South Dakota Roughometer Comparison Tests—1962

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• THE South Dakota Department of Highways obtained a commercially produced Bureau of Public Roads type road roughness indicator in March 1960 for use in a flexible pavement research study (1). After using the equipment during 1960, 1961 and 1962 and comparing roughness data with three similar machines at different times, it was obvious that the results obtained with any one machine varied from time to time for various reasons and that the results obtained with different machines at any specific time would not necessarily be in agreement. This raised some doubt as to the reliability of the data being obtained with the equipment, and suggested additional study of the equipment.

It was decided to invite personnel from neighboring States that used similar devices to bring their roughometers to South Dakota for the purpose of comparing, calibrating and standardizing the equipment. It was believed that the comparative studies would lead to a better understanding of the capabilities and limitations of the equipment, and also provide a means for comparing roughness index values being obtained by the various participating agencies. During the week of August 20, 1962, roughometers from seven organizations were assembled at Sioux Falls. The organizations represented included the highway departments of North Dakota, South Dakota, Nebraska, Minnesota, Iowa, and Illinois and the Bureau of Public Roads.

During the course of the AASHO Road Test at Ottawa, Ill., another machine was developed to provide a measure of pavement roughness. This device is called the CHLOE longitudinal profilometer (2), and has been used in the determination of the present serviceability index (PSI) (3) at the Road Test project and of various other roads. Use was made of the PSI in the mathematical formulas that were developed to describe the results of the pavement research in the AASHO Road Test. By correlating results obtained with the longitudinal profilometer and the roughness indexes obtained with the roughometers, it has been demonstrated that a present serviceability formula can be developed for each roughometer for which sufficient correlation data are available (4, 5). This correlation provides an essential linkage for maximum application of the AASHO Road Test results by the States. For this reason, and because some attending personnel had not seen this equipment in operation, a CHLOE profilometer was brought from Illinois for this series of tests. Figures 1 and 2 show some of the equipment assembled.

SELECTION OF TEST LOCATIONS

Sioux Falls was selected as headquarters for the roughometer tests because of the large number of paved highways with various characteristics in the immediate area, and because of the availability of adequate meeting and housing facilities. Several miles of both bituminous and portland cement concrete highways exhibiting roughness indexes from very low to very high were needed. The test sections should also be located in a compact area so that travel time from section to section could be kept at a minimum.

Many miles of Interstate, Federal, State and county highways were tested with the South Dakota roughometer to find highways satisfying the criteria. A circuit meeting

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Figure 1. Assembled equipment.

Figure 2. Assembled equipment.

most requirements was found directly northeast of Sioux Falls. It formed a square with sides about seven miles long. The south side was a new section of portland cement concrete Interstate highway, the east side was a bituminous State highway with a medium rough chip seal, the north side was a county road with a rough bituminous surface treatment, and the west side was an old portland cement concrete Federal highway. To obtain a smoother bituminous surfacing, a 6-mi stretch of county highway southwest of Sioux Falls was selected. The northeast circuit was used in both directions providing 48 miles, and the southwest section was run in a southerly direction only, providing 6 more miles for a total of 54 test miles (Fig. 3 and Table 1). These 54 miles provided roughness indexes as measured with the South Dakota device ranging from approximately 75 to 160 in. per mi for portland cement concrete, and from 65 to 185 in. per mi for bituminous-surfaced roads.

TEST EQUIPMENT AND PROCEDURES

In tests of this nature, an attempt must be made to eliminate as many extraneous variables as possible to obtain comparable results. This was done, insofar as was practicable. Possible differences caused by such factors as wind and temperature variations were minimized by having the tests conducted in one week and completing each series with all machines in a few hours. Other factors that might lead to minor differences, such as differing techniques of operation used by the individual crews operating the machines, could not be controlled. Each unit had a different driver and operator. Although the techniques used by each crew could be expected to vary, no attempt was made to utilize the same personnel for all equipment. Also, drivers operating the same vehicle on successive runs could not be expected to follow exactly the same wheelpaths each time. For these and similar reasons, the results obtained with different machines and successive runs with the same machine, can be expected to vary. However, such differences are not believed to have a significant effect on the ultimate results.

An important source of variation is the inherent difference built into each machine. Although all seven of these devices were constructed to Bureau of Public Roads' specifications, there are significant differences such as tire size, tire tread, sensing and recording systems, and such possible influencing factors as standard and automatic transmissions and suspension differences in the towing vehicles. Table 2 gives some of the significant characteristics of each of the roughometers.

Most of the variables that could be eliminated or controlled satisfactorily were concerned with the procedures used in obtaining the roughness indexes.

It was necessary to conduct all testing in the outer wheelpath to obtain the required range in roughness. The hitch in one vehicle had to be altered slightly to allow it to tow the roughometer in this path.

The wheel revolutions per mile for each roughometer were determined by running each machine over an accurately measured mile a number of times. The revolutions per mile on different devices varied from 735.5 to 754 depending on tire size. The results were compared with the revolutions per mile used by each organization in its normal operations and differences of up to 2.4 revolutions per mile were found.

A warm-up of approximately five miles was given all machines when starting tests in the morning or after any period of inactivity in an effort to bring all components up to stabilized operating temperature before measurements were begun. Because some of the roughometer trailers could not be supported by means other than the main wheel when not in use, they developed flat tire areas by standing. An important function of the 5-mi run was to help remove the flat area that is prone to develop on the tire when it remains in the same position under load over a considerable period of time. Arrangements used by some of the agencies indicated that auxiliary means for supporting the trailers so that the wheels swing free when the devices are not being used in recording are feasible, and it is recommended that some such system be adopted.

To obtain a measure of reproducibility of results for each machine, it was decided to run each test mile five times with each roughometer. All runs were made at 20 mph with each run at approximately the same time so that possible influence of temperature and wind could be held to a minimum. Minor difficulties with some of the equipment caused delays, but most problems were easily handled at the State maintenance shop.

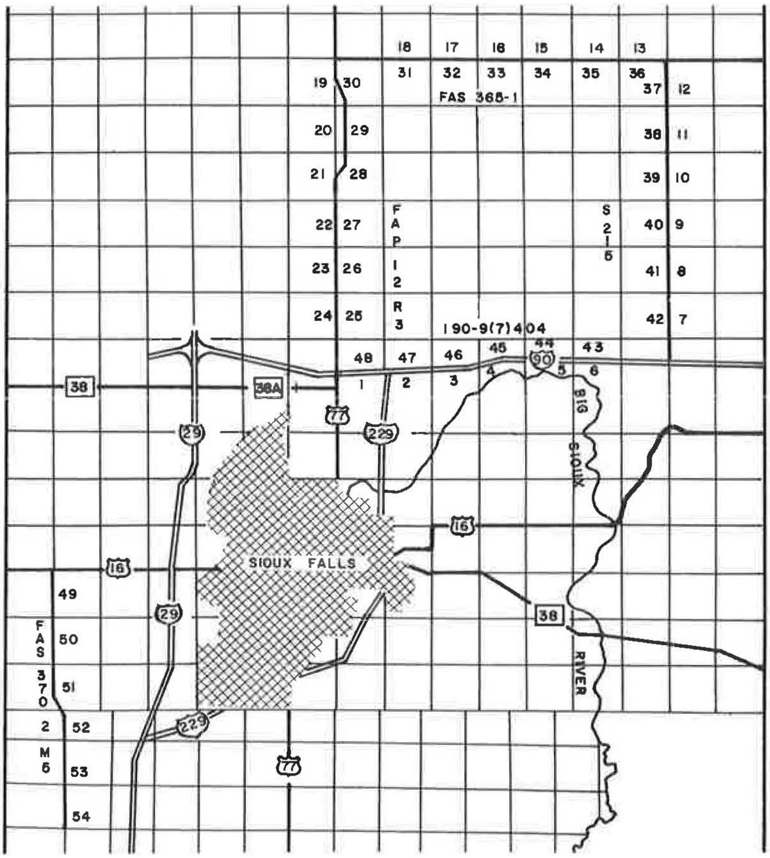


Figure 3. Test section location.

TABLE 1
TEST SECTION DATA

Route	Sections	Project	Surfacing Type	Pavement Width (ft)	Thickness			Year Built
					Surfacing (in.)	Base Course (in.)	Subbase (in.)	
Interstate 90	1-6 43-48	I 90-9(7)404	P. C. concrete	24	9	0	4 to 10	1962
S. Dak. 11	7-12 36-42	S-21-5	Bit. asphalt mat	24	1½	5 to 6	5 to 15	1954
County 122	13-18 31-36	FAS 265-1	Bit. surface treatment	24	3/4	6	0	1949
U.S. 77	19-30	FAP 12 R 3	P. C. concrete	20	9, 6, 9	0	4	1933
County 139	49-51	S-616 (1)	Bit. asphalt mat	24	2	8	0	1957
County 139	52-54	FAS 370 (2)	Bit. asphalt mat	24	1½	5	0	1955

TABLE 2

ROAD ROUGHNESS INDICATOR SPECIFICATIONS

State	Tow Vehicle	Trailer	Recording Method
Iowa	1962 Internt. Travelall S 100, V-8, 3-speed trans.; tachometer used to maintain correct operating speed.	BPR spec.; 6.70 × 15 General st. road tread.	Mech. integ.
N. Dak.	1958 Chev. Apache 38 panel, V-8, 4-speed trans.	BPR spec. by Soiltest; 6.70 × 15 special treadless.	Mag. rdg. head.
Ill.	1961 Chev. Apache 30 panel, V-8, 4-speed trans.	BPR spec.; U. S. Royal 6.70 × 15 special treadless.	Mech. integ.
Neb.	1960 Chev. Apache 30 panel, 6-cyl., 4-speed trans.	BPR spec.; Goodyear 6.00 × 16 ribbed implement.	Mech. integ.
S. Dak.	1960 Chev. Apache 30 panel, V-8, 4-speed trans.	BPR by Soiltest spec.; 6.70 × 15 U. S. Royal special smooth tread.	Mag. rdg. head operating Berkely elec. counter; a mech. integ. operating mag. counter.
Minn.	1961 Ford F-100 panel, V-8, auto. trans.	BPR spec.; 6.00 × 16 Armstrong hwy. tread.	Mech. integ. and Mag. rdg. head.
BPR	1961 Plymouth sta. wag., V-8, auto. trans.	BPR spec. by BPR; 6.00 × 16 U. S. Royal tread.	Mech. integ. operating mag. counter.

One exception was the South Dakota machine. After three complete circuits, it consistently yielded higher readings than most others. A small amount of wear was found in the universal joints supporting the dampening devices. They were replaced and the next two runs produced results which were about 10 percent lower than the first three. The new readings were found to be consistent with the majority of the other roughometers. Because this change had altered the characteristics of the device significantly, an additional three runs were made with the South Dakota machine so that five complete runs would be available with the alterations. The results of the first three runs are given in Tables 3 and 4, and the results of the last five, in 5 and 6. For data comparison and analysis, only the last five runs were used.

Results obtained with the other devices are given in Tables 7 through 13. All machines recorded roughness information by one method only except those of South Dakota and Minnesota. These two were equipped with both mechanical and electrical devices. Each set of data is presented in a separate table.

A CHLOE longitudinal profilometer was used in conjunction with the roughometers during this series of tests. The major difference in these two types of equipment is the means by which the relative roughness or smoothness of a road is measured. The

TABLE 3

SOUTH DAKOTA MECHANICAL INTEGRATOR[1]

Section	Run No. 1A	2A	3A	Avg.
1	103	101	105	103
2	96	99	99	98
3	85	89	90	88
4	85	88	88	87
5	83	84	87	85
6	101	102	101	101
7	119	119	120	119
8	108	108	105	107
9	117	118	116	117
10	105	101	104	103
11	131	130	128	130
12	112	110	108	110
13	139	138	138	138
14	159	156	151	155
15	182	175	169	175
16	173	171	164	169
17	182	191	183	185
18	201	204	193	199
19	183	184	180	182
20	175	177	172	175
21	168	171	165	168
22	162	161	159	161
23	139	140	138	139
24	140	146	146	144
25	135	138	134	136
26	138	138	140	139
27	152	156	152	153
28	159	163	162	161
29	160	163	161	161
30	161	167	156	161
31	207	215	213	212
32	184	191	188	188
33	202	207	196	202
34	198	206	194	199
35	158	159	155	157
36	131	143	135	136
37	118	112	119	116
38	108	105	108	107
39	104	105	107	105
40	126	124	126	125
41	114	111	113	113
42	123	129	127	126
43	99	103	103	102
44	84	86	87	86
45	81	84	88	84
46	88	89	92	90
47	98	99	102	100
48	99	99	99	99
49	—	70	68	69
50	—	75	71	73
51	—	92	84	88
52	—	87	83	85
53	—	76	74	75
54	—	80	78	79

[1] Readings obtained before repair of equipment.

