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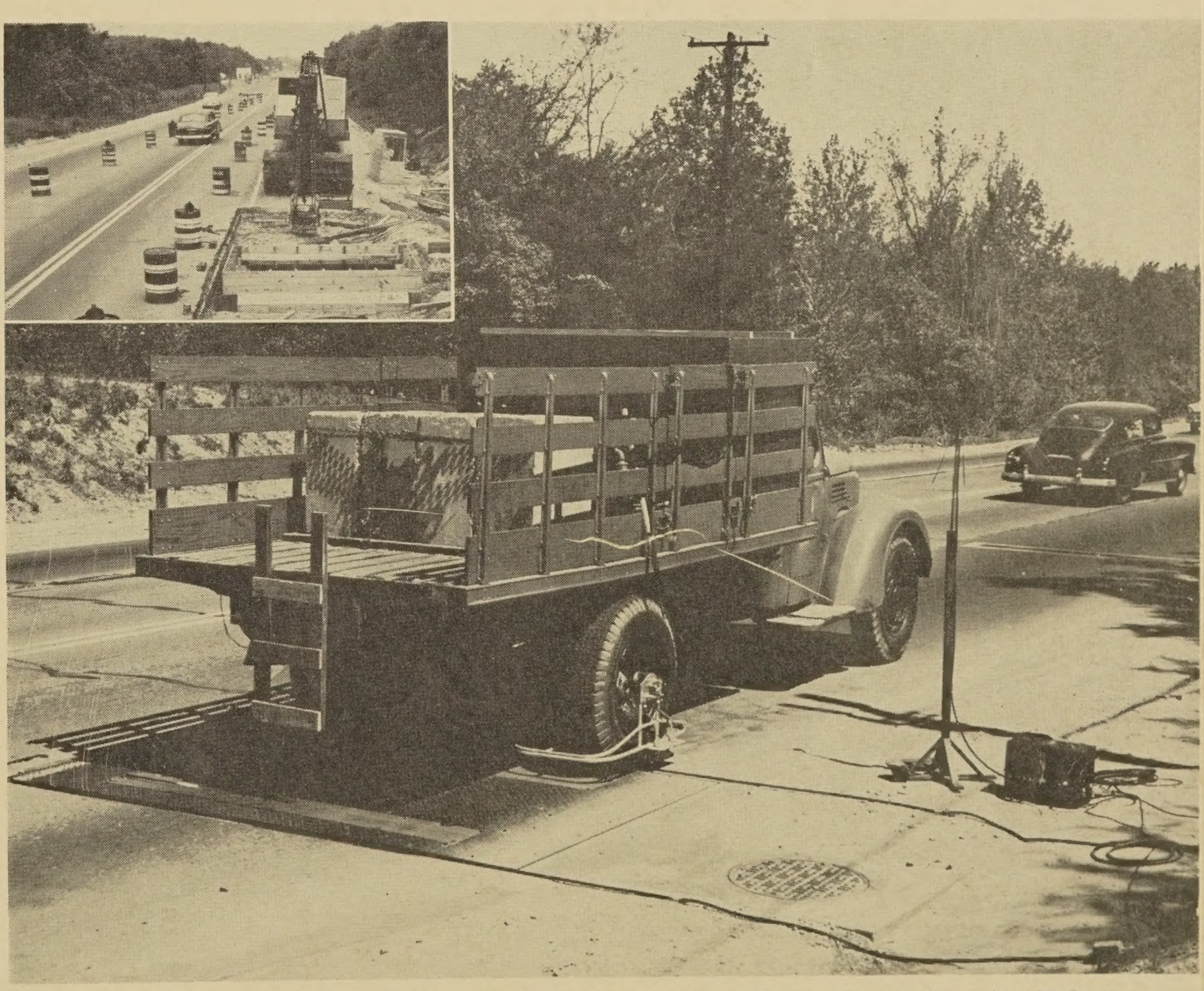

In this issue: A comparison of methods for measuring loads transferred through vehicle tires. (Inset: Installation of electronic scale)

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C. M. Billingsley, *Editor*

IN THIS ISSUE

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A Comparison of Methods Used for Measuring Variations in Loads Transferred Through Vehicle Tires to the Road Surface

BY THE DIVISION OF HIGHWAY TRANSPORT RESEARCH
BUREAU OF PUBLIC ROADS

Reported [1] by RICHARD C. HOPKINS, Electrical Engineer, and HOWARD H. BOSWELL, Highway Research Engineer

An earlier study involving the weighing of vehicles moving over the highways by means of an electronic scale gave promise of an efficient enforcement tool of the States in detecting vehicles carrying loads in excess of the legal limit. It was found at that time that the electronic scale was quite reliable in measuring gross weights of vehicles, but in determining the weights of individual axles the error exceeded 5 percent for about 35 percent of the axles weighed.

The axle weights recorded by the electronic scale while the vehicles were in motion were sometimes greater, smaller, or equal to the static weights. Such a random pattern suggested that trucks undulate on their springs while in motion. As a result the axle weights recorded by the electronic scale varied with the amplitude and frequency of the oscillations and depended upon what part of the cycle was measured on the electronic scale platform. The amplitude of the oscillations increased with the roughness of the roadway and the highest frequencies occurred on the smoother surfaces.

In this article, three different methods for obtaining a continuous record of the magnitudes and variations in the weights transferred through the tires to the road surface are discussed in conjunction with weights recorded by the electronic scale. Comparisons are made of the changes in the axle-housing strain, changes in tire sidewall deflection, and changes in the air pressure within the tire as a result of variations in wheel loads. Of the three methods studied, the air pressure method proved to be the most practical. Dual-tire equipment introduced an additional factor of a changing lever arm in measuring axle-housing strain, and the installation of sidewall detectors between the tires of a dual assembly for measuring deflection was exceedingly difficult.

THE load transmitted to the road surface through the tires of a vehicle in motion s not constant but varies in frequency and magnitude with several factors such as the speed of the vehicle, the smoothness of the road surface, tire pressure, and the vehicle's suspension system. An adequate means for obtaining a continuous record of the frequency and magnitude of these load variations has not been available.

The development of the electronic scale has not only made it possible to weigh vehicles in motion but also has made available a means for measuring the load transmitted to the road surface over a limited distance, thus providing a means for checking the accuracy of other methods that could be employed on a vehicle to obtain a continuous record.

The results of studies made of the electronic scale [2] near Woodbridge, Va., showed that while most vehicles in motion registered close to their static weight and there was little error in the gross tonnage, the error was in excess of 5 percent for about 35 percent of the individual axles weighed. The dynamic weight was just as likely to be either heavier or lighter than the static weight.

This suggests that trucks are undulating on their springs while moving over the highways. The axle weight as recorded by the electronic scale would depend on the amplitude of this oscillation and what part of the oscillation cycle was measured by the scale. The amplitude can be controlled somewhat by a smooth pavement surface, but the measured part of the cycle cannot be fixed and the scale will record random parts of the cycle. This would account for some axles being recorded as heavier, some lighter, and some equal to their static weight.

Purpose of Study

This report is the result of a study to determine, if possible, the best means for measuring the magnitude and frequency of these variations in weight. Some preliminary work had been done in connection with the WASHO Road Test.[3] Information was also obtained to determine whether the electronic scale records the changes accurately, or whether there is an error in the basic design of the electronic scale.

The electronic scale used for these investigations was recently constructed in the northbound lane of U. S. Route 1 about 1,000 feet south of the Virginia State Official Weighing Station near Woodbridge. The scale was constructed as a cooperative project of the Virginia Department of Highways, a manufacturer of electronic scales, and the Bureau of Public Roads in an effort to improve the accuracy of electronic scales and to determine the feasibility of their use in connection with the enforcement of legal weight limits.

The scale has a 7-foot platform in the direction of traffic and extends across the right-hand lane of the two northbound lanes. It embodies all the improvements that were determined as a result of research conducted on the first electronic scale constructed for weighing vehicles in motion on the Shirley Memorial Highway (Virginia) in April 1951.

In conjunction with the electronic scale which records wheel loads at one place on a highway, three different methods for obtaining a continuous record of the magnitudes and variations in the weight transferred by the tires to the road surface were developed and tested simultaneously. These were as follows: changes in the axle-housing strain near the spring mounting; the change of bulge or spread of the tire sidewalls directly above the center of contact with the pavement surface; and the changes in air pressure within the tire.

The vehicle, shown in figure 1, on which the instruments were mounted for the three types of measurements is a 2-axle single-unit truck with 9.00 x 20 tires. The inside tire on each dual wheel was removed to permit the installation of the tire sidewall detectors. Four 1,000-pound concrete blocks were placed on

[1] This article was presented at the 36th Annual Meeting of the Highway Research Board, Washington, D. C., January 1957.

[2] *Weighing vehicles in motion*, by O. K. Normann and R. C. Hopkins. PUBLIC ROADS, vol. 27, No. 1, April 1952.

[3] *The WASHO Road Test, Part 2: Test Data, Analysis, and Findings*. Highway Research Board, Washington, D, C., 1955, Special Report 22, Section 5e, pp. 170-174.

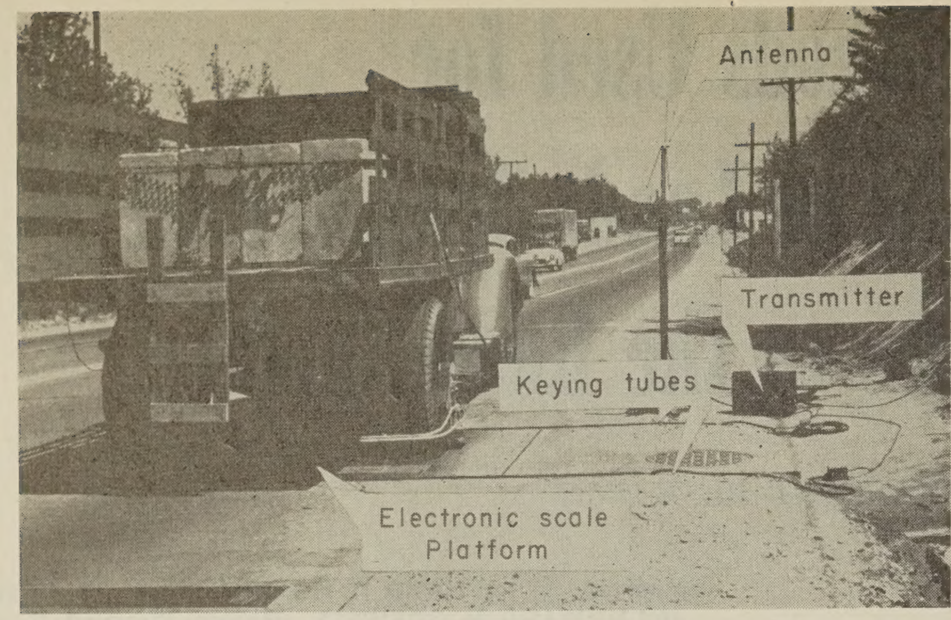


Figure 1.—Single-unit truck equipped with apparatus used in measuring wheel loads.

the truck bed to give a 9,000-pound rear-axle load. This produced a tire load of 4,500 pounds which is equal to that allowed by the many States having an 18,000-pound single-axle load limit. The right rear wheel only was instrumented.

