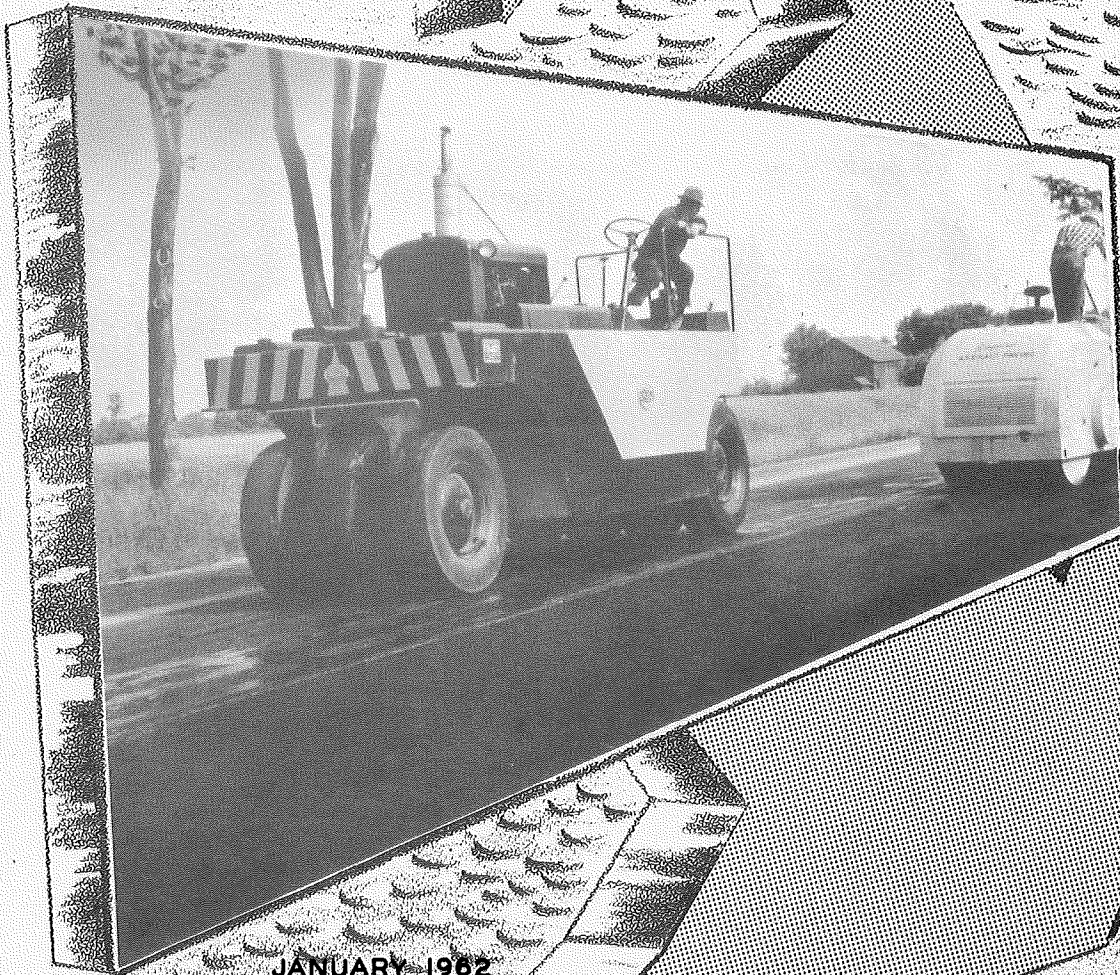


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# COMPARATIVE STUDIES of PNEUMATIC TIRE ROLLING



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COMPARATIVE STUDIES  
of  
PNEUMATIC TIRE ROLLING

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## INTRODUCTION

In recent years the subject of compaction of bituminous mixtures has become increasingly important to bituminous engineers. Besides the studies made on this subject in the Laboratories, the industries have contributed much towards the development of equipment, such as the pneumatic-tire roller, in order to obtain higher densities in the pavements themselves. The pneumatic-tire roller has in recent years been studied by several organizations in order to properly evaluate its performance and capabilities.

To this end the Michigan State Highway Department, for the past several years, has been conducting comparative studies of the compaction of bituminous concrete mixtures. The compaction obtained with pneumatic-tire rollers was compared with that obtained using standard steel rollers. This comparison was necessary to properly evaluate the pneumatic-tire rollers because past experience has, in general, shown that stable, durable, pavements of Michigan State Highway Department specification mixtures were obtained using standard steel rollers when proper rolling techniques were followed.

Random pavement samples obtained from the first few studies indicated that many variable factors were involved in the compaction process and some sort of control was necessary before a reliable evaluation of the results could be undertaken. For this reason standard construction procedures were modified on projects selected for comparative studies so that rolling operations, mixture deviations, and rolling temperatures were closely controlled or measured. The evolution of these controls led to two comprehensive comparative studies conducted in 1960 and 1961. It is these last two studies which form the basis for this report.

### Project Descriptions:

The 1960 comparative study was performed on a bituminous concrete resurfacing project. Construction consisted of a 1-1/4-inch wearing course placed over a 1-1/4-inch leveling course which was a recap of the existing bituminous surfaced portland cement concrete pavement. At the time of construction this was widened an extra foot on each side using a bituminous binder course material. This project was constructed from September 14 to October 28, 1960. The original concrete pavement was constructed in 1927 followed by a bituminous concrete resurfacing performed in 1943.

The 1961 comparative study was also performed on a bituminous concrete resurfacing project. Construction consisted of a 1-1/4-inch wearing course placed over a 2-inch binder course which was a recap of the existing portland

cement concrete pavement. This was widened an extra two feet on one side at the time of construction using portland cement concrete base course. This project was constructed from June 19 to July 25, 1961. The southern 8.2 miles of the existing concrete pavement was constructed in 1933 and the northern 4.0 miles in 1938.

Table I shows the typical mixture analyses and physical properties of Michigan State Highway Department 4.12 specification bituminous concrete mixtures similar to those used on both of the above projects.

#### Rolling Procedures:

The original intent in these studies was to control rolling operations within certain temperature ranges. Due to the temperature variations experienced plus the time required for rolling it was found that such a restriction would interfere considerably with normal construction procedures. Thus rolling operations were started as soon as a test area was paved with the hope that the temperatures recorded could be evaluated later.

Tandem axle steel-wheel rollers were used for breakdown rolling and finish rolling. Various types of pneumatic-tire rollers and standard tandem axle steel-wheel rollers were used on the various test sections.

Breakdown rolling began as soon as the paving operations were completed in a test section. As soon as the breakdown rolling was completed, test rolling commenced, and immediately following test rolling the finish rolling was started. Rolling was completed section by section so coring operations could commence as soon as possible.

The breakdown and finish rollers each made only one pass in a given test area except for a one pass 6-inch stripe rolled to "pinch" the centerline joint by the breakdown roller. (One pass is defined as a trip forward and back). Thus the breakdown and finish rolling was a constant compactive effort expended on all test areas, and the only variable due to rolling was the variable pass pattern by the test rollers on the individual sections. The variable pass pattern by each test roller combination was controlled so that results obtained could be compared between the test areas.

The number of passes used on each test section is shown in the tables and graphs shown later in this report in the discussion of the results.

#### Temperature Observations:

Initial studies utilized hand thermometers to determine pavement temperatures. This method was found to be impractical for two reasons: (a) It became impossible to insert the thermometers into the mat after the second or

Table I. Typical Mixture Analyses and Properties of MSHD  
Type 4.12 Specification Bituminous Concrete

Sieve Size	Binder	Leveling	Wearing
	Accumulative Percent Passing		
1-1/4-inch	100		
3/4-inch	70		
5/8-inch		100	100
1/2-inch		99	99
3/8-inch	32	84	88
No. 4	28	46	64
No. 10	26	27	43
No. 40	21	11	19
No. 80	7	3	9
No. 200	1.6	1.8	5.0
Bitumen, %	4.5	5.0	5.9
<u>Test Results of Marshall Compacted Specimens</u>			
Air Voids, %	5.5	4.3	4.8
Voids filled W/Bit., %	65	73	74
Voids in Mineral Agg., %	15.8	15.6	18.5
Stability (lbs.)	1850	2040	2510
Flow, (0.01 in.)	12	11	8
Unit Weight (lbs./cu. ft.)	154.4	153.1	151.9

third roller pass, and (b) The time required to determine the temperatures interfered with rolling operations.

In 1960 the Michigan State Highway Department acquired a Bristol Portable Potentiometric Test Set Model 98A accurate to within one-third of a degree fahrenheit with which was used a 28-point rotary selector switch. Figure 1 shows a photograph of each of these units in operation on one of the above projects. These were utilized with 24 gauge iron-constantan duplex fibre glass insulated thermocouple wire and 16 gauge weatherproof iron-constantan duplex thermocouple extension wire to continuously measure pavement mat temperatures.

The thermocouple wire was laid on the roadway to be paved and secured in place with metal staples. A typical test area showing the locations of thermocouples in each test section and the relative position of the test set and selector switch is shown in Figure 2. A thin layer of mix from the paver hopper was placed on each side of the wire where the paver crawlers would cross to prevent damage to the thermocouple wire. Initially the thermocouple junction was simply bent up to protrude approximately half-way into the mat as it was laid. However, it was found that the mix was flattening the junction down against the roadway resulting in low temperature readings. This was corrected by using chair leg glides (metal buttons with prongs) or #4 box nails to support the junction and hold it in position. Figure 3 shows a typical installation of the thermocouple wire using chair leg glides for supporting the ends of the wires.

Temperature measurements were made at two points in each test area far enough from each end to allow rollers to maneuver and change direction. The interval between readings for a particular thermocouple increased as the number of thermocouples registering increased. This was due to the time required for switching or selecting and operating the potentiometric test set. In general one reading could be made and recorded approximately every 30 seconds.

