Report of Committee on Load-Carrying Capacity of Roads as Affected by Frost Action

C. L. Motl, *Chairman*
Maintenance Engineer,
Minnesota Department of Highways

This report includes final information by Oregon, and extensive information submitted by Indiana, which has started work on a project of considerable magnitude and has now completed the first cycle of tests.

The six reports previously issued cover the activities of the committee during the years 1948 to 1953 inclusive and comprise information furnished by Indiana, Iowa, Michigan, Minnesota, Nebraska, New Hampshire, New York, North Dakota, Ohio, and Oregon.

The work being done by Indiana is a substantial addition to previous contributions, and it is believed that after the Indiana project has been completed, the committee activity can be terminated, with a final report.

All of the reports submitted to date contain information that discloses loss of carrying capacity by highways when subjected to substantial freezing and thawing action. The information submitted by Oregon and Indiana discloses the diminishing effect of frost action during mild winters when there is little frost penetration. Influence of frost action on carrying capacity of roads is not to be confused with surface disintegration caused sometimes by shallow freezing and thawing.

To those who may be interested in reports submitted by this committee during previous years, attention is called to the following publications of the Highway Research Board: Proceedings, Vol. 28; *Research Report 10-D, Bulletin 40; Bulletin 54;* and *Bulletin 96.*

OREGON

● The following report was submitted by the State of Oregon covering work performed during and following the winter of 1953–1954.

Oregon reports that it has now completed its work on the project, with the submittal of this report.

While the several reports submitted by Oregon show a wide variation in the comparative results secured at the several points tested, it is nevertheless true that there is a clear indication that the roads tested had a lower carrying capacity during the spring of year after the frost had left the ground.

The fourth and final annual cycle of plate bearing tests has been completed in Oregon. Tests have been continued on the same 18 points covered by Progress Reports 1, 2 and 3. The same equipment and test methods were employed.

The winter of 1953–54 was again comparatively mild in the area of the tests. The maximum frost penetration observed in the Madras vicinity (Groups A, B, C and D) was 5 inches. The maximum frost penetration in the Chemult vicinity (Groups E and F) was 7 inches.

In general, the strength reductions were not as great as for some previous years, but the reductions were of a longer duration. Group B did not show any reduction below the previous fall strength.

Figure 1 shows the locations of the test points and groups. Figures 2 to 7 show the curves for the four annual cycles.

The equipment was dismantled after completion of the 1953–54 cycle.

—W. W. Stiffler
Assistant State Highway Engineer

INDIANA

Indiana began its series of test for this committee work in September 1953. The 31 sites selected for testing, 8 in the southern half of the state and 23 in the northern half were described in detail in our original re-

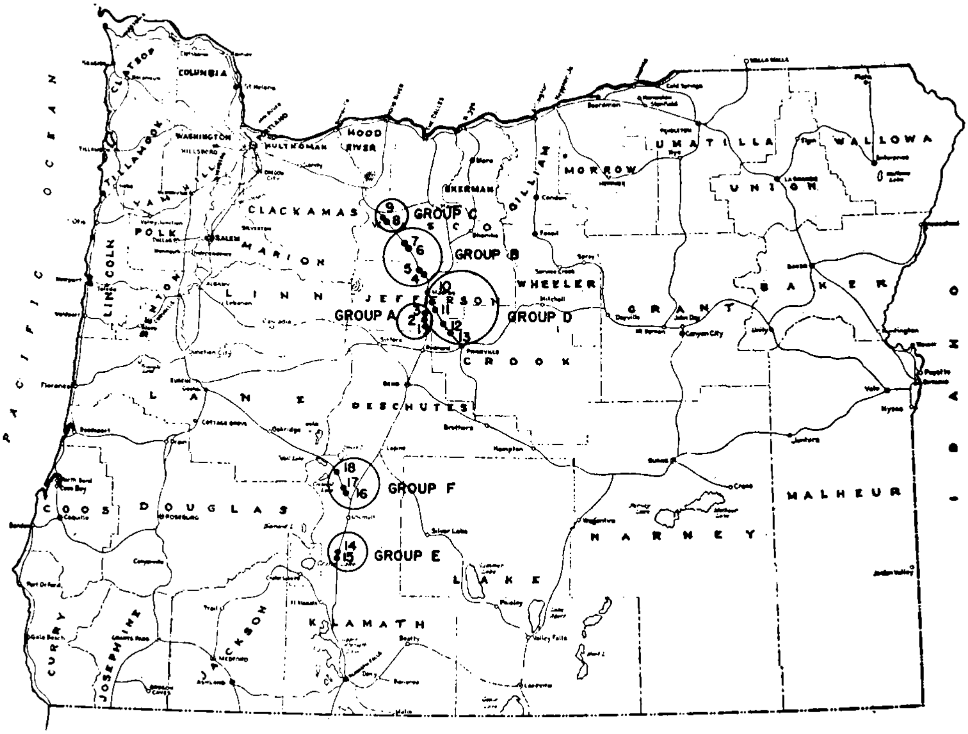

Figure 1. Test point locations.

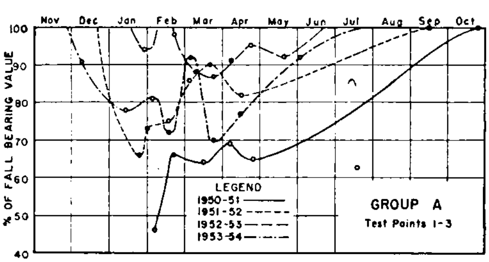

Figure 2

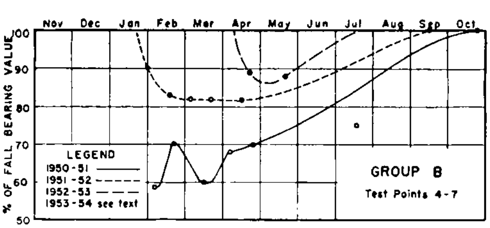

Figure 3

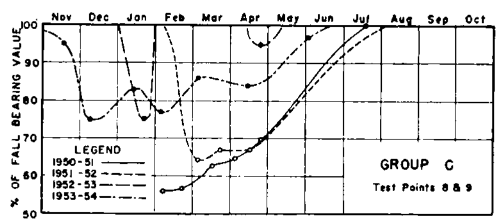

Figure 4

port. During the initial phase plate bearing tests were run only on the surface at each site. The results obtained represented the pavement's maximum strength. This information was reported to the Committee in January 1954.