Conclusions

1. The most practical of the three methods for measuring the weight variations involving all wheels of a vehicle is the tire pressure method. The changing lever arm for dual tires, when the axle-housing strain is measured, and the difficulty of mounting rollers between dual wheels to measure tire sidewall deflection make these two methods less desirable. It is possible by incorporating the refinements outlined in the subsequent discussion of measuring the changes in tire air pressure to continuously record, with acceptable accuracy, the force exerted on the pavement by each tire of a vehicle.

2. Pavement deflections can now be related to the actual load applied by a vehicle in motion.

3. It is also possible to compare the load transfer characteristics of the many different suspension systems now in common use on the undercarriage of trucks.

4. Differences in weight of more than 5 percent between the static axle weight and the dynamic weight as shown by the electronic scale with a stable platform are probably due to the undulating load of a vehicle in motion rather than to errors of the scale.

Axle-Housing Strain

Four strain gages were used as the arms of a resistance bridge circuit to record the changes in axle-housing strain due to variations in the load on the wheel. The gages were cemented to the rear axle housing just inside the spring mount, two gages on top and two on the botton as shown in figure 2. The axle housing is a continuous cantilever beam which transfers the load on the springs to the wheel resting on the pavement. Any change in the wheel load causes a change of strain in the axle housing.

The calibration of the axle strain gages was easily done. The wheel of the vehicle was placed on a scale platform, a loadometer in this case, and the load changed on the bed of the truck. For each change in load the recording instruments registered a corresponding change in strain, which then gave a calibration curve.

This is a simple means of recording the change in wheel load, and it worked very well in this study. There are, however, factors which limit its usefulness. As the pavement surface becomes rough and the truck speed increases, the axle-housing strains are influenced not only by the load resting on the springs, the sprung load, but also by the weight or inertia of the truck undercarriage, the unsprung load. On a smooth surface and at slow speeds the unsprung load would have little or no effect since it would have practically no vertical motion or acceleration.

Another complicating factor is the addition of the second wheel of a dual assembly. The addition of this second wheel would change the lever arm of the cantilever axle-housing beam, depending upon which of the two tires was carrying the greater proportion of the momentary load. Therefore, the calibration would continually change due to the changing lever arm. Again, on a smooth surface this would have little or no effect because each tire would carry the same proportion of the load, provided the inflation pressure of each was the same.

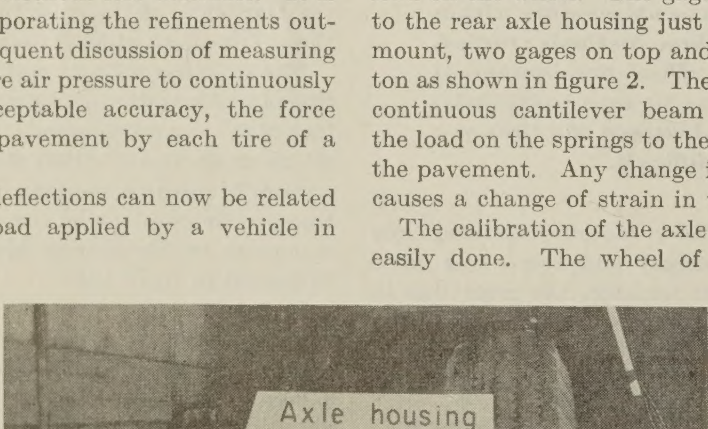


Figure 2.—A view of the mounting of the 4 strain gages on the rear axle housing.

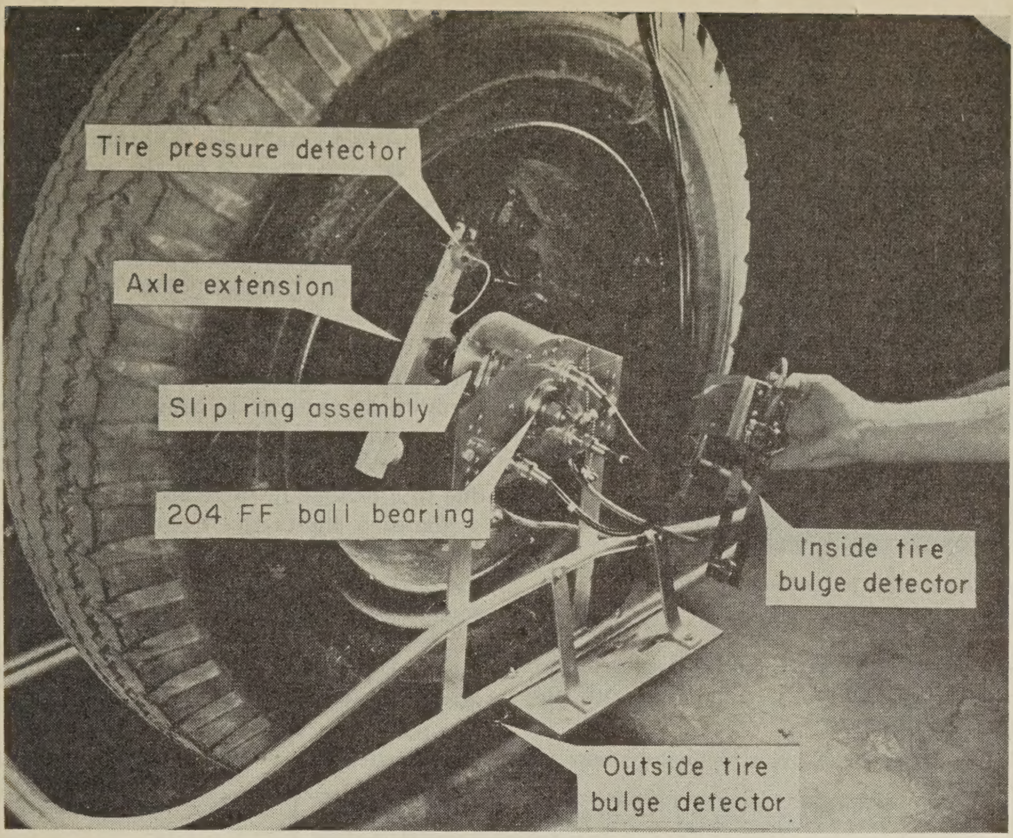
Bulge or Spread of Tire Sidewalls

The second method of determining wheel-load changes was suggested by Endres and Bombard.[4] As the load increases on a pneumatic tire, the lower part of the tire casing bulges or spreads due to its contact with the pavement surface. This tire sidewall deflection can be calibrated in a manner similar to the axle-housing strain, with the exception that the wheel must be rotated between each change in load to allow the sidewall to attain its normal deflection for the load as it would with the vehicle in motion.

Equipment Used to Measure Deflection

Figure 3 shows the instrument used to measure the tire sidewall deflection. This assembly was built in the Bureau of Public Roads laboratory and consisted of two 1/16 x 3/4-inch pieces of spring steel 9½ inches long riveted to a ¼ x 3 x 3-inch aluminum plate. The two pieces of spring steel were spaced ¾ inch apart to allow for the mounting of a 200 SFF ball bearing which acted as a roller running against the tire sidewall. The ball bearing was mounted between the two pieces of spring steel which were used to measure the spread of the tire sidewall by the amount that the roller caused them to bend. Thus, when the plate was held rigid and the roller was in contact with the tire sidewall, any deflection

[4] *Vertical forces between the road surfaces and tires*, by Professor W. Endres and Dipl. Engineer J. Bombard. Institute for Testing Mechanical and Chemical Materials, Unter Den Eichen No. 87, Berlin-Dahlen, Germany. (Translated from the German by A. C. Benkelman, Bureau of Public Roads.)



Figures 3.—Instruments used to measure tire sidewall deflections and pressure changes.

of the sidewall would cause the spring steel straps to bend.

Strain gages were cemented to each side of both spring steel straps to provide a resistance bridge for measuring the amount of bend in the straps and thereby the bulge of the tire sidewall with increased load. The aluminum plate holding the steel straps was mounted vertically and bolted to an aluminum angle which was in turn bolted to a horizontal aluminum plate ¼ x 4 x 12 inches. Both the vertical and horizontal faces of the angle were slotted to permit an adjustment in the position of the roller with respect to the tire sidewall. A framework made by bending ¾-inch thin wall tubing was used to support the horizontal plate to which the sidewall bulge detector was attached. This plate was also slotted to permit a longitudinal adjustment. The framework of ¾-inch tubing was rectangular in shape with rounded corners and encircled the wheel.

A second framework of ½-inch tubing was placed above the ¾-inch framework. It had the same general shape as the ¾-inch framework but the sides were raised 4 inches at the center to make a more rigid framework. The two frameworks of tubing were brazed together at each end. This frame was then hung from the truck spring mounting bolts on the inside of the wheel and from a special axle extension on the outside of the wheel.

The axle extension was built from a broken truck axle and was long enough to extend about 3 inches beyond the plane of the tire sidewall as shown in figure 1. The face plates of the axle and the axle extension were placed back to back and held in position with the normal axle bolts. The end of the extension was trued with the axis rotation by means of a micrometer dial before the nuts were tightened. A 204FF ball bearing was placed near the end of the extension to provide a mounting for the plate on which the framework constructed of tubing was hung. Through this bearing, the framework was rigidly supported even though the axle extension rotated with the wheel. A sidewall bulge detector as previously described was placed on each side of the tire. Both were held in position by the rigid frame supported by the axle housing on the inside of the wheel and by the extension of the axle on the outside of the wheel, as shown in figure 2. Electrical cables from the gages on the bulge detectors were wired to sockets in the hanger plate to permit the cables leading to the recording equipment to be connected or disconnected with ease.

