smoother with age for a short period of time before becoming rough as it deteriorates.

In order that the relationship between age and roughness might be determined, it is suggested that annual roughness measurements be made on specific pavement sections. These pavement sections could be picked from

among the new sections which were tested during this study.

Another factor that was considered as perhaps affecting road roughness was traffic-age of the pavements. Thus, not only the actual age of the pavement was considered, but also the amount of traffic that has used the facility. For example, if two pavement sections were constructed the same year but the first has had twice as much traffic as the second, the traffic-age of the first would be considered twice that of the second. The traffic-age which is considered here is the estimated number of repetitions of 18,000 pound axle loads that have been applied to the pavement during its lifetime.

Taking all the pavements as a whole, there appears to be a trend of increasing roughness with increase in traffic-age, although its magnitude is not definite because of other variables. The same problem arises here as arose when roughness was being correlated with age of pavement. The increase of roughness of the pavement from what it was originally must be known before one can definitely correlate the effect of traffic-age with road roughness. As pointed out previously, there is such a wide spread among roughness values for new pavements that it is impractical to determine how much of the present roughness was built into the pavement and how much has developed through other causes. This further emphasizes the need for a continuous study over a period of time.

An attempt was made to correlate road roughness with transverse cracking for a large group of the roads for which the number of transverse cracks was counted, but no such relationship appeared to exist. This can probably be explained by the fact that as long as the crack is held together by the pavement reinforcement and there is no displacement of the slab across the crack, the tire of the Roughometer will pass across it without registering any roughness.

SUMMARY OF FINDINGS

The findings of this study are:

1. The Purdue Roughometer, built in accordance with the Bureau of Public Roads' Relative Roughness Indicator design, is a convenient, satisfactory, and rapid means of evaluating the riding quality of a pavement.
2. From the magnetic counters that record the road roughness units and the distance traveled, the test results can be recorded in a form convenient for study and comparison of two or more road sections.
3. A comparison between measurements made with the Purdue Roughometer and those made previously by the Bureau of Public Roads for the same pavement sections gave results that were almost identical.
4. In general, the new rural portland cement concrete pavements are relatively smooth. They range from a low of 67 inches of roughness per mile to a high of 85 inches per mile with the overall weighted average of 75 inches per mile.
5. Riding qualities and therefore road roughness measurements of new pavements are affected by workmanship during construction.
6. There appears to be very little relationship between road roughness and type of base course used when that is the only factor considered.
7. Although in general the road sections which are older showed a tendency to be rougher, it may not be necessarily true that age alone is the cause of this greater roughness. It is suggested that a large portion of this difference in roughness between old pavements and new ones may be due to improved finishing methods during recent years.

8. There appears to be a trend of increased roughness with increase in traffic-age of concrete pavements. As with the correlation of age with roughness, the original roughness values for the pavements must be known before the increase in roughness can be evaluated.

9. Transverse cracking of concrete pavements appears to have little or no effect on road roughness as long as there is no displacement of the slab across the crack.

10. More research is needed to determine the effect of age, traffic, and other factors, on road roughness. To determine these effects, periodic roughness measurements must be made on selected roads over an extended period of time. It is suggested that some or all of the new pavement sections tested in the present study be used as a basis for this further research.

11. The psychological effect from the publication of the road roughness measurements of all new projects constructed should tend to develop a competitive spirit among contractors which would result in smoother riding pavements.