This report describes the work done during the 1954 Spring season and compares the results obtained with the 1953 Fall series. The equipment used in both series of tests was the same.

General

Indiana has now completed its first cycle of bearing tests. The 1954 Spring series started on the southern circuit during the last week of February. These loadings were completed and tests on the northern circuit begun during

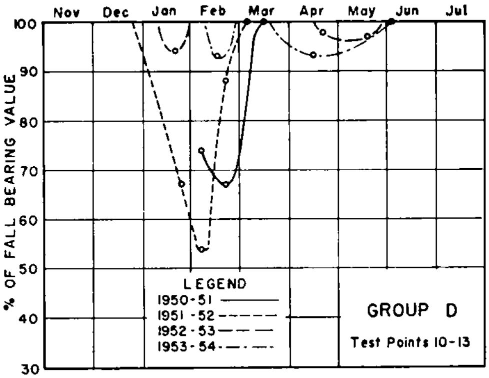

Figure 5

the second week of March. During the first part of the Spring series bearing tests were run only on the surface. At the same time test holes were dug at each site to more accurately check the pavement depths and to obtain subgrade samples for moisture content determination and laboratory analysis. The northern circuit was completed in the first week of April.

The wide differential in the loss of bearings during these early Spring series confirmed our original belief that more detailed information was needed. Accordingly six sites were selected for complete testing of the surface, base, and subgrade. The sites selected were 4-S, 6-S, and 7-S in the southern circuit, and 2-N, 3-N, and 4-N in the northern circuit. This phase of testing, listed in the table as "later in the Spring", was begun during the third week of April and completed in May. Bearing tests were run on the surface, base, and subgrade at each of the above mentioned sites. Densities and moisture contents for base and subgrade were also determined. Samples of base and subgrade were obtained for laboratory analysis.

All loadings for the Fall series and the early Spring series were run in the center of the traffic lane. It seemed desirable at this stage to determine how bearing values would vary when run near the pavement edge. Therefore, at sites 2-N, 3-N, and 4-N, tests were also run on the surface, base, and subgrade approximately 1.5 feet from the edge, which approximates the outer edge of the outside wheel track. Density and moisture tests were also run at these same locations.

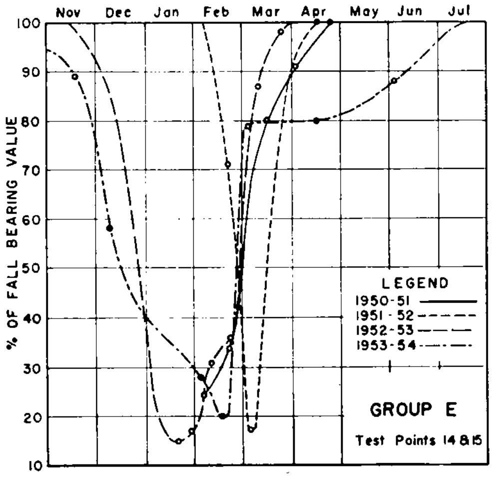

Figure 6

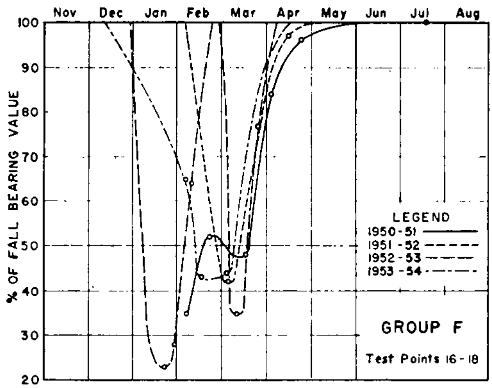

Figure 7

Test Results

The results obtained during the "first Spring" series of tests are shown in Table I, Table II combines last Fall's results with the Spring results.

Table III shows the variations in loss of bearing value for the various subgrade soil types. Investigation has shown that at many of the sites the thickness of pavement is not uniform throughout the site and it may vary considerably from the design thickness. No attempt was made to correct for these variations in Table III. Hence, the column headed "% of Fall value" does not consider the variable introduced by the difference in pavement thickness at each site. The column headed

"Thickness Ratio" is the ratio of the total pavement thickness at each test site in the Spring 1954 to the design thickness plus resurfacing. A "Thickness Ratio" greater than 1.0 indicates that the thickness at the location tested in the Spring was greater than the combined design and resurface thickness, therefore, the "% of Fall Value" is probably high. A "Thickness Ratio" less than 1.0 indicates the opposite.

The Spring 1954 bearing values as listed in Table II ranged from 52% to 95% of the 1953 Fall values, or a loss of 5% to 48%. In general the sites having the least amount of loss have sand or sandy loam subgrades, with bearing values ranging from 67% to 95% of the Fall values as shown in Table III. The 33% loss at sites 17-N and 25-N, each having a sandy loam subgrade, appear quite high for that type of subgrade. It should also be noted that the moisture content at these two sites appears to be less in the Spring than in the previous Fall. However, Tables II and VII show that at these two sites the lower soil layers are different and have higher moisture contents in the Spring. This probably accounts for the low Spring bearing values.

The sites having clay and clay loam subgrades had Spring bearing values ranging from 52% to 77% of the Fall values. It will be noted in Table III that the Spring moisture contents for sites 8-S, 16-N and 24-N are equal to or less than the Fall moisture content. Here again it is pointed out that the underlying soils have higher moisture contents than the upper part of the subgrade as shown in Table III.

For the other subgrade soil types the loss of bearing values at sites 3-S and 4-S, with losses of 9% and 6% respectively, appears too low. It will be noted that the Spring moisture content at those two sites is lower than for the Fall, thus explaining their slight loss.

Figure 8 shows the relationship of surface bearing values to total thickness of pavement for various subgrade soil types. Only the clay, clay loam, sandy loam, and sand soil types are shown. There was not enough tests on other soil types to establish definite trends. These results show that increasing pavement thicknesses on clay, clay loam, and sandy loam subgrade increases the surface bearing values for the type of pavements and the range of thicknesses tested. However, at the sites having sand subgrades this relationship was not apparent.