An initial bending moment was placed in the spring steel straps to obtain negative as well as positive readings for deflections of the sidewalls. The roller of the bulge detector was first adjusted so that it was in contact with the sidewall of the tire. A ½-inch steel block was then placed between the roller and the tire. After the resistance bridge circuit had been balanced to a zero reading, the block was removed and the bulge detector repositioned until a zero reading was again obtained on the recorder. This assured contact between the roller of the detector and the tire for all expected sidewall deflections.

A linear calibration curve, used to measure the deflection of the tire sidewalls, was obtained by a laboratory test calibration of the tire sidewall bulge detectors. A micrometer screw was utilized to move the roller of the detector through a one-inch range. A greater displacement was not tried because the original ½ inch plus or minus ½ inch was thought to be sufficient to record the expected range in the bulge of the sidewalls of the tire. This proved to be the case.

After the roller of the detector was in place and rolling along the tire sidewall as the truck wheel turned, a smooth path had to be provided on each side of the tire. Also, since the plane of the tire sidewall was not exactly perpendicular to the axis of rotation, that part of the tire in contact with the roller of the detector had to be trued. Otherwise, the wobble of the tire sidewall would have been recorded and could not have been distinguished from actual sidewall deflection due to a change in the load on the tire.

An emery wheel, placed in a fixed position while the jacked-up truck wheel was rotating, was used to provide a smooth and true path on each side of the tire for the roller of a detector. The largest amount of rubber removed at any one point was less than 1/16 inch. Some slight imperfections remained, however,

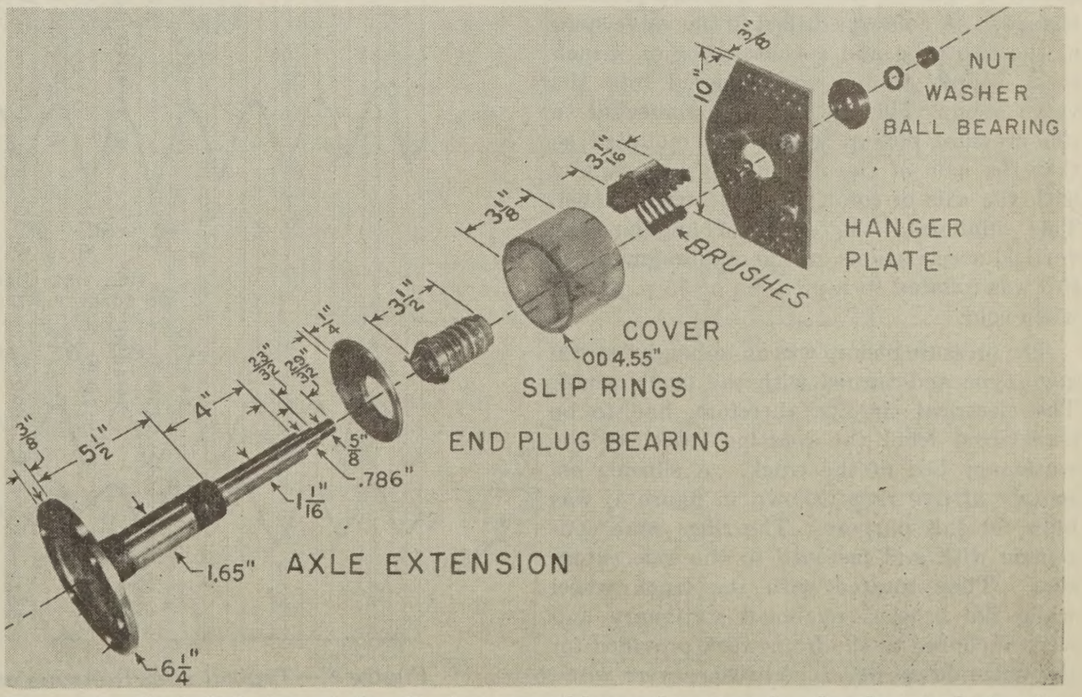


Figure 4.—Exploded view of the slipring assembly used to transfer the electrical circuits from the rotating wheel to the recording instruments installed on the truck bed.

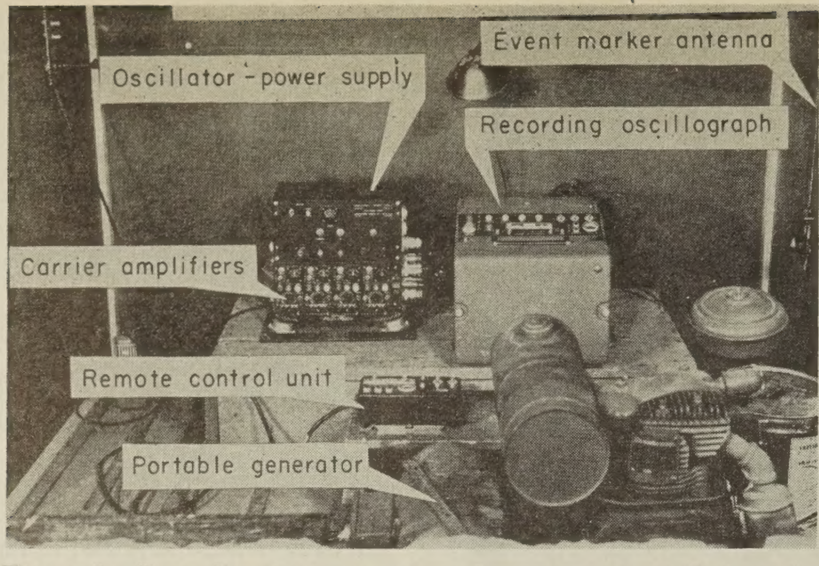


Figure 5.—Recording instruments and generator installed at the forward end of the truck bed.

and undoubtedly accounted for some error in the recordings.

Changes in Tire Air Pressure

The third method of measuring momentary changes in the load imparted to the tire was that of recording the changes in the air pressure within the tire. It was believed that the distortion of the tire casing at the point of contact with the pavement surface must cause a slight change in the volume of the inflated chamber of the tire. A change in volume would be accompanied by a change in pressure. The purpose of this phase of the study was to measure this change and calibrate its magnitude in terms of pounds of weight on the tire. There was considerable uncertainty as to whether the change would be great enough to measure accurately since no record could be found of any previous research on this phenomenon.

A Consolidated Electrodynamics Corp. pressure pickup gage, type 4–311,0–50 p. s. i. g., shown in figure 3, was used to record pressure changes. A hole was drilled in the valve stem of the tire tube and a short piece of ⅛-inch o. d. copper tubing was soldered into the valve stem. This tubing was connected to the pressure pickup which was mounted so that the axis of the diaphragm was parallel with the axis of rotation of the truck wheel. This minimized the effect of angular and vertical accelerations on the diaphragm. The tire was inflated to a pressure of 55 p. s. i. g. when cold.

The pressure pickup was an unbonded strain gage type and turned with the truck wheel. The electrical circuits, therefore, had to be transferred from the rotating wheel to the stationary bed of the truck. A slipring assembly of five rings, shown in figure 4, was built for this purpose. The rings were concentric with and fastened to the axle extension. They rotated with the truck wheel while the brushes remained stationary and were anchored to the framework provided for the bulge detectors. The brushes were wired to a socket in the hanger plate to permit an easy connection with the recording equipment in the truck. A plastic cover was provided for the slipring assembly to keep out dust and other foreign matter.

Calibration of the pressure pickup was accomplished by comparing the pressure pickup oscillogram with the maximum and minimum weights as recorded from the axle-housing strain and the tire sidewall deflection. It was not possible to make the calibration statically in the same manner as for the axle and sidewalls, because the galvanometer readings for the same air pressure were different with the sliprings stationary than when they were in rotation. The plotted points of comparison show some scatter due to normal imperfections in the sliprings and brushes. The use of high quality instrument-type sliprings would permit a more accurate calibration and would also make an oscillogram more representative of the actual magnitude of pressure change due to a change in the load on a tire.

Figure 5 shows the recording instruments for the three tests mounted on the forward end of the truck bed. A recording oscillograph with its standard oscillator, power supply, and carrier amplifier circuits was used to record the data. Power to operate this equipment was furnished by a portable generator which was placed on the truck bed just behind the instrument shelter. The shelter was built of

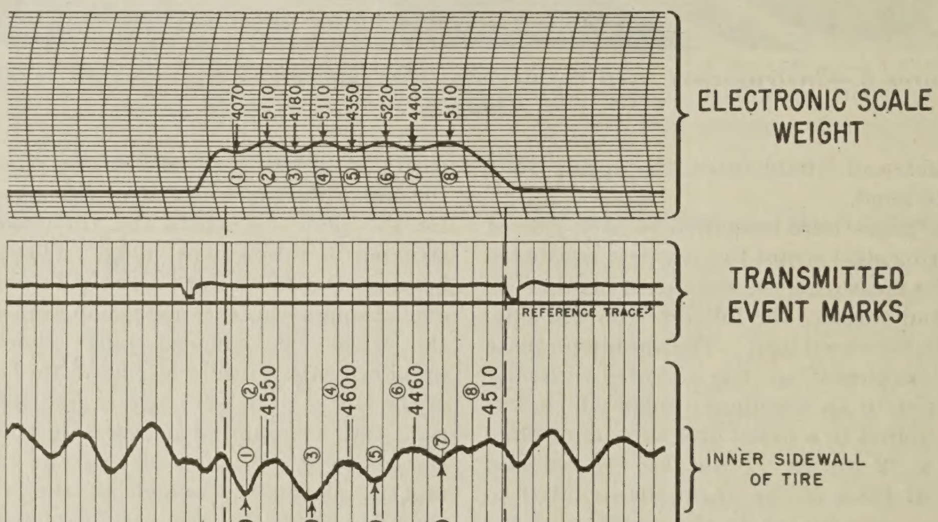


Figure 6.—Typical simultaneous oscillograms of wheel-load measurements registered by the electronic scale, axle-housing strain gages, tire sidewall detectors, and tire pressure pickup.