TABLE 4

SOUTH DAKOTA MAGNETIC READING HEAD[1]

Section	Run No. 1A	2A	3A	Avg.
1	103	104	109	105
2	97	100	102	100
3	86	92	94	91
4	87	90	92	90
5	85	87	91	88
6	103	104	105	104
7	119	120	119	119
8	108	109	107	108
9	118	119	116	118
10	102	100	107	103
11	133	131	131	132
12	113	112	110	111
13	141	140	142	141
14	160	157	155	157
15	183	179	174	180
16	172	175	167	171
17	185	193	186	188
18	202	206	199	202
19	184	188	187	186
20	178	179	176	178
21	173	175	172	164
22	164	166	164	173
23	142	143	145	143
24	143	148	149	147
25	142	142	140	141
26	139	141	143	141
27	156	160	159	158
28	161	168	169	166
29	165	175	167	169
30	161	163	161	162
31	206	218	220	215
32	185	195	191	190
33	198	215	203	205
34	197	206	196	200
35	156	160	159	158
36	137	146	140	141
37	116	112	119	116
38	109	106	113	109
39	106	107	108	107
40	127	126	128	127
41	115	112	116	114
42	124	128	130	127
43	103	106	108	105
44	88	89	91	89
45	90	86	88	88
46	85	92	93	90
47	101	100	102	101
48	100	100	103	101
49	–	–	73	73
50	–	80	75	77
51	–	95	89	92
52	–	91	89	90
53	–	79	79	79
54	–	83	82	83

[1] Readings obtained before repair of equipment.

TABLE 5

SOUTH DAKOTA MECHANICAL INTEGRATOR

Section	Run No. 1	2	3	4	5	Avg.
1	95	94	93	92	93	93
2	84	88	88	86	87	87
3	79	79	81	81	81	80
4	81	81	82	80	79	81
5	79	77	80	79	80	79
6	96	92	96	92	92	94
7	110	105	109	107	109	108
8	94	98	100	99	100	98
9	103	105	109	108	109	107
10	87	94	99	93	94	93
11	116	119	123	118	119	119
12	97	100	106	102	104	102
13	118	125	128	131	126	126
14	141	139	140	139	141	140
15	157	154	164	158	163	158
16	149	149	148	152	151	150
17	167	157	166	162	168	160
18	181	175	186	181	178	180
19	161	157	159	163	164	161
20	156	154	156	159	159	157
21	144	146	150	148	150	148
22	140	141	147	148	144	144
23	122	123	126	128	125	125
24	130	127	131	133	129	130
25	118	120	124	125	121	122
26	120	122	126	127	125	124
27	134	138	142	140	140	139
28	143	145	149	150	150	147
29	141	147	144	147	143	144
30	143	144	146	145	142	144
31	178	181	184	186	187	183
32	160	166	165	168	167	165
33	173	177	175	179	179	177
34	167	167	171	174	177	171
35	136	134	137	141	140	138
36	115	122	123	121	123	121
37	101	106	105	105	105	104
38	94	100	97	98	98	97
39	94	93	91	99	93	94
40	109	110	110	111	111	110
41	99	104	104	102	102	102
42	112	111	113	113	116	113
43	93	92	91	96	94	93
44	77	79	80	79	78	79
45	75	75	75	78	75	76
46	80	81	80	81	82	81
47	89	87	88	92	88	89
48	89	90	90	91	90	90
49	69	62	68	66	63	66
50	68	70	70	67	68	69
51	82	82	80	79	79	80
52	80	77	83	82	85	81
53	75	77	72	71	73	74
54	77	74	75	76	75	75

TABLE 6

SOUTH DAKOTA MAGNETIC READING HEAD

Section	Run No. 1	2	3	4	5	Avg.
1	89	92	96	94	95	93
2	84	86	91	89	91	88
3	78	81	83	83	83	82
4	79	81	84	83	82	82
5	77	80	83	82	83	81
6	92	95	95	94	95	94
7	104	104	110	108	107	107
8	93	97	100	98	98	98
9	103	107	109	107	107	107
10	88	93	97	95	93	89
11	116	120	124	120	121	120
12	98	99	104	103	101	101
13	121	125	130	132	130	128
14	139	140	140	140	142	140
15	160	157	165	160	164	161
16	152	152	152	155	154	153
17	165	166	168	166	170	165
18	185	172	188	180	182	181
19	162	163	164	164	167	164
20	157	157	159	161	163	159
21	146	150	154	151	156	151
22	141	143	149	149	147	146
23	125	127	128	130	127	127
24	132	127	134	133	132	132
25	118	122	125	127	124	123
26	122	125	126	130	127	126
27	136	141	143	143	143	141
28	145	147	151	152	149	149
29	144	146	146	148	146	146
30	145	143	148	148	146	146
31	178	183	185	188	191	185
32	162	166	168	169	170	167
33	176	179	178	184	184	180
34	170	165	174	177	182	174
35	138	137	138	143	143	140
36	118	123	124	126	127	124
37	101	104	105	105	104	104
38	95	94	96	98	96	96
39	94	93	91	95	93	93
40	110	109	109	110	112	110
41	99	100	101	101	101	100
42	113	111	112	112	116	113
43	95	95	94	97	95	95
44	79	80	81	80	80	80
45	77	77	77	80	78	78
46	81	83	83	83	82	82
47	91	90	91	94	91	91
48	91	90	91	92	92	91
49	71	64	70	68	66	68
50	70	71	71	68	71	70
51	85	82	82	80	80	82
52	82	78	86	82	86	83
53	76	77	74	72	73	74
54	77	76	76	76	74	76

TABLE 7

NORTH DAKOTA MAGNETIC READING HEAD

Section	Run No. 1	2	3	4	5	Avg.
1	106	103	102	104	103	104
2	100	100	100	99	99	100
3	—	88	89	89	90	89
4	—	90	90	89	90	90
5	—	86	88	87	88	87
6	104	102	103	104	104	103
7	141	140	139	144	139	141
8	125	126	125	127	128	126
9	138	136	137	138	134	137
10	124	120	127	124	124	124
11	140	140	145	145	144	143
12	124	124	131	124	124	126
13	142	136	135	136	137	137
14	—	156	157	156	155	156
15	—	176	170	176	174	174
16	166	169	168	168	168	170
17	185	185	182	177	175	181
18	—	198	192	198	195	196
19	186	190	184	183	185	186
20	186	187	177	177	179	181
21	170	174	170	165	166	169
22	164	168	159	159	161	162
23	140	140	139	140	139	140
24	143	147	145	143	146	145
25	134	—	133	135	137	135
26	136	—	134	134	138	136
27	152	—	153	152	158	154
28	162	—	168	158	163	163
29	160	—	163	160	160	161
30	160	—	162	159	162	161
31	202	—	—	199	199	200
32	184	—	—	183	181	183
33	195	—	190	188	193	189
34	198	—	191	192	190	193
35	158	—	157	157	156	157
36	140	—	136	135	136	137
37	140	—	136	133	137	137
38	129	—	130	129	131	130
39	122	—	127	128	128	126
40	142	—	142	140	142	142
41	138	—	130	134	141	136
42	152	—	148	151	147	150
43	100	—	101	101	103	101
44	87	—	86	87	88	87
45	84	—	84	84	90	86
46	92	—	92	91	93	92
47	98	—	99	97	101	99
48	98	—	100	100	99	99
49	76	—	73	73	77	75
50	81	—	80	80	80	80
51	96	—	94	91	93	94
52	90	—	91	92	92	91
53	81	—	83	82	83	82
54	82	—	84	84	83	83

TABLE 8

NEBRASKA MECHANICAL INTEGRATOR

Section	Run No. 1	2	3	4	5	Avg.
1	82	83	86	87	89	85
2	73	77	79	79	82	78
3	68	71	74	73	74	72
4	65	68	70	70	73	69
5	64	68	70	73	72	69
6	83	87	90	89	90	88
7	91	97	94	96	96	95
8	79	79	78	80	79	79
9	94	95	97	94	96	95
10	73	74	78	78	79	76
11	106	105	111	108	108	108
12	78	81	81	82	85	81
13	118	118	110	113	113	114
14	136	137	137	137	142	138
15	156	155	147	153	157	154
16	144	144	148	151	149	147
17	170	167	154	154	152	159
18	173	181	169	172	182	175
19	167	169	170	164	174	169
20	165	164	165	161	171	165
21	144	146	146	146	148	146
22	136	139	140	141	141	139
23	113	112	115	114	114	114
24	119	117	122	117	120	119
25	109	110	111	111	113	111
26	113	113	114	115	114	114
27	134	138	135	137	141	137
28	144	144	145	145	150	146
29	140	144	144	150	149	145
30	139	144	144	143	150	144
31	181	181	185	186	191	185
32	163	157	161	160	163	161
33	184	190	180	175	177	181
34	181	178	178	183	177	179
35	130	137	133	136	137	135
36	115	116	112	116	118	115
37	86	87	83	93	87	87
38	80	81	84	84	84	83
39	77	80	78	84	79	79
40	101	101	102	102	104	102
41	88	90	90	91	91	90
42	101	101	101	101	103	101
43	84	88	89	90	89	88
44	68	69	71	72	71	70
45	64	66	68	69	68	67
46	70	72	73	75	73	73
47	81	80	83	85	84	83
48	83	85	84	87	84	85
49	–	48	46	51	49	49
50	–	49	48	51	51	50
51	–	67	64	61	64	64
52	–	66	73	69	71	70
53	–	55	57	57	58	57
54	–	58	58	57	57	58

TABLE 9

MINNESOTA MECHANICAL INTEGRATOR

Section	Run No. 1	2	3	4	5	Avg.
1	100	100	101	98	105	101
2	92	92	91	94	96	93
3	87	88	87	88	89	88
4	88	86	86	88	88	87
5	86	89	88	87	89	88
6	104	107	105	106	106	106
7	109	115	113	116	118	114
8	95	97	99	100	102	99
9	107	110	109	109	115	111
10	96	97	96	97	99	97
11	113	116	–	118	120	117
12	106	100	102	105	110	105
13	119	118	124	124	122	121
14	133	135	140	137	134	136
15	142	141	143	143	150	144
16	140	137	137	144	144	140
17	147	146	143	149	148	147
18	153	150	154	155	155	153
19	136	135	136	134	128	134
20	125	134	140	133	135	133
21	123	136	137	141	131	134
22	133	129	133	126	135	131
23	123	118	123	127	126	123
24	125	127	126	125	127	126
25	120	121	121	121	123	121
26	122	119	124	122	122	122
27	132	132	142	136	140	136
28	130	135	150	148	145	142
29	134	139	135	142	140	138
30	123	132	129	129	131	129
31	165	168	165	169	169	167
32	153	148	152	152	167	154
33	155	154	156	157	164	157
34	155	156	153	147	152	153
35	130	134	130	133	133	132
36	114	113	115	118	115	115
37	106	108	110	108	108	108
38	102	103	103	106	106	104
39	104	105	101	103	108	104
40	116	116	114	109	115	114
41	102	107	109	110	112	108
42	114	110	116	113	115	114
43	103	101	104	103	107	104
44	87	81	88	86	89	86
45	82	82	84	86	86	84
46	88	90	90	86	89	87
47	98	98	101	102	101	100
48	99	96	100	100	100	99
49	–	72	70	70	71	71
50	–	74	71	72	74	73
51	–	78	78	84	79	80
52	–	79	82	83	81	81
53	–	72	73	72	72	72
54	–	73	74	73	74	73

TABLE 10

MINNESOTA MAGNETIC READING HEAD

Section	Run No. 1	2	3	4	5	Avg.
1	101	101	94	104	107	101
2	97	97	83	92	101	94
3	89	92	65	83	92	84
4	90	89	81	86	91	87
5	88	90	82	89	90	88
6	104	110	95	104	111	105
7	112	123	98	121	123	115
8	101	105	—	102	108	104
9	108	120	—	115	120	116
10	101	104	83	103	105	99
11	117	124	—	125	125	123
12	108	103	98	111	116	107
13	118	123	129	132	133	127
14	132	148	148	145	149	144
15	142	153	153	151	162	152
16	144	156	158	159	158	155
17	147	164	153	167	170	160
18	152	170	166	170	175	167
19	130	167	165	166	166	159
20	125	161	162	161	163	154
21	120	152	154	156	153	147
22	137	148	149	145	149	146
23	120	128	131	128	130	127
24	122	133	133	129	131	130
25	104	126	126	124	127	121
26	117	124	125	126	127	124
27	130	143	—	147	149	142
28	130	144	126	157	155	142
29	129	137	144	153	153	143
30	129	126	145	147	151	140
31	167	189	187	189	189	184
32	155	172	179	177	187	174
33	155	181	180	187	185	178
34	154	183	176	175	175	173
35	133	147	145	144	149	144
36	112	127	132	128	129	126
37	105	100	115	114	115	104
38	97	95	108	111	110	104
39	111	96	106	107	113	107
40	101	108	123	118	126	115
41	117	98	116	117	121	114
42	121	103	123	123	126	119
43	103	102	99	106	109	104
44	87	84	90	89	91	88
45	83	81	87	89	88	86
46	89	88	94	88	92	90
47	98	98	104	105	105	102
48	99	98	103	104	102	101
49	—	76	74	75	75	75
50	—	80	76	76	78	77
51	—	88	87	89	85	87
52	—	85	89	90	88	88
53	—	77	77	76	77	77
54	—	79	77	80	78	79