Results for the detailed bearing tests on the surface, base, and subgrade are given in Table IV. It should be noted again from this Table that the lower bearing values occur at sites having the more plastic subgrades while the more granular subgrades yield higher values. This table also shows the values for the outside wheel tracks as compared with those in the center of the lane at sites 2-N, 3-N, and 4-N. At these three sites the shoulder was approximately 2 inches lower than the surface of the pavement. At sites 2-N and 4-N the bearing values in the outside track are less than those in the center of the traffic lane. This could be due to the combination of two factors, namely, the low shoulder and nearness to the edge of pavement. Pavement width at these sites was 21 feet. On wider roads the wheel track will be farther from the edge and the bearing value, or strength, in the wheel track should be greater. At site 3-N the subgrade in both the inside and outside wheel tracks was rutted, the base being 11 to 16 inches in depth in the ruts. This increased base thickness caused higher bearing values than in the center of the lane. However, the bearing values obtained in the outside track are less than those in the inside track.

Table V was prepared to show the thickness of both the base and surface at the locations where tests were made.

Laboratory analysis of the subgrade soils at each site are given in Tables VI and VII for the south and north circuits, respectively.

Analysis of the base materials at the sites where detailed tests were run are shown in Table VIII.

The winter of 1953-1954 was a comparatively mild one. No frost penetration data is available. However, Table IX shows the temperature and precipitation data for the state from the time the first tests were run last Fall till the completion of the series of tests this Spring. This Table was prepared from the monthly reports "Climatological Data for Indiana" by the U. S. Department of Commerce, Weather Bureau. The test sites of the southern circuit are in the southern division of the state. Sites 24-N and 25-N are in the

TABLE I
SUMMARY OF BEARING VALUES
Spring of 1954; Tests Run on Surface

Site No.	Bearing Value PSI	Ave.	Present Thickness At Test Site Inches			Moist. Content of Subgrade %	Subgrade Soil Type	Type of Base
			Base	Surface	Total			
1-S	128, 125	126	5½	3	8½	17.7	A-6(10) SiClL	Traffic bound stone
2-S	157, 149	153	8	2½	10½	18.4	A-6(9) SiL	Waterbound macadam
3-S	131, 141	136	5	2	7	12.6	A-4(8) SiL	Traffic bound stone*
4-S	133, 127	131	6½	1	7½	13.6	A-6(9) SiClL	Traffic bound stone
5-S	70, 70	70	7¼	¾	8	24.1	A-6(9) SiCl	Traffic bound stone
6-S	58, 68	63	6	1	7	22.6	A-7-6(13) Cl	Traffic bound stone
7-S	121, 100, 95	105	5–7	2	7–9	14.0	A-6(8) ClL	Traffic bound stone*
8-S	84, 79	82	5½	1½	7	15.3	A-6(10) Cl	Traffic bound stone*
1-N	125, 119	122	9	2	11	12.5	A-4(5) ClL	Traffic bound gravel
2-N	222, 260	241	8	1	9	9.1	A-4(2) SL	Traffic bound gravel
3-N	100, 114	107	5½	1½	7	14.3	A-6(6) ClL	Traffic bound gravel
4-N	185, 174	180	7¼	3¼	10½	12.2	A-4(1) SL	Traffic bound stone
5-N	238, 242	240	7½	1½	9	12.4	A-3(0) S	Traffic bound stone
6-N	343, 339	341	5	4	9	5.8	A-2-4(0) S	Traffic bound stone
7-N	361, 350	356	6	3½	9½	3.8	A-3(0) S	Traffic bound stone
8-N	340, 363	352	5½	4	9½	4.8	A-3(0) S	Traffic bound stone
9-N	260, 255	258	5	4	9	7.2	A-3(0) S	Traffic bound stone
10-N	301, 308	304	5	5	10	8.5	A-2-4(0) S or SL	Traffic bound stone
11-N	†		6	2	8	4.4	A-3(0) S	Soil cement
13-N	†		6	2	8	3.7	A-3(0) S	Soil-cement
15-N	213, 218	216	8	5¾	13¾	10.5	A-3(0) S	Traffic bound stone
16-N	126, 112	119	9	1	10	12.1	A-4(7) ClL	Traffic bound gravel
17-N	160, 153	156	8½	1½	10	6.5	A-2-4(0) SL	Traffic bound gravel
18-N	238, 227	232	9	1½	10½	7.9	A-2-4(0) SL	Traffic bound gravel
19-N	156, 157	156	9	1½	10½	10.0	A-4(4) L	Traffic bound gravel
20-N	95, 112	104	7½	1	8½	13.1	A-4(5) Cl	Traffic bound gravel
21-N	345, 326	336	6½	1½	8	4.1	A-3(0) S	Traffic bound gravel
22-N	317, 317	317	7	2	9	6.6	A-1-b S	Traffic bound stone
23-N	172, 170	171	10	2	12	18.5	A-4(2) SL	Traffic bound gravel
24-N	110, 105	108	5	2	7	12.4	A-4(1) SL	Traffic bound stone*
25-N	130, 126	128	5½	2	7½	6.8	A-2-4(0) SL	Traffic bound stone*

* Bituminous stabilized stone in upper course.
† Exceeded capacity of equipment.

central division while the remainder of the sites are in the northern division. Averages for each division and the state are shown in Table IX. It is seen that the Fall 1953 phase of testing was begun under quite dry conditions. At the beginning of September 1953 the state had a deficiency of 2.22 inches of precipitation. During the next 8 months, which covers the period to the completion of the Spring 1954 tests, there was a deficiency of 6.88 inches of precipitation for the entire state. Study of the temperatures shows December 1953 and January 1954 to be the coldest months, yet, the state average temperatures were above normal in each month.

Temperature of the surface was taken at each site at time of test for both the Spring and Fall series. At no time did the surface temperature get high enough to materially affect the results.

Summary

The initial phase of testing was begun under dry conditions. The winter of 1953–1954 was quite dry and mild, there being a deficiency of 6.88 inches precipitation for the state and above normal temperatures for the 8 month period from September 1953 to April 1954. Indiana did not experience a Spring "break-up" in 1954.

At a number of sites the total pavement thickness was not uniform throughout and varied from the design thicknesses. Bearing values are clearly dependent on total pavement thicknesses for various subgrade soil types.

The Spring 1954 bearing values appear to range from 52% to 95% of the Fall 1953 values.

In general the moisture content of the subgrade was higher in the Spring than it was last Fall.