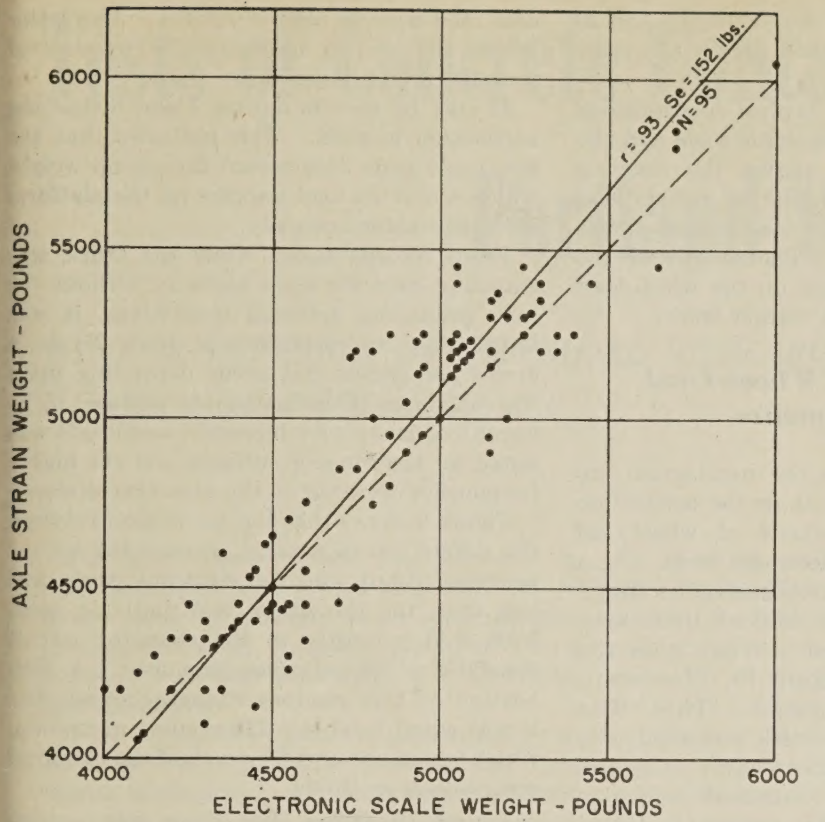


Figure 7.—Correlation between weights determined by the axle-housing strain gages and the electronic scale.

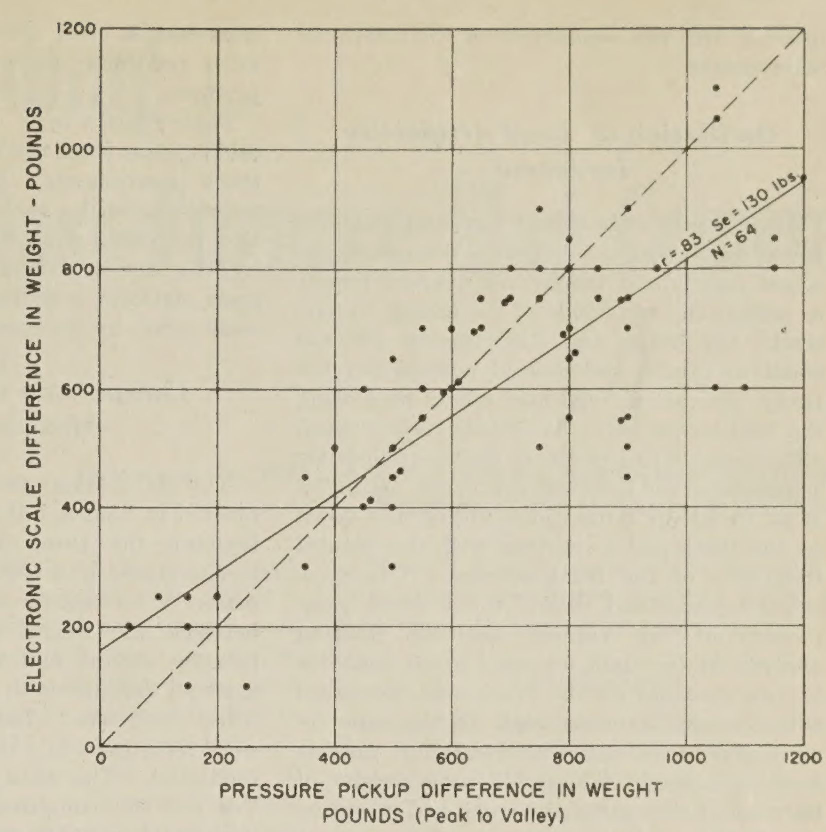


Figure 9.—Correlation between differences in weights recorded by the electronic scale and the pressure pickup.

⅜₆-inch tempered pressed-fiber panels which not only provided protection from the elements but also darkened the space as an aid to the operator in viewing the screen on the oscillograph. The rear panel of the instrument shelter was removed in figure 5 to permit a photographic view of the recording instruments.

All test runs included travel over the new electronic scale where simultaneous weight recordings were made for each run using a Brush amplifier and ink recorder. The Brush recorder was calibrated by placing known wheel and axle weights on the scale platform and recording these static weights. The static wheel and axle weights were obtained by weighing at the nearby Virginia weighing station. Only the right side of the vehicle passed over the platform since only the right rear wheel was instrumented.

In order to synchronize the recording of axle strain, tire bulge, and tire pressure with the wheel weight as recorded by the electronic scale, pneumatic detectors were placed at the beginning and end of the scale platform. The air switches of these detectors keyed a radio transmitter which was placed on the roadway shoulder as indicated in figure 1.

When a tire rolled over a pneumatic detector, the transmitter sent out a signal which was picked up by an antenna on the wall of the instrument shelter located on the truck. The signal was rectified by a germanium diode which had its output connected to one of the galvanometers in the oscillograph. This made a pip on the oscillogram each time a pneumatic detector was depressed by a tire. This marked the oscillogram of the wheel-load measurements so that it could be compared

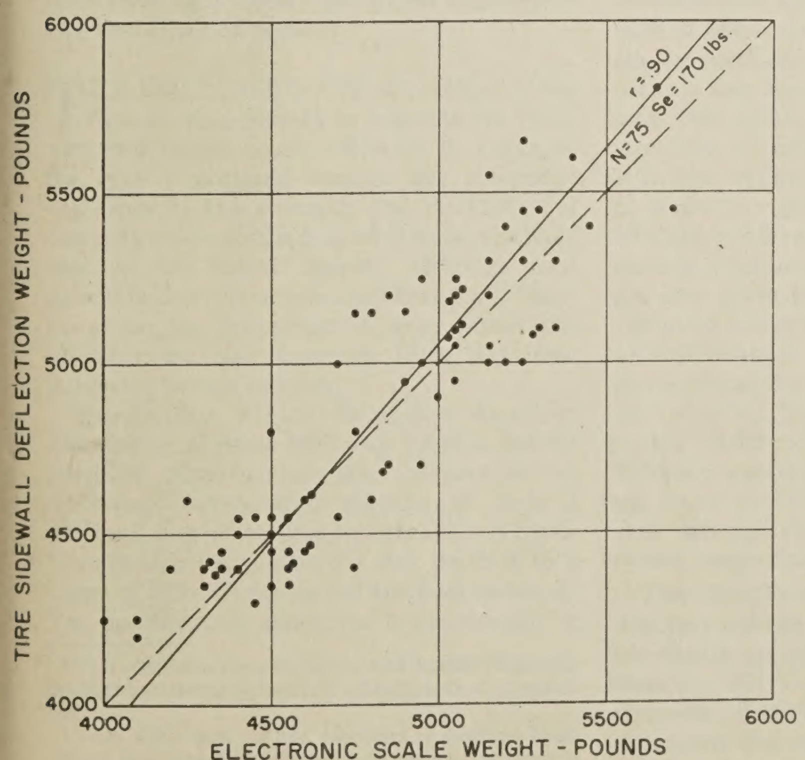


Figure 8.—Correlation between weights determined by the tire sidewall deflections and the electronic scale.

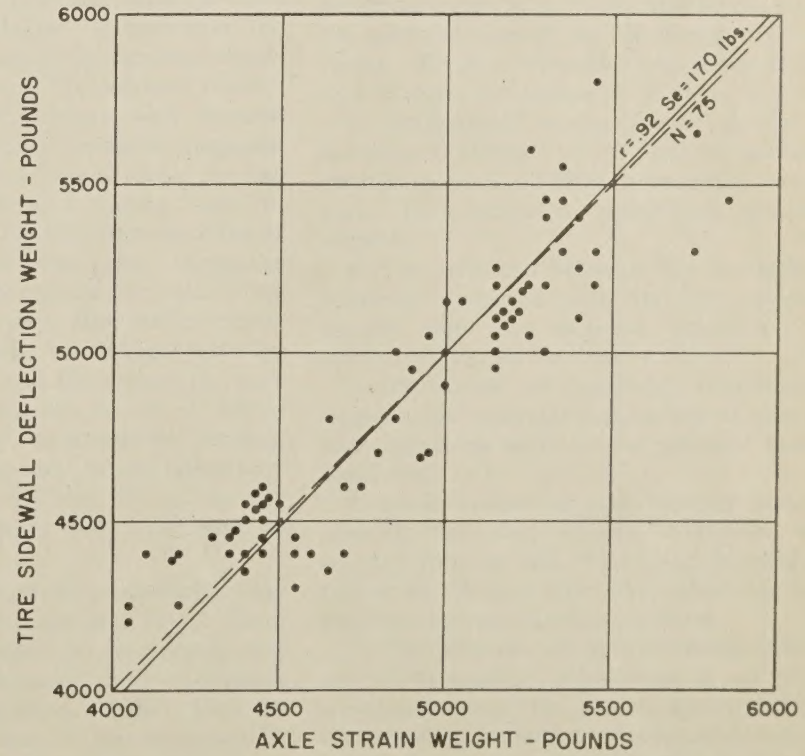


Figure 10.—Correlation between weights determined by the tire sidewall detectors and the axle-housing strain gages.

directly with the oscillogram of the electronic scale weight.

Oscillation of Load Artificially Increased

During trial runs across the scale platform it was found that the difference between static wheel weight and the dynamic wheel weight as well as the amplitude of the change in axle strain, tire bulge, and tire pressure was too small to obtain the desired comparison between the various trial methods of measuring the load on the tire. To obtain these desired differences and to establish definite points for comparison, the load was artificially oscillated at all speeds by a man jouncing up and down on the truck bed in rhythm with the natural frequency of the truck springs. This gave definite peaks and valleys for a direct comparison of the various methods. During analysis of the data an oscillogram peak for the instruments on the truck was compared with the simultaneous peak on the scale record, and similarly the valleys or low weights were compared. The additional weight of the man at the rear of the truck bed increased the static load on the right rear tire to about 4,750 pounds.

