ROUGHNESS MEASUREMENTS OF BRIDGE DECKS AND APPROACHES

R. E. Hooper
L. T. Oehler

Research Laboratory Division
Office of Testing and Research
Report No. 325
Research Project 59 F-51

Michigan State Highway Department
John C. Mackie, Commissioner
Lansing, March 1960

ROUGHNESS MEASUREMENTS OF BRIDGE DECKS AND APPROACHES

This investigation of bridge roughness was made at the request of Mr. C. B. Laird, Chief Construction Engineer. The original request was that bridge roughness be measured by the Department's Roughometer truck, in the same manner as pavement roughness. However, because of the short lengths of bridge spans, the procedures used for pavement roughness were not suitable for bridge roughness without major modifications. As an alternative, the Research Laboratory Division proposed the use of a 10-ft rolling straight-edge which had been used previously to measure roughness on short sections of pavement. This instrument was used in the study. Mr. Laird had stated that information on bridge roughness was required to correlate riding qualities with deck pour widths, bridge types, kinds of screeds and strikes used, and a number of other factors. Mr. Paul A. Nordgren, Bridge Construction Engineer, specifically selected the following six bridges for a preliminary study of bridge roughness:

1. B2 of 9-10-5, M 20 over US 23, 1.5 mi west of Bay City.
2. B1 of 13-3-4, Climax Road over US 12, 3 mi southwest of Battle Creek.
3. B1 of 25-7-3, US 23 over the Flint River, 1/2-mi west of Flint.

4. B2 of 63-11-4, US 16 over Milford Road, 1/2-mi north of New Hudson.

5. X1 of 63-13-4, US 16 over the C & O RR, 1/2-mi northwest of Novi.

6. B1 of 83-11-11, US 131 over the Manistee River, 5.7 mi north of Manton.

Figure 1 shows plan views of the selected bridges. To compare the straight-edge technique with conventional vehicular methods of roughness measurement, Mr. E. A. Finney, Director, Research Laboratory Division, requested that the University of Michigan's Pavement Profilometer truck measure the riding quality of these same bridges. This report discusses the procedure and test results obtained with the rolling straight-edge and includes a comparison of this method and the Profilometer truck.

TEST EQUIPMENT AND PROCEDURE

The device used by the Laboratory in this bridge roughness study consists essentially of a 10-ft straight-edge with a hard rubber wheel attached at either end to allow propulsion along a desired path (Fig. 2). A third wheel, suspended at the midpoint of the straight-edge, is so mounted as to allow displacement in a vertical direction only. A metal arm attached to the third wheel can make contact at any one of ten equidistant points on a fixed scale. Each interval between adjacent contact