At sites where tests were run at the outer edge of the outside wheel track, approximately 1.5 feet from edge of pavement, the bearing values were less than in the center of the lane. Thus, the portion of the pavement which quite frequently carries the load, par-

TAB
SUMMARY OF
Fall of 1953 and Spring of

Site No.	Type of Base	Subgrade Soil Type	Bearing Value at 0.2″ Deflection—Psi							
			Fall—1953		Spring—1954			Later in Spring—1954		
				Ave.		Ave.	% of Fall Value		Ave.	% of Fall Value
5-S	Traffic bound stone	A-6(9) SiC	88, 84	86	70, 70	70	81			
6-S	Traffic bound stone	A-7-6(13) Cl	79, 97	88	58, 68	63	72	70	70	80
8-S	Traffic bound stone, bit. stab. stone	A-6(10) Cl	103, 108	106	84, 79	82	77			
4-S	Traffic bound stone	A-6(9) SiClL	134, 146	140	133, 127	131	94	119	119	85
24-N	Traffic bound stone, bit. stab. stone	A-4(1) SL	147, 141	144	110, 105	108	75			
3-S	Traffic bound stone, bit. stab. stone	A-4(8) SiL	158, 141	149	131, 141	136	91			
7-S	Traffic bound stone, bit. stab. stone	A-6(8) ClL	154, 161	157	121, 100, 95	105	67	85	85	54
1-S	Traffic bound stone	A-6(10) SiClL	158, 162	160	128, 125	126	79			
2-S	Waterbound macadam	A-6(9) SiL	174, 180	177	157, 149	153	86			
20-N	Traffic bound gravel	A-4(5) Cl	167, 187	177	95, 112	104	59			
23-N	Traffic bound gravel	A-4(2) SL	176, 185	180	172, 170	171	95			
1-N	Traffic bound gravel	A-4(5) ClL	180, 191	185	125, 119	122	66	130, 136	133	72
25-N	Traffic bound stone, bit. stab. stone	A-2-4(0) SL	189, 191	190	130, 126	128	67			
16-N	Traffic bound gravel	A-4(7) ClL	175, 200, 202	192	126, 112	119	62			
3-N	Traffic bound gravel	A-6(6) ClL	216, 197	206	100, 114	107	52	168, 145, 182	165	80
4-N	Traffic bound stone	A-4(1) SL	215, 210	212	185, 174	180	85	209, 208	208	98
17-N	Traffic bound gravel	A-2-4(0) SL	237, 231	234	160, 153	156	67			
2-N	Traffic bound gravel	A-4(2) SL	260, 277	268	222, 260	241	90	259, 255, 227	247	92
15-N	Traffic bound stone	A-3(0) S	270, 273	272	213, 218	216	79			
18-N	Traffic bound gravel	A-2-4(0) SL	273, 275	274	238, 227	232	85			
5-N	Traffic bound stone	A-3(0) S	268, 282	275	238, 242	240	87			
9-N	Traffic bound stone	A-3(0) S	288, 277	282	260, 255	258	91			
19-N	Traffic bound gravel	A-4(4) L	266, 299, 312	292	156, 157	156	53			
10-N	Traffic bound stone	A-2-4(0) S or SL	344	344	301, 308	304	88			
22-N	Traffic bound stone	A-1-B S	361, 348	354	317, 317	317	90			
6-N	Traffic bound stone	A-2-4(0) S	328, 387, 363	359	343, 339	341	95			
7-N	Traffic bound stone	A-3(0) S	387	387	361, 350	356	92			
8-N	Traffic bound stone	A-3(0) S	396	396	340, 363	352	89			
21-N	Traffic bound gravel	A-3(0) S	420,396	408	345, 326	336	82			
11-N	Soil cement	A-3(0) S	Exceeded capacity of equipment for both fall and spring							
13-N	Soil cement	A-3(0) S	Exceeded capacity of equipment for both fall and spring							

LE II
BEARING VALUES
1954; Tests Run on Surface

Total Pavement Thickness Inches				Moisture Content of Subgrade, %			Opt. Moisture Content of Subgrade, %	
Design	Fall 1953	Spring 1954	Later in Spring 1954	Fall 1953	Spring 1954	Later in Spring 1954		
6¾	6¾	8		20.2	24.1			
6¾	6¾	7	7	24.9	22.6	26.6	21.5	
6¾	7½	7		17.3	15.3*			*15.3 to −2.0′, 23.8 at 2.0′
6¾	6¾	7½	7½	17.1	13.6	17.2	15.4	
6¾	7¼	7		22.8	12.4*			*12.4 to −0.5′, 16.4% at −0.5 to −1.5′; 24.3% from −1.5′ to 2.5′
6¾	7	7		18.7	12.6			
6¾	8	8	5–8¾	10.4	14.0	13.3	12.9	
6	7	8½		12.7	17.7			
8¾	10½	10½		18.3	18.4			
9	9¾	8½		10.7	13.1			
9	9	12		14.4	18.5*			*18.5% to −0.5′; 15.9% from −0.5′ to −1.5′; 16.2% to 2.0′
9	11	11		8.0	12.5*			*12.5% to −0.8′; 5.1% at 0.8′
6¾	7¼	7½		21.0	6.8*			*6.8% to −0.4′; 15.0% at −0.4′ to −1.0′; 23.4% at −1.0′ to −1.5′; 25.8% to −2.5′
9	10¾	10		12.1	12.1*			*12.1% to −1.0′; 16.7% at −1.0′ to −2.0′
9	10	7	11	10.1	14.3	14.8	17.0	
6	9	10½	11	7.2	12.2*	12.3	12.5	*12.2% to −0.75′; 25.6% to −2.25′
9	10	10		10.4	6.5*			*6.5% to −0.5′; 11.0% at −0.5′ to −1.5′; 16.7% at −1.5′ to −3.0′
9	10	9	12	5.9	9.1*	5.2	8.4	*9.1% to −0.4%; 7.3% at −0.4′ to −1.0′
8	13¾	13¾		8.7	10.5			
9	10¼	10½		8.0	7.9*			*7.9% to −0.65′; 11.8% at −0.65′ to −1.25′
8¾	9	9		10.0	12.4*			*12.4% to −0.75′; 11.5% at −0.75′ to −2.25′
6¾	9½	9		12.1	7.2*			*7.2% to −0.25′; 9.7% at −0.25′ to −0.8′; 12.7% to −0.8′ to −1.5′; 14.5% to −2.5′
9	10	10½		7.7	10.0			
6¾	9½	10		6.6	8.5*			*8.5% to −1.5′; 5.2% at −1.5′ to −3.0′
6	9	9		7.6	6.6			
6¾	9	9		4.5	5.8			
6¾	9	9½		5.3	3.8			
6¾	9½	9½		7.9	4.8			
9	9	8		5.1	4.1			
7	8	8		5.	4.4			
7	8	8		5.1	3.7			