At creep speed the load was oscillated through 6 or 6½ cycles during the time the wheel was crossing the 7-foot scale platform. At 10 miles per hour, 1 or 1½ cycles were recorded; and at 20 miles per hour, about half a cycle was recorded. Speeds above 20 miles per hour were not included in this study because too many trips would have been necessary before a definite peak or valley was recorded on the electronic scale oscillogram. As speed appeared to have no effect within the range of the study, the data for all speed groups were combined for the analysis. Four trips each at creep speed and 5, 10, 15, and 20 miles per hour were made across the scale platform.

Figure 6 is a copy of typical simultaneous oscillograms from the electronic scale and the truck instruments. It shows the varying weight caused by the undulating vehicle load and the continuous wheel-load measurement by the three methods. The length of the scale platform is indicated on the wheel-load oscillogram by the event marker trace.

Comparison of Wheel-Load Measurements

The data taken from the oscillogram are plotted in figures 7–9 to show the correlation between the three methods of wheel-load measurement and the electronic scale. As a matter of interest the correlation is also shown between the weight as derived from axle-housing strains and that derived from tire sidewall deflections in figure 10. The static wheel load was 4,750 pounds. These data were recorded while the truck was artificially oscillated. The solid lines shown in figures 7–9 are the computed statistical regression lines which would be used to predict the weight recorded by the electronic scale from any of the other three recordings. The solid line in figure 10 is the relation between weights as shown by the axle-housing strain and the tire sidewall bulge.

The 45° broken line represents a hypothetical line of perfect correlation on which all plotted points would fall if there were no differences in the weights as indicated by the various methods. The regression lines would approach the ideal case as the weighing methods increase in accuracy. Correlation coefficients (r) and standard errors of estimate (Se) were calculated for each of these sets of data and appear on the graphs. The letter N on the graphs indicates the number of samples or observations.

It may be seen in figures 7 and 8 that the correlation is good. This indicates that the electronic scale does record the actual weight which a moving load imposes on the platform with reasonable accuracy.

From records taken while the truck was traveling over the open highway without the man producing artificial oscillations, it was found that an oscillation of from 2½ to 4 cycles per second did occur depending upon the roughness of the pavement surface. The lower frequency with increased amplitude was noted on the rougher surfaces and the higher frequencies occurred on the smoother surfaces.

Figure 9 shows that the correlation between the differences in weights as recorded by the pressure pickup and the electronic scale was less than for the other two methods used. This is due mostly to the changing circuit constant of the slipring assembly. A calibration of this random change showed that it was equal to about 225 pounds maximum, which would account for much of the observed error in this method.

Figure 10 shows that there was a high degree of correlation between the weights as recorded by the axle-housing strain and the tire sidewall deflection.

Three possibilities are being considered for improving the performance of the pressure pickup for future studies. The first is better quality sliprings. The second is a differential-type pressure pickup (5 p. s. i. differential) which should give a strong signal output compared to any slipring noise. The third is that of using a rotating pressure slip joint to eliminate the electrical sliprings between the pressure transducer and the recording equipment.

Tests of Concrete Containing Portland Blast-Furnace Slag Cement

BY THE DIVISION OF PHYSICAL RESEARCH
BUREAU OF PUBLIC ROADS

Reported [1] by WILLIAM E. GRIEB and GEORGE WERNER,
Highway Physical Research Engineers

Portland blast-furnace slag cement, a relatively new product in this country, is being used increasingly as an alternate for portland cement. Because of this fact there is need for greater knowledge of its strength and durability.

This article discusses the preliminary results of research undertaken by the Bureau's laboratory. The tests reported here are being continued, and it is contemplated that a final report will be prepared in 1958.

In general, the tests show good results for the portland blast-furnace slag cements. Air-entrained concretes containing portland blast-furnace slag cements give lower compressive and flexural strengths at curing ages of 3 and 7 days, equal strengths at 28 days, and higher strengths at 90 days than comparable concretes containing portland cements.

Varying the water-cement ratios of concretes containing portland blast-furnace slag cement or portland cement had only a limited effect on the relations of their compressive and flexural strengths. Tests to determine shrinkages due to loss of moisture indicated about the same results for the two types of cement.

THE INCREASED USE of portland blast-furnace slag cement in concrete for highway and bridge construction as an alternate for type I portland cement has interested engineers in the strength and durability of concrete made with a cement that is relatively new in the United States. Although considerable data have been published by Europeans on the properties of slag or portland blast-furnace slag cements, little has been published in this country.

Specification M 151–53 of the American Association of State Highway Officials defines portland blast-furnace slag cement as an intimately interground mixture of type I portland cement clinker and granulated blast-furnace slag and limits the slag content to a range of 25 to 65 percent of the final product.[2] The specification also gives requirements for the chemical composition of the cement and the slag constituent, together with requirements for physical tests of neat cement and mortar. The requirements for compressive strengths of mortar are identical with those for type I portland cement as given in AASHO specification M 85–53. As the slag does not require burning in a kiln, the output of a portland cement mill can be increased through the production of this cement without the use of additional equipment.

Information concerning the strength, durability, and resistance to attack by chloride salts of concrete prepared with portland blast-furnace slag cement is needed. Some data, now available, indicate that the strengths at early ages of this concrete are lower than those of concretes containing portland cement, but little information on the behavior of these concretes at advanced ages can be found. Values for the modulus of elasticity are also needed, particularly if portland blast-furnace slag cement is used in prestressed concrete.

This article presents data on the physical properties of air-entraining concretes prepared with type IS portland blast-furnace slag cements and type I portland cements from each of five cement plants. In each case, the clinker used in preparing the portland blast-furnace slag cement and the portland cement was the same. Compressive and flexural strengths of moist-cured concretes prepared with 5½, 6½, and 7½ gallons of water per bag of cement are given for ages ranging from 3 to 90 days, with values for the sonic modulus of elasticity for most of these ages. Strengths are also given for 5½ gallons per sack mixes tested at an age of 28 days after either normal or intermittent curing. Shrinkage tests on mixes containing 5½ and 6½ gallons per sack are reported for two conditions of initial curing followed by intermittent curing. Freezing and thawing tests in the laboratory on mixes containing 5½ and 6½ gallons per sack are reported up to 100 cycles and 50 cycles, respectively.

The strength and modulus of elasticity tests will be continued to an age of 1 year. Tests for shrinkage and resistance to freezing and thawing will be continued until conditions warrant their termination. Other tests to determine the resistance of the concretes to scaling caused by calcium chloride in removing ice are in progress but no results are now available. Strength tests will be repeated on specimens prepared with concrete containing 4½ gallons of water per bag of cement.

Conclusions

In general, the results of these tests show that air-entraining concretes containing portland blast-furnace slag cements, type IS, give lower compressive and flexural strengths at ages of 3 and 7 days, equal strengths at 28 days, and higher strengths at 90 days than comparable concretes containing portland cements, type I.

Detailed conclusions for air-entraining concretes with water-cement ratios of 5½, 6½, and 7½ gallons of water per sack of cement and containing portland blast-furnace slag cement, type IS, or portland cement, type I, follow:

1. Four of the five portland blast-furnace slag cements gave lower compressive and flexural strengths in moist-cured concretes at 3 and 7 days, equal strengths at 28 days, and higher strengths at 90 days than portland cements used in comparable concretes.

2. One portland blast-furnace slag cement gave lower compressive strengths in moist-cured concretes at 3, 7, 28, and 90 days than the portland cement used in comparable concretes. Flexural strengths were lower at 3, 7, and 28 days, but higher at 90 days.

3. Intermittent curing caused greater reductions in strength at 28 days for concretes containing portland blast-furnace slag cements than for concretes containing portland cements.

4. The relations between the strengths of concretes prepared with the two types of cement were not affected appreciably by changes in the water-cement ratio.

5. Shrinkages of portland blast-furnace slag cement concretes due to loss of moisture were the same as those for portland cement concretes.

6. Sonic moduli of elasticity for portland blast-furnace slag cement concretes were slightly lower at ages of 3, 7, and 28 days and higher at 90 days than the values for comparable portland cement concretes.

7. The amount of air-entraining solution needed to produce 5½ percent of air in the concretes varied for the 5 portland blast-furnace slag cements from approximately the same amount as used with the portland cements to about 2½ times that quantity.

[1] This article was presented at the 36th Annual Meeting of the Highway Research Board, Washington, D. C., January 1957.

[2] Tests were made by the producers of portland blast-furnace slag cement to determine the optimum amount of slag. Approximately 40 percent of slag was used in the cements included in these tests.