Figure 4 shows the pavement cooling curves of bituminous concrete wearing course mixtures for various ranges of air temperatures obtained from the 1960 and 1961 data. These curves were plotted from data obtained by continuously measuring the temperatures indicated by the thermocouples placed in each test section on both comparative studies. When this temperature data was analyzed as shown in Table II, it was noted that there was a marked similarity between results for days which had common average ambient air temperatures. It is noted that those days with higher average temperatures had lower initial pavement temperatures. For years it has been a common practice in Michigan to increase mix temperatures during late fall construction or when average daily temperatures are lower.



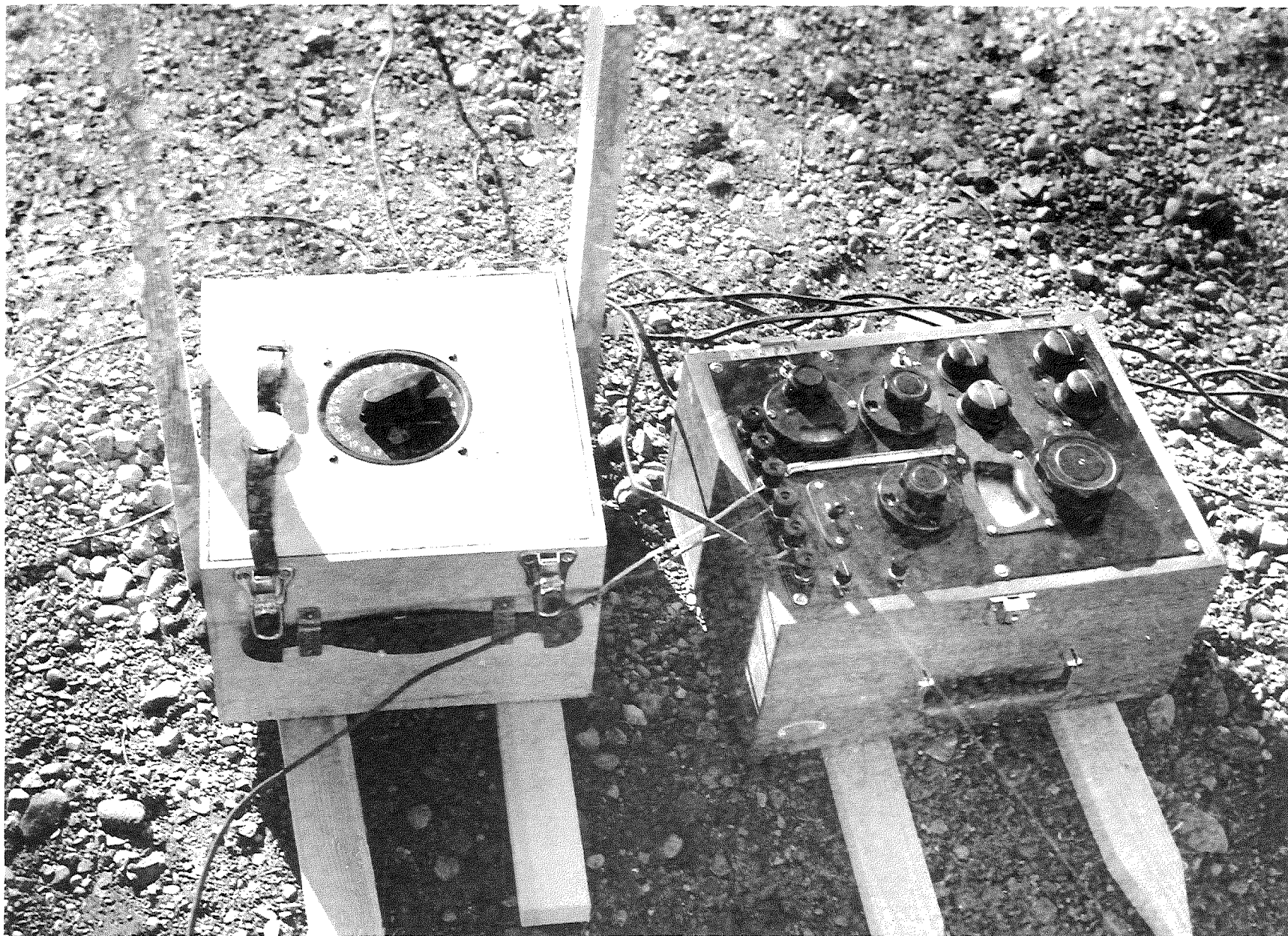


Figure 1. View of temperature indicating potentiometric test set and rotary selector switch used to determine pavement temperatures.

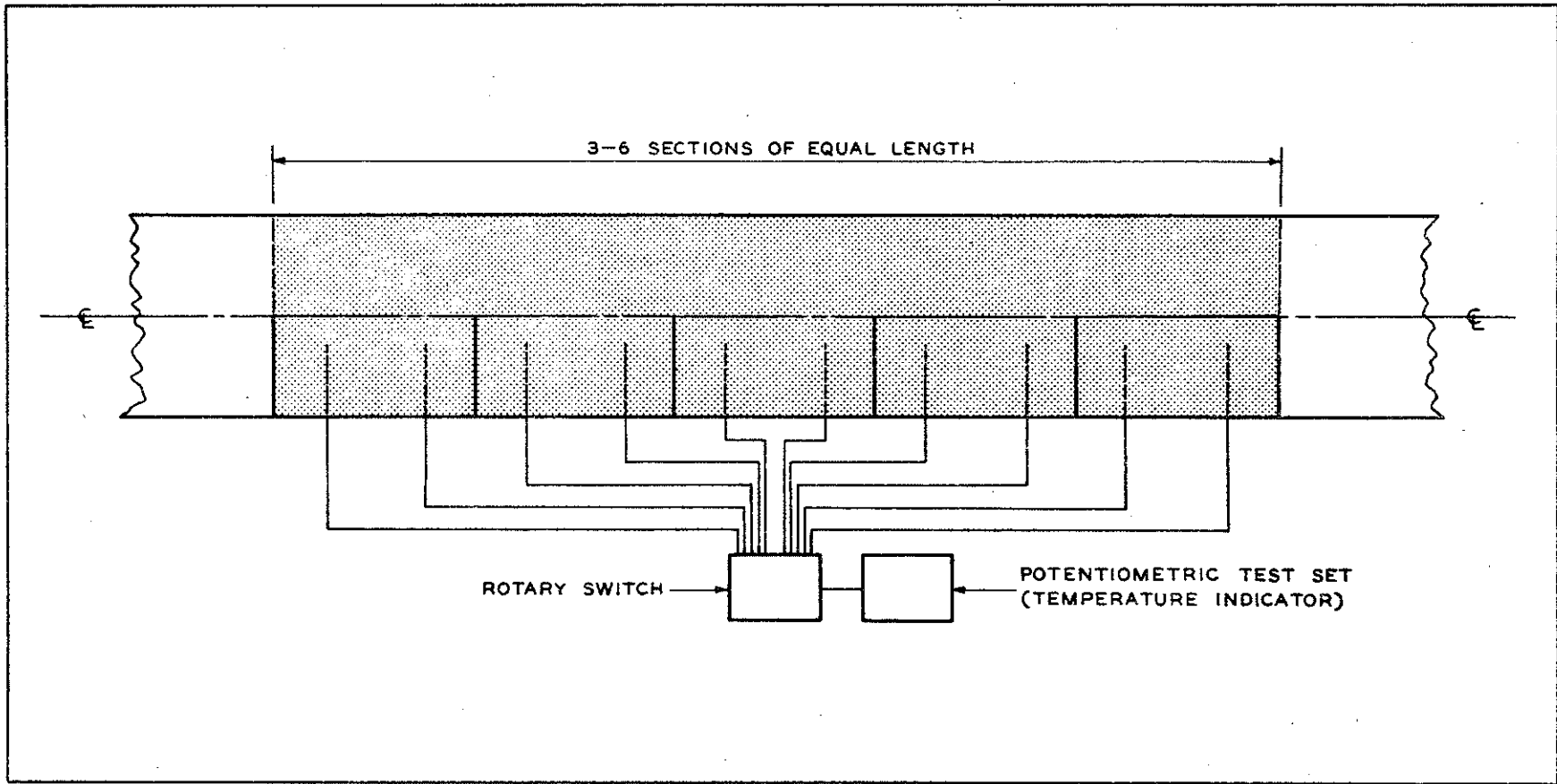


Figure 2. Typical pavement test area showing thermocouple locations, extension wire, rotary switch, and test set.





Figure 3. Showing a typical installation of the thermocouple wires using chair leg glides for supporting the ends of the wires.