TABLE 11

IOWA MECHANICAL INTEGRATOR

Section	Run No. 1	2	3	4	5	Avg.
1	103	98	102	98	104	101
2	93	94	93	92	97	94
3	88	88	90	87	89	88
4	86	86	84	83	86	85
5	85	86	85	86	86	86
6	101	101	101	101	100	101
7	112	109	115	107	114	111
8	99	95	99	95	100	98
9	113	110	110	108	115	111
10	99	93	95	94	97	96
11	125	121	120	124	125	123
12	101	100	98	97	104	100
13	127	124	126	121	125	125
14	144	144	144	141	146	145
15	159	156	156	152	155	156
16	155	154	155	149	156	154
17	166	160	159	157	160	160
18	184	175	180	175	187	181
19	165	165	167	158	160	163
20	164	162	166	156	161	162
21	154	154	158	148	150	153
22	151	152	152	145	147	149
23	129	127	131	124	125	127
24	131	130	131	124	126	128
25	127	124	126	121	122	124
26	128	125	127	126	125	126
27	147	147	148	145	145	146
28	153	153	154	148	151	152
29	152	151	152	144	149	150
30	155	153	153	149	150	152
31	183	181	181	173	170	178
32	165	162	160	167	162	163
33	176	178	173	173	168	174
34	177	177	174	175	168	175
35	144	142	141	141	141	142
36	126	126	122	120	126	124
37	106	103	106	101	102	104
38	101	100	97	97	95	98
39	98	96	94	92	93	95
40	117	116	114	112	111	114
41	107	105	105	106	99	104
42	116	115	114	111	113	114
43	103	102	101	101	98	101
44	86	86	86	84	83	85
45	83	83	83	82	80	82
46	88	87	87	87	85	87
47	96	98	95	96	95	96
48	97	98	95	98	97	97
49	–	70	70	70	67	69
50	–	71	70	70	69	70
51	–	83	81	81	80	81
52	–	81	77	76	73	77
53	–	76	73	74	73	74
54	–	72	75	71	71	72

TABLE 12

ILLINOIS MECHANICAL INTEGRATOR

	Run No.					
Section	1	2	3	4	5	Avg.
1	91	94	92	93	97	93
2	85	85	83	87	90	86
3	78	79	77	79	81	79
4	76	78	77	79	82	78
5	76	78	76	79	82	78
6	93	95	93	94	97	95
7	102	101	100	104	108	103
8	90	87	86	88	94	89
9	100	102	99	100	104	101
10	87	87	86	87	94	82
11	114	111	112	118	117	115
12	91	94	89	92	94	92
13	121	120	120	118	122	120
14	136	136	135	140	149	139
15	158	155	151	157	165	157
16	148	158	142	151	157	151
17	148	159	149	155	162	155
18	180	174	172	180	182	177
19	157	165	167	167	170	165
20	160	171	165	167	171	167
21	146	154	150	156	154	152
22	143	152	149	153	151	149
23	119	127	122	124	124	123
24	124	134	129	130	130	129
25	102	122	124	119	123	121
26	124	123	126	123	126	124
27	141	142	145	140	144	142
28	156	153	160	149	157	155
29	143	147	151	141	147	146
30	145	156	154	147	147	150
31	185	194	190	176	195	188
32	159	166	168	160	175	166
33	179	177	182	167	183	178
34	175	176	140	170	189	170
35	136	138	140	136	141	138
36	119	123	127	120	128	123
37	92	100	101	96	97	97
38	89	93	92	87	91	90
39	85	92	89	85	88	88
40	104	113	109	106	110	108
41	90	95	96	91	94	94
42	106	107	112	111	109	109
43	91	92	96	91	89	92
44	76	77	79	75	76	77
45	74	74	76	74	72	74
46	77	78	81	77	78	78
47	75	87	88	86	84	86
48	89	91	92	88	89	90
49	–	56	60	58	62	59
50	–	61	62	63	66	63
51	–	78	79	79	79	79
52	–	73	74	79	78	76
53	–	69	72	71	71	71
54	–	66	65	69	65	66

TABLE 13

BUREAU OF PUBLIC ROADS MECHANICAL INTEGRATOR

	Run No.					
Section	1	2	3	4	5	Avg.
1	99	99	99	102	98	99
2	90	90	92	92	88	90
3	80	80	80	83	80	80
4	81	82	79	80	80	80
5	81	81	79	82	79	80
6	98	97	97	98	96	97
7	114	112	111	111	109	111
8	96	96	95	92	94	95
9	108	110	107	108	109	108
10	92	97	93	94	95	94
11	122	121	122	120	123	122
12	99	97	97	96	98	97
13	128	123	124	120	123	124
14	142	138	138	139	139	139
15	156	158	152	159	161	157
16	155	153	154	157	157	155
17	159	160	159	161	161	160
18	175	172	173	172	172	173
19	165	168	164	163	166	165
20	164	162	162	161	161	162
21	153	150	150	151	152	151
22	148	149	147	147	147	148
23	126	122	124	124	126	124
24	130	135	130	129	130	131
25	120	120	120	122	123	121
26	122	121	122	120	122	122
27	140	146	143	138	143	142
28	147	151	149	148	150	149
29	149	148	149	147	148	148
30	150	151	152	149	150	150
31	185	184	190	189	189	187
32	165	166	167	166	167	166
33	181	179	181	176	172	178
34	174	175	176	174	173	174
35	138	140	143	139	138	140
36	123	123	123	123	121	123
37	106	108	110	107	105	107
38	96	96	99	98	99	98
39	94	93	95	94	95	94
40	117	114	114	114	112	114
41	106	100	104	109	103	102
42	116	114	113	112	112	113
43	96	95	96	97	94	96
44	79	78	79	79	77	79
45	75	73	74	75	74	74
46	83	82	84	82	81	82
47	92	91	89	91	92	91
48	88	91	90	91	89	90
49	—	62	63	63	62	62
50	—	66	66	67	67	66
51	—	81	76	81	81	80
52	—	76	85	79	79	79
53	—	68	68	69	69	68
54	—	71	71	71	72	71

Figure 4. CHLOE profilometer in operation, followed by warning truck.

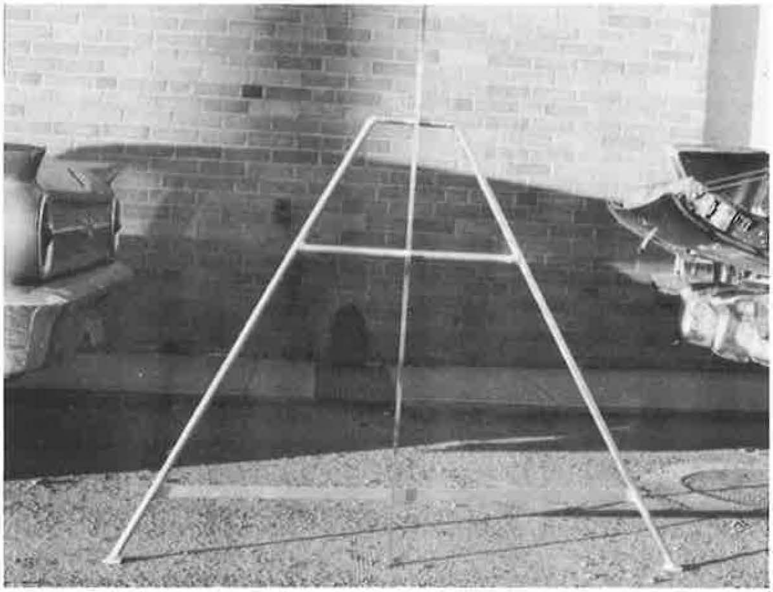


Figure 5. Rut depth measuring device.

roughometer measures the vertical movement of a wheel with respect to a datum as the wheel traverses irregularities in the driving surface; the CHLOE longitudinal profilometer measures the angular deviation of the road surface from a datum which is parallel to the overall road surface. The roughometer operates at 20 mph; the CHLOE from 3 to 5 mph.

The CHLOE profilometer was first used on the AASHO Road Test, and is now being used by the Illinois Division of Highways primarily for calibrating the roughometers. It also has been used as the standard from which PSI formulas for several roughometers have been derived.

TABLE 14

LONGITUDINAL PROFILOMETER DATA

Section	N	Y	Y^2
1 A	995	18,409	341,789
1 B	1,002	18,373	338,007
2 A	1,006	18,336	335,648
2 B	999	18,629	348,131
3 A	1,006	18,246	332,086
3 B	1,006	18,552	342,784
4 A	1,003	18,528	343,322
4 B	998	18,405	340,215
5 A	1,008	18,565	342,845
5 B	1,004	18,628	346,282
6 A	1,003	18,773	352,243
6 B	1,004	18,603	346,155
7 A	985	18,311	343,535
7 B	983	18,567	353,147
8 A	995	18,019	360,458
8 B	988	18,704	356,110
9 A	979	18,210	338,738
9 B	976	18,285	344,597
10A	877	26,073	336,605
10B	987	18,278	340,936
11A	981	18,375	346,211
11B	986	18,512	352,252
12A	961	18,019	343,427
12B	979	18,422	348,654
13A	981	18,830	365,624
13B	1,002	19,390	377,872
14A	996	19,112	371,890
14B	1,003	19,425	378,235
15A	991	19,062	373,602
15B	1,000	19,394	380,380
16A	1,005	19,616	388,472
16B	976	19,170	380,599
17A	989	19,336	381,538
17B	979	18,930	373,326
18A	1,004	19,207	368,577
18B	970	18,744	368,498
19A	997	18,802	358,270
19B	995	19,107	371,007
20A	988	18,546	353,210
20B	993	19,268	376,994
21A	1,012	18,882	355,892
21B	1,003	19,602	386,884
22A	997	19,267	375,935
22B	989	18,866	363,520
23A	997	19,169	371,089
23B	995	19,085	368,637
24A	1,000	19,122	368,490
24B	957	18,308	352,162
25A	1,124	21,219	403,277
25B	993	18,863	360,615
26A	984	18,712	357,942
26B	968	18,375	350,873
27A	996	18,877	360,861
27B	994	19,207	373,841
28A	994	19,193	374,323
28B	993	18,864	361,790
29A	996	18,899	361,471
29B	995	18,896	364,092
30A	995	18,543	87,375
30B	999	19,252	374,402
31A	1,006	21,109	446,689
31B	1,003	19,388	375,892
32A	991	18,756	365,036
32B	998	18,745	355,623
33A	992	18,353	346,269
33B	1,003	18,397	340,907
34A	989	18,568	352,912
34B	991	18,231	341,241
35A	1,001	19,138	368,728
35B	1,002	19,144	369,320
36A	992	18,266	339,572
36B	995	18,158	335,948
37A	920	17,096	320,944
37B	954	17,516	326,720
38A	959	17,878	335,696
38B	982	18,171	338,317
39A	980	18,061	335,551
39B	966	18,008	338,468
40A	973	17,981	334,863
40B	950	17,725	333,491
41A	988	18,384	343,506
41B	939	17,170	317,842
42A	928	17,562	335,738
42B	956	18,102	347,298
43A	1,009	18,937	356,401
43B	1,006	18,404	337,740
44A	1,003	18,771	352,069
44B	1,003	18,302	334,602
45A	1,007	18,593	344,097
45B	1,005	18,347	335,493
46A	1,008	18,651	345,921
46B	1,010	18,933	355,693
47A	1,009	18,367	335,113
47B	1,004	18,807	353,247
48A	1,005	18,657	347,717
48B	1,001	18,579	345,619
49A	1,005	19,201	367,295
49B	998	18,886	356,682
50A	990	18,513	347,393
50B	978	18,229	341,115
51A	992	18,572	349,298
51B	985	18,601	349,505
52A	975	18,190	340,296
52B	979	18,260	342,214
53A	970	17,910	331,452
53B	993	18,383	341,203
54A	995	18,335	338,467
54B	993	18,522	346,208