Table 1.—Chemical composition [1] and physical properties of cements

	Source A cement		Source B cement		Source C cement		Source D cement		Source E cement	
	Type I	Type IS	Type I	Type IS	Type I	Type IS	Type I	Type IS	Type I	Type IS
Chemical composition (percent):										
Silicon dioxide	20.2	25.0	20.8	26.2	21.1	25.5	21.0	26.7	21.3	26.1
Aluminum oxide [2]	6.4	9.2	5.4	8.0	5.4	7.1	5.8	7.8	5.9	7.2
Ferric oxide	2.8	2.1	3.1	2.3	2.1	1.7	3.3	2.9	3.5	2.4
Calcium oxide	63.4	53.0	63.6	53.6	65.5	59.2	63.4	54.6	62.5	55.7
Magnesium oxide	2.7	3.7	2.8	3.6	2.4	1.8	2.2	3.3	1.7	2.8
Sulfur trioxide	2.3	2.0	1.8	2.3	1.3	1.4	1.9	2.3	2.3	2.2
Loss on ignition [3]	1.5	1.6	1.6	.8	1.4	1.3	1.2	.04	1.3	1.7
Sodium oxide	.8	.12	.09	.09	.04	.07	.10	.10	.15	.15
Potassium oxide	.36	.38	.15	.20	.43	.82	.17	.18	1.02	.91
Equivalent alkalies as Na_2O	.32	.37	.19	.22	.32	.61	.21	.22	.82	.75
Manganic oxide	.53	.87	.51	.85	.03	.08	.29	.32	.07	.50
Sulfide sulfur	.09	.56	.10	.68	.01	.33	.08	1.04	.03	.40
Insoluble residue	.28	.57	.16	.73	.22	.98	.08	.20	.20	.26
Chloroform-soluble organic substances	.003	.005	.003	.006	.003	.002	.003	.005	.003	.008
Calculated compounds (percent):										
Tricalcium silicate	51	---------	55	---------	63	---------	49	---------	41	---------
Dicalcium silicate	20	---------	18	---------	13	---------	23	---------	30	---------
Tricalcium aluminate	12	---------	9	---------	11	---------	10	---------	10	---------
Tetracalcium aluminoferrite	8	---------	9	---------	6	---------	10	---------	11	---------
Calcium sulfate	3.9	---------	3.0	---------	2.2	---------	3.2	---------	3.9	---------
Merriman sugar test:										
Neutral point ml	31.4	3.4	17.7	6.9	46.2	19.2	5.5	2.2	8.3	4.2
Clear point ml	44.9	4.0	23.3	8.0	68.0	26.2	6.2	2.2	9.7	5.3
Physical properties:										
Apparent specific gravity	3.14	2.99	3.12	3.03	3.12	3.05	3.14	3.03	3.14	3.03
Specific surface (Blaine) cm.²/g.	3,810	5,000	3,325	4,820	3,425	3,775	3,680	4,040	3,555	3,605
Passing No. 325 sieve percent	92.4	96.0	87.5	97.6	80.0	82.9	94.4	98.2	96.2	94.9
Autoclave expansion do	.10	.01	.06	.00	.09	.04	.07	−.02	.04	.00
Normal consistency do	25.2	27.6	23.8	27.2	20.4	22.6	26.6	31.2	26.5	26.6
Time of setting (Gillmore):										
Initial hours	2.9	2.8	3.7	3.4	1.7	2.6	4.2	3.5	2.9	2.8
Final do	5.1	6.8	5.6	6.2	3.4	3.9	6.5	7.9	4.8	6.2
Compressive strength (1:2.75 mortar):										
At 3 days p. s. i.	2,700	2,555	1,620	1,730	1,960	1,740	2,635	1,740	2,465	1,525
At 7 days p. s. i.	3,860	4,170	2,625	2,630	3,440	2,940	3,940	2,750	3,525	2,360
At 28 days p. s. i.	5,645	6,120	4,150	5,190	5,145	5,120	5,615	4,615	4,965	3,900
Tensile strength (1:3 mortar):										
At 3 days p. s. i.	295	290	280	265	265	240	305	265	320	245
At 7 days p. s. i.	365	420	355	335	360	345	390	340	375	315
At 28 days p. s. i.	450	500	450	445	415	425	420	460	435	455
Mortar air content percent	11.6	8.4	10.4	7.4	8.4	8.1	10.7	8.3	9.4	9.2

[1] All determinations made in accordance with current ASTM methods for portland cement.
[2] Values for aluminum oxide include any titanium and phosphorous oxides that may be present.
[3] Values for type IS cements do not represent accurately the volatile matter. Oxidation of sulfide sulfur during the test affects these results.

Materials and Proportions

In order to avoid repetition of the terms "portland blast-furnace slag cement, type IS," and "portland cement, type I," they are hereafter referred to as slag cement [3] and portland cement, respectively.

The five slag cements used in these tests were obtained from two mills of one producer and from one mill of each of three producers. Portland cements ground from the same clinkers as those used to prepare the slag cements were also supplied for the study. Chemical analyses and physical properties of all cements are given in table 1. Values for free lime are not shown because determinations on all cements had not been completed at the time of this report. Time of setting by the Vicat test method is not given for the slag cements but the values obtained were within the specified limits of AASHO specification M 151.

The grading and physical properties of the fine and coarse aggregates used are given in table 2. Mix data for all concretes are given in table 3. The mixes were designed on a water-cement ratio basis for air-entrained concrete of 5½ percent air, 2- to 3-inch slump, and a b/b_o of 0.72.[4] The cement contents were approximately 6.1, 4.9, and 4.1 bags per cubic yard of concrete for water contents of 5½, 6½, and 7½ gallons of water per bag of cement. An exception occurred in the mix containing 6½ gallons of water for slag cement from source D; a cement content of 5.1 bags was necessary to maintain a slump of 2 inches. It is noted also that the slumps of concretes containing 5½ and 7½ gallons of water with this cement were less than 2 inches but no adjustments in proportions were made. Air was entrained in the concrete by use of a commercial solution of neutralized Vinsol resin.

[3] Portland blast-furnace slag cement is not to be confused with slag cement which is defined in ASTM tentative specification C358–55 as a finely divided material consisting of water-quenched granulated blast-furnace slag and hydrated lime.

[4] The term b/b_o is defined as "the dry, rodded volume of coarse aggregate in a unit volume of concrete" in the article *A Method for Proportioning Concrete for Compressive Strength, Durability and Workability*, by A. T. Goldbeck and J. E. Gray. National Crushed Stone Association, Washington, D. C., Bulletin No. 11, Dec. 1942, p. 10.

Table 2.—Grading and physical properties of the aggregates

Grading and physical properties	White Marsh sand	Riverton limestone
GRADING OF AGGREGATES—PERCENTAGE PASSING SIEVES		
Sieve size		
1-inch	------	100
¾-inch	------	70
½-inch	------	40
⅜-inch	100	24
No. 4	96	0
No. 8	79	------
No. 16	66	------
No. 30	50	------
No. 50	23	------
No. 100	7	------
Fineness modulus	2.79	7.06
PHYSICAL PROPERTIES OF AGGREGATES		
Bulk specific gravity:		
Dry	2.63	2.78
Saturated surface dry	2.65	2.79
Absorption percent	0.4	0.4
Strength ratio (Ottawa sand):		
Compressive strength:		
At 7 days percent	158	------
At 28 days do	167	------
Tensile strength:		
At 7 days do	106	------
At 28 days do	116	------
Los Angeles wear test, grading A, loss percent	------	20.2
Accelerated soundness, Na_2SO_4, loss percent	------	3.5

Mixing, Molding, and Curing Specimens

All mixing was done in an open pan-type laboratory mixer of 1¾-cubic foot capacity. Both fine and coarse aggregates were used in a wet condition and the amount of mixing water needed for each batch of concrete was corrected for the free water in the aggregates. The following mixing procedure was employed: The cement and the wet sand were mixed for 30 seconds and part of the required amount of water and all of the air-entraining solution were then added and mixed for 30 seconds. The wet coarse aggregate was then added with the necessary amount of additional water. The concrete was mixed for 2½ minutes after the addition of the coarse aggregate. Determinations of the slump and unit weight and air content by the pressure method were made. The portions of the concrete used for the slump and unit weight tests were returned to the concrete in the mixer and remixed for 15 seconds before the test specimens were prepared.

All beams were made in individual molds. Beams and cylinders that were to be tested after continuous moist curing were molded, cured, and tested in accordance with applicable AASHO procedures.

Specimens for outdoor exposure to determine the resistance of the concrete to scaling

Table 3.—Mix data for laboratory specimens

Cement		5½ gallons of water per sack of cement [1]				6½ gallons of water per sack of cement [1]				7½ gallons of water per sack of cement [1]			
Source	Type	Cement content	Slump	Air	Vinsol resin added	Cement content	Slump	Air	Vinsol resin added	Cement content	Slump	Air	Vinsol resin added
		Sacks/ cu. yd.	*Inches*	*Percent*	*Ml./sack*	*Sacks/ cu. yd.*	*Inches*	*Percent*	*Ml./sack*	*Sacks/ cu. yd.*	*Inches*	*Percent*	*Ml./sack*
A	I	6.07	2.9	5.5	18.8	4.94	2.6	5.4	20.6	4.15	2.1	5.7	20.8
A	IS	6.06	2.8	5.3	25.2	4.93	2.7	5.6	32.3	4.12	2.3	5.6	32.3
B	I	6.06	2.9	5.6	15.8	4.93	2.4	5.6	19.7	4.15	2.2	5.4	19.4
B	IS	6.04	2.7	5.2	38.2	4.91	2.6	5.5	48.3	4.14	2.3	5.2	49.3
C	I	6.09	3.3	5.4	18.1	4.94	2.4	5.5	20.7	4.16	2.1	5.4	23.2
C	IS	6.07	3.2	5.5	17.8	4.93	2.2	5.5	22.0	4.14	2.3	5.7	23.2
D	I	6.07	2.3	5.6	17.7	4.95	2.1	5.4	21.0	4.14	1.9	5.6	21.4
D	IS	6.06	1.3	5.5	26.5	[2] 5.14	2.0	5.4	29.2	4.15	1.6	5.7	30.7
E	I	6.09	2.8	5.4	19.3	4.94	2.2	5.5	22.2	4.15	2.0	5.4	23.9
E	IS	6.06	2.2	5.5	21.6	4.94	2.0	5.3	22.8	4.15	1.8	5.5	24.8

[1] Proportions by oven-dry weight except as noted: 5½ gal. mix=94-190-315, 6½ gal. mix=94-255-390, and 7½ gal. mix=94-325-460. (Each value in table is an average of 5 tests.)
[2] Proportions by oven-dry weight: 94-240-375.

caused by freezing and the removal of ice by calcium chloride were slabs 16 by 24 by 4 inches. A raised edge was cast around the perimeter of each slab. After being moist cured for 28 days under standard conditions, the slabs were placed in the exposure plot for freezing.

Beams for freezing and thawing in water by the slow cycle procedure described in ASTM Method C 292 were moist cured for 7 days, cured in laboratory air at 72° F. and 50 percent relative humidity for 14 days, and immersed in water for 7 days at 72° F.

Cylinders and beams that were cured intermittently for strength tests and beams that were cured intermittently for shrinkage tests were stored in moist air or water at 72° F. and in laboratory air at 72° F. and 50 percent relative humidity.

Discussion of Test Results

The results of tests for strength of continuously moist-cured specimens and of intermittently cured specimens are shown in tables 4–7. Data for sonic modulus of elasticity are given in table 8, and a comparison of the sonic and static moduli is given in table 9. Data for freezing and thawing tests are shown in table 10. Average values for strengths are shown in figures 1 and 2 and for shrinkage tests in figures 3 and 4. These data are discussed mainly by comparing the results of tests of concretes containing slag cement with those of concretes containing portland cement.