TABLE III
LOSS OF BEARING VALUES ACCORDING TO SUBGRADE SOIL TYPES

Subgrade Soil Type	Site No.	Spring Bearing Value as % of Fall Value	Ave.	Thickness Ratio*	Moist. Content Fall 1953, %	Moist. Content Spring 1954, %
Clay	20-N	59		0.87	10.7	13.1
	6-S	72		1.04	24.9	22.6
	8-S	77	69	0.93	17.3	15.3
Silty clay loam	1-S	79		1.21	12.7	17.7
	4-S	94	86	1.15	17.1	13.6
Silty clay	5-S	81		1.18	20.2	24.1
Loam	19-N	53		1.05	7.7	10.0
Silty loam	2-S	86		1.0	18.3	18.4
	3-S	91	88	1.0	16.7	12.6
Clay loam	3-N	52		0.70	10.1	14.3
	16-N	62		1.08	12.1	12.1
	1-N	66		1.0	8.0	12.5
	7-S	67	62	1.0	10.4	14.0
Sandy loam	17-N	67		1.0	10.4	6.5
	25-N	67		1.03	21.0	6.8
	24-N	75		0.97	22.8	12.4
	4-N	85		0.97	7.2	12.2
	18-N	85		1.02	8.0	7.9
	10-N	88		1.05	6.6	8.5
	2-N	90		0.90	5.9	9.1
	23-N	95	82	1.33	14.4	18.5
Sand	15-N	79		1.0	8.7	10.5
	21-N	82		0.89	5.1	4.1
	5-N	87		1.0	10.0	12.4
	8-N	89		1.0	7.9	4.8
	22-N	90		1.0	7.6	6.6
	9-N	91		0.95	12.1	7.2
	7-N	92		1.05	5.3	3.8
	6-N	95	88	1.0	4.5	5.8

* Ratio of total pavement thickness at test sites in Spring 1954 to the design thickness plus resurfacing.

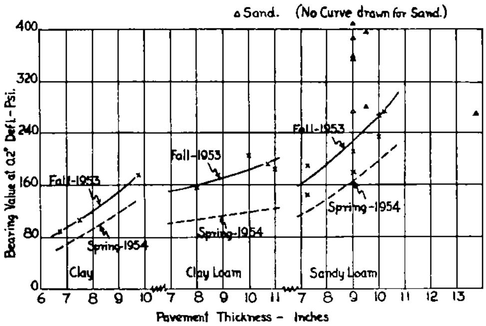

Figure 8. Relationship of surface bearing values to total thickness for various subgrade soil types.

ticularly on a narrower road, was the weakest. This condition might have been further aggravated by low shoulders at the sites tested in the outside wheel track.

Since Indiana did not experience a Spring "break-up" in 1954, another complete cycle of tests will be run. The Fall series were started in September 1954. The Spring series will be run in 1955. A complete report for both cycles will be available in 1955.

—C. E. VOGELGESANG
Chief Engineer

TABLE IV
SUMMARY OF DETAILED PLATE BEARING TESTS
Tests Run on Surface, Base, and Subgrade

Site No.	Location	Plate on	Later Spring Bearing Value at 0.2" Defl.	Previous Bearing Value Center of Lane		Later Spring Dry Dens.	Max. Dry Dens.	Later Spring Moist. Cont., %	Opt. Moist.	
				Fall 1953	Early Spring 1954					
4-S	Center W. bound lane	1" surface 6½" base 6½" base Subgrade	119 85 43	140	131	119.3 115.9	136.6 110.0	3.7 17.2	7.3 15.4	A-6(9) SiCL
6-S	Center W. bound lane	1" surface 6" base 6" base Subgrade	70 60 24	88	63	126.5 90.2	135.2 98.5	3.0 26.6	7.2 21.5	A-7-6(13) C
7-S	Center S. bound lane	2½" surface 1¼" stone base 2½" bit. stab. base Subgrade	85 59 44 62	157	105	102.2 113.1	* 116.7	5.0 13.3	* 12.9	Base is quite variable at this site A-6(8) CL
2-N	Center N. bound lane	2½" surface 9" base 9" base Subgrade Subgrade	247 231 111 103	268	241	139.4 118.0	136.8 132.5	2.8 5.2	7.6 8.4	A-4(2) SL
	Outside track N.b. lane	2" surface 9" base 9" base Subgrade	149 122 88			130.7 124.6	136.8 131.9	5.0 5.3	7.6 8.6	A-4(6) SL
3-N	Center N. bound lane	2" surface 8" base 8" base Subgrade	165 110 48	206	107	133.5 115.2	133.3 110.1	4.0 14.8	8.2 17.0	
	Inside track N.b. lane	2" surface 9" base 9" base Subgrade	266 143 53			132.4 111.9	133.3 110.1	5.5 16.0	8.2 17.0	Subgrade rutted here, the base being 11" in ruts
	Outside track N.b. lane	2" surface 9" base 9" base 8" base	178 124 99			133.9 133.9	132.8 132.8	5.1 5.1	9.4 9.4	Subgrade rutted here, the base being 11" to 16" in ruts, otherwise 7" to 9"
4-N	Center E. bound lane	4" surface 7" base 7" base Subgrade	208 140 70	212	180	132.9 114.9	136.7 117.7	4.3 12.3	7.9 12.5	A-4(1) SL
	Outside track E.b. lane	4½" surface 7" base 7" base Subgrade	144 109 66			135.5 124.7	136.7 117.7	3.8 7.5	7.9 12.5	A-4(1) SL

* Not run.