TABLE 15

PRESENT SERVICEABILITY INDEX DATA

Surface	Mi.	$\overline{SV}$	C + P /1,000 Sq Ft	$\overline{RD}$	PSI	Avg.
Concrete	1	6.7857	—	—	3.81	
	2	6.2374	—	—	3.86	
	3	4.6300	—	—	4.06	
	4	4.8305	—	—	4.03	
	5	3.6461	—	—	4.22	
	6	6.8415	—	—	3.80	3.96
Asphalt	7	21.0256	—	0.14	-[a]	
	8	17.9550	—	0.29	-[a]	
	9	14.6433	—	0.15	-[a]	
	10	18.0172	—	0.10	-[a]	
	11	25.8917	—	0.14	-[a]	
	12	30.1471	—	0.18	-[a]	
Asphalt	13	26.2458	545.7	0.19	-[a]	
	14	27.4577	356.5	0.24	-[a]	
	15	46.2676	445.5	0.28	-[a]	
	16	36.6917	410.6	0.24	-[a]	
	17	43.4678	245.5	0.24	-[a]	
	18	29.2410	378.0	0.32	-[a]	
Concrete	19	30.0672	9.8	—	2.44	
	20	32.0506	27.0	—	2.21	
	21	28.0038	5.1	—	2.58	
	22	27.8270	8.0	—	2.53	
	23	18.6665	2.0	—	2.95	
	24	17.4926	1.9	—	3.01	2.62
Concrete	25	16.9394	4.2	—	2.97	
	26	15.1175	1.8	—	3.12	
	27	21.6384	2.5	—	2.83	
	28	27.6497	9.3	—	2.52	
	29	31.4296	21.5	—	2.27	
	30	25.7115	10.3	—	2.55	2.71
Asphalt	31	17.5290	325.4	0.45	-[a]	
	32	54.9345	349.8	0.24	-[a]	
	33	40.2847	366.4	0.25	-[a]	
	34	40.4019	370.3	0.23	-[a]	
	35	23.9811	311.0	0.22	-[a]	
	36	30.2638	362.6	0.19	-[a]	
Asphalt	37	34.3069	—	0.16	-[a]	
	38	16.5975	—	0.17	-[a]	
	39	20.7434	—	0.16	-[a]	
	40	20.5797	—	0.16	-[a]	
	41	20.6055	—	0.30	-[a]	
	42	32.4922	—	0.16	-[a]	
Concrete	43	5.5793	—	—	3.94	
	44	2.9461	—	—	4.34	
	45	2.6957	—	—	4.39	
	46	3.7346	—	—	4.19	
	47	4.2561	—	—	4.11	
	48	6.0644	—	—	3.88	4.14
Asphalt	49	0.7867	—	0.17	-[a]	
	50	7.9316	—	0.15	-[a]	
	51	11.3232	47.4	0.15	-[a]	
	52	8.1202	54.6	0.23	-[a]	
	53	4.1039	4.4	0.13	-[a]	
	54	2.6631	0.8	0.09	-[a]	

[1] The PSI formula for the dense-graded bituminous concrete of the AASHO Road Test does not apply to chip-seal asphalt treatments.

The CHLOE operated at such a slow speed that time did not permit the determination of the slope variance for the entire length of each test mile. A 500-ft section located at the midpoint of each half of every test mile was measured and marked. This provided two 500-ft profilometer test areas in each mile, or roughly a 20 percent sample. The slope variance readings were obtained in the outer wheelpath only, as were the roughometer data. As a safety precaution during operation, a large truck with a flashing amber light was driven immediately behind the profilometer to warn traffic of the slow moving test equipment on the highway (Fig. 4).

Besides the slope variance, it is necessary to measure cracking, patching and rut depth to use the present serviceability index formulas developed at the AASHO Road Test. The cracking and patching were determined in the single lane in both 500-ft sections on all 54 mi. The rut depth was measured on flexible pavements only. Measurements were obtained every 25 ft within each 500-ft section, and were alternately taken in the inner and outer wheelpaths. The rut depths were measured with the device shown in Figure 5. This device was constructed with a distance of 4 ft between the support legs.

The readings taken with the longitudinal profilometer are given in Table 14. Calculated slope variances, cracking, patching, and rut depth measurements, and the calculated present serviceability indexes for the portland cement concrete pavements are given in Table 15. The present serviceability index formula developed at the AASHO Road Test for a dense-graded bituminous concrete surface does not apply to chip-seal bituminous surfaces; therefore, no present serviceability indexes are presented for them.

ANALYSIS OF DATA

The measurement of road surface roughness has assumed considerable importance in view of the methods adopted for determining the performance of the pavements of the AASHO Road Test. The PSI used to describe the pavement performance being rendered at a given moment in time is a combination of mathematical values obtained from a series of physical measurements including pavement roughness.

As indicated previously, other investigators have found that the BPR-type roughometer may be used to furnish roughness measurements in determining the PSI of pavements. By correlating roughometers with equipment used to determine roughness at the Road Test, or with equipment which has been previously correlated with that equipment, highway agencies may use them in applying the present serviceability concept. This concept has proved valuable in studying the performance of existing pavements, and also in studying and applying the results of AASHO Road Test pavement studies.

The major analysis of the present study was directed toward the development of PSI equations for each of the BPR-type roughometers that participated. The total analysis covered the use of the machines on both portland cement concrete and chip-sealed bituminous-surfaced pavements. However, it became obvious early in the analytical work that the slope-variance profilometer, and probably the roughometers, were reacting differently to the bituminous chip seals as used in South Dakota than to the flexible pavement of the AASHO Road Test. Therefore, the PSI equations for the bituminous pavements of the Road Test were not applicable to the chip-sealed surfaces, and no PSI equations are reported.

Detailed analyses of the data for the individual machines and comparisons of results obtained by the individual machines are not covered in this report. However, it is assumed that each participating State will make such analyses for its own machine.

An indication of how the machines performed with respect to each other may be obtained from Figures 6 through 9, which show a relatively rough and relatively smooth section of each portland cement concrete and bituminous surfacing.

The PSI equations evolved through correlations of each machine with the Illinois machine based on results of the measurements of the segments of pavement. The Illinois machine was the only one which was correlated with the CHLOE profilometer based on separate roughness recordings for the 500-ft sections for which slope-variance values were determined with the profilometer.

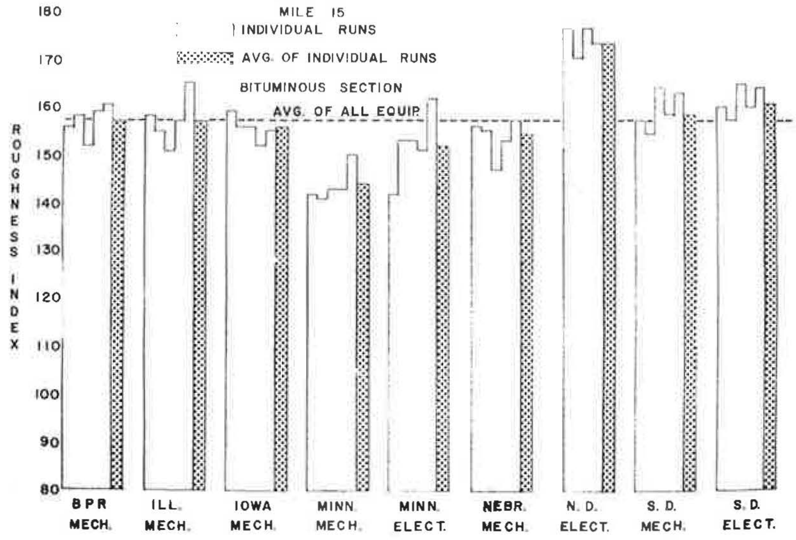


Figure 6 Machine performance.

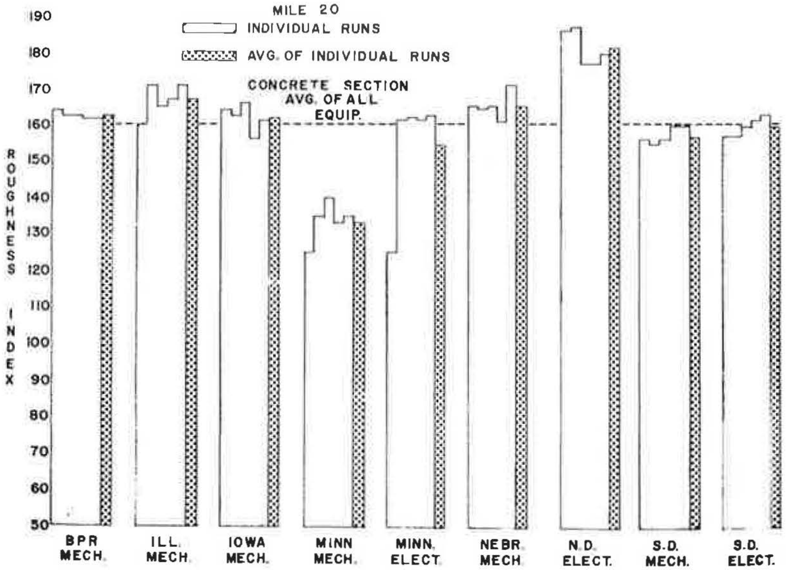


Figure 7. Machine performance.

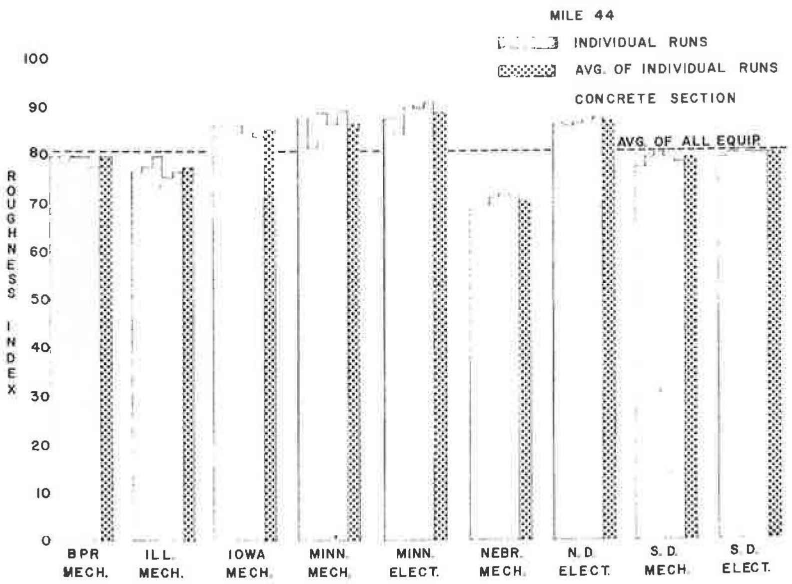


Figure 8. Machine performance.

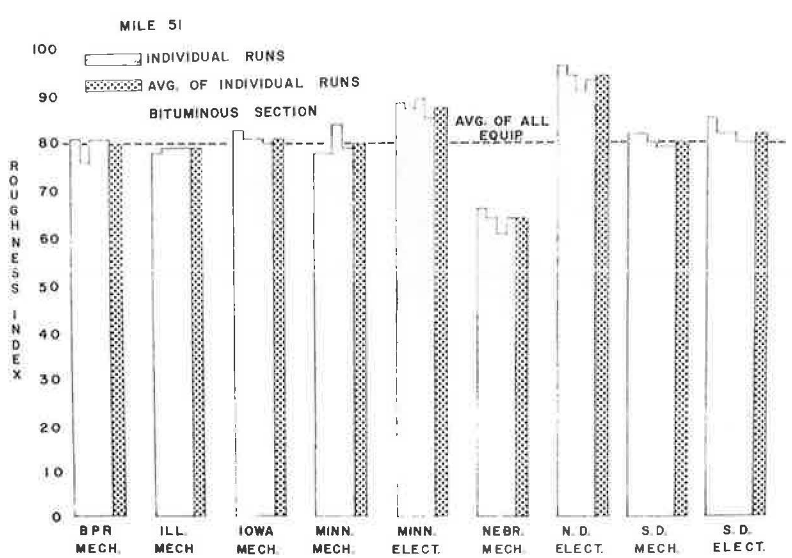


Figure 9. Machine performance.

The relationships between roughness readings obtained with the Illinois machine and the others were obtained by linear regression analyses. In this type of analysis, a straight line is established in which the sum of the squares of the deviations of the individual points from the line is at a minimum. In Figures 10 through 25 the equations are for the lines of best fit, and standard deviations S_y and coefficients of correlation r are also shown. Correlations are very good in all cases.

The CHLOE profilometer is a simplified version of the AASHO Road Test longitudinal profilometer used to determine the present serviceability index values of pavement sections. The slope-variance output of the CHLOE has been made the same as that of the longitudinal profilometer, and it appears that the two devices yield very similar results. Therefore, the Road Test PSI equations are applicable directly for use with the CHLOE profilometer. The simplified device was not fully developed until the Road Test neared completion; hence, the reliance on the more complicated version in the Road Test studies.

The present serviceability equations as developed at AASHO using slope-variance measurements are:

For portland cement concrete pavement:

$$PSI = 5.41 - 1.80 \log (1 + \overline{SV}) - 0.09\sqrt{C + P}$$

in which

PSI = present serviceability index;
$\overline{SV}$ = mean slope variance in the two wheelpaths as measured by the profilometer or CHLOE;
C = lineal feet of cracking per 1,000 sq ft of pavement area (including the lengths taken parallel or perpendicular to the pavement, whichever is greater, of all cracks that are sealed, opened, or spalled at the surface for a width of ¼ in. or more for at least half of their length); and
P = square feet of bituminous pathhing per 1,000 sq ft of pavement area.