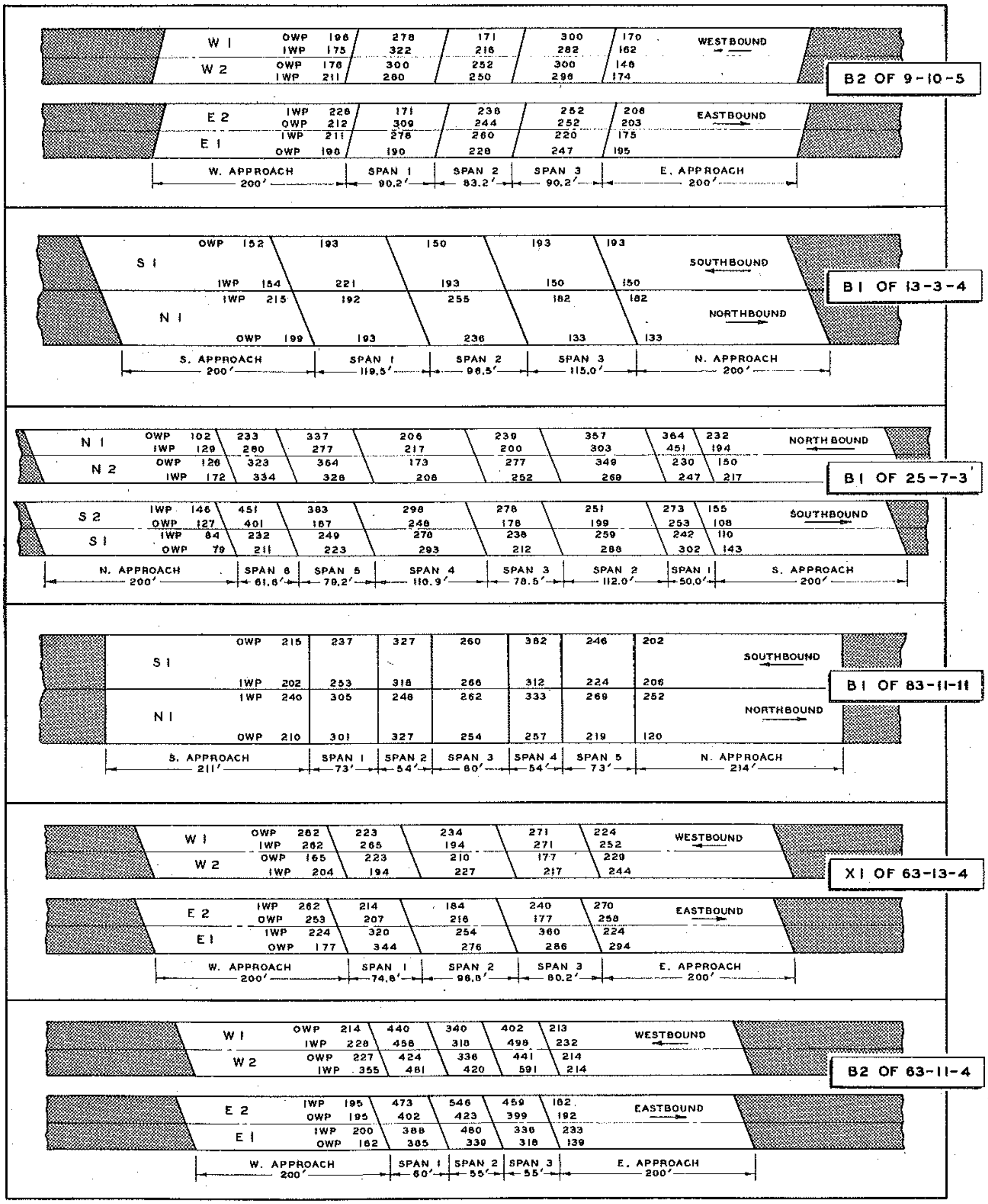

Figure 1. Plan views of six test bridges, showing straight-edge profilometer roughness for each span and 200-ft approach; IWP indicates the inner wheel path, OWP the outer.