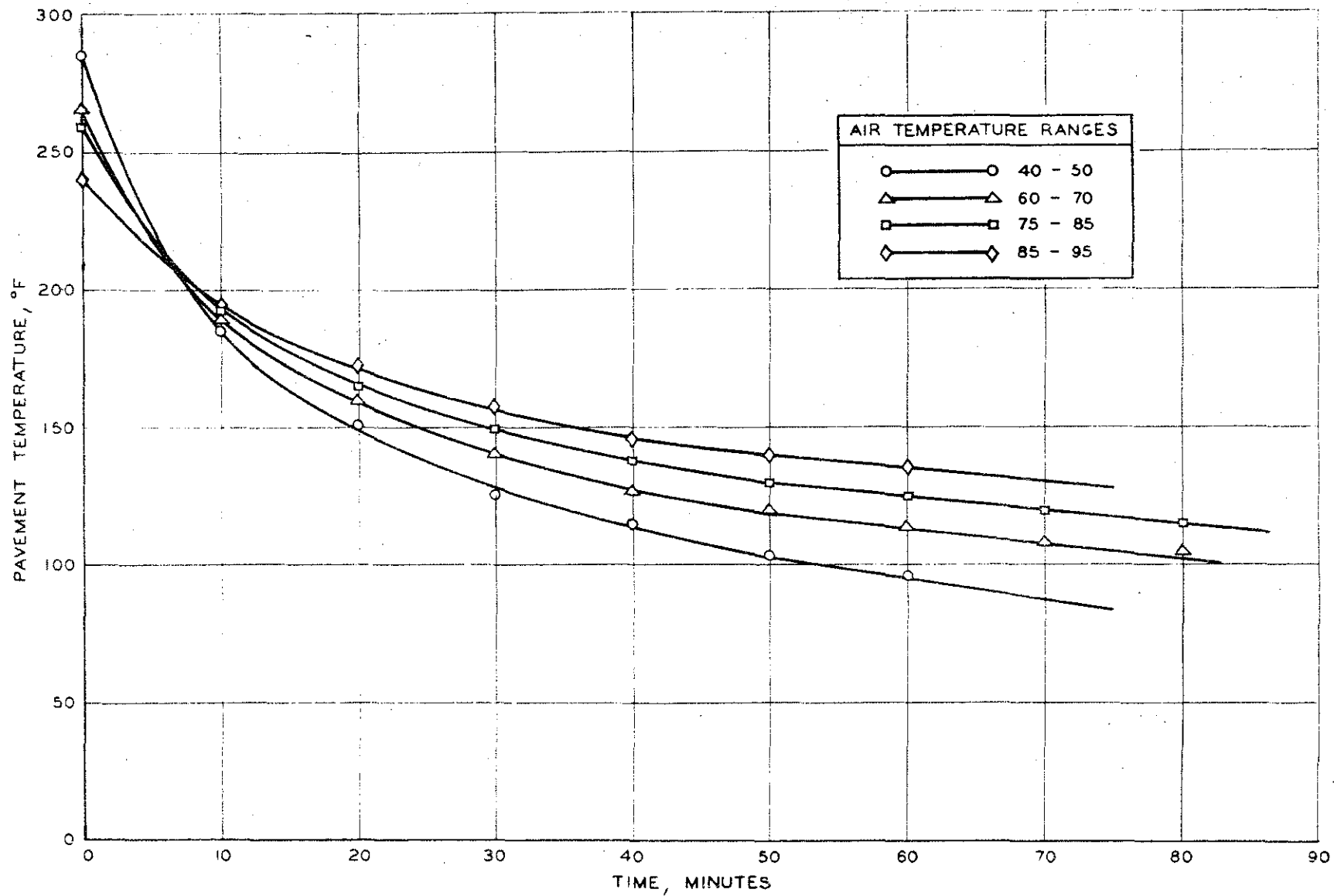


Figure 4. Pavement cooling curves of bituminous concrete wearing course mixture for various ranges of air temperatures.

Table II. Pavement Cooling Data of Bituminous Concrete Wearing Course Mixture for Various Ranges of Air Temperatures

Air Temp. Range	40-50	60-70	75-85	85-95
Time (Min.)	Temperature (°F.)			
0	285	266	259	240
1	265	251	244	238
2	250	238	235	226
3	248	225	232	222
4	234	222	217	215
5	219	214	215	216
6	217	214	205	210
7	208	204	207	202
8	197	200	200	205
9	200	195	192	196
10	185	190	192	194
11	186	187	192	189
12	177	183	186	188
13	176	180	185	192
14	173	177	184	180
15	169	174	178	182
16	160	168	178	179
17	162	169	171	177
18	153	165	175	179
19	157	164	172	175
20	151	160	165	172
21	150	154	164	168
22	138	158	167	169
23	145	153	162	164
24	141	155	160	166
25	140	145	159	160
26	139	148	157	165
27	131	142	157	158
28	134	143	155	161
29	134	144	148	160
30	125	139	150	157
35	-	135	147	-
40	115	127	138	145
45	109	122	135	-
50	103	120	131	140
55	100	117	128	-
60	96	113	125	135
65	-	112	122	-
70	-	108	119	-
75	-	106	118	-
80	-	105	115	-

The rate of change of pavement temperature with time is less for those days with higher average ambient air temperatures. Consequently, with a slower cooling rate, higher pavement temperatures are maintained for longer periods of time, and additional compactive effort can be more effectively utilized.

#### Sampling Procedures:

A total of 844 pavement core samples have been taken from the 1960 comparative study project and 768 from the 1961 project. Core samples were taken as close to the thermocouple locations in each test section as was possible. As soon as rolling operations were completed on a test section, the pavement areas to be cored were frozen using slab dry ice and sampling operations began immediately. No traffic was allowed on the test sections until the test rolling and coring operations were completed.

On the 1960 project, core samples were taken from six locations for each test area. (1) Three cores were taken from the right wheel track, (2) three cores were taken from approximately the center of the lane, (3) and three cores were taken along the longitudinal joint. This was done at each thermocouple location, and since there were two thermocouple locations for each test section, this made a total of 18 core samples from each test section.

On the 1961 project three core samples were taken from the right wheel track at each thermocouple location in each test section, and four core samples were taken from approximately the center of the lane at each thermocouple location in those sections rolled with pneumatic-tire rollers.

Samples of mix were taken during paving operations on each section for Marshall test specimens and also for the maximum theoretical specific gravity determinations. The Marshall specimen samples were compacted and tested in the field by the Mobile Bituminous Laboratory. Additional samples of mix were submitted to the Testing Laboratory in Ann Arbor where check Marshall specimens were compacted and tested.

#### Testing Procedures:

For control purposes, 80 maximum theoretical specific gravity determinations were run and 112 Marshall specimens compacted for the 1960 project. For the 1961 project, 55 maximum theoretical specific gravity determinations were run and 132 Marshall specimens compacted.

Maximum theoretical specific gravity determinations were made by the Michigan Method.<sup>1</sup> Marshall specimens were compacted using 50 blows hand compaction in the field and 40 blow mechanical compaction in the laboratory. Marshall compaction temperature was maintained at 275°F. by heating in an oven if necessary.

Core samples and Marshall specimens were allowed to dry before actual specific gravity determinations were run. Actual specific gravity determinations were made by weighing the samples and specimens in air first, then in water in accordance with ASTM Method D 1188-56 except that no paraffin coating was used.

Originally it was intended that rolling and coring would be done one day and testing the next. However, on the 1960 project extenuating circumstances resulted in rolling and coring operations being conducted several days in a row. Consequently, testing operations fell behind and gradually a backlog of samples and specimens developed and the core tests delayed until laboratory time was available after completion of the test sections.

On the 1961 project, additional personnel plus a new coring unit made it possible to core and test the specimens the same day. This schedule was rigorously adhered to. The only tests performed at a later date were Marshall stability, and flow determinations and the maximum theoretical specific gravities. These were done in the Ann Arbor Laboratory on samples submitted from the field.

Core samples were sawed into layers representing binder, leveling, or wearing course as soon as they were obtained. All samples were then allowed to air dry for four hours after the time of sawing before the actual specific gravity determinations were made. The same interval was applied to the Marshall specimens compacted in the field.

#### Compaction Variables:

The compaction results obtained from previous studies indicated that density is a function of many variables. Some of the more apparent variables are:

- (a) Type of Mix
- (b) Temperature of Mix
- (c) Compactive Effort

The type of mix will affect the density obtainable, for any given compactive effort, due to its' inherent properties of aggregate interlock, cohesion, and viscous resistance. The properties of aggregate interlock and cohesion should remain fairly uniform with adequate control of the gradation of the aggregate and rigid control of the proportioning of the materials for a given type mixture. However, the viscous resistance factor will vary with temperature depending on the temperature-viscosity relationship for the type bitumen used.

The temperature of the mix will affect the density obtainable for a given type mix. In recent years considerable importance has been given to this subject by many bituminous engineers and was well pointed out in the 1959 Conference Discussions of the Highway Research Board.<sup>2</sup> The temperature of the mix relative to the ambient air temperature will affect the rate of cooling and consequently limit the time during which any given compactive effort can be effectively utilized. The temperature of the mix will affect the viscous resistance as stated previously, and will also affect the hardening or aging properties of the bitumen used.

The compactive effort, when considered as a load per unit area, will affect the density obtainable for a given type mix and a given compaction temperature. By increasing the load per unit area an increasing density should occur, up to some maximum value. To attain this maximum condition some repositioning and realignment of the aggregate particles is required but as is pointed out by Nevitt<sup>3</sup> this may adversely affect stability. Past experience in Michigan has shown that with proper steel-wheel rolling techniques and control of mix production and construction procedures, pavement densities are achieved which produce stable, durable bituminous pavements.

With these variables defined it was necessary to evaluate pneumatic-tire rolling results against steel-wheel rolling results on some common datum so that a comparison could be made.

The original intent on these projects was to make a comparison of the densification resulting from various compactive efforts utilizing the air void results of the samples tested from the finished pavement. The difference in mixtures (type of aggregates, mix proportions, type asphalt, etc.) between the two projects resulted in different Marshall test results which, when expressed in terms of per cent air voids, amplified the differences resulting from compaction variables making it difficult to observe any correlation of the data.

However, when these same test results were expressed as a per cent of Marshall density, better correlation could be observed. For this reason, pavement densities reported as a per cent of Marshall density were used in the comparative analysis of the results obtained on the 1960 and 1961 roller studies.

#### Discussion of Results:

Figure 5 shows the compaction of the wearing course obtained at the various number of passes that each test roller made for the 1960 project. The tire pressure for the 12 ton pneumatic-tire roller was maintained at



60 psi, and for the 22 ton pneumatic-tire roller the tire pressure was maintained at 90 psi. Rather than plotting a large number of points, the test results were averaged for each individual number of passes tested and these average results were then plotted.