For bituminous concrete pavement:

$$PSI = 5.03 - 1.91 \log (1 + \overline{SV} - 0.01\sqrt{C + P} - 1.38 \overline{RD}^2$$

in which

C = square feet of cracking per 1,000 sq ft of pavement area (including only cracking that has progressed to the stage where cracks have connected together to form a grid-type pattern or where the surfacing segments have become loose); and
$\overline{RD}$ = mean depth of rutting in both wheelpaths measured in inches under a 4-ft straightedge.

All other terms are as previously defined.

Following a series of correlative tests in 1960, correlation equations were established between the Illinois roughometer and the profilometer. Regression lines were developed for log (1 + $\overline{SV}$) regressed on log $\overline{RI}$, where $\overline{SV}$ is the slope variance measured with the profilometer and $\overline{RI}$ the roughness measured with the roughometer. Separate equations were established for portland cement concrete surfaces and dense-graded bituminous concrete surfaces as used in the Road Test.

In the present study, similar regression analyses were performed for measurements on the 500-ft sections, and the results are shown in Figures 26 and 27. The correlation for portland cement concrete pavement is quite satisfactory; the correlation for bituminous surfaces is less satisfactory.

A comparison between these correlation equations and those originally developed for the Illinois machine (dash lines are used to indicate the original equations) shows a slight change for the rigid pavement equation, and a more significant change for the flexible pavement equation. The difference between the original and new correlations for concrete pavement can be attributed logically to changes in the Illinois machine over the past two years. The significant difference between the original and new correlations for flexible surfaces is attributable mainly to the different responses of the machines to the South Dakota and Illinois surfaces. For this reason, the final step in developing PSI equations using Road Test data was limited to portland cement concrete pavements.

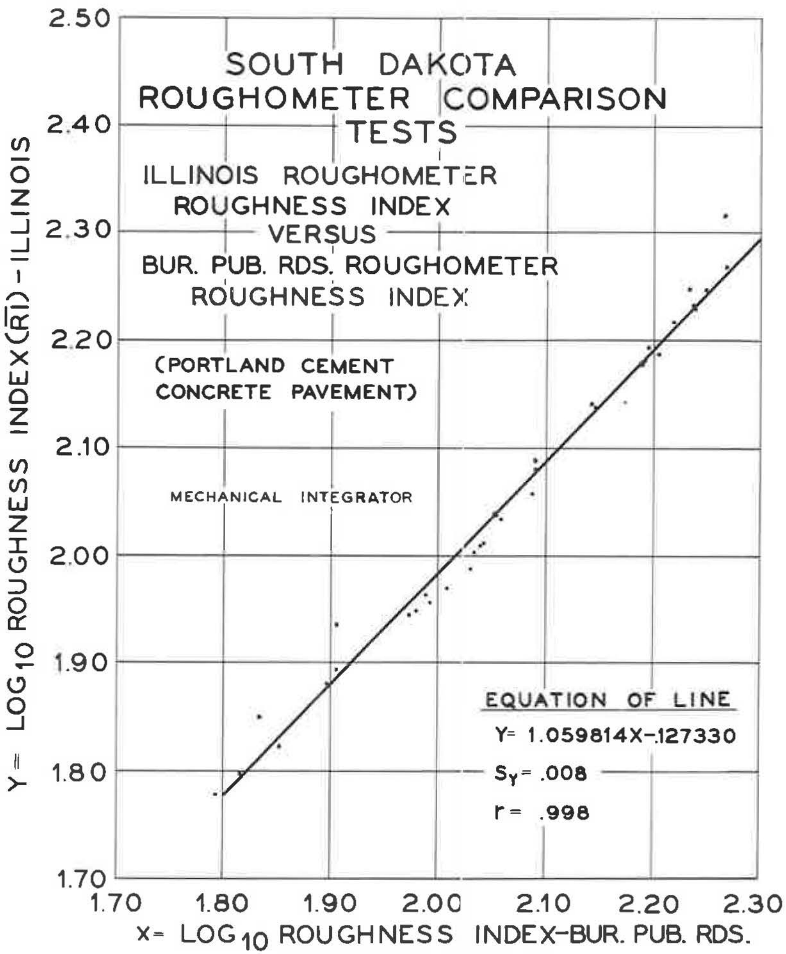


Figure 10. Machine performance.

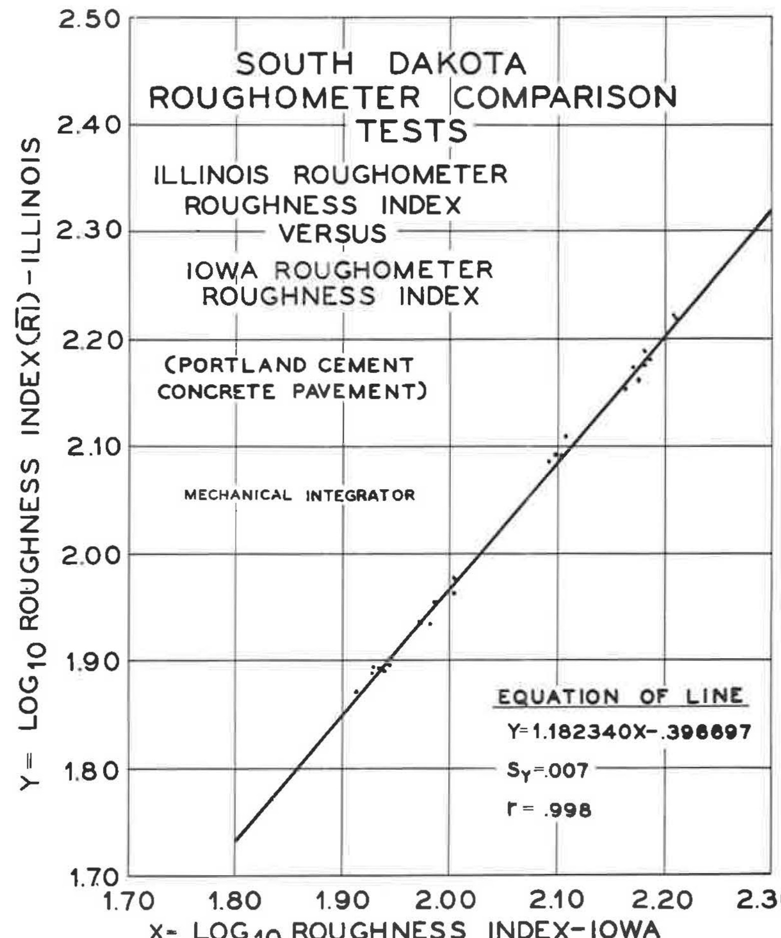


Figure 11. Machine performance.

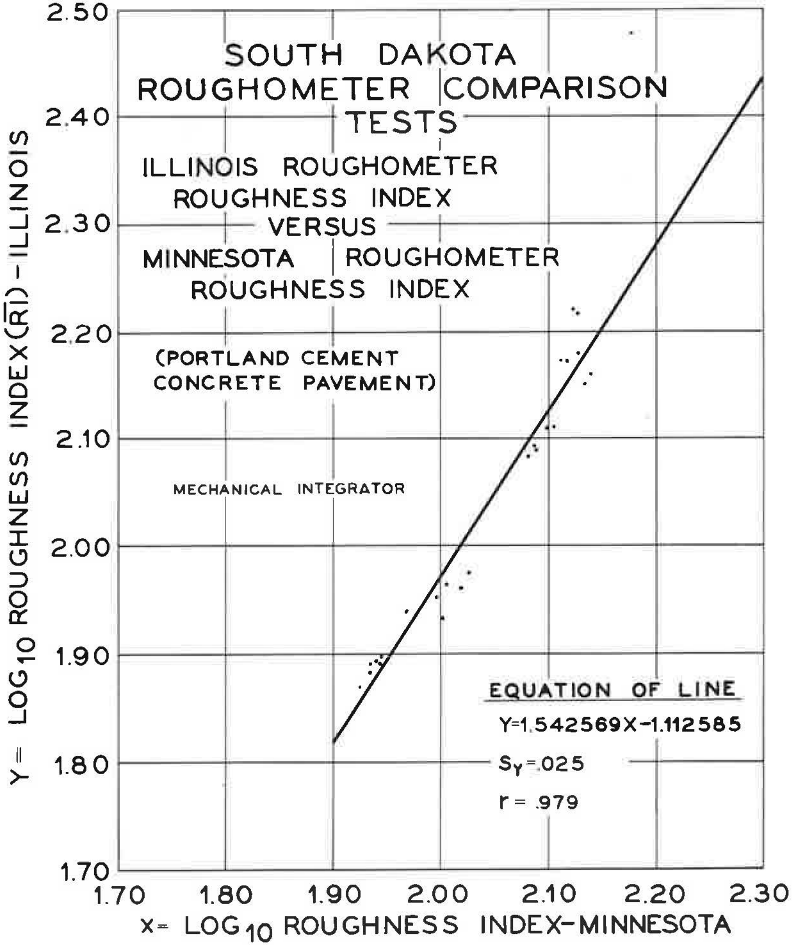


Figure 12. Machine performance.

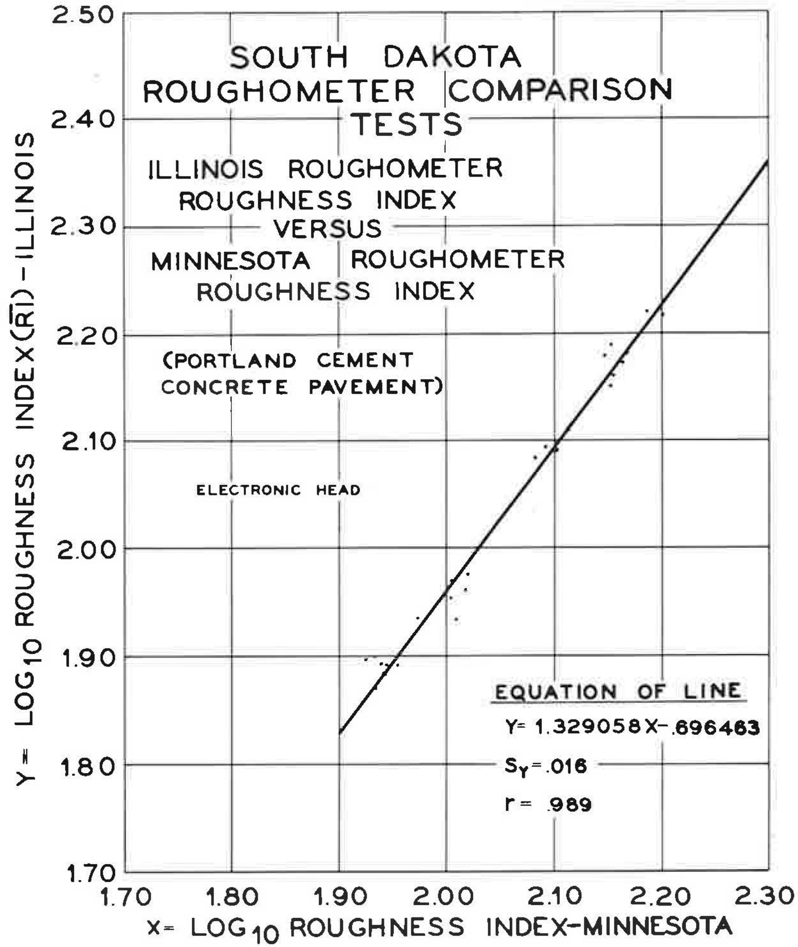


Figure 13. Machine performance.

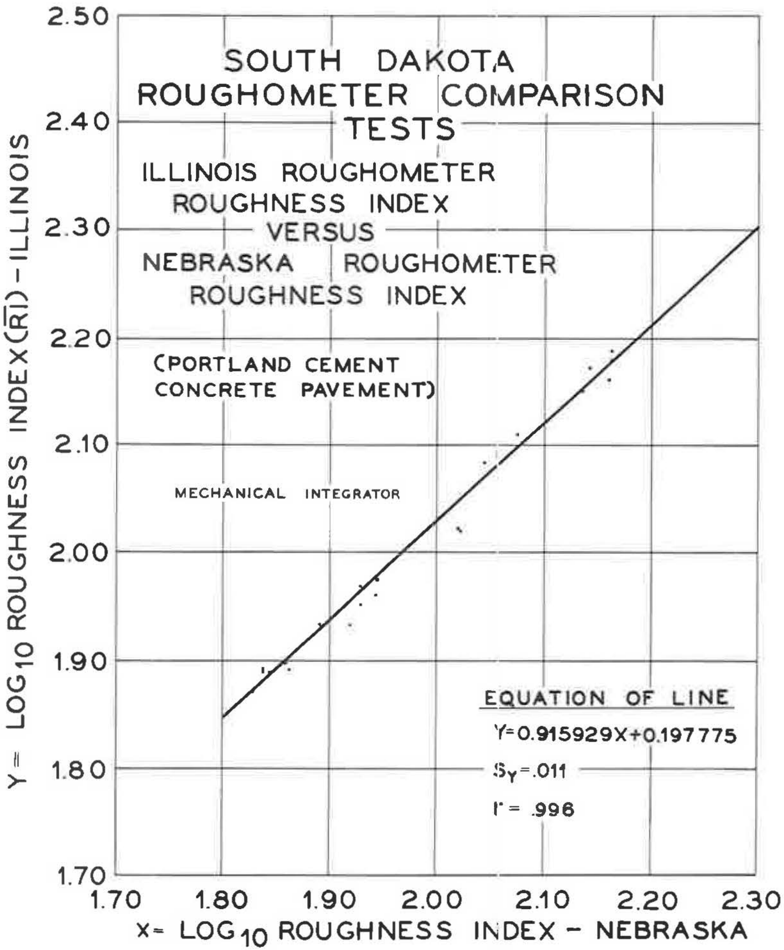


Figure 14. Machine performance.