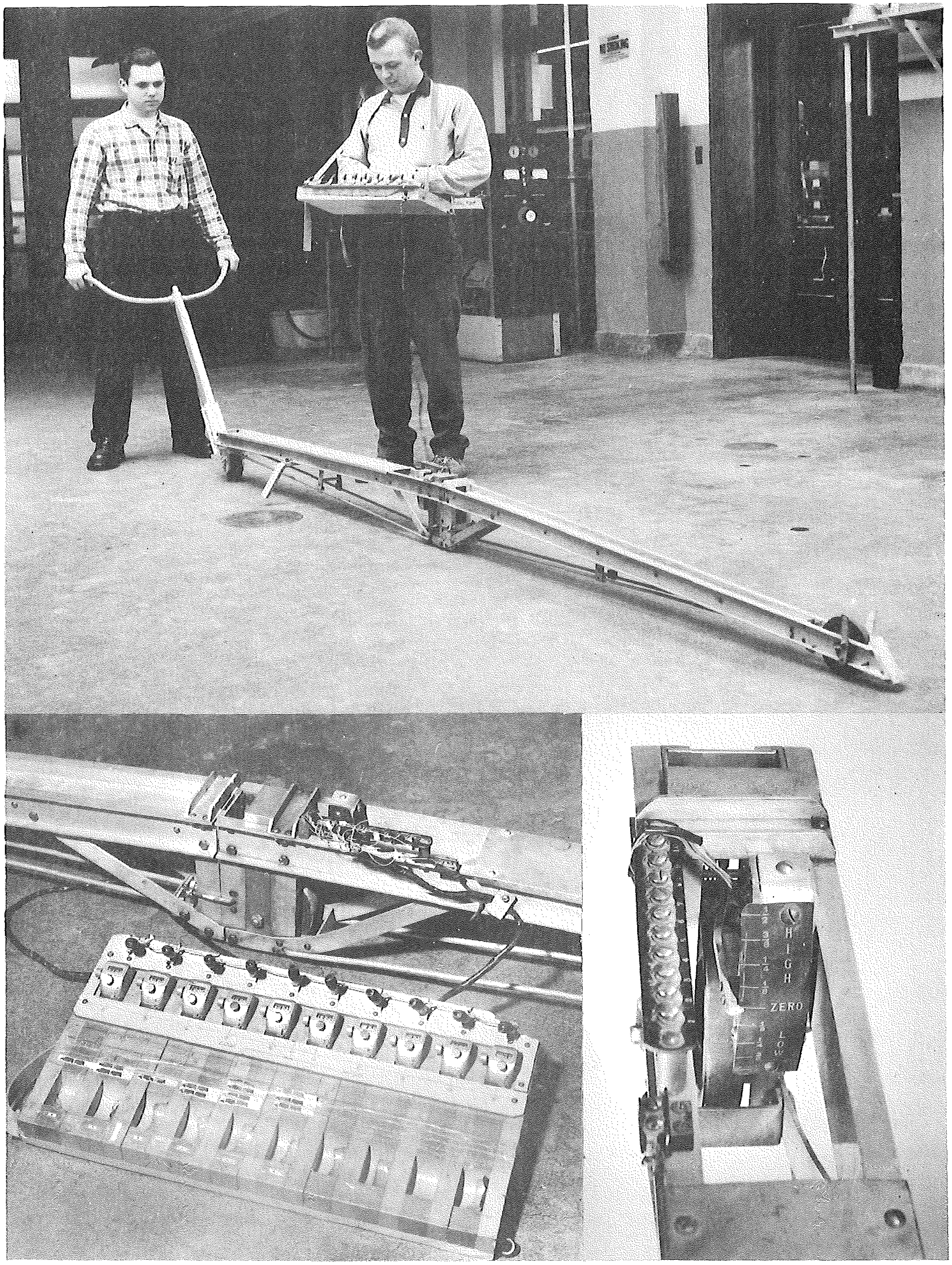

Figure 2. The 10-ft straight-edge profilometer (top) using a measuring arm and a calibrated scale (bottom right) to register vertical increments of surface irregularity, and the manually operated control board (bottom left) with hand counter for each increment.

points on this scale is equivalent to 1/8-in. of actual vertical displacement. As the metal arm makes contact with one of the ten points, a light flashes on a portable control board for the corresponding 1/8-in. of vertical slab displacement. The minimum recordable vertical slab displacement is ±1/16- and the range is ±1/2-in. As the lights flash on the control board, the operator punches corresponding hand counters. Thus, a continuous record of vertical displacement due to slab surface irregularities is obtained on the counters.

The field measurements were conducted in October and December 1959. A crew of five men conducted the bridge roughness tests: a supervisor, an operator for the straight-edge profilometer, a man for the control panel, and two flagmen. In field notation and in the figures and tables of this report, the bridge traffic lanes were designated according to the direction of traffic: N1, S1, E1, or W1. Similarly, on four-lane pavement, center passing lanes were designated N2, S2, E2, or W2. Each traffic or passing lane was divided into an inner wheel path (IWP) and an outer wheel path (OWP). This notation is used in the accompanying figures and tables. The general procedure used throughout the study was as follows:

1. Bridge span lengths were measured and recorded.

2. The 200-ft approach distances were measured and marked for each wheel path to be tested.

3. The fixed dial was adjusted to read zero while the suspended third wheel was maintained at its zero position.

4. Two profilometer runs were taken for each wheel path; where sizable discrepancies occurred, a third run was made.

A typical example of the data recorded is shown in Table 1, for Bridge B2 of 9-10-5, after reduction from the recorded information. The values are the average of two profilometer runs. High readings (upward displacement) and low readings (downward displacement) are tabulated separately. To obtain the final straight-edge profilometer roughness index, the high and low readings were added and substituted into the following formula:

$$RI = \frac{1(a) + 2(b) + 4(c) + 6(d) + 8(e)}{16} \times \frac{5280}{L}$$

where a = the total number of 1/16-in. displacements,
b = the total number of 1/8-in. displacements,
c = the total number of 1/4-in. displacements,
d = the total number of 3/8-in. displacements,
e = the total number of 1/2-in. displacements,
L = the length of the span in ft, and
RI = the roughness index in in. per mi.