Examination of the curves on Figure 5 shows that there is an increase in density up to a certain number of passes followed by a decrease and again an increase with increased number of passes. At first this variation was thought to be due to experimental error, however, as more data was obtained from the 1961 experimental rolling project, as shown in Figure 6, the additional results indicated a possible cyclic pattern that develops for the pavement density versus compactive effort. This increase in density to some peak value then decrease has been experienced on all projects where the number of passes have been varied. The cyclic appearing pattern of density due to varying the number of passes is different for different mixes of the same type and varies for different types of rollers used.

A possible explanation for this phenomena is the fact that when compactive effort is given to a bituminous mixture, it eventually reaches an initial maximum densification. However, if the compactive effort is continued, while the bitumen is still in a semi-fluid state, the maximum density structure may become disturbed resulting in lower density. If compactive effort is continued further, even under traffic conditions, this densification may again increase and approach a new maximum. It is conceivable that if the temperature of the bitumen could be maintained while further compactive effort was given, the density may again decrease somewhat followed by further reorganization of particles and with continued compaction may reach a new maximum density and this phenomena repeated.

It has been observed during the construction of oil type bituminous mixtures that rolling is usually kept to a minimum while the mixture is still hot. During warm weather, one pass of the roller is made shortly after the mat is placed and additional rolling is done the next day after the pavement has cooled somewhat.

This data illustrates that bituminous mixtures can be over-rolled especially if the asphalt in the mixture remains in a semi-fluid condition at the time of rolling. However, past experience with steel-wheel rollers has not indicated that over-rolling is a problem, if anything, the problem has been from insufficient rolling or not rolling soon enough while the pavement is still hot. Once a hot bituminous mixture is placed on the road it cools down rapidly, as illustrated in Figure 4 shown previously in this report, and as a result the over-rolling phenomena is seldom realized.

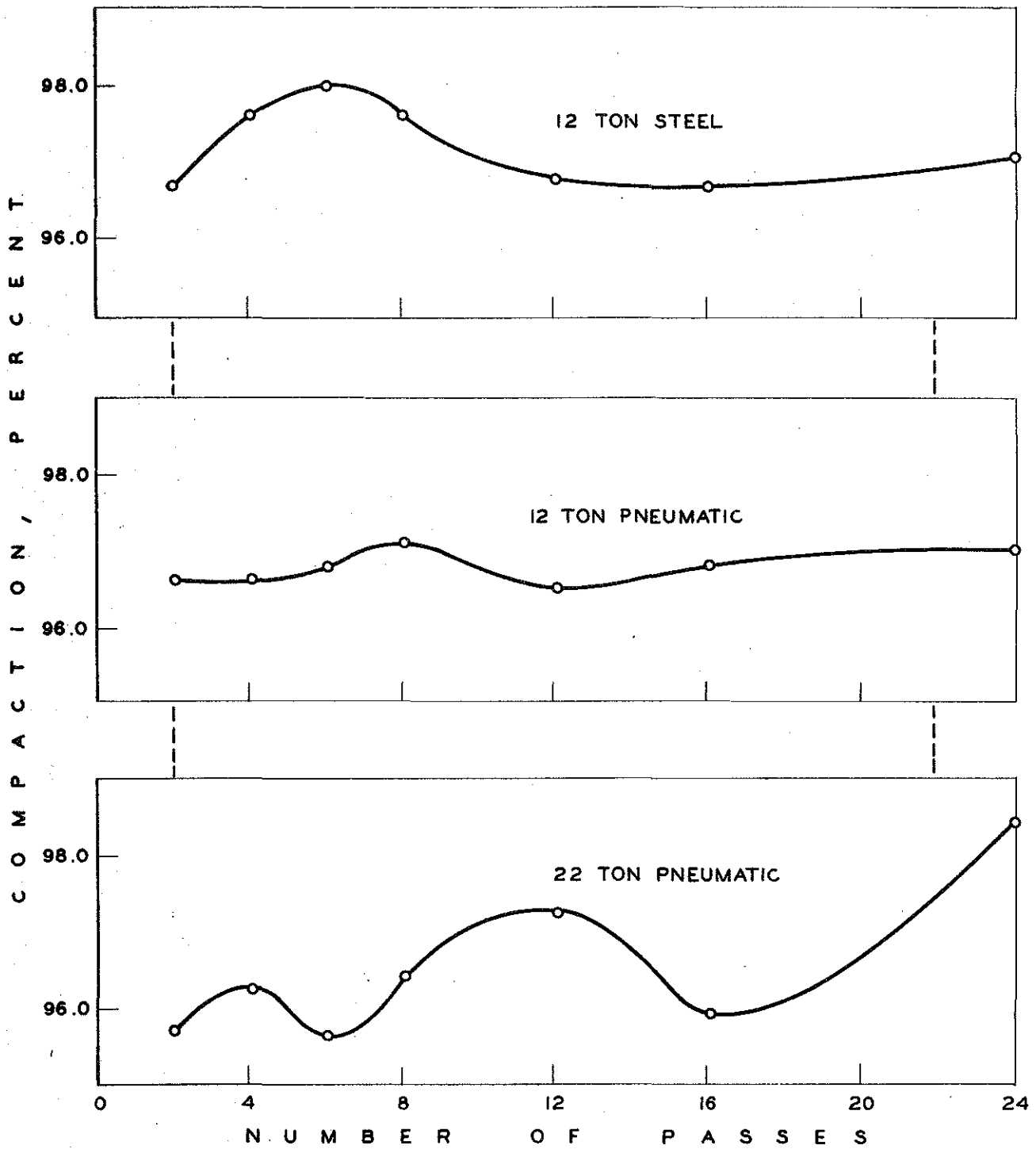


Figure 5. Curves showing compaction obtained at various number of passes for each test roller used on 1960 project with compaction expressed as a percent of Marshall density.

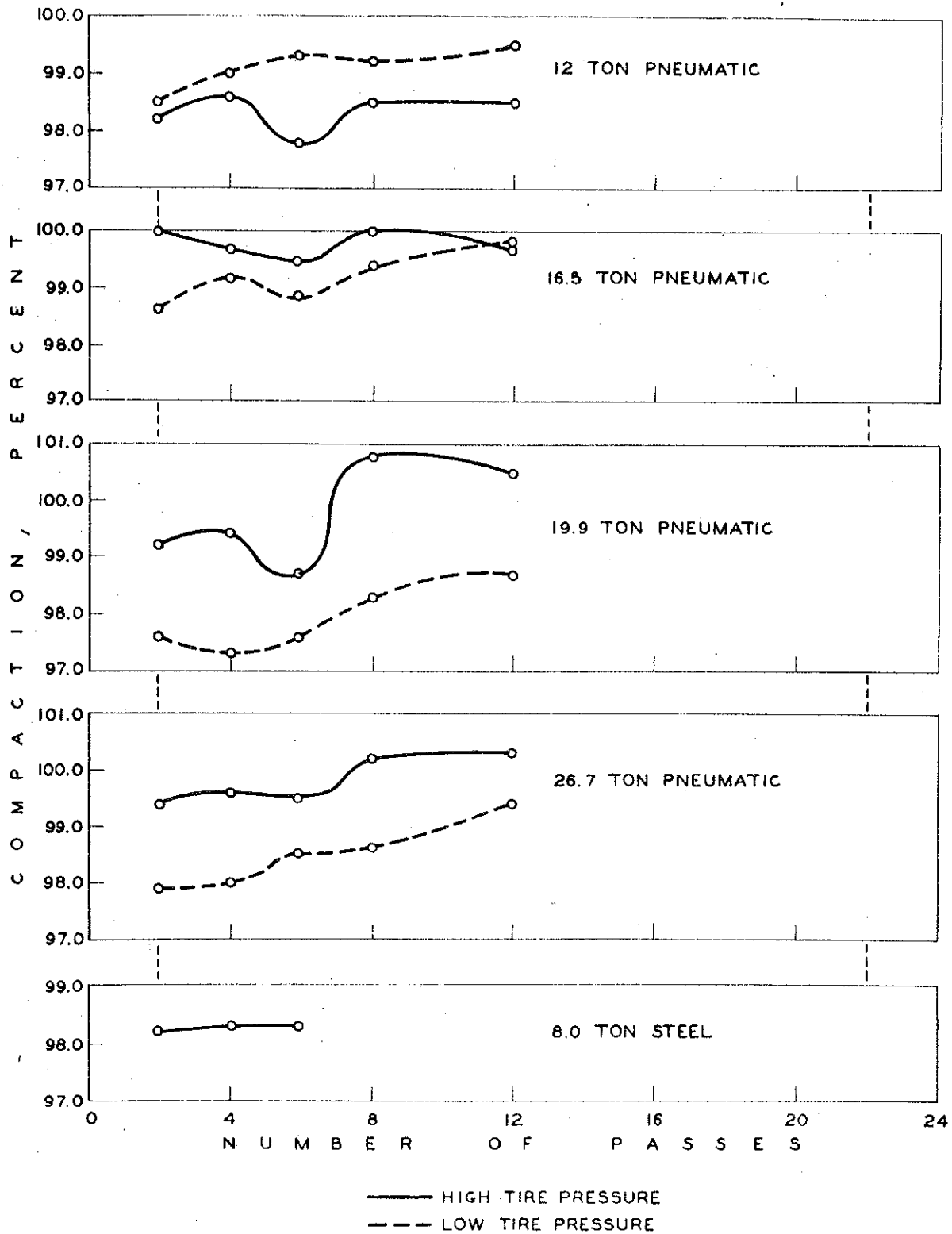


Figure 6. Curves showing compaction obtained at various number of passes for each test roller used on 1961 project with compaction expressed as a percent of Marshall density.