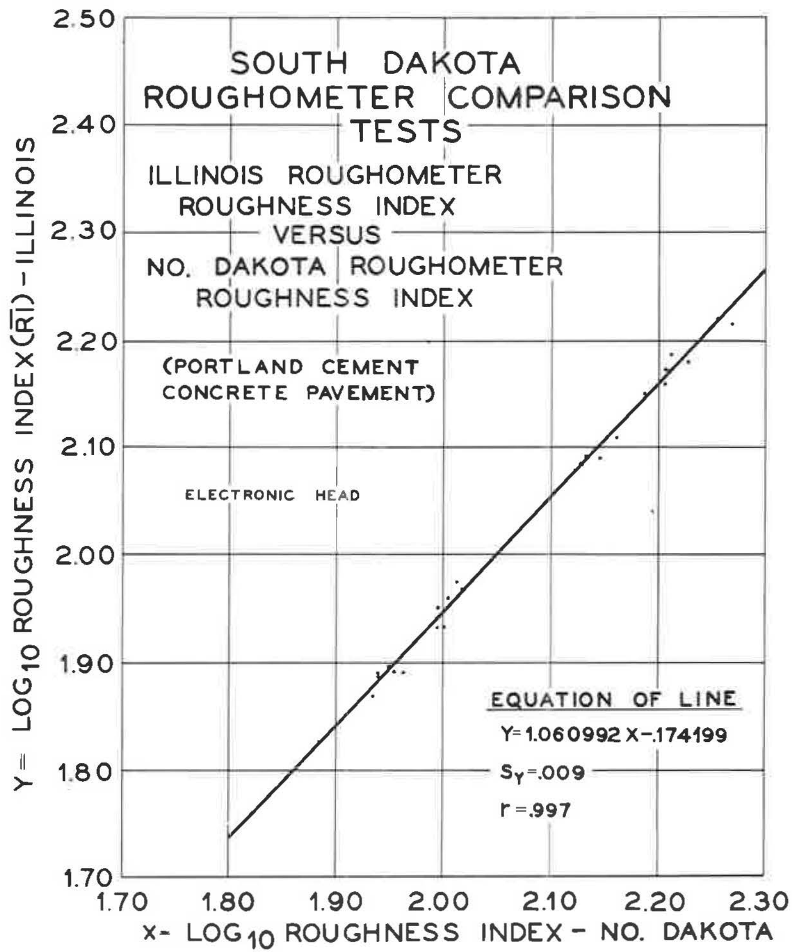


Figure 15. Machine performance.

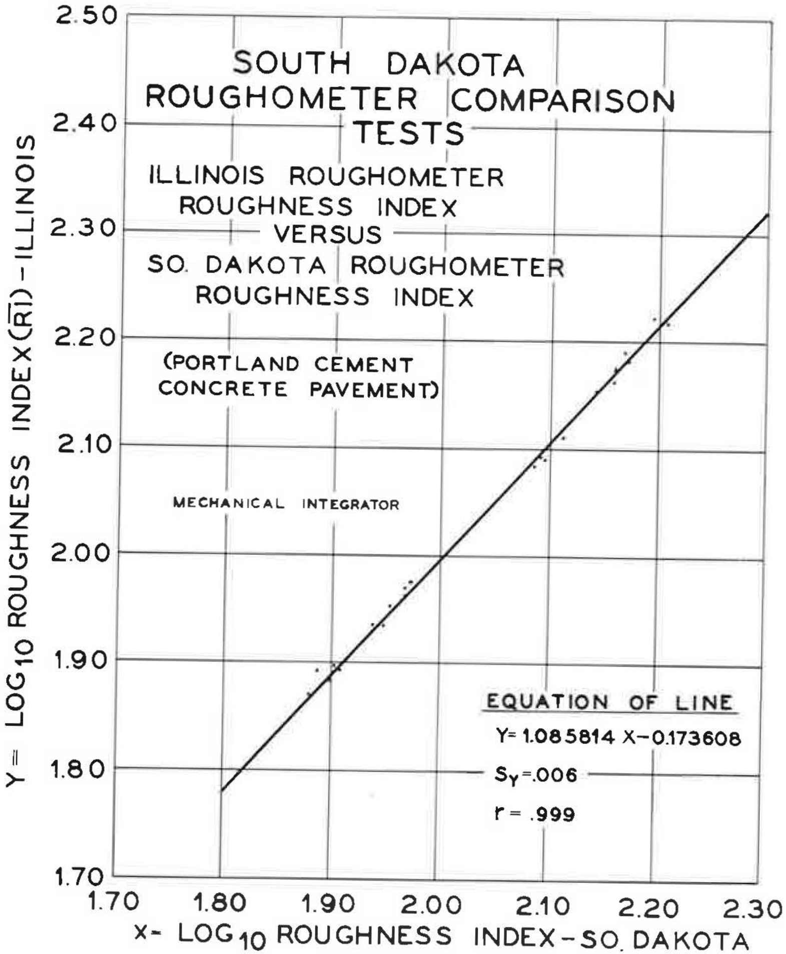


Figure 16 Machine performance.

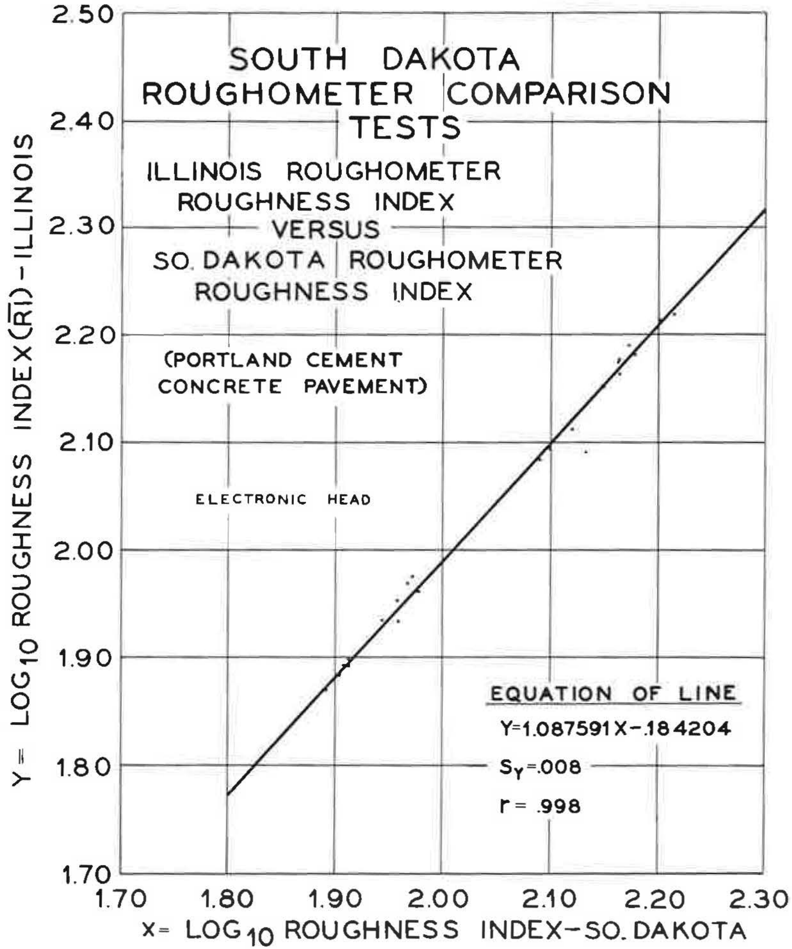


Figure 17. Machine performance.

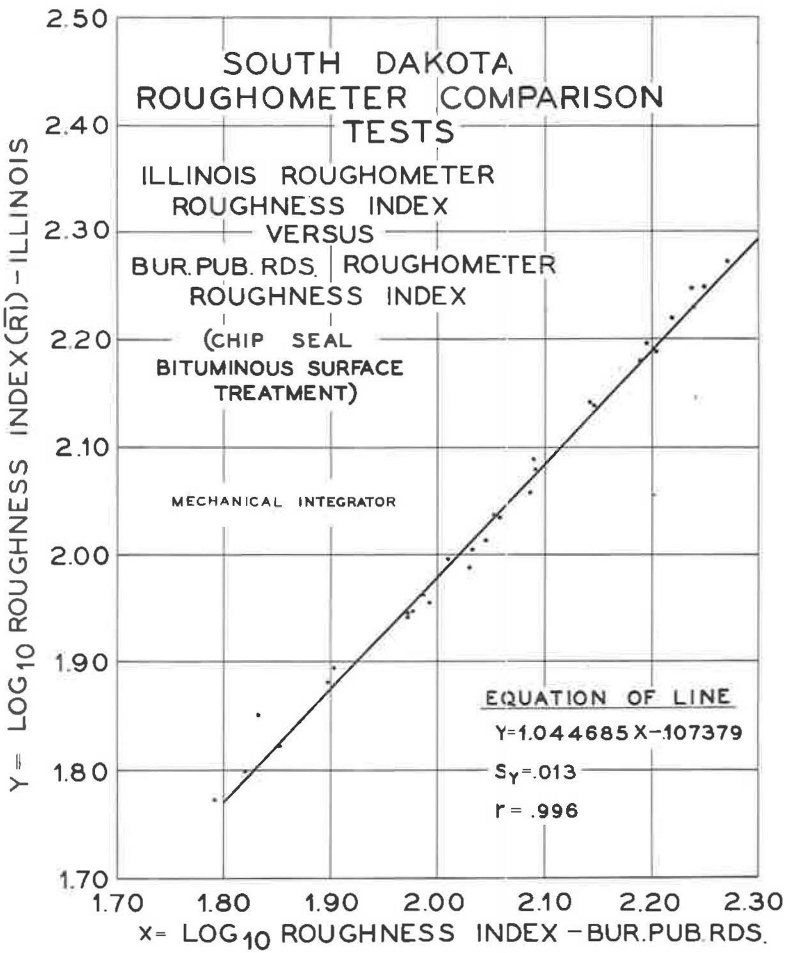


Figure 18. Machine performance.