DATA EVALUATION

Decks

Table 2 summarizes the results of this study. In the column "Bridge Deck" three subcolumns are titled "Length," "Straight-Edge Profilometer," and "Truck Profilometer." The linear feet figures refer to the total bridge deck lengths. The straight-edge roughness index was obtained

TABLE 1
TYPICAL RECORDED DATA
Bridge B2 of 9-10-5, Bay City

Lane[1]	Wheel Path[2]	Area	Length ft	Avg. High Readings, inches					Avg. Low Readings, inches				
				1/16	1/8	1/4	3/8	1/2	1/16	1/8	1/4	3/8	1/2
E-1	OWP	W. App.	200.0	30.5	34.5	2.0	2.0	0.0	10.0	0.5	0.0	0.0	0.0
E-1	OWP	Span 1	90.2	5.0	9.5	3.5	0.0	0.0	4.0	3.0	1.0	0.0	0.0
E-1	OWP	Span 2	83.2	3.0	10.0	3.5	1.5	0.0	8.5	1.5	0.0	0.0	0.0
E-1	OWP	Span 3	90.2	1.5	23.0	0.5	0.0	0.0	4.0	7.0	0.0	0.0	0.0
E-1	OWP	E. App.	200.0	31.5	37.0	1.0	0.0	0.0	4.5	1.0	0.0	0.0	0.0
W-1	OWP	W. App.	200.0	21.0	33.3	1.3	1.6	0.0	14.3	1.3	0.0	0.0	0.0
W-1	OWP	Span 1	90.2	1.5	19.0	2.5	0.0	0.0	6.5	4.0	3.0	0.0	0.0
W-1	OWP	Span 2	83.2	3.0	14.0	0.0	0.0	0.0	5.0	0.5	1.5	0.0	0.0
W-1	OWP	Span 3	90.2	2.5	10.5	4.0	2.0	0.0	10.5	4.0	3.0	0.0	0.0
W-1	OWP	E. App.	200.0	27.5	28.5	2.5	0.0	0.0	6.5	1.0	0.0	0.0	0.0
E-1	IWP	W. App.	200.0	42.5	24.0	5.0	1.0	0.0	7.5	2.0	0.0	0.0	0.0
E-1	IWP	Span 1	90.2	3.5	9.5	5.0	1.0	0.0	7.5	5.5	2.5	0.0	0.0
E-1	IWP	Span 2	83.2	5.5	9.0	4.5	1.0	0.0	12.0	3.0	0.0	0.0	0.0
E-1	IWP	Span 3	90.2	4.0	17.5	1.0	0.0	0.0	8.0	4.5	0.0	0.0	0.0
E-1	IWP	E. App.	200.0	32.0	33.5	0.0	0.0	0.0	3.0	0.0	1.0	0.0	0.0
W-1	IWP	W. App.	200.0	29.5	24.0	1.0	2.0	0.0	9.5	1.5	0.0	0.0	0.0
W-1	IWP	Span 1	90.2	6.0	15.5	5.5	0.0	0.0	9.0	5.0	2.5	0.0	0.0
W-1	IWP	Span 2	83.2	1.0	13.5	2.0	0.0	0.0	11.5	3.5	0.0	0.0	0.0
W-1	IWP	Span 3	90.2	9.0	11.5	3.0	1.5	0.0	20.0	2.0	0.0	0.0	0.0
W-1	IWP	E. App.	200.0	41.0	24.0	0.0	0.0	0.0	7.5	1.0	0.0	0.0	0.0
E-2	OWP	W. App.	200.0	22.5	35.0	5.0	1.0	0.0	10.0	0.0	0.0	0.0	0.0
E-2	OWP	Span 1	90.2	1.5	6.0	7.5	2.0	0.0	11.0	4.0	2.5	0.0	0.0
E-2	OWP	Span 2	83.2	4.0	10.0	4.5	0.0	0.0	7.5	6.0	0.0	0.0	0.0
E-2	OWP	Span 3	90.2	8.5	17.5	2.5	0.0	0.0	10.5	2.5	0.0	0.0	0.0
E-2	OWP	E. App.	200.0	29.5	36.5	2.0	0.0	0.0	6.5	1.5	0.0	0.0	0.0
W-2	OWP	W. App.	200.0	27.0	31.0	1.0	1.0	0.0	6.5	0.5	0.0	0.0	0.0
W-2	OWP	Span 1	90.2	1.5	19.0	3.5	0.0	0.0	5.5	4.5	3.5	0.0	0.0
W-2	OWP	Span 2	83.2	0.0	15.0	3.5	0.0	0.0	11.5	4.5	0.0	0.0	0.0
W-2	OWP	Span 3	90.2	3.0	19.0	4.5	0.0	0.0	5.0	8.0	0.5	0.0	0.0
W-2	OWP	E. App.	200.0	30.0	20.5	3.0	0.0	0.0	2.5	1.0	0.0	0.0	0.0
E-2	IWP	W. App.	200.0	23.5	33.0	5.0	1.0	1.0	13.0	1.0	0.0	0.0	0.0
E-2	IWP	Span 1	90.2	3.0	10.5	9.0	0.0	0.0	4.0	7.5	3.0	0.0	0.0
E-2	IWP	Span 2	83.2	1.5	11.0	2.0	1.0	0.0	8.5	7.0	0.0	0.0	0.0
E-2	IWP	Span 3	90.2	1.0	8.0	7.5	0.0	0.0	11.5	5.0	0.0	0.0	0.0
E-2	IWP	E. App.	200.0	30.5	39.0	2.0	0.0	0.0	8.5	0.0	0.0	0.0	0.0
W-2	IWP	W. App.	200.0	32.5	32.5	2.5	0.0	0.0	12.5	1.5	0.0	0.0	0.0
W-2	IWP	Span 1	90.2	9.0	14.0	3.5	0.0	0.0	9.5	3.0	2.5	0.0	0.0
W-2	IWP	Span 2	83.2	4.5	13.0	3.0	1.0	0.0	7.5	2.5	0.5	0.0	0.0
W-2	IWP	Span 3	90.2	0.0	16.5	4.0	0.0	0.0	15.0	8.5	0.0	0.0	0.0
W-2	IWP	E. App.	200.0	30.0	19.0	5.5	1.0	0.0	8.5	0.5	0.0	0.0	0.0