Strengths of Moist-Cured Specimens

The average compressive strengths of concretes given in table 4 show that the concretes containing slag cements from sources A, B, C, and D were about the same or greater at ages of 28 and 90 days than the strengths of corresponding concretes prepared with portland cements. In general, the strengths of the slag cement concretes were less than the corresponding portland cement concretes at ages of 3 and 7 days. In no case did the strengths of concrete made with slag cement E equal the strengths of concrete made with portland cement from the same source. With few exceptions, the strengths of concretes made with slag cement E did not equal those of corresponding concretes containing slag cements from any of the other sources.

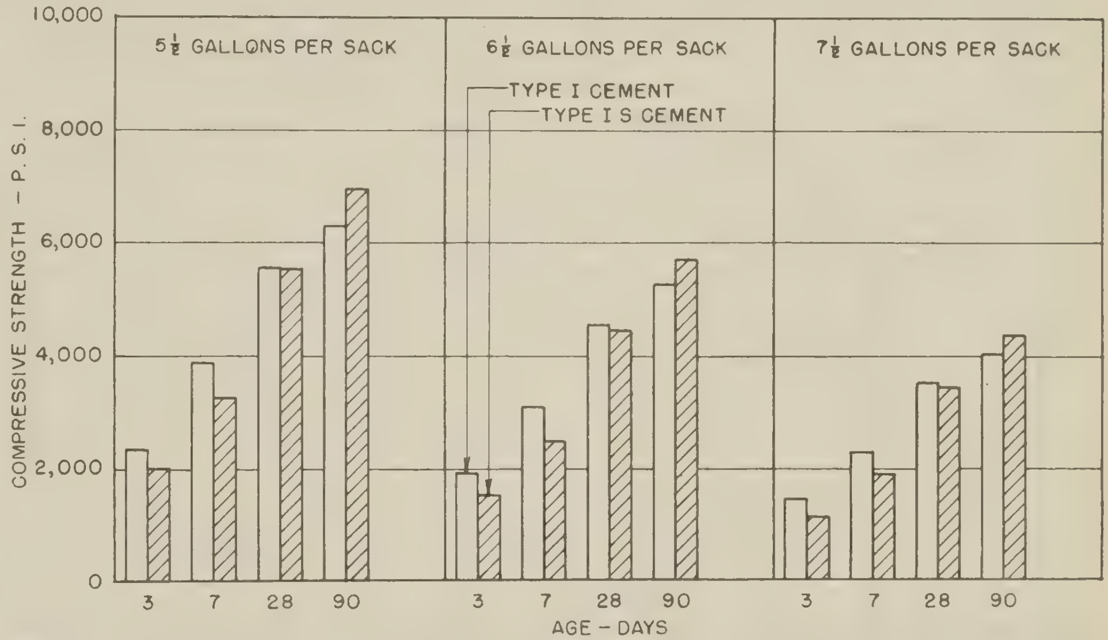


Figure 1.—Comparison of compressive strengths of concrete containing portland cements (type I) and portland blast-furnace slag cements (type IS) from 5 sources.

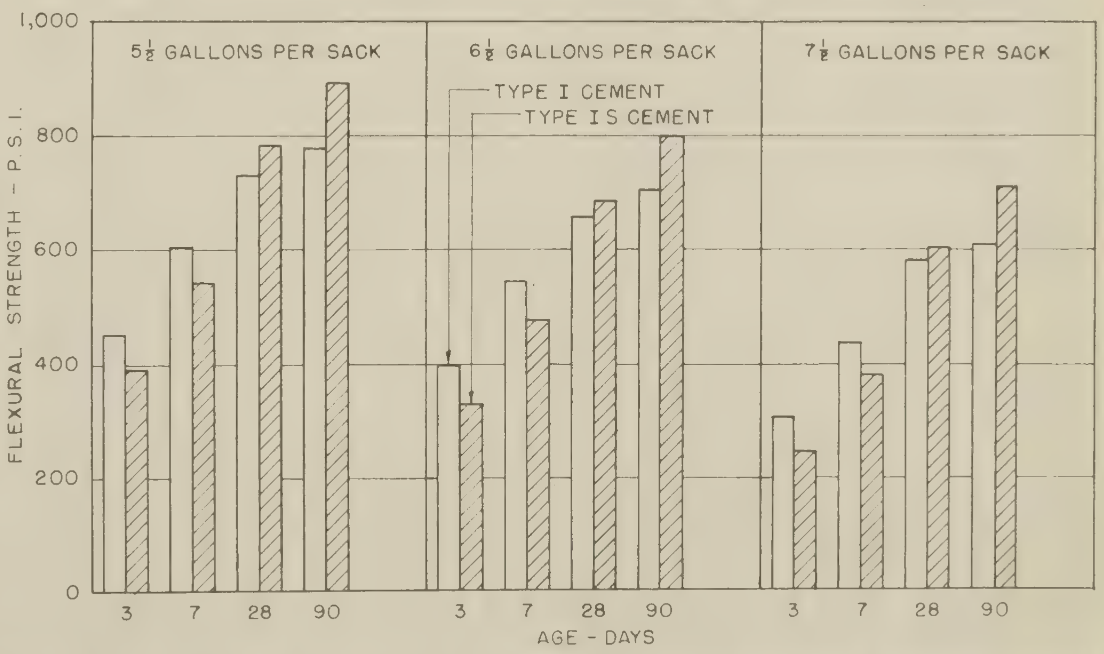


Figure 2.—Comparison of flexural strengths of concretes containing portland cements (type I) and portland blast-furnace slag cements (type IS) from 5 sources.

The average flexural strengths given in table 5 for all slag cement concretes are, in general, lower at 3 and 7 days and higher at 28 and 90 days than the strengths of the corre-

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Table 4.—Compressive strength tests on moist-cured specimens [1]

Cement		5½ gallons of water per sack of cement. Compressive strength after—				6½ gallons of water per sack of cement. Compressive strength after—				7½ gallons of water per sack of cement. Compressive strength after—			
Source	Type	3 days	7 days	28 days	90 days	3 days	7 days	28 days	90 days	3 days	7 days	28 days	90 days
		P. s. i.	*P. s. i.*	*P. s. i.*	*P. s. i.*	*P. s. i.*	*P. s. i.*	*P. s. i.*	*P. s. i.*	*P. s. i.*	*P. s. i.*	*P. s. i.*	*P. s. i.*
A	I	2,610	4,030	5,620	6,440	2,050	3,260	4,670	5,440	1,500	2,350	3,710	4,130
A	IS	2,340 (90)	3,810 (95)	5,940 (106)	7,140 (111)	1,770 (86)	3,060 (94)	4,960 (106)	6,170 (113)	1,320 (87)	2,250 (96)	3,780 (102)	4,720 114)
B	I	1,940	3,330	5,400	6,380	1,510	2,580	4,180	5,190	1,000	1,740	2,980	3,620
B	IS	1,940 (100)	3,020 (91)	5,790 (107)	7,640 (120)	1,440 (95)	2,310 (90)	4,560 (109)	6,460 (124)	1,070 (107)	1,770 (102)	3,700 (124)	4,970 (137)
C	I	2,070	3,710	5,070	5,500	1,770	2,950	4,100	4,650	1,320	2,240	3,250	3,640
C	IS	1,720 (83)	3,220 (87)	5,320 (105)	6,390 (116)	1,360 (77)	2,430 (82)	4,240 (102)	5,030 (108)	1,010 (77)	1,810 (81)	3,160 (97)	3,870 (106)
D	I	2,650	4,160	6,050	6,920	2,180	3,400	4,970	5,780	1,600	2,350	3,810	4,580
D	IS	2,110 (80)	3,390 (81)	6,150 (102)	7,600 (110)	1,630 (75)	2,440 (72)	4,860 (98)	6,110 (106)	1,230 (77)	2,120 (90)	3,670 (96)	4,720 (103)
E	I	2,680	4,150	5,660	6,240	2,200	3,310	4,790	5,320	1,750	2,760	3,860	4,150
E	IS	1,830 (68)	2,790 (67)	4,460 (79)	5,900 (95)	1,350 (61)	2,220 (67)	3,680 (77)	4,770 (90)	1,010 (58)	1,620 (59)	2,780 (72)	3,600 (87)
Average, type I		2,390	3,880	5,560	6,300	1,940	3,100	4,540	5,280	1,430	2,290	3,520	4,020
Average, type IS		1,990 (83)	3,250 (84)	5,530 (99)	6,930 (110)	1,510 (78)	2,490 (80)	4,460 (98)	5,710 (108)	1,130 (79)	1,910 (83)	3,420 (97)	4,380 (109)

[1] Figures in parentheses represent ratios (in percent) of the strength of the concrete containing type IS cement to the strength of the corresponding concrete containing type I cement. Each value is an average of 5 tests. Specimens, capped with neat Lumnite cement, were 6- by 12-inch cylinders stored in moist air until tested.

Table 5.—Flexural strength tests on moist-cured specimens [1]

Cement		5½ gallons of water per sack of cement. Flexural strength after—				6½ gallons of water per sack of cement. Flexural strength after—				7½ gallons of water per sack of cement. Flexural strength after—			
Source	Type	3 days	7 days	28 days	90 days	3 days	7 days	28 days	90 days	3 days	7 days	28 days	90 days
		P. s. i.	*P. s. i.*	*P. s. i.*	*P. s. i.*	*P. s. i.*	*P. s. i.*	*P. s. i.*	*P. s. i.*	*P. s. i.*	*P. s. i.*	*P. s. i.*	*P. s. i.*
A	I	495	605	730	760	420	560	635	695	315	425	590	605
A	IS	420 (85)	610 (101)	880 (121)	920 (121)	365 (87)	535 (96)	715 (113)	800 (115)	270 (86)	435 (102)	660 (112)	730 (121)
B	I	380	570	740	790	330	485	695	760	240	370	520	645
B	IS	395 (104)	520 (91)	750 (101)	885 (112)	305 (92)	440 (91)	690 (99)	800 (105)	235 (98)	365 (99)	640 (123)	780 (121)
C	I	410	550	630	695	345	505	565	600	270	430	530	530
C	IS	365 (89)	550 (100)	730 (116)	815 (117)	315 (91)	475 (94)	690 (122)	775 (129)	220 (81)	355 (83)	555 (105)	630 (119)
D	I	500	610	750	780	435	555	640	720	335	455	600	625
D	IS	400 (80)	525 (86)	775 (103)	925 (119)	345 (79)	485 (87)	730 (114)	835 (116)	275 (82)	395 (82)	630 (105)	760 (122)
E	I	495	670	805	855	440	620	730	745	355	490	670	635
E	IS	375 (76)	505 (75)	790 (98)	915 (107)	310 (70)	445 (72)	610 (84)	780 (105)	225 (63)	340 (69)	540 (81)	650 (102)
Average, type I		455	600	730	775	395	545	655	705	305	435	680	610
Average, type IS		390 (86)	540 (90)	785 (108)	890 (115)	330 (84)	475 (87)	685 (105)	800 (113)	245 (80)	380 (87)	605 (104)	710 (116)

[1] Figures in parentheses represent ratios (in percent) of the strength of concrete containing type IS cement to the strength of the corresponding concrete containing type I cement. Each value is an average of 5 tests. Specimens, stored in moist air until tested, were 6- by 6- by 21-inch beams tested in accordance with ASTM Method C-78 with third point loading on an 18-inch span—side as molded in tension.

sponding portland cement concretes. The superior strengths of concretes made with slag cement B as found in the compressive strength tests do not appear in the results for flexural strength. Slag cement from source E, however, showed better relative strengths in the tests for flexural strength than for compressive strength. The concretes prepared with slag cement E had lower compressive strengths than those prepared with portland cement E at all ages, but the flexural strengths obtained with the slag cement were higher than those for portland cement only at an age of 90 days.