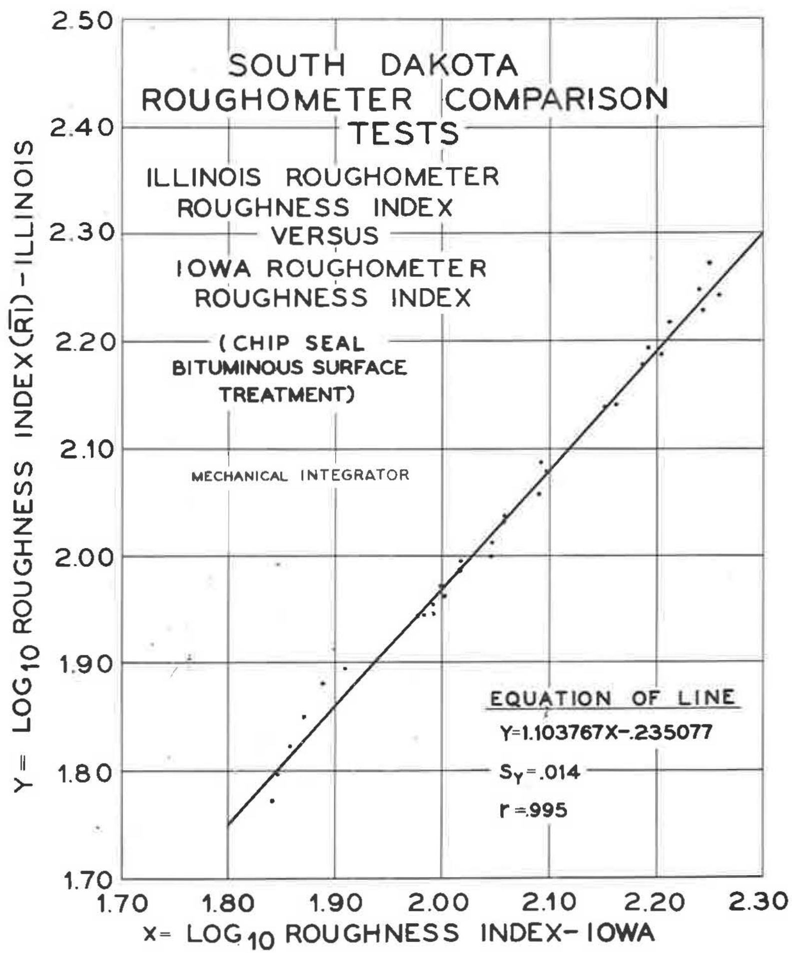
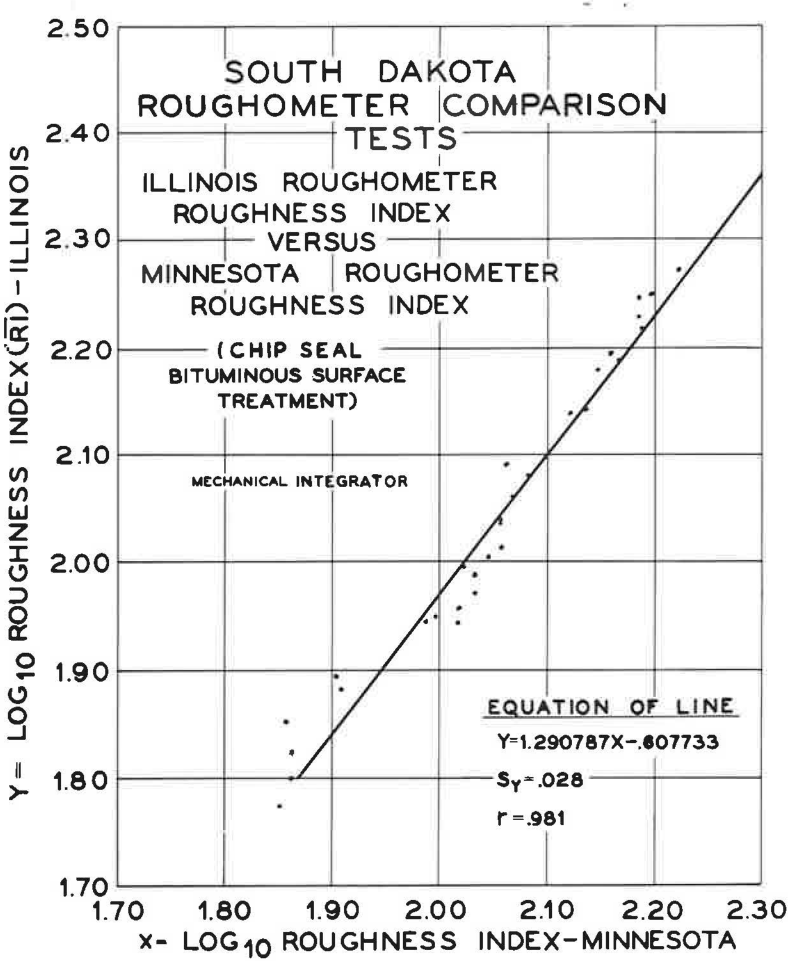


Figure 19. Machine performance.



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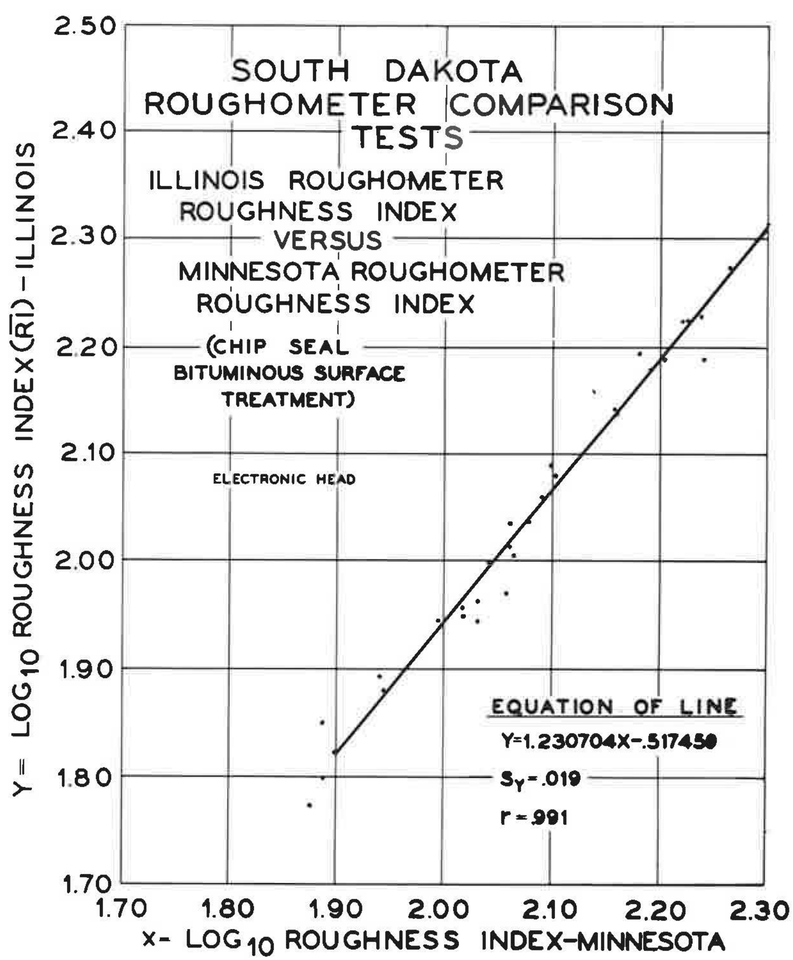

Figure 21. Machine performance.

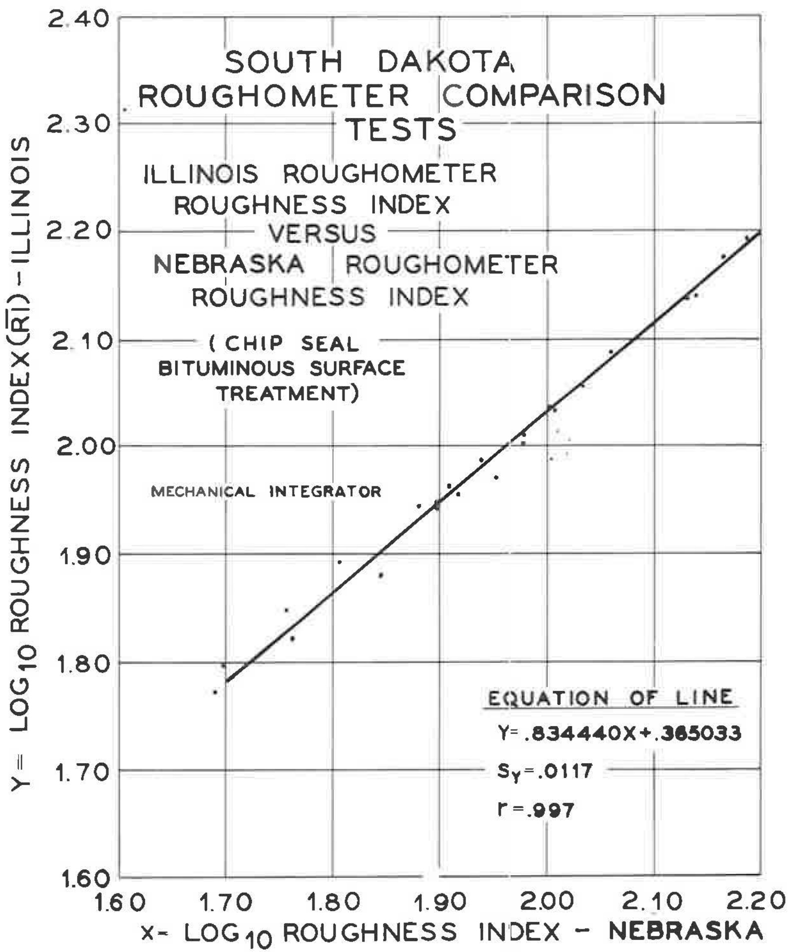

Figure 22. Machine performance.

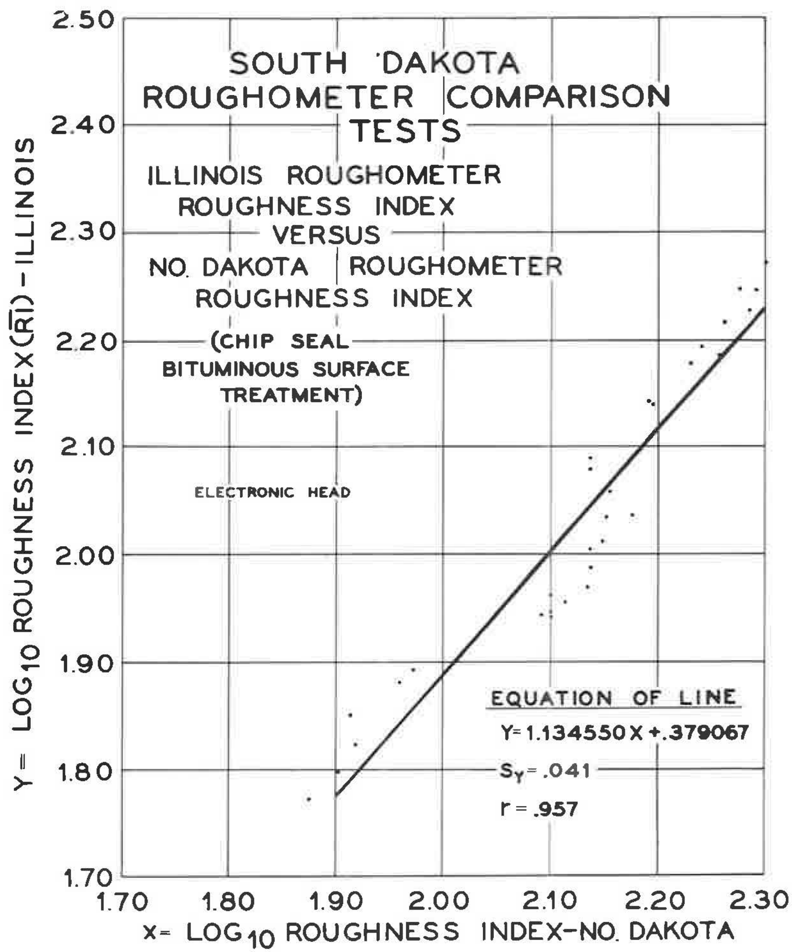

Figure 23. Machine performance.

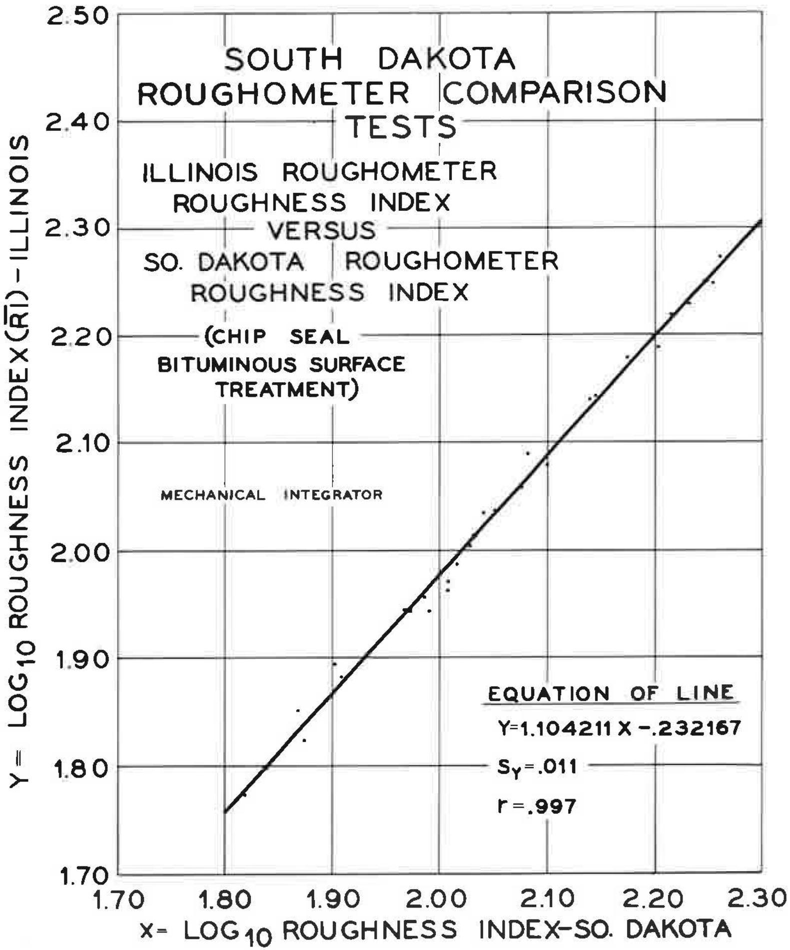

Figure 24. Machine performance.