Bituminous pavements laid several years ago may continue to densify in a decreasing rate from the heavy traffic, particularly during hot weather. This is illustrated in the Test Road Report<sup>4</sup> which shows the progressive densification after four years of traffic.

This year cores were obtained from last years (1960) experimental roller project on which density determinations were made (see Table A - Appendix). Figure 7 shows the changes in density of the wearing course which occurred on this project after one year of traffic. Of interest is the fact that in this particular study less change in density occurred in the 8 pass sections for all types of rollers even though this section was not the peak density value realized in 1960 for two of the rollers tested.

Table III lists the compaction of the wearing course obtained at the various number of passes each test roller made for the 1961 project. These results in most cases indicate an increasing density to some peak value and then a decrease again. There does not appear to be any correlation between type of roller, total weight, wheel load or tire size and the compaction obtained. The compaction results are higher percentage-wise than the 1960 results shown in Table IV, which supports the belief that better compaction is realized during warm weather since the average daily ambient air temperature was approximately 30 degrees higher.

In spite of the problems that are sometimes found with poorly compacted centerline joints, the analysis of core samples taken along the centerline or longitudinal joint on the 1960 project, as listed in Table V, showed good compaction using either the steel-wheeled roller or pneumatic-tire roller. This indicates that good compaction can be achieved with either type of roller at the longitudinal joint if rolling operations are properly maintained.

Random core samples from the 1960 project were submitted to the laboratory for checks on the gradation of the extracted aggregate. These results did not show that any significant degradation of aggregate had occurred on this project regardless of the type of roller used or the number of passes rolled (see Table B - Appendix).

In attempting to quantitatively analyze the data from these comparative studies it was found that too much variation existed to warrant any sound conclusions. An attempt is being made to establish some empirical relationships and by utilizing the Michigan State Highway Department electronic computing facilities and matrix solution programs, determine coefficients or factors for some of the variables in order to eliminate their effect. This is in the process at the present time and shows some promise.

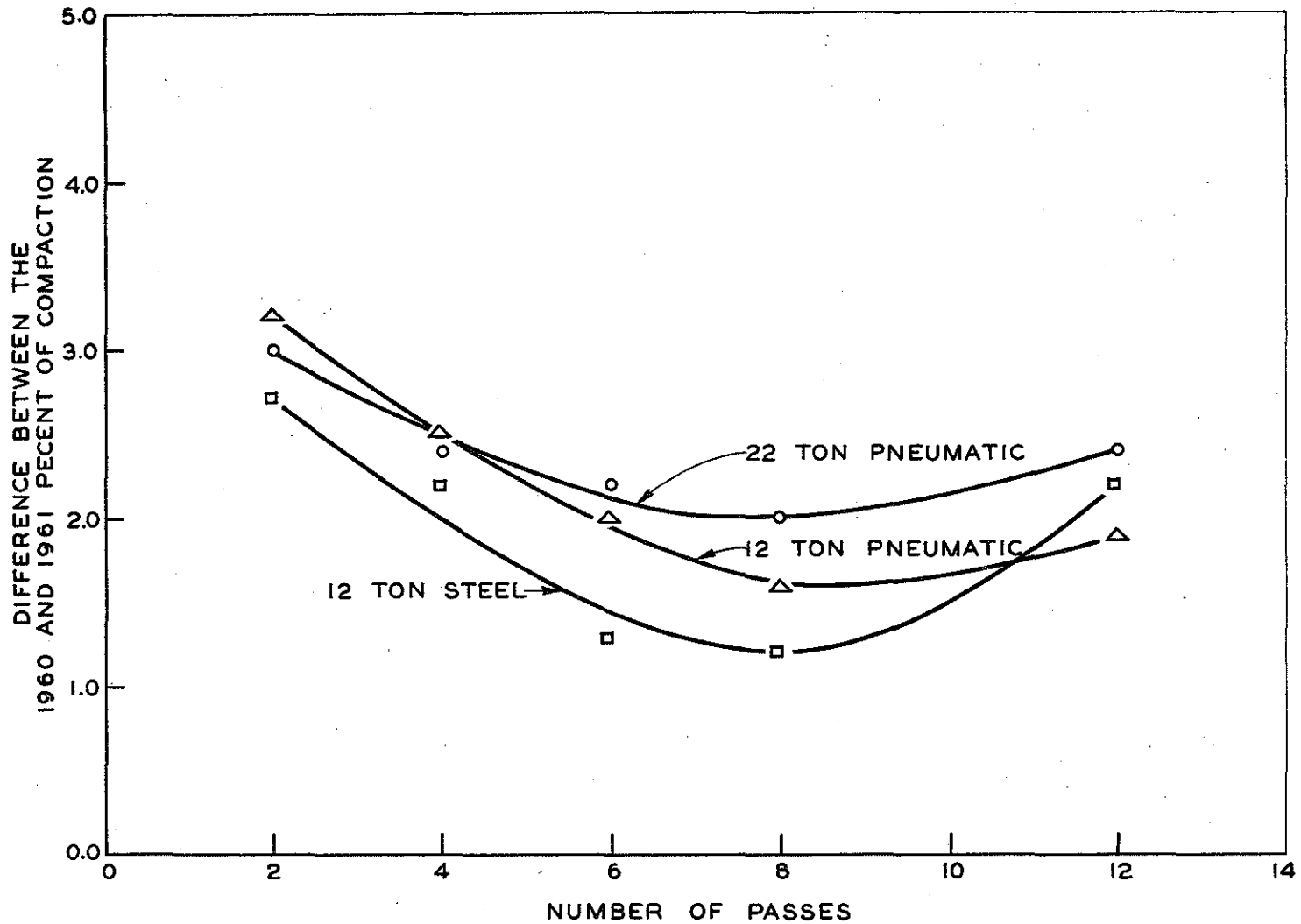


Figure 7. Curves showing increased densification due to one year's traffic on various test sections showing difference percent between the 1961 percent of compaction and the 1960 percent of compaction.

Table III. Compaction of Bituminous Concrete Pavement Cores (Wearing Course)  
 Obtained at Various Number of Passes  
 for Each Test Roller Used on 1961 Project.

Type Test Roller	Total Weight (Tons)	Ground Pressure (psi)	Number of Passes				
			2	4	6	8	12
Pneumatic	12.0	60-64	98.5	99.0	99.3	99.2	99.5
Pneumatic	12.0	84-89	98.2	98.6	97.8	98.5	98.5
Pneumatic	16.5	74-79	98.6	99.2	98.9	99.4	99.8
Pneumatic	16.5	79-84	100.0	99.7	99.5	100.0	99.7
Pneumatic	19.9	70-75	97.6	97.3	97.6	98.3	98.7
Pneumatic	19.9	92-96	99.2	99.4	98.7	100.8	100.5
Pneumatic	26.7	79-81	97.9	98.0	98.5	98.6	99.4
Pneumatic	26.7	90-92	99.4	99.6	99.5	100.2	100.3
Pneumatic	28.7	96-99		99.2			
Steel	8.0	--	98.2	98.3	98.3		

Note:

1. Test rolling number of passes shown are in addition to one pass 10.2 ton breakdown and one pass 8.2 ton finish rolling.
2. Compaction expressed as a per cent of Marshall Density.



Table IV. Compaction of Bituminous Concrete Pavement Cores (Wearing Course)  
Obtained at Various Number of Passes  
for Each Test Roller Used on 1960 Project.

Type Test Roller	Total Weight (Tons)	Ground Pressure (psi)	Number of Passes						
			2	4	6	8	12	16	24
Pneumatic	22	87-91	95.7	96.2	95.6	96.4	97.2	95.9	98.4
Pneumatic	12	62-65	96.6	96.6	96.8	97.1	96.5	96.8	97.0
Steel	12	--	96.8	97.6	98.2	97.6	96.8	96.7	97.1
Pneumatic*	27	96-99	95.8	96.2	96.4	97.8	97.8		
Pneumatic*	27	83-85	94.7	95.3	95.6	96.1	97.1		

Table V. Compaction Along Longitudinal Joint of Bituminous Concrete  
Pavement Cores (Wearing Course) Obtained at Various Number  
of Passes for Each Test Roller Used on 1960 Project.

Type Test Roller	Total Weight (Tons)	Ground Pressure (psi)	Number of Passes				
			2	4	6	8	12
Pneumatic	22	87-91	97.4	97.3	96.6	96.3	98.6
Pneumatic	12	62-65	97.6	97.1	95.5	96.9	98.1
Steel	12	--	97.6	98.4	98.3	97.1	96.2
Pneumatic*	27	96-99	96.4	96.5	97.8		
Pneumatic*	27	83-85	98.4	95.2	96.4		

\*Short test areas with no temperature measurements made.

Note:

1. Test rolling number of passes shown are in addition to one pass 8.1 ton breakdown and one pass 8.2 ton finish rolling.
2. Compaction expressed as a per cent of Marshall Density.

The main variation affecting the results appears to be temperature. Although good correlation was obtained at each thermocouple location, the correlation of average results between adjacent thermocouples in the same test section were poor. Generally, higher average densities resulted from higher average rolling temperatures, however, these average rolling temperatures varied enough in the individual sections and between sections to substantially affect the density results.

In attempting to set up the empirical relationships mentioned above, another variation not previously recognized became evident. This variation is in tire pressures and wheel loads and their relation to the ground pressures exerted by the pneumatic-tire rollers.