[1] Letters designate traffic direction; Numerals: 1 = traffic lane, 2 = passing lane.
[2] OWP = outer wheel path; IWP = inner wheel path.

TABLE 2
SUMMARY OF ROUGHNESS DATA

Project No. (Year Built)	Lane[1]	Wheel Path[2]	Bridge Deck: Length, ft	Bridge Deck: Roughness, in./mi, Straight Edge Profilometer	Bridge Deck: Roughness, in./mi, Truck Profilometer	Bridge Approach[3]: Length,[4] ft	Bridge Approach[3]: Rough, in./mi, Straight Edge Profilometer	Bridge Approach[3]: Avg. Length,[4] ft	Bridge Approach[3]: Rough, in./mi, Truck Profilometer
B2 of 9-10-5 (1956)	W1	OWP	264	252	175	200	183	65	140
		IWP		275	143		168		100
	W2	OWP	264	284	150	200	162	65	101
		IWP		276	148		192		123
	E2	IWP	264	276	208	200	217	65	133
		OWP		269	166		208		138
	E1	IWP	264	252	149	200	193	65	106
		OWP		222	164		196		160
			Avg.	263	163		190		125
B1 of 13-3-4 (1958)	S1	OWP	331	184	157	200	172	200	145
		IWP		191	152		152		171
	N1	IWP	331	215	175	200	198	200	222
		OWP		227	187		166		203
			Avg.	204	168		172		185
B1 of 25-7-3 (1958)	N1	OWP	492	351	186	200	167	90	157
		IWP		349	199		161		205
	N2	OWP		353	181		138	90	148
		IWP		321	218		194		243
	S2	IWP	492	401	158	200	150	63.5	101
		OWP		313	131		118		125
	S1	IWP		345	115		97	63.5	83
		OWP		315	148		111		148
			Avg.	344	167		142		151
B1 of 83-11-11 (1958)	N1	OWP	334	270	210	212	190	90	155
		IWP		281	184		241		179
	S1	IWP	334	270	176	212	203	90	160
		OWP		283	206		209		182
			Avg.	276	194		218		169
X1 of 63-13-4 (1958)	W1	OWP	252	243	164	200	243	136	276
		IWP		240	135		257		193
	W2	OWP		203	135		196	136	209
		IWP		214	149		224		226
	E2	IWP	252	211	134	200	265	90	156
		OWP		201	164		258		199
	E1	IWP		308	134		224	90	220
		OWP		300	134		236		260
			Avg.	240	144		238		217
B2 of 63-11-4 (1958)	W1	OWP	170	395	263	200	214	50.5	187
		IWP		423	203		230		229
	W2	OWP		401	244		220	50.5	175
		IWP		497	273		284		235
	E2	IWP	170	492	237	200	188	58	115
		OWP		408	221		194		145
	E1	IWP		401	193		216	58	137
		OWP		348	220		160		143
			Avg.	421	232		213		172