12. The possibility of using road roughness measurements as part of the basis for acceptance of new construction should be given consideration. It is suggested that the following standards be considered in evaluating new pavements:

<u>Roughness Index</u> <u>(in. per mile)</u>	<u>Riding Qualities</u>
Below 75	Good (Acceptable)
75 - 90	Fair (Acceptable)
Above 90	Poor (Not Acceptable)

13. For evaluating the surface riding qualities of older pavements as a part of a highway condition survey, in connection with the determination of resurfacing and reconstruction needs, the following standards are suggested:

<u>Roughness Index</u> <u>(in. per mile)</u>	<u>Riding Qualities</u>
Below 60	Excellent
60 - 75	Good
75 - 90	Fair
90 - 150	Poor (possible resurfacing)
Above 150	Very Poor (resurfacing required)

BIBLIOGRAPHY

1. Hogentogler, C. A., "Apparatus Used in Highway Research Projects," Bulletin of the National Research Council, Vol. 6, Part 4, No. 35, August 1923, pp. 14-16.
2. "An Instrument for the Measurement of Relative Road Roughness," Public Roads, Vol. 7, No. 7, September 1926, page 144.
3. Dana, Homer J., "The Dana Automatic Recording Roughometer for Measuring Highway Roughness," Proceedings, Highway Research Board, Vol. 12, Part I, December 1932, page 362.
4. Buchanan, J. A. and Catudal, A. L., "Standardizable Equipment for Evaluating Road Surface Roughness," Proceedings, Highway Research Board, Vol. 20, 1940, page 621.
5. Buchanan, J. A. and Catudal, A. L., "Standardizable Equipment for Evaluating Road Surface Roughness," Public Roads, Vol. 21, No. 12, February 1941, page 227.
6. Manual of Information Regarding the Operation and Maintenance of the Public Roads Relative Road Roughness Indicator, prepared by the Bureau of Public Roads, 1951.
7. Moyer, R. A. and Shupe, J. W., "Roughness and Skid Resistance Measurements of Pavements in California," Bulletin No. 37, Highway Research Board, 1951.
8. "Concrete Highways and Public Improvements," Portland Cement Association, Summer 1955, page 5.
9. Thanos, H., "A Road Roughometer," A Thesis submitted to the faculty of Purdue University in partial fulfillment of the requirements for the degree of Master of Science in Electrical Engineering, May 1951.
10. Moyer, R. A., "Motor Vehicle Operating Costs and Related Characteristics on Untreated Gravel and Portland Cement Concrete Road Surfaces," Proceedings, Highway Research Board, Vol. 19, 1939, page 68.
11. "Improved Apparatus for Measuring Roughness," Better Roads, Vol. 11, No. 6, June 1941, page 22.
12. Pooli, R., "Estimating the Surface Qualities of Highways," Highway Research Board Abstracts, Vol. 22, No. 7, July 1942, page 12.

13. Moyer, R. A., "Motor Vehicle Operating Costs, Road Roughness and Slipperiness of Various Bituminous and Portland Cement Concrete Surfaces," Proceedings, Highway Research Board, Vol. 22, 1942, page 13.
14. Hveem, F. N., "Laboratory Builds Profilograph to Measure Pavement Roughness," California Highways and Public Works, Vol. 22, No. 3 and 4, March-April 1944, page 6.
15. Scott, W. J. O., "Roads and Their Riding Qualities," Proceedings, Institution of Civil Engineers, Road Paper No. 25, Session 1947-1948, pp. 3-55.
16. Sheppe, R. L., "Road Roughness Measurements of Virginia Pavements," Proceedings, Highway Research Board, Vol. 28, 1948, pp. 137-153.
17. Moyer, R. A., "Report of Committee on 'Antiskid' Properties of Road Surfaces," Bulletin No. 27, Highway Research Board, 1950.
18. Moyer, R. A., Gallagher, R., and Shupe, J. W., "A Rating Method for Resurfacing Secondary Street System in Berkeley," Proceedings, Second California Institute on Street and Highway Problems, 1950, page 150.
19. "Design and Uses of Roughometer," Western Construction, Vol. 25, No. 10, October 1950, pp. 90-92.
20. Moyer, R. A., "Results of Bureau of Public Roads Road Roughness Indicator Tests," Abstracts, Highway Research Board, Vol. 22, No. 7, July 1952, page 20.
21. Morgan, A. D., "Correlation of Roughometer and Skid Tests with Pavement Type, Design, and Mix," Bulletin No. 37, Highway Research Board, 1951.