Figures 8 and 9 show the ground pressures resulting from various wheel loads and tire inflation pressures for two manufacturers of compactor tires. Considerable difference is noted between the curves for each manufacturer which may be due to the difference in design and construction of these tires. Other roller manufacturers may have curves or data for their machines that differ from both of these curves even though their tires are the same size and type from one of the manufacturers shown above. At the higher inflation pressures these differences are great enough to warrant consideration in any evaluation. Perhaps the manufacturers of either the tires, or of pneumatic-tire rollers should get together to standardize these conversion charts.

The test rollers utilized on the 1961 project were weighed with both axles on the scales, then the front axle, and then the rear axle. Substantial variations generally were noted between the front and rear axle weights. When these axle weights were converted to wheel loads, an even greater variation was experienced since most pneumatic-tire rollers have an odd number of tires. These variations amounted to wheel load values as observed on this test project, which were 86.5% to 116.7% of the average wheel load values. Similar variations in loading have been noted with steel-wheel rollers. These variations in compression per lineal inch of roller width were found to vary between 75% to 125% of the average compression values.<sup>5</sup>

These percentage variations listed for both pneumatic and steel rollers are the maximum values experienced. The percentages vary depending on the roller manufacturer and on the amount of ballast added for individual rollers.

Tire pressures were found to increase as tires warmed up while rolling. Within the accuracy of the tire gauges used on these comparative studies, this increase was found to be approximately 5% over the

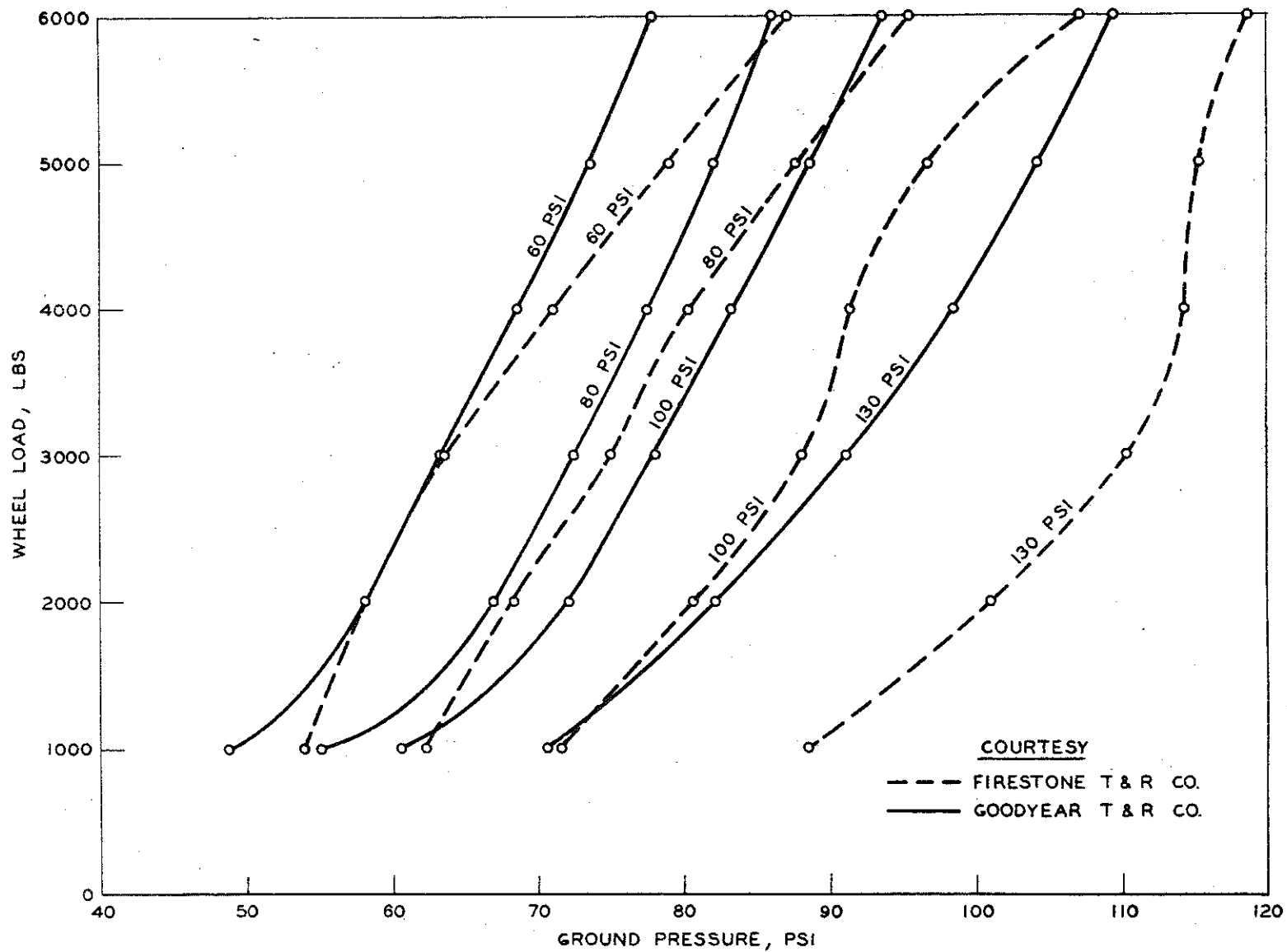


Figure 8. Ground pressure-vs-wheel load curves for 7:50-15 size, 10 ply rated and above compactor tires at various inflation pressures.

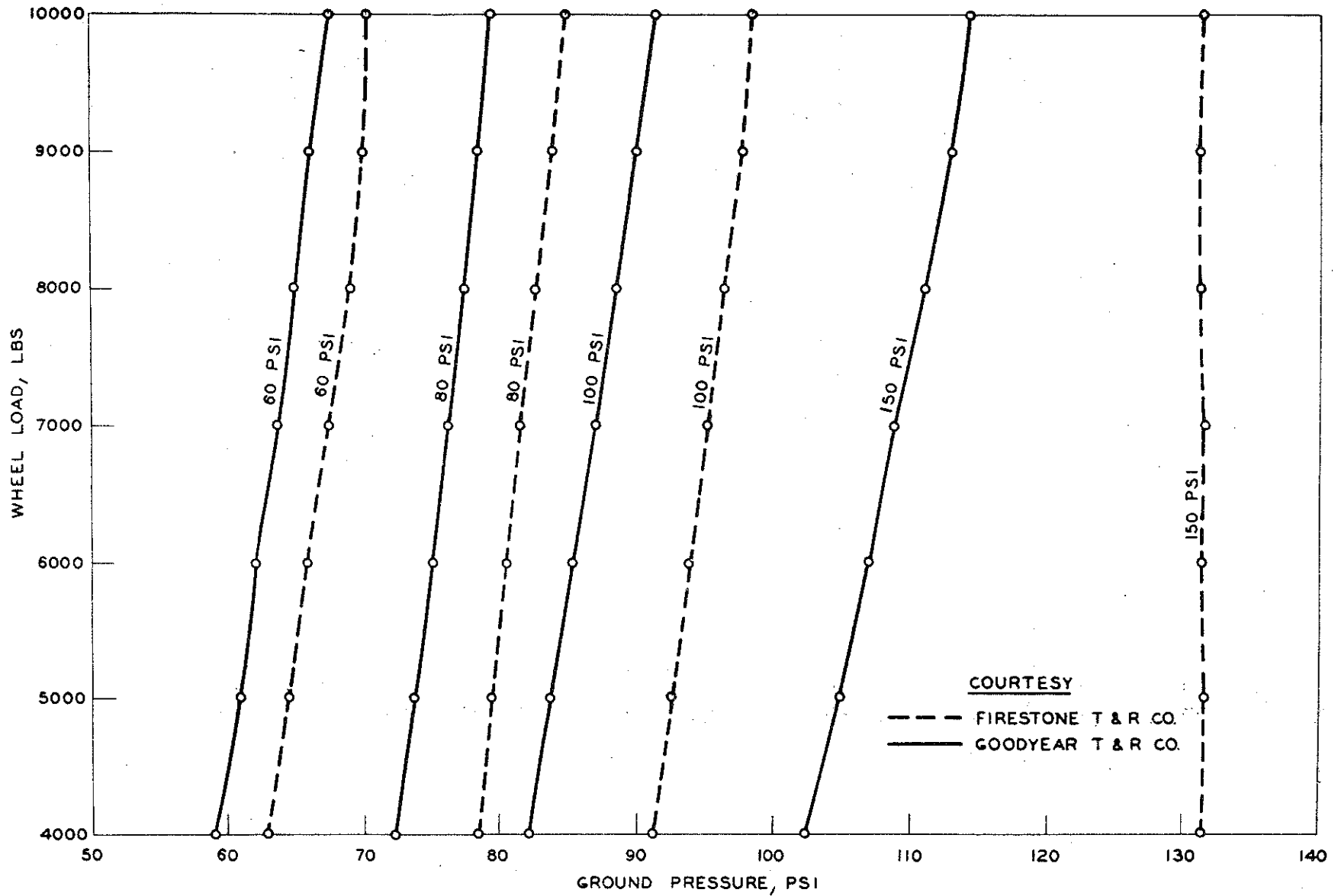


Figure 9. Ground pressure-vs-wheel load curves for 13:00-24 size, 26 ply rated compactor tires at various inflation pressures.

cold tire pressure for all types of pneumatic rollers and both types of tires. We have been advised that some manufacturers of pneumatic-tire rollers are installing equipment on their machines that would permit adjusting the tire pressures while the rollers are under actual rolling operations.

All the variations which have been cited in this report are factors to be considered in any proper evaluation of the results obtained. For this reason simple arithmetic averages of all results for particular conditions are reported with the assumption that these averages are at least an indication of trends.

#### Visual Results:

A visual result which has been prominent on all projects studied to date has been the tighter or more "closed" surface texture which results from pneumatic-tire rolling. Since no significant density increases have been found to result from pneumatic-tire rolling, this tighter surface texture may result from the flexibility or kneading action of the tires and appears to be only a skin or surface condition.