1 Letters designate traffic direction; Numerals: 1 = traffic lane, 2 = passing lane.
2 OWP = outer wheel path; IWP = inner wheel path.
3 The tests for the two methods measured different lengths on approaches.
4 Represents the average length of each approach at each bridge tested. For example, "65" means two 65-ft approaches, and "200" means two 200-ft approaches.

by averaging the values for each bridge span along the entire length of the wheel path. These individual span roughness values for each wheel path of each bridge are included on the plan views shown in Fig. 1.

Values for the truck Profilometer roughness index are taken from Professor William S. Housel's Departmental Report No. 2 on Measurement of the Riding Qualities of Bridge Decks (Nov. 1959).

Approaches

In Table 2, approach roughness indices are presented for both measuring methods, even though different bridge approach lengths were used for the two methods. These various bridge approach lengths are also shown in Table 2. Naturally, direct comparison of approach roughness values is impossible, because of this variation in the lengths measured.

Roughness Comparison of Decks and Approaches

Both methods indicated that the bridge decks were generally rougher than the bridge approaches, as shown by the percentages of deck roughness in excess of approach roughness in Table 3. For the straight-edge method, there was one exception, X1 of 73-13-4, where deck and approach indices were equal. The extreme variation occurred at B1 of 25-7-3, where the deck was 142 percent rougher than the approach; however, the variation at this location is somewhat exaggerated because the approach roughness index was notably lower than for the other approaches, while the deck was considerably rougher.

Table 3 shows that the relationship between bridge roughness and approach roughness for the two methods is markedly different for several bridges. This disparity in results may be attributed to the fact that the truck Profilometer generally measured roughness over shorter distances on the approach pavements, in areas immediately adjacent to the deck. This near-deck approach region generally contains pavement of great roughness. Thus, the truck method would produce deck and approach figures more nearly equal than those obtained with the straight-edge.

TABLE 3
BRIDGE DECK ROUGHNESS IN EXCESS OF APPROACH ROUGHNESS*

Project No.	Straight-Edge, percent	Truck, percent
B1 of 25-7-3	142	10
B2 of 63-11-4	98	35
B2 of 9-10-5	38	30
B1 of 83-11-11	27	15
B1 of 13-3-4	18	-10
X1 of 63-13-4	0	-51

*The tests for the two methods measured different lengths on approaches.

Table 4 presents various pavement roughness ratings, obtained by the Bureau of Public Roads and MSHD truck roughometers as well as the two Profilometers. The descriptive ratings for given measurements are shown for each instrument, although these measurements and ratings cannot be compared directly. Ratings shown for the MSHD straight-edge profilometer are only tentative, since this instrument has been used on an experimental basis only in the tests described in this report; more extensive testing would be necessary to determine final criteria for "good," "average," and "poor" pavement roughness values. The measurements on the six bridges generally fall in the "average" or "poor" categories, on the basis of the tentative values selected. However, readings as low as 79 were obtained on bridge approach pavement, well below the upper limit of 150 for the "good" classification.