TABLE V
PAVEMENT THICKNESSES AT LOCATION TESTED

Site No.	Pavement Thicknesses—Inches											
	Design			Fall 1953			Early in Spring 1954			Later in Spring 1954		
	Base	Surface	Total	Base	Surface	Total	Base	Surface	Total	Base	Surface	Total
1-S	6		6	6	1	7	5½	3	8½			
2-S	8	¾	8¾	8	2½	10½	8	2½	10½			
3-S	6	¾	6¾	6	1	7	5	2	7			
4-S	6	¾	6¾	6	¾	6¾	6½	1	7½	6½	1	7½
5-S	6	¾	6¾	6	¾	6¾	7¼	¾	8			
6-S*	6	¾	6¾	6	¾	6¾	6¼	¾	7	6	1	7
7-S†	6	¾	6¾	6	2	8	6	2	8	2½–6¼	2½	5–8¾
8-S	6	¾	6¾	6	1½	7½	5½	1½	7			
1-N	9		9	9	2	11	9	2	11			
2-N	9		9	9	1	10	8	1	9	9	3	12
3-N‡	9		9	9	1	10	5½	1½	7	9	2	11
4-N	6		6	6	3	9	7¼	3¼	10½	7	4	11
5-N	8	¾	8¾	8	1	9	7½	1½	9			
6-N	6	¾	6¾	6	3	9	5	4	9			
7-N	6	¾	6¾	6	3	9	6	3½	9½			
8-N	6	¾	6¾	6	3½	9½	5½	4	9½			
9-N	6	¾	6¾	6	3½	9½	5	4	9			
10-N	6	¾	6¾	6	3½	9½	5	5	10			
11-N	6	1	7	6	2	8	6	2	8			
13-N	6	1	7	6	2	8	6	2	8			
15-N	8		8	8	5¾	13¾	8	5¾	13¾			
16-N	9		9	9	1¾	10¾	9	1	10			
17-N	9		9	9	1	10	8½	1½	10			
18-N	9		9	9	1¼	10¼	9	1½	10½			
19-N	9		9	9	1	10	9	1½	10½			
20-N	9		9	9	¾	9¾	7½	1	8½			
21-N	8	1	9	8	1	9	6½	1½	8			
22-N	6		6	6	3	9	7	2	9			
23-N	7½	1½	9	7½	1½	9	10	2	12			
24-N	6	¾	6¾	6	1¼	7¼	5	2	7			
25-N	6	¾	6¾	6	1¼	7¼	5½	2	7¼			

* 3″ of stone worked down into subgrade.
† Base thickness is extremely variable at this particular spot.
‡ Subgrade is rutted in wheel tracks, the base being 11″ to 16″ thick in tracks.

TABLE VI
SUMMARY OF SOIL TESTS; SUBGRADE SOILS—SOUTHERN CIRCUIT

Site No.	Depth of Sample	Ret. 1"	Pass. 1" Ret. 3/4"	Pass. 3/4" Ret. 1/2"	Pass. 1/2" Ret. No. 4	Pass. No. 4 Ret. No. 10	Pass. No. 10 Ret. No. 40	Pass. No. 40 Ret. No. 270	Silt	Clay & Colloids	Liquid Limit	Plasticity Index	Shrinkage Limit	Vol. Change	Lineal Shrink.	Max. Dry Density	Opt. Moisture	
1-S	0 to −0.5′			0	2	5	6	15	45	27	35.0	15.2	15.3	22.0	6.4			A-6(10) CIL†
	0 to −1.5′			0	1	2	4	8	61	24	34.6	16.3	16.4	19.6	2.2			A-6(10) SiCIL*
2-S	0 to −0.5′			0	2	3	2	4	70	19	34.8	13.2	17.5	21.0	6.1			A-6(9) SiL†
	0 to −1.5′			0	2	3	2	3	75	15	33.8	13.0	19.2	12.2	1.7			A-6(9) SiL†
3-S	0 to −0.5′			0	2	2	4	8	64	20	24.2	3.6	20.6	1.2	0.3			A-4(8) SiL or SiCIL†
	0 to −1.5′			0	3	3	5	8	64	17	28.3	9.6	18.0	12.0	1.6			A-4(8) SiL*
4-S	0 to −0.5′			0	1	1	1	13	58	26	32.6	14.8	15.1	20.1	6.0			A-6(10) SiCIL†
	0 to −1.0′					0	1	17	55	27	28.5	11.5	14.8	1.8	0.9	110.0	15.4	A-6(9) SiCIL*
5-S	0 to −0.5′		0	1	0	1	1	4	47	46	44.2	22.0	20.7	17.7	5.2			A-7-6(14) Cl†
	0 to −0.5′				0	4	4	6	43	43	42.8	21.1	18.1	23.8	6.7			A-7-6(13) Cl
	0 to −1.5′					0	2	7	52	39	36.8	12.7	15.6	20.5	6.1			A-6(9) SiCl*
6-S	0 to −0.5′					0	1	2	43	54	52.8	26.6	22.2	20.1	6.0			A-7-6(18) Cl†
	0 to −0.5′				0	1	1	3	41	54	50.7	26.0	21.3	23.2	6.7			A-7-6(16) Cl
	0 to −1.5′				0	1	1	9	44	45	43.5	20.1	17.7	22.9	6.7	98.5	21.5	A-7-6(13) Cl*
7-S	0 to −0.5′				0	1	4	19	47	29	31.4	14.1	14.8	15.1	4.5			A-6(10) CIL†
	0 to −2.0′			0	1	2	7	27	39	24	29.7	14.9	11.1	25.3	7.4	116.7	12.9	A-6(8) CIL*
8-S	0 to −0.5′				0	1	4	19	37	49	37.3	18.6	14.5	25.2	7.3			A-6(12) Cl†
	0 to −2.0′			0	1	2	4	14	40	39	32.4	14.6	14.3	19.6	6.0			A-6(10) Cl*

*Samples taken in Spring of 1954. All others taken in Fall of 1953.
†Samples taken from subgrade at edge of pavement. All others taken from beneath pavement in center of lane.