Another visual result was that ridging could be reduced somewhat by increasing the pneumatic rolling speed. There appears to be a difference of opinion between engineers as to the reason for this.

Profilometer studies were run on both projects in 1961 to check any deviations in roughness due to roller type. Since the terrain and topography are different between the projects, the roughness indexes obtained could not be compared but it was felt the relative differences in roughness between rollers utilized on one project might show something (see Table C - Appendix). Very little difference was evident between the average roughness for pneumatic rolled test areas and steel rolled test areas on each respective project. Also, little difference occurred between pneumatic and steel rolled areas compacted during normal construction operations. However, in general some increase in roughness was noted for the pneumatic warm-up areas where excessive number of passes were made. These warm-up areas were usually very short, thus it is difficult to compare the results against the longer test or normal construction areas with any degree of reliability. Of interest is the fact that the 1961 project pneumatic test areas rolled at high tire pressures generally showed a higher roughness index than those rolled at lower pressures. Conversely, the 1960 project low pressure areas showed higher roughness index than the high pressure areas after being subjected to traffic for one year. (see Table D - Appendix).

Figure 10 shows scrape marks produced by a straight edge rubbed across a lane rolled with pneumatic-tire rollers in which a steel-wheel roller was used for breakdown and finish rolling during normal construction operations. The broken line produced across the lane indicates that some ridges or high spots still remain in this area. Whether this condition exists throughout the project where pneumatic rollers were used or is simply a localized situation has not been determined. Shadow marks and a streaky pattern usually remain in those areas where high tire pressure pneumatic-tire rollers were used in these studies.

### Rolling Problems:

Several problems were experienced while rolling with pneumatic-tire rollers. Most of these problems can be eliminated by paying closer attention to rolling operations or exercising proper control. If these problems are allowed to develop, a rough unsightly surface would result.

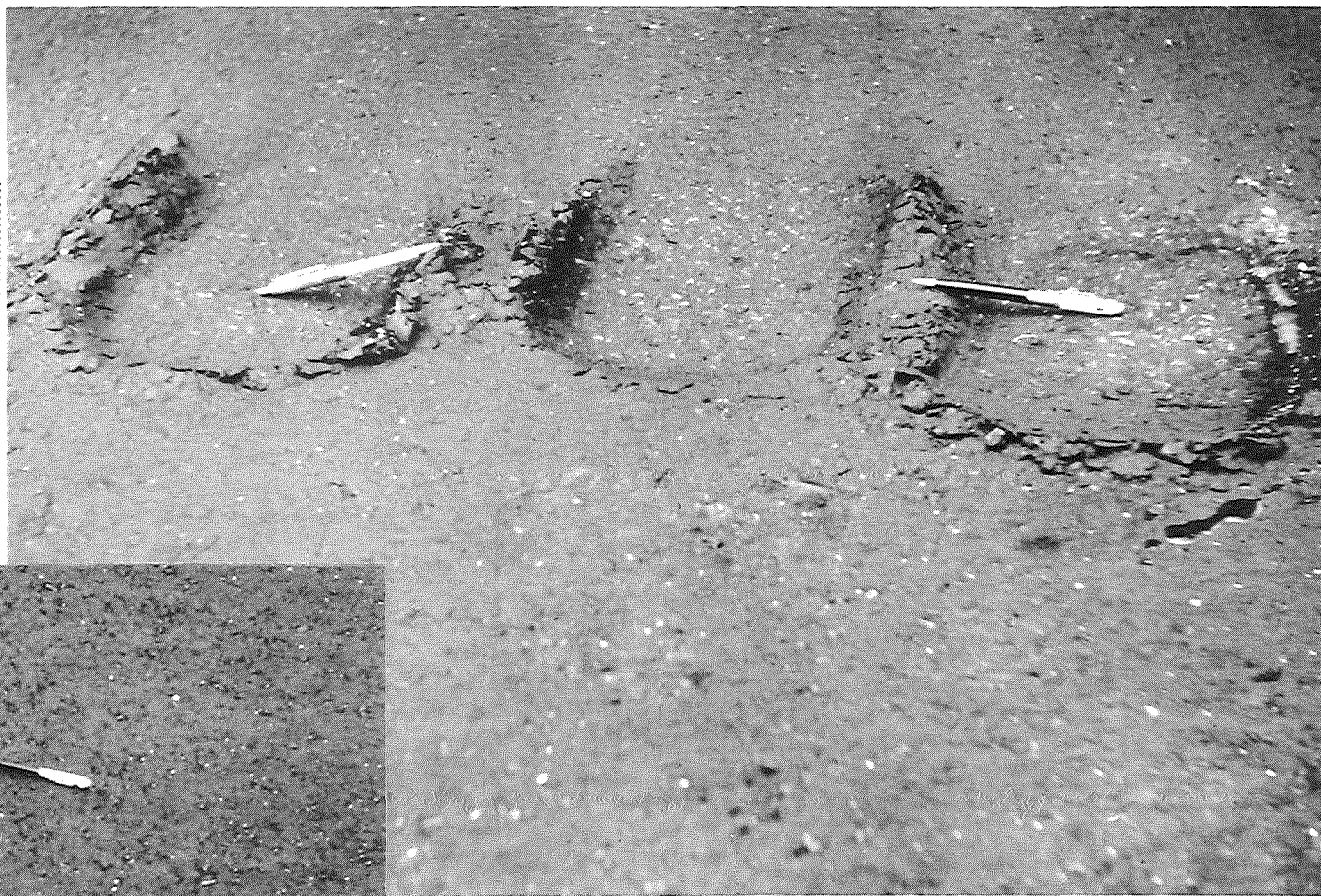
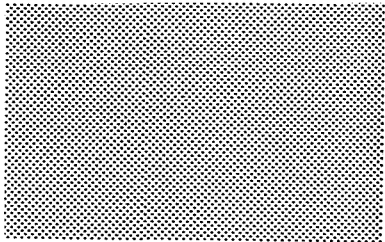
Figure 11 shows marks which are produced if the steering wheels are turned while the pneumatic roller is standing still. This may require considerable additional rolling to eliminate these scars. Figure 12 shows chatter or scuff marks which are produced when the pneumatic-tire roller starts too quickly. Figure 13 shows tire marks and ridges which develop during pneumatic-tire rolling and also show pick-up spots which develop if tires are not warmed up before pneumatic rolling operations begin.

The illustrations of these marks which are produced by the pneumatic-tire rollers show why steel-finish rollers are required in Michigan. If steel-finish rollers are utilized in time, while the mixture is still hot, most of these marks can be eliminated. The bridging action of steel rollers which comes into play on bumps or irregularities is ideally utilized for smoothing out the marks and ridges produced by the pneumatic-tire rollers.

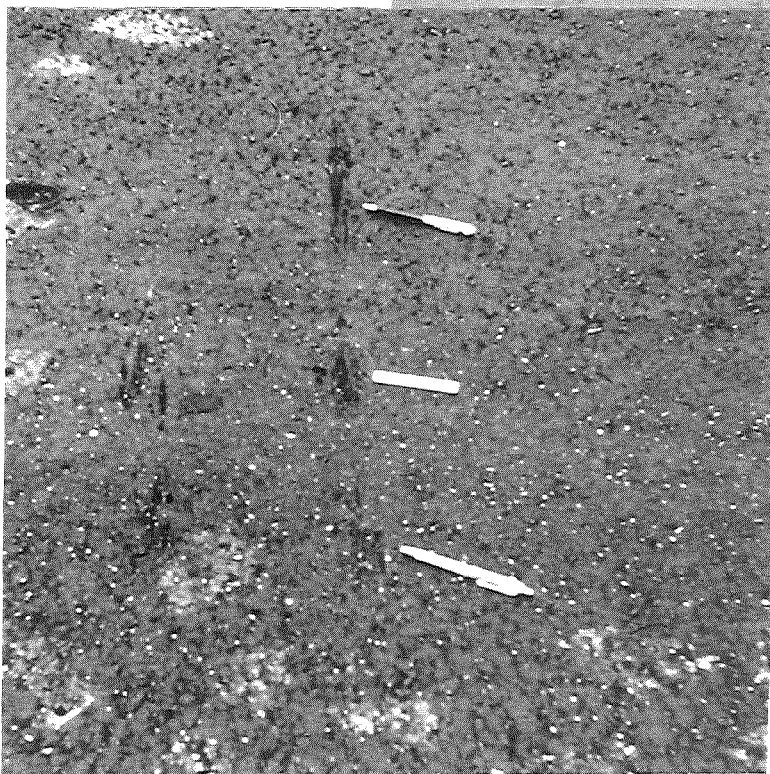
### Conclusions:

The results of the comparative studies of pneumatic-tire rollers, conducted on rigid pavement resurfacing projects, have shown certain trends but have not proven conclusively that there is any significant difference in the bituminous pavement densities obtained due to roller type, total weight, wheel load, tire size, or tire pressure. The results do indicate quite dramatically that the compaction process is a complex problem and that density is a function of many interdependent variables.





▲ Figure 11. Marks produced by steering wheels being turned while pneumatic roller is standing still.



◀ Figure 10. Showing scrape marks produced by a straightedge rubbed across a lane rolled with pneumatic tire roller.



Figure 12. Showing chatter or scuff marks produced when pneumatic tire roller starts too quickly.