TABLE 4

COMPARISON OF PAVEMENT ROUGHNESS RATINGS OF SEVERAL AGENCIES

Vertical Displacement, Inches Per Mile

Rating	Bureau of Public Roads Roughometer	Truck Profilometer	Rating	MSHD Straight-Edge Profilometer	MSHD Roughometer
Exceptionally smooth	Less than 100	Less than 50			
Very good	100 - 125	50 - 75	Good	Less than 150	Less than 130
Good	125 - 150	75 - 100			
Fair	150 - 175	100 - 125	Average	150 - 275	130 - 175
Acceptable	175 - 200	125 - 150			
Poor	200 - 225	150 - 175	Poor	More than 275	More than 175
Very Poor	225 - 250	175 - 200			
Extremely rough	More than 250	More than 200			

COMPARISON OF ROUGHNESS MEASURING METHODS

Test results for the straight-edge and truck Profilometer methods are compared in Figure 3. Statistical analysis of these data indicates a high correlation between the two methods. A correlation coefficient of 0.63 was computed, which is extremely significant for this small sample. The standard error of estimate was determined to be ± 30 in. per mi for the truck Profilometer when compared to a given value for the straight-edge Profilometer. This means truck Profilometer roughness can be predicted from known straight-edge roughness values, with a probability that 68 times out of 100 the prediction will be within ± 30 in. per mi of the reading which could be obtained by actual truck measurement.

The graph in Fig. 4 compares average roughness indices for the six bridges tested. By using an average roughness index for an entire bridge, a better correlation coefficient was obtained, in this case 0.73, with a standard error of estimate of ± 20 in. per mi.

The evidence in these two graphs (Figs. 3 and 4) indicates the close agreement on bridge roughness values which can be obtained by the two methods. Within certain limits the straight-edge method can produce the same results as the truck Profilometer. As more data is obtained, an even closer relationship will undoubtedly be established.

The straight-edge profilometer has some specific advantages over the truck Profilometer: 1) lightness and flexibility of use, 2) utility