TABLE VII
SUMMARY OF SOIL TESTS
Subgrade Soils—Northern Circuit

Site No.	Depth of Sample	Ret. 1"	Pass. 1" Ret. ¾"	Pass. ¾" Ret. ½"	Pass. ½" Ret. No. 4	Pass. No. 4 Ret. No. 10	Pass. No. 10 Ret. No. 40	Pass. No. 40 Ret. No. 270	Silt	Clay & Colloids	Liquid Limit	Plasticity Index	Shring. Limit	Vol. Change	Lineal Shrink.	Max. Dry Density	Optimum Moisture	
1-N	0 to −0.5′			0	10	12	13	24	26	15	21.5	6.9						A-4(2) SL
	0 to −0.8′			1	2	4	9	27	34	23	23.6	8.7	12.0	12.5	4.0			A-4(5) CIL*
2-N	0 to −0.25′			0	10	13	18	28	20	11	21.1	5.9						A-2-4(0) SL
	0 to −0.25′		2	1	7	8	12	29	23	18	18.1	4.7	11.2	8.4	2.9			A-4(2) SL*
	−0.25′ to −1.0′		5	7	13	18	21	25	4	7	13.1	0.9	12.0	4.0	1.5			A-1-b S*
	0 to −0.5′		0	3	10	12	14	28	21	12	15.1	3.3	9.8			131.9	8.0	A-4(0) SL*
3-N	0 to −0.5′			0	3	8	12	27	31	19	26.1	10.7	13.7	17.9	5.2			A-6(4) SL
	0 to −1.0′				2	3	9	28	29	29	27.8	10.6	12.4	20.3	6.1			A-6(6) CIL*
	0 to −0.4′	0	3	1	5	8	11	25	33	14	20.7	6.9	12.5			121.2	12.0	A-4(3) SL*
4-N	0 to −0.5′			0	9	14	19	18	31	9	17.6	2.3						A-4(1) SL
	0 to −0.75′		0	3	12	10	14	22	29	10	21.7	3.4	14.0	7.7	3.5			A-4(1) SL*
	−0.75′ to −2.25′		0	1	3	2	5	14	59	16	40.0	14.6	17.6	21.4	6.4			A-6(10) SiL*
	0 to −0.4′	0	6	5	12	13	12	14	29	9	22.5	4.9	9.6			118	12.5	A-4(1) SL*
5-N	0 to −0.75′				0	1	2	90	3	4	14.4	NP						A-3(0) S*
	−0.75′ to −2.25′		0	1	1	1	2	82	7	6	15.3	NP						A-2-4(0) S*
6-N	0 to −2.25′					0	1	93	2	4	17.1	NP						A-2-4(0) S*
7-N	0 to −3.0′					0	1	97	1	1	18.6	NP						A-3(0) S*
8-N	0 to −2.25′					0	2	94	1	3	15.7	NP						A-3(0) S*
9-N	0 to −0.25′			0	3	1	4	88	1	3	16.2	NP						A-3(0) S*
	−0.25′ to −0.8′			0	1	0	1	86	6	6	13.8	NP						A-2-4(0) S*
	−0.8′ to −1.5′				0	1	1	88	4	6	15.2	NP						A-2-4(0) S*
	−1.5′ to −2.5′			0	1	1	2	71	13	12	19.0	NP						A-2-4(0) S*
10-N	0 to −1.5′	0	1	0	3	5	13	57	11	10	12.8	NP						A-2-4(0) S or SL*
	−1.5′ to −3.0′				0	1	3	93	1	2	15.1	NP						A-3(0) S*
11-N	0 to −3.0′					0	2	93	0	5	17.0	NP						A-3(0) S*
13-N	0 to −3.0′					0	4	94	1	1	14.7	NP						A-3(0) S*
15-N	0 to −1.5′			0	7	7	26	54	1	5	13.1	NP						A-3(0) S*
16-N	0 to −1.0′			0	3	3	4	22	42	26	22.4	6.5	11.4	14.6	4.5			A-4(7) CIL*
	−1.0′ to −2.0′		0	1	2	2	5	15	45	30	21.2	5.4	14.2	9.0	3.0			A-4(8) CIL*
17-N	0 to −0.5′		0	4	16	10	9	39	10	12	15.1	3.8	9.3	9.3	5.5			A-2-4(0) SL*
	−0.5′ to −1.5′	0	1	1	2	1	5	51	19	20	16.3	4.5	9.6	11.6	3.8			A-4(1) SL*
	−1.5′ to −3.0′					0	3	17	42	38	20.9	5.2	12.0	11.5	3.8			A-4(8) CL*
18-N	0 to −0.65′			0	2	4	15	50	17	12	13.6	0.7	10.8	4.1	1.5			A-2-4(0) SL*
	−0.65′ to −1.25′			0	1	1	12	57	16	13	14.5	2.1	10.9	7.3	2.5			A-2-4(0) SL*
	−1.25′ to −1.75′		0	4	10	7	17	43	10	9	13.5	NP	11.8	5.9	2.1			A-2-4(0) S*
	−1.75′ to −2.0′		0	4	11	9	18	42	9	7	12.0	NP	11.7	5.1	1.7			A-2-4(0) S*

19-N	0 to −2.0′		0	1	8	6	6	29	40	10	19.3	5.7	12.2	12.8	4.1			A-4-(4) L*
20-N	0 to −0.5′			0	3	4	7	27	34	25	26.8	11.3	13.3	15.7	4.6			A-6(6) ClL
	0 to −2.25′			0	2	3	10	31	23	31	24.7	9.2	11.3	10.0	3.2			A-4(5) Cl*
21-N	0 to −0.5′		0	4	13	9	23	42	5	4	NP	NP						A-2-4(0) S†
	0 to −1.0′	0	2	6	14	7	19	45	3	4	13.9	NP						A-3(0) S*†
22-N	0 to −0.5′			0	13	9	23	44	7	4	NP	NP						A-2-4(0) S†
	0 to −1.0′	3	2	4	9	9	24	39	7	3	13.5	NP						A-1-b S*†
23-N	0 to −0.5′			0	4	13	15	24	30	14	7.4	9.6	14.6	21.0	6.1			A-4(2) SL
	0 to −0.5′			0	3	7	17	33	24	16	24.7	7.9	13.5	12.1	3.9			A-4(2) SL*
	−0.5′ to −1.5′		0	1	5	7	18	28	26	15	23.1	5.7	14.1	10.2	3.2			A-4(2) SL*
	−1.5′ to −2.0′		0	3	10	14	20	16	22	15	29.9	12.8	12.4	21.9				A-6(2) SL*
24-N	0 to −0.5′			0	1	5	6	19	42	27	40.2	19.4	15.3	28.4	8.0			A-6(11) ClL†
	0 to −0.5′		0	1	3	7	31	22	23	13	24.4	4.9	7.2	28.3	8.1			A-4(1) SL*
	−0.5′ to −1.5′			0	1	3	17	24	35	20	29.3	8.2	12.5	25.0	7.3			A-4(5) L or ClL*
	−1.5′ to −2.5′			0	1	1	6	20	43	29	38.7	16.0	18.6	19.9	6.0			A-6(10) ClL*
25-N	0 to −0.5′				0	4	13	24	36	23	27.5	9.8	14.7	22.9	6.6			A-4(5) ClL†
	−0.5′ to −1.0′			0	1	1	7	22	44	25	29.2	10.1	16.4	20.8	6.0			A-4(7) ClL†
	0 to −0.4′	0	3	1	6	9	40	19	14	8	16.0	1.5	13.7	2.6	1.0			A-2-4(0) S or SL*
	−0.4′ to −1.0′		0	1	1	1	11	28	39	19	22.3	3.3	14.7	10.9	3.6			A-4(5) L*
	−1.0′ to −1.5′				0	2	8	21	41	28	32.7	8.0	15.8	20.0	6.0			A-4(7) ClL*
	−1.5′ to −2.5′			0	1	4	4	16	40	35	44.7	24.3	10.1	50.6	12.7			A-7-6(15) Cl*