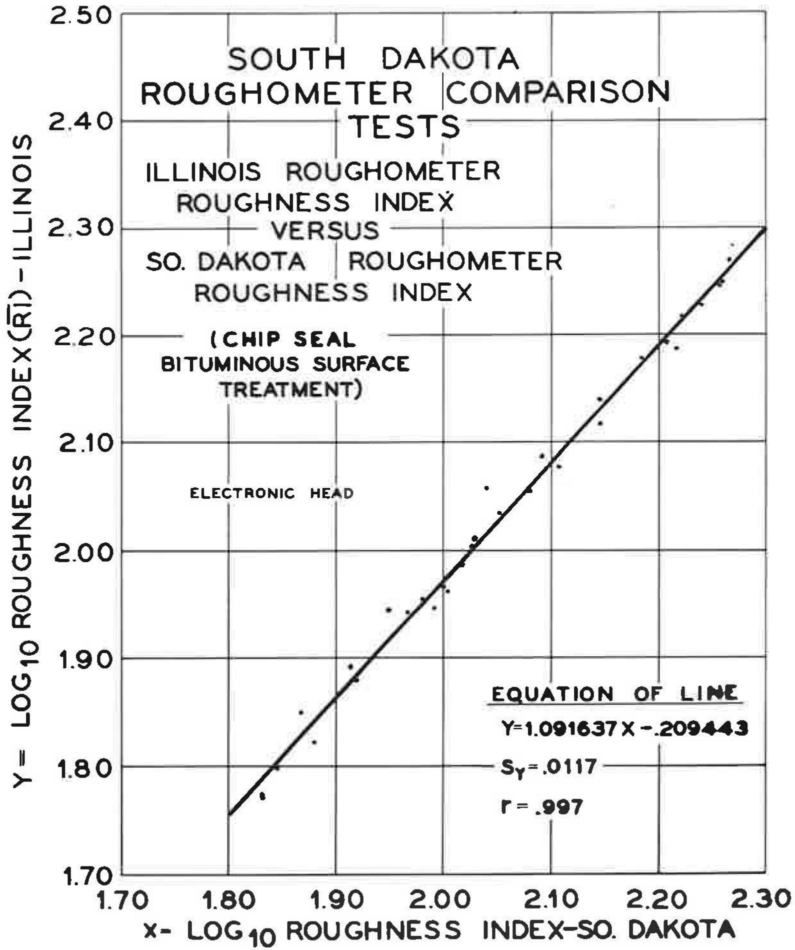

Figure 25. Machine performance.

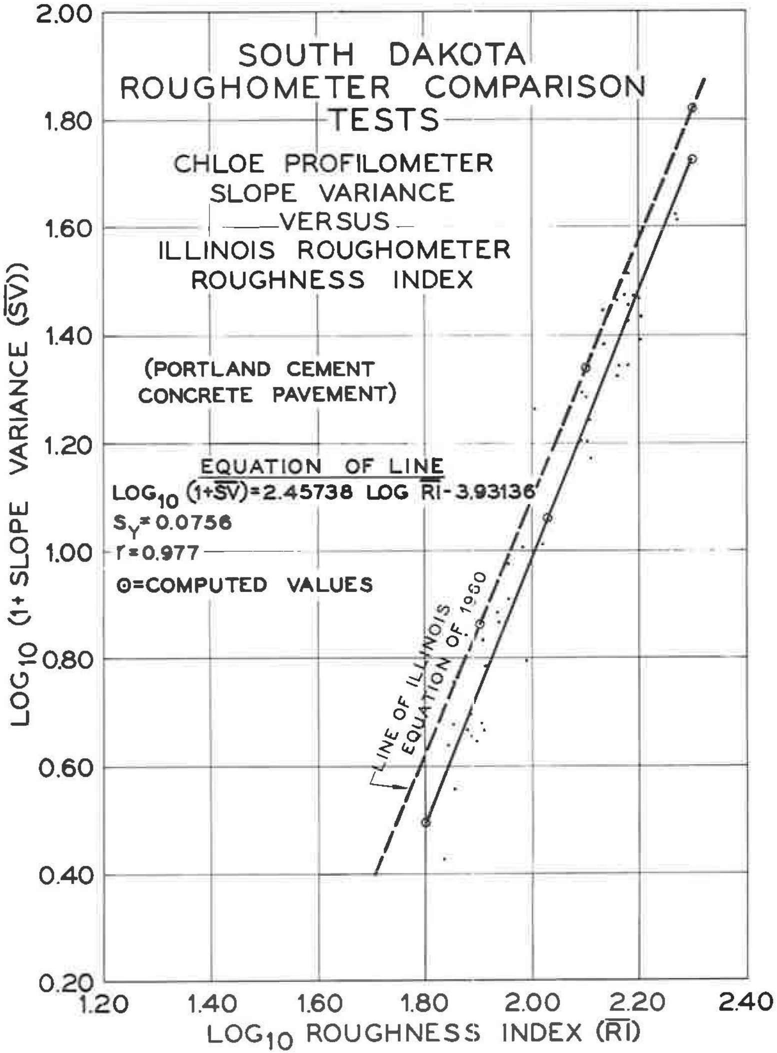

Figure 26. Machine performance.

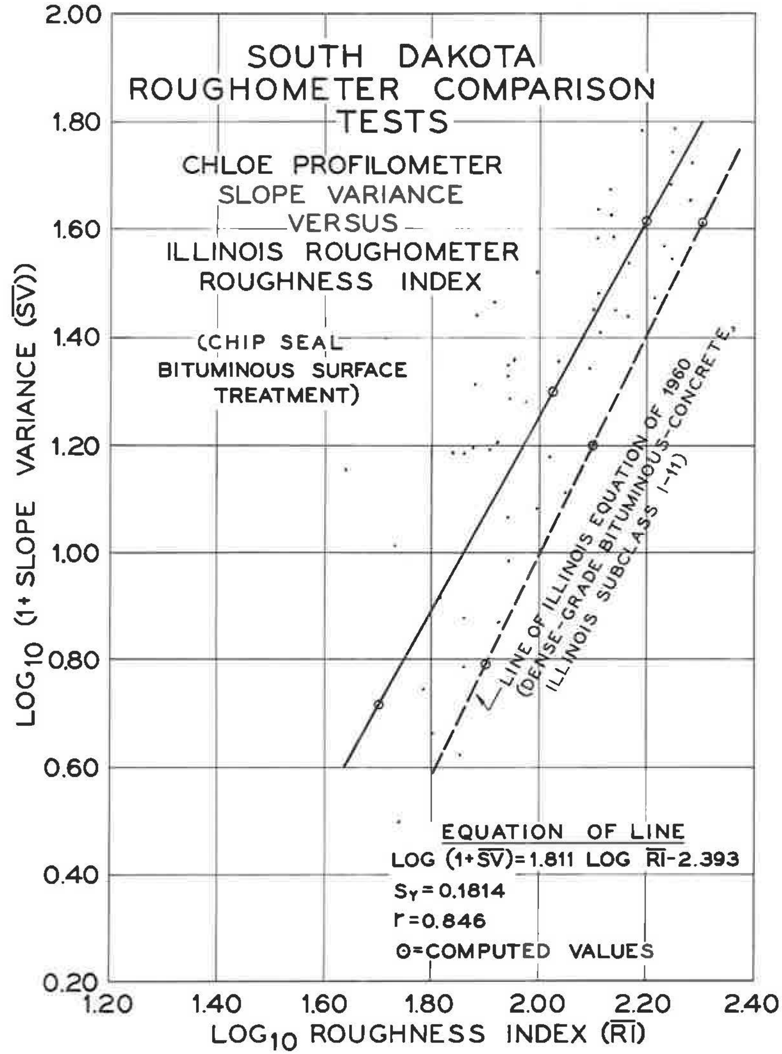

Figure 27. Machine performance.

TABLE 16

PRESENT SERVICEABILITY INDEX EQUATIONS[1]
DETERMINED BY SOUTH DAKOTA COMPARISON TESTS, 1962

Agency and Recording Method	PSI Equation
BPR mech. integ.	$PSI = 12.96 - 4.64 \log_{10} \overline{RI} - 0.09\sqrt{C + P}$
Ill. mech. integ.	$PSI = 12.41 - 4.37 \log_{10} \overline{RI} - 0.09\sqrt{C + P}$
Iowa mech. integ.	$PSI = 14.14 - 5.17 \log_{10} \overline{RI} - 0.09\sqrt{C + P}$
Minn.	
Mech. integ.	$PSI = 17.27 - 6.75 \log_{10} \overline{RI} - 0.09\sqrt{C + P}$
Magn. rdg. head	$PSI = 15.45 - 5.81 \log_{10} \overline{RI} - 0.09\sqrt{C + P}$
Neb. mech. integ.	$PSI = 11.54 - 4.01 \log_{10} \overline{RI} - 0.09\sqrt{C + P}$
N. Dak. mag. rdg. head	$PSI = 13.17 - 4.64 \log_{10} \overline{RI} - 0.09\sqrt{C + P}$
S. Dak.	
Mech. integ.	$PSI = 13.17 - 4.75 \log_{10} \overline{RI} - 0.09\sqrt{C + P}$
Mag. rdg. head	$PSI = 13.21 - 4.76 \log_{10} \overline{RI} - 0.09\sqrt{C + P}$

[1] Portland cement concrete surfaces only.

Having determined the mathematical relationship between readings obtained with the Illinois device and the CHLOE profilometer, a PSI equation for the Illinois machine was obtained by simple substitution of terms developed for the slope-variance profilometer. Equations for each of the other devices that took part in the study were established on the basis of the relationships that were developed between the Illinois and the other roughometers (Table 16). Two equations are given for machines with both mechanical and electronic reading heads.

RESULTS

Some of the roughometers provided readings consistently higher than the average; others, consistently lower readings. Deviations from the average also differed somewhat in the high and low ranges. Overall, however, the readings and correlations are considered to be remarkably consistent, particularly for the rigid pavement.

Long-term variations in the BPR-type roadometer equipment are indicated by the differences in the results of the 1960 and 1962 correlations of the Illinois device with the slope-variance profilometer (Figs. 26 and 27). For satisfactory comparisons between roughness index readings made at different times by any one of these devices, it is apparently necessary that they be adjusted to a constant base. In Illinois, the 1960 calibration of the machine has been accepted as the base to which all subsequent readings are adjusted.

It is concluded that the BPR-type roughometer is a well-designed and reliable piece of equipment. Experience in the tests indicated, however, that it is a delicate scientific device and must be handled as such. Breakdowns and erratic readings sometimes occur, but these usually can be detected without great difficulty by the operators after they have gained some experience. Most malfunctions can be corrected in the field and false readings recognized before they are reported.

To discuss the results obtained with the CHLOE longitudinal profilometer (Table 14), a brief explanation of its operation is necessary. The profilometer measures the slope variance at approximately 6-in. intervals. This provides about 1,000 readings in a 500-ft section. The number of counts in each section is shown in the column headed N in Table 14. The slope-variance readings are fed into a binary computer in the towing vehicle which sums and records the readings (Y). It also computes and records the sums of the squares of the slope-variance readings (Y^2).

Although successive runs were not made on any section with the CHLOE to check its reproducibility, experience indicates that wide deviations are unlikely. The device is so constructed that there is no reason to believe that its output had changed since its original construction and correlation.

There is some indication (Table 14) that the CHLOE profilometer may not have consistently yielded a complete series of slope-variance readings for the chip-seal surfaces and some of the rougher surfaces elsewhere. For these sections, the count values (N) were frequently well below the 1,000 that would be expected for a measured 500-ft length. It is possible that in some instances extremely sharp slope variations were skipped entirely, and at other times were beyond the limits of the machine and were recorded lower than actual. However, this is not believed to have occurred with any great frequency.

Overall, the results obtained with the CHLOE profilometer are credible and satisfactory for use in the correlations reported herein with respect to portland cement concrete pavements.

The CHLOE profilometer operated satisfactorily except for a short-circuited switch and a broken circuit. Such malfunctions can be repaired without much difficulty by someone familiar with the maintenance of electronic equipment. The major disadvantages in its use were the limited coverage due to its slow speed, and the constant danger during its operation in the faster-moving regular traffic stream.

It was apparent that the reaction of both the CHLOE profilometer and the BPR-type roadometers was influenced by the surface texture of the bituminous chip-seal treatments to the extent that the PSI formulas developed for the flexible pavements of the AASHO Road Test were not applicable. The inconsistencies substantiated the belief that a high priority should be assigned to further study of the development of PSI formulas for surface textures differing appreciably from those of the AASHO Road Test. Such a study might well include such paved surfaces as brick and sheet asphalt, and although no verification was possible through the South Dakota study, it should also include bituminous-concrete resurfaced rigid pavements to determine the influence of reflection cracking on the PSI formula.

The South Dakota Department of Highways conducted a series of auxiliary tests in which its roughometer was used to record roughness of 11 bituminous mat pavements prior to and immediately following the application of a chip seal. The roughness indexes were found to have increased on each project following the application, ranging from 14 in. per mi to 37 in. per mi and averaging 24 in. per mi.

Although deficiencies were found in both the BPR-type equipment and the CHLOE profilometer, their overall behavior was encouraging. The behavior or the BPR-type devices was particularly encouraging, and no reasons were apparent that would indicate that they should be supplanted by other equipment or that their use should be curtailed. However, frequent calibrations are necessary to furnish reliable results, and occasional tests of the magnitude and scope of the South Dakota tests are necessary for wide-area correlation.

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