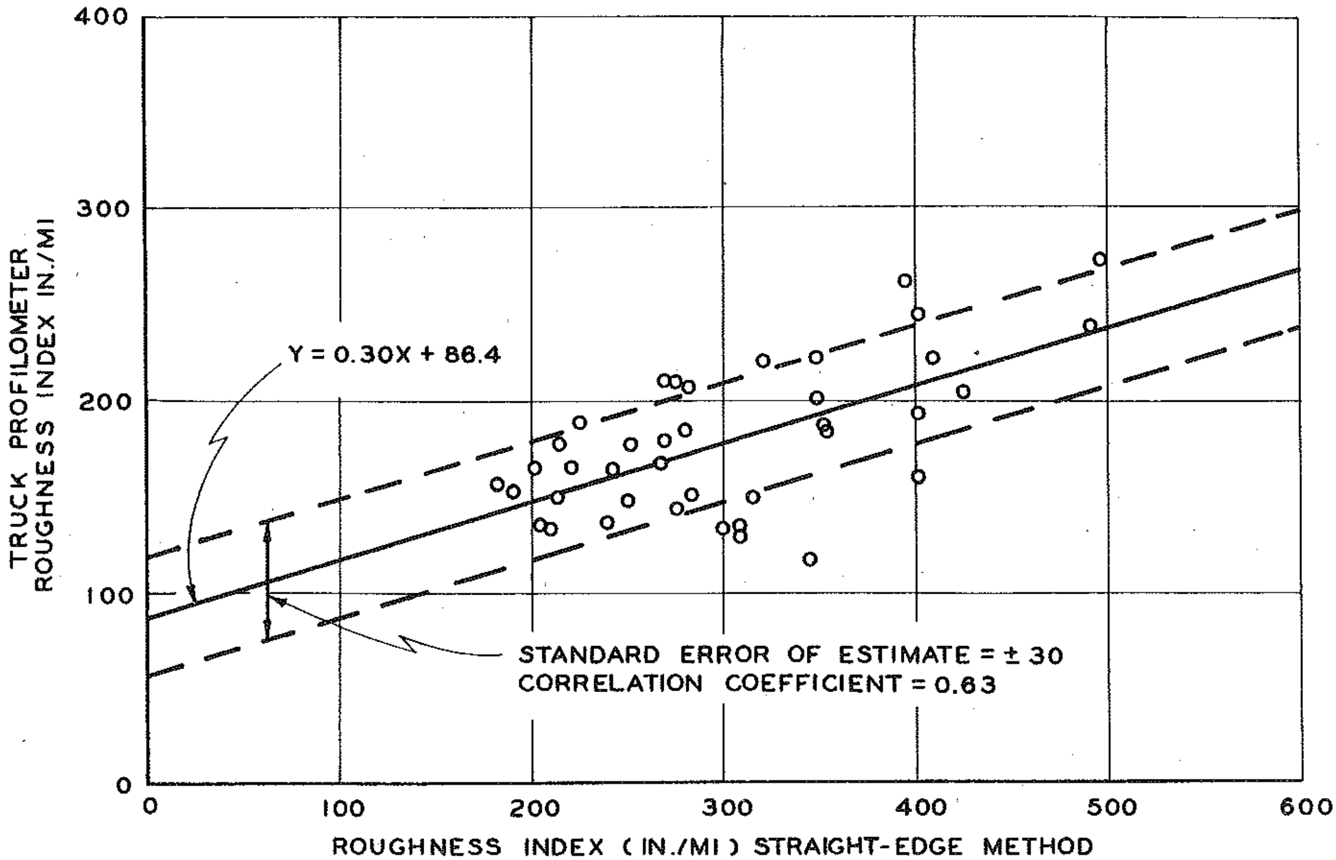

Figure 3. Comparison of roughness indices obtained by truck and straight-edge profilometer, for corresponding wheel paths.

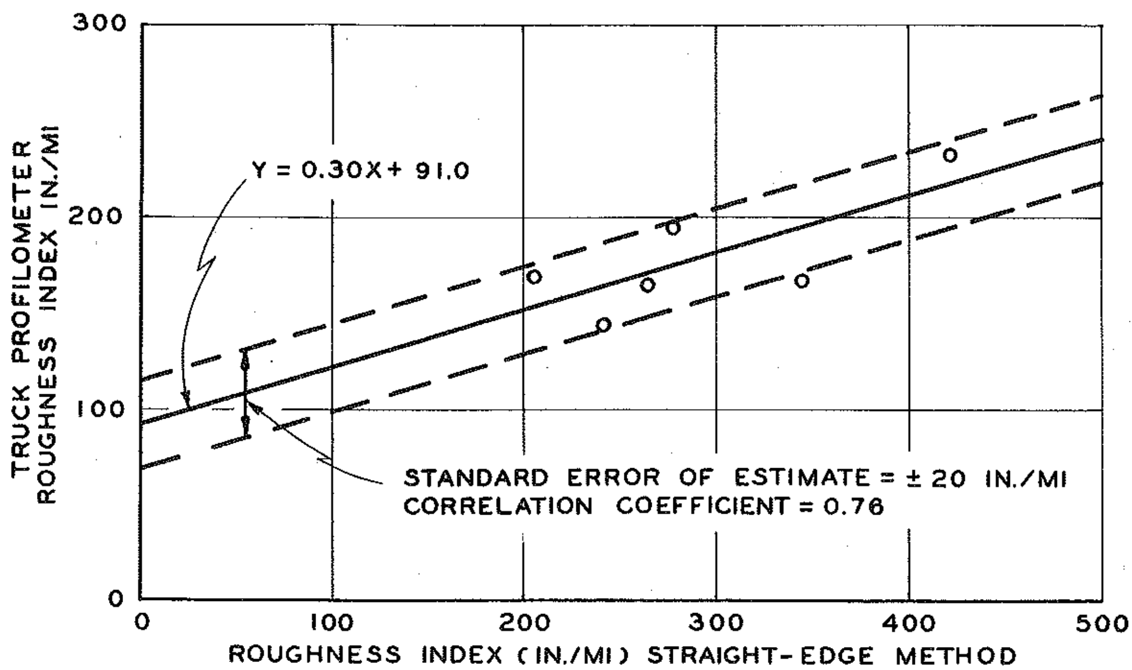

Figure 4. Comparison of average roughness indices obtained by truck and straight-edge profilometer.

prior to completion of approach pavements, and 3) easy maneuverability along a designated wheel path at any velocity desired.

Current disadvantages include several features which will be relatively easy to remedy. Counts are obtained manually and are therefore subject to human error in recording flashing lights on counters, but this source of error can be eliminated with very little expense by using electronic counters or an automatic profile recorder. The present device is also susceptible to misalignment in the vertical plane, because any tipping from the perpendicular introduces inaccurate readings of vertical slab irregularities. This source of error can be corrected by substituting dual wheel assemblies for the present single wheels. In addition, a longer wheel base would probably improve the accuracy of this instrument.