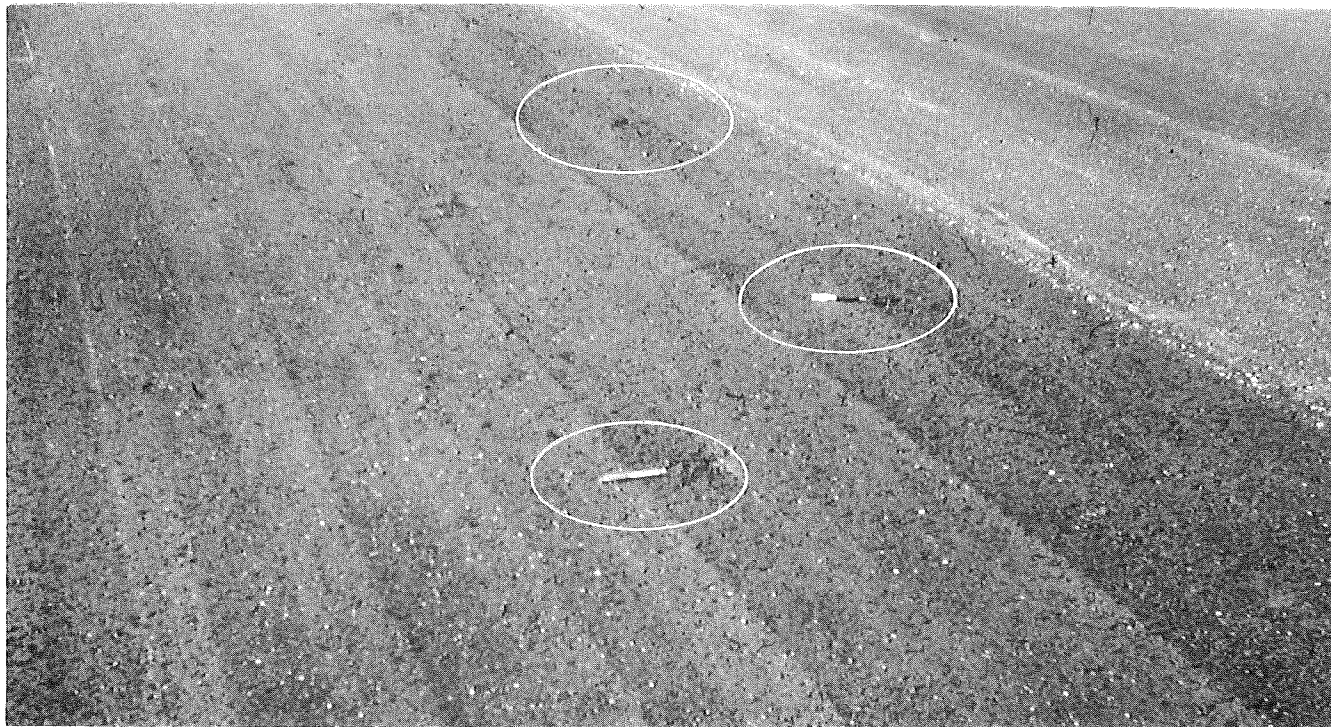


Figure 13. Showing tire marks and ridges which develop during pneumatic tire rolling and also pick-up spots which develop if tires are not warmed up before rolling operations begin.

Although no reliable conclusions regarding density comparisons can be based on the data obtained from these comparative studies of pneumatic-tire rollers, the prominence or importance of some factors involved in the compaction process have been substantially illustrated.

The temperature at which the mix is compacted appears to be of primary importance. Although the roller weight and compactive effort should affect the density results, they apparently are subjugated, or dependent to a large extent, upon the temperature at which the compaction process occurs.

Time, an important element on any construction project, is another factor dependent on temperature. The time available for effective utilization of any compactive effort is a function of the temperature of the mix and the ambient air temperature.

Michigan is confronted with few months of warm summer weather and a large bituminous program. This situation appears to warrant the use of pneumatic-tire rollers for several reasons which developed from the results of these comparative studies. The tighter surface texture resulting from pneumatic-tire rolling would be advantageous during late fall construction. The increased coverage available with pneumatic-tire rollers would prove an asset in accomplishing the compaction process in a shorter time thus eliminating the necessity for excessive mix temperatures during cooler weather. The steel-finish roller, which has been found necessary on Michigan projects where pneumatic-tire rollers were used, will require that the compaction process be accomplished quickly in order for it to properly eliminate tire marks and ridges.

Since only small density changes have been obtained regardless of roller type or weight, it appears that a compaction specification is needed which will specify some end result density requirement with some minimum equipment requirements to assure that detrimental pavement effects will not result. This type specification would leave equipment selection up to the contractor as long as the minimum equipment requirements are met and would assure the best utilization of compactive effort and proper temperature control.

Any research usually leads itself into additional research. This applies to this case, where in spite of the volume of work that was expended in gathering the information for this report, it is felt that additional work remains to be done. This report covers the study of pneumatic-tire rolling of bituminous mixtures proportioned according to the Michigan design using materials found in Michigan and under local weather and traffic conditions. The subject is relatively new and therefore should be further investigated by other organizations having different local conditions whereby their findings may substantiate our findings or may show some deviation from those offered in this report.



## ACKNOWLEDGEMENTS

Projects of the size and nature as those referred to in this report and those preliminary projects investigated previously would not have been possible without the assistance and cooperation of many people.

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Recognition is also given to the Michigan Pavement Performance Study Project of the University of Michigan for providing the roughness index information used in this report.

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## APPENDIX

Table A. Compaction of Bituminous Concrete Pavement Cores (Wearing Course)  
Obtained in 1961 for Various Number of Passes  
Each Test Roller Made on 1960 Project.

Type Test Roller	Total Weight (Tons)	Ground Pressure (psi)	Number of Passes				
			2	4	6	8	12
Pneumatic	22	87-91	98.7	98.6	97.8	98.4	99.6
Pneumatic	12	62-65	99.8	99.1	98.8	98.7	98.4
Steel	12	--	99.5	99.8	99.5	98.8	99.0
Pneumatic	27	96-99	99.5	99.4	99.2		
Pneumatic	27	83-85	98.7	98.8	99.0		

Note:

1. Test rolling number of passes shown are in addition to one pass 8.1 ton breakdown and one pass 8.2 ton finish rolling.
2. Compaction expressed as a per cent of Marshall Density.



APPENDIX

Table B. Gradation of Extracted Aggregate from Wearing Course Core Samples Obtained on 1960 Project.

Roller		Tire Pressure (psi)	No. Passes		Cumulative Per Cent Passing							
Type	Weight (Tons)				5/8	1/2	3/8	4	10	40	80	200
Pneumatic	22	90	8			100	91	66	43	18	8	5.2
Pneumatic	22	90	16		100	100	96	68	44	19	8	5.1
Pneumatic	22	90	24			100	94	66	43	19	7	4.8
Pneumatic	12	60	4		100	98	87	62	41	18	7	4.2
Pneumatic	12	60	8			100	87	60	40	18	7	4.3
Pneumatic	12	60	12			100	90	65	41	17	7	4.4
Pneumatic	12	60	12			100	89	59	42	17	7	4.3
Steel	12	—	4			100	89	64	42	17	7	4.8
Steel	12	—	8			100	92	66	43	18	8	5.0
Steel	12	—	12		100	99	88	65	43	18	7	4.3
Steel	12	—	16			100	93	66	43	17	7	4.6
Steel	12	—	24			100	91	66	44	17	7	4.6
Pneumatic	27	100	2		100	99	89	63	42	17	7	4.3
Pneumatic	27	100	4			100	90	61	40	16	7	4.4
Pneumatic	27	100	8			100	87	63	42	17	7	4.3
Pneumatic	27	100	12		100	99	89	62	40	16	6	4.4
Pneumatic	27	80	2		100	99	88	62	40	17	7	4.4
Pneumatic	27	80	4		100	99	88	63	41	17	7	4.4
Pneumatic	27	80	8		100	99	89	62	40	16	7	4.0
Pneumatic	27	80	12			100	93	65	43	18	8	4.6
Average Core Aggregate Gradation						100	90	64	42	17	7	4.5
Average of Field and Laboratory Results					100	99	88	64	43	19	9	5.0

## APPENDIX

Table C. Roughness Index of Various Areas Rolled on 1961 Project.

Type Area	Steel Rolled		Pneumatic Rolled		Pneumatic Warm-up	
Outer & Inner Wheel Paths	OWP	IWP	OWP	IWP	OWP	IWP
Roughness Index (in./mi.)	80	62	80	63	73	66
	68	60	73	59	81	81
	73	64	73	62	94	89
	89	67	69	58	67	67
	85	73	62	59	63	53
	72	56	56	57	142*	94*
	67	66	57	49	72	46
	70	62	52	47	99	90
	65	65				
	51	48				
	58	55				
	62	65				
	59	58				
	Averages	69	62	65	57	78

\*Not included in average because of extraneous roughness due to road intersection.

## APPENDIX

Table D. Roughness Index of Test Areas Rolled on Both 1960 and 1961 Projects  
with Pneumatic Rolled Areas Listed as High and Low Ground Pressure Areas.

Type Area	Pneumatic Test				Pneumatic Test				Steel Test			
Project	1960				1961				1960		1961	
Ground Pressure	High Pressure		Low Pressure		High Pressure		Low Pressure					
Outer & Inner Wheel Paths	OWP	IWP	OWP	IWP	OWP	IWP	OWP	IWP	OWP	IWP	OWP	IWP
Roughness Index (in./mi.)	60	55	76	53	83	60	61	53	71	62	60	49
	62	61	70	76	77	64	65	67	58	63	85	53
					84	57	61	50			76	69
					62	56	75	52			86	72
											67	54
											73	46
											72	61
											67	56
Averages	61	58	73	64	76	59	66	56	64	62	73	58

Note: Comparative figures shown above are for individual rollers used on both projects and are not comparisons between the different rollers. As a general rule High pressure ranges are from 79 to 99 psi ground pressures and Low pressure ranges are from 60 to 85 psi ground pressures.