* Samples taken in Spring of 1954. All others taken in Fall of 1953.
† Samples taken from subgrade at edge of pavement. All others taken from beneath pavement in center of lane.

TABLE VIII
SUMMARY OF TESTS OF BASE MATERIALS
Northern and Southern Circuits

Site No.	Thickness of Base	Location of Sample	Ret. 1"	Pass. 1" Ret. 3/4"	Pass. 3/4" Ret. 1/2"	Pass. 1/2" Ret. No. 4	Pass. No. 4 Ret. No. 10	Pass. No. 10 Ret. No. 40	Pass. No. 40 Ret. No. 200	Pass. No. 200	Liquid Limit	Plasticity Index	Max. Wet Density	Max. Dry Density	Optimum Moisture	
4-S	4½"	Center W. bound lane	2	6	13	28	15	15	7	14	15.1	0.4	146.7	136.6	7.3	
6-S	3"	Center W. bound lane	4	8	17	29	13	10	7	12			145.1	135.2	7.2	
2-N	4"	Center N. bound lane	3	6	5	22	20	25	7	12	17.1	1.4	147.3	136.8	7.6	
3-N	8"	Center N. bound lane	1	5	7	23	20	27	7	10	19.5	4.2	144.6	133.3	8.2	
	8"	Outside track N.b. lane	3	8	8	24	20	23	5	9	17.2	0.8	145.3	132.8	9.4	
4-N	2"	Outside track E.b. lane	12	16	13	17	10	9	13	10	13.5	NP	148	137	7.9	Base
	3"	Outside track E.b.	5	2	4	13	14	29	19	14	10.8	NP	146	135	7.8	Subbase

TABLE IX
CLIMATOLOGICAL DATA
From Report of U.S. Dept. of Commerce

Month	Division of State	Temperature		No. of Days			Precipitation			
		Ave.	Dep. from normal	Max. 32° or below	Min. 32° or below	Min. 0° or below	Ave.	Dep. from normal	Accum. 23.61* 27.42* 24.74* 25.22*	Accum. dep. −1.28* −0.01* −5.57* −2.22*
Sept. 1953	North	65.7	0.0	0	0	0	1.74	−1.48	25.35	−2.76
	Central	67.1	0.1	0	1	0	1.11	−2.30	28.53	−2.31
	South	69.8	0.3	0	2	0	0.67	−2.55	25.41	−8.12
	State	67.4	0.1				1.20	−2.08	26.42	−4.30
Oct. 1953	North	57.3	3.8	0	0–7	0	1.31	−1.39	26.66	−4.15
	Central	57.8	2.7	0	0–9	0	1.21	−1.53	29.74	−3.84
	South	59.7	2.5	0	0–7	0	1.42	−1.46	26.83	−9.58
	State	58.2	3.0				1.31	−1.46	27.73	−5.76
Nov. 1953	North	43.2	3.0	0–4	7–20	0	1.34	−1.44	28.00	−5.59
	Central	43.6	1.5	0–4	10–26	0	1.53	−1.47	31.27	−5.31
	South	44.9	0.2	0	7–24	0	1.48	−1.83	28.31	−11.41
	State	43.9	1.7				1.45	−1.57	29.18	−7.33
Dec. 1953	North	32.2	3.0	3–9	21–28	0–5	1.44	−0.88	29.44	−6.47
	Central	33.1	1.7	3–7	21–28	0–3	2.23	−0.41	33.50	−5.72
	South	34.9	−0.1	2–6	19–29	0–3	2.36	−0.91	30.67	−12.32
	State	33.3	1.6				1.99	−0.73	31.17	−8.06
Jan. 1954	North	28.1	2.3	6–18	26–31	0–4	1.98	−0.37	1.98	−0.37
	Central	31.0	2.6	5–10	23–29	0–4	3.15	0.24	3.15	0.24
	South	34.0	1.7	3–8	20–29	0–1	3.38	−0.47	3.38	−0.47
	State	30.9	2.2				2.80	−0.20	2.80	−0.20
Feb. 1954	North	37.0	9.4	1–6	16–25	0–1	2.69	0.70	4.67	0.33
	Central	39.8	9.4	0–3	14–23	0	2.32	0.03	5.47	0.27
	South	43.1	8.9	0–2	7–23	0	2.34	−0.65	5.72	−1.12
	State	39.8	9.2				2.46	0.06	5.26	− 0.14
Mar. 1954	North	35.2	−2.2	2–7	16–28	0	3.42	0.40	8.09	0.73
	Central	37.9	−2.6	1–4	18–26	0	2.59	−1.20	8.06	−0.93
	South	41.7	−2.4	0–3	12–24	0	1.90	−2.56	7.62	−3.68
	State	38.1	−2.4				2.67	−1.05	7.93	−1.19
Apr. 1954	North	53.8	5.2	0–1	3–10	0	4.50	1.23	12.59	1.96
	Central	57.2	6.1	0	3–7	0	3.38	−0.25	11.44	−1.18
	South	60.0	5.7	0	1–9	0	3.25	−0.68	10.87	−4.36
	State	56.9	5.7				3.74	0.15	11.67	−1.64
Ave. for 8 mo. period	North						18.42	−3.23		
	Central						17.52	−6.89		
	South						16.80	−11.11		
	State						17.62	−6.88		

* As of Aug. 31, 1953.