Effect of Intermittent Curing on Strength

In table 6, comparisons are given showing the effect of intermittent or partial curing on the compressive strength of concrete. One group of specimens prepared with each cement was moist cured for 28 days. Other groups were moist cured for 1 or 7 days, followed by curing in laboratory air. Two groups were immersed in water for 24 hours immediately prior to testing, and one group was tested in an air-dry condition. As was expected, the specimens moist cured for 8 days or less failed to develop the strength of the specimens moist cured continuously. The specimens prepared with portland cement usually showed less reduction in strength than those containing slag cement, but the difference is not marked.

Similar tests for flexural strength are shown in table 7. These data show the same trend as found in tests for compressive strength in that the concrete specimens prepared with portland cement show less reduction in strength due to the intermittent or partial curing. However, 4 of 5 concretes prepared with portland cement and one prepared with

Table 6.—Compressive strength tests on specimens cured intermittently [1]

Cement		5½ gallons of water per sack of cement. Compressive strength after curing for—			
Source	Type	1 day moist, 27 days dry [2]	1 day moist, 26 days dry,[2] 1 day soak	7 days moist, 20 days dry,[2] 1 day soak	28 days moist [3]
		P. s. i.	*P. s. i.*	*P. s. i.*	*P. s. i.*
A	I	4,420 (77)	3,980 (69)	5,100 (88)	5,770
A	IS	4,080 (69)	3,760 (63)	5,360 (90)	5,940
B	I	3,420 (63)	3,050 (56)	4,660 (86)	5,400
B	IS	4,000 (67)	3.270 (55)	4,790 (81)	5,950
C	I	3,320 (64)	3,030 (59)	4,720 (91)	5,160
C	IS	3,180 (61)	2,840 (55)	4,490 (86)	5,200
D	I	4,140 (72)	3,620 (62)	5,260 (91)	5,790
D	IS	4,050 (69)	3,450 (59)	5,010 (86)	5,830
E	I	4,040 (75)	3,820 (70)	4,960 (92)	5,420
E	IS	3,700 (80)	2,870 (62)	4,180 (91)	4,600
Average, type I		3,870 (70)	3,500 (64)	4,940 (90)	5,510
Average, type IS		3,800 (69)	3,240 (59)	4,770 (87)	5,500

[1] Figures in parentheses represent the ratios (in percent) of the strength of the intermittently cured specimens (6- by 12-inch cylinders) to the strength of the 28-day moist-cured specimens. Each value is an average of 5 tests.
[2] Specimens capped with sulfur cement.
[3] Specimens capped with neat Lumnite cement.

Table 7.—Flexural strength tests on specimens cured intermittently [1]

Cement		5½ gallons of water per sack of cement. Flexural strength after curing for—			
Source	Type	1 day moist, 27 days dry	1 day moist, 26 days dry, 1 day soak	7 days moist, 20 days dry, 1 day soak	28 days moist
		P. s. i.	*P. s. i.*	*P. s. i.*	*P. s. i.*
A	I	435 (58)	565 (76)	715 (96)	745
A	IS	470 (54)	585 (67)	730 (83)	875
B	I	445 (63)	425 (60)	750 (106)	710
B	IS	470 (63)	515 (69)	785 (105)	745
C	I	445 (63)	420 (59)	710 (100)	710
C	IS	395 (51)	410 (53)	730 (95)	770
D	I	485 (64)	570 (75)	765 (101)	760
D	IS	490 (59)	465 (56)	815 (99)	825
E	I	480 (63)	570 (75)	785 (103)	765
E	IS	435 (55)	465 (59)	720 (91)	790
Average, type I		460 (62)	510 (69)	745 (101)	740
Average, type IS		450 (56)	490 (61)	755 (94)	800

[1] Figures in parentheses represent the ratios (in percent) of the strength of the intermittently cured specimens to the strength of the 28-day moist-cured specimens. Each value is an average of 5 tests. Specimens were 6- by 6- by 21-inch beams tested in accordance with ASTM Method C 78 with third point loading on an 18-inch span—side as molded in tension.

Table 9.—Comparison of sonic and static moduli of elasticity for concretes containing 7½ gallons of water per sack of cement and tested at 90 days

Cement		Sonic modulus of elasticity	Static modulus of elasticity
Source	Type		
		P. s. i. x 10^6	*P. s. i.* x 10^6
A	I	6.07	5.57
A	IS	6.16	5.90
B	I	6.00	5.42
B	IS	6.27	6.10
C	I	5.98	5.26
C	IS	6.20	5.60
D	I	6.04	5.90
D	IS	6.33	6.44
E	I	6.19	5.58
E	IS	6.11	5.64
Average, type I		6.06	5.55
Average, type IS		6.21	5.94

Table 8.—Sonic modulus of elasticity [1]

Cement		Sonic modulus of elasticity—pounds per square inch x 10^6													
		5½ gallons of water per sack of cement					6½ gallons of water per sack of cement					7½ gallons of water per sack of cement			
Source	Type	3 days	7 days	28 days	90 days	180 days	3 days	7 days	28 days	90 days	180 days	3 days	7 days	28 days	90 days
A	I	------	------	6.38	6.76	6.82	4.95	5.73	6.32	6.66	6.80	4.18	5.22	5.80	6.07
A	IS	------	------	6.17	6.70	6.84	4.79	5.45	6.04	6.71	6.92	3.85	4.86	5.72	6.16
B	I	------	5.70	6.46	6.52	6.62	4.44	5.44	6.19	6.57	6.79	3.66	4.84	5.62	6.00
B	IS	------	4.95	6.11	6.72	6.91	4.26	4.97	5.86	6.41	6.71	3.59	4.61	5.51	6.27
C	I	------	5.75	6.33	6.55	6.69	4.62	5.57	6.15	6.33	6.46	3.99	5.06	5.83	5.98
C	IS	------	5.65	6.39	6.57	6.67	4.38	5.42	6.20	6.57	6.76	3.65	4.72	5.73	6.20
D	I	------	6.08	6.43	6.69	6.75	4.91	5.69	6.27	6.59	6.72	4.36	5.19	5.89	6.04
D	IS	------	5.95	6.65	7.01	7.18	4.66	5.35	6.22	6.63	6.89	4.00	4.76	5.82	6.33
E	I	------	6.20	6.65	6.78	6.95	5.06	5.84	6.45	6.69	6.77	4.56	5.51	6.15	6.19
E	IS	------	5.57	6.27	6.54	6.91	4.58	5.30	5.97	6.59	6.81	3.94	4.73	5.67	6.11
Average, type I		------	5.93	6.45	6.65	6.77	4.80	5.65	6.28	6.57	6.69	4.15	5.16	5.86	6.06
Average, type IS		------	5.53	6.32	6.71	6.90	4.53	5.30	6.06	6.58	6.82	3.81	4.74	5.69	6.21

[1] Sonic modulus determined on 6- by 6- by 21-inch beams prior to testing for flexural strength. Specimens were continuously moist cured. Each value is an average of 5 or more tests.

slag cement developed as much or more strength when given the initial 7-day moist curing with 24 hours immersion in water prior to testing as when moist cured continuously. It is possible that these results were caused by the so-called "shell effect," where only the outer portion of the beam was wetted by the 24-hour immersion treatment before testing and the major portion of the beam was relatively dry. As failure to saturate the specimen thoroughly affects the flexural strength in many ways, it is unwise to consider that only 7 days initial moist curing for concrete is adequate for concrete tested under laboratory conditions. It should be emphasized that only one water-cement ratio (5½ gallons of water per sack of cement) was used in these intermittent curing tests for strength. The effect of this curing on mixes of higher or lower water-cement ratio might furnish somewhat different data.

Sonic Modulus of Elasticity

The data given in table 8 for sonic modulus of elasticity, in general, show the same trends as the tests for compressive strength. At

Table 10.—Results of freezing and thawing tests [1]

Cement		Percent of original N^2 after freezing and thawing for indicated cycles													
		5½ gallons of water per sack of cement									6½ gallons of water per sack of cement				
Source	Type	10 cycles	20 cycles	30 cycles	40 cycles	50 cycles	60 cycles	70 cycles	80 cycles	100 cycles	10 cycles	20 cycles	30 cycles	40 cycles	50 cycles
A	I	94	101	102	104	100	101	101	101	99	99	100	100	98	96
A	IS	99	104	102	107	102	104	105	106	106	101	102	103	103	101
B	I	97	104	102	103	99	103	102	99	100	100	100	100	98	96
B	IS	99	105	103	106	103	106	107	106	106	101	104	104	104	103
C	I	99	106	103	102	96	98	98	97	94	100	101	101	100	96
C	IS	101	105	102	105	103	103	104	103	102	100	102	103	102	101
D	I	100	104	104	103	102	103	101	101	98	101	103	103	100	96
D	IS	101	104	102	103	103	105	104	104	103	98	98	98	99	100
E	I	102	104	104	102	101	101	101	101	102	99	100	99	98	96
E	IS	98	102	102	102	101	104	104	105	105	101	102	103	102	100

[1] Specimens were 3- by 4- by 16-inch beams frozen and thawed in accordance with ASTM Method C-292 for slow freezing and thawing in water. Each value is an average of tests on 5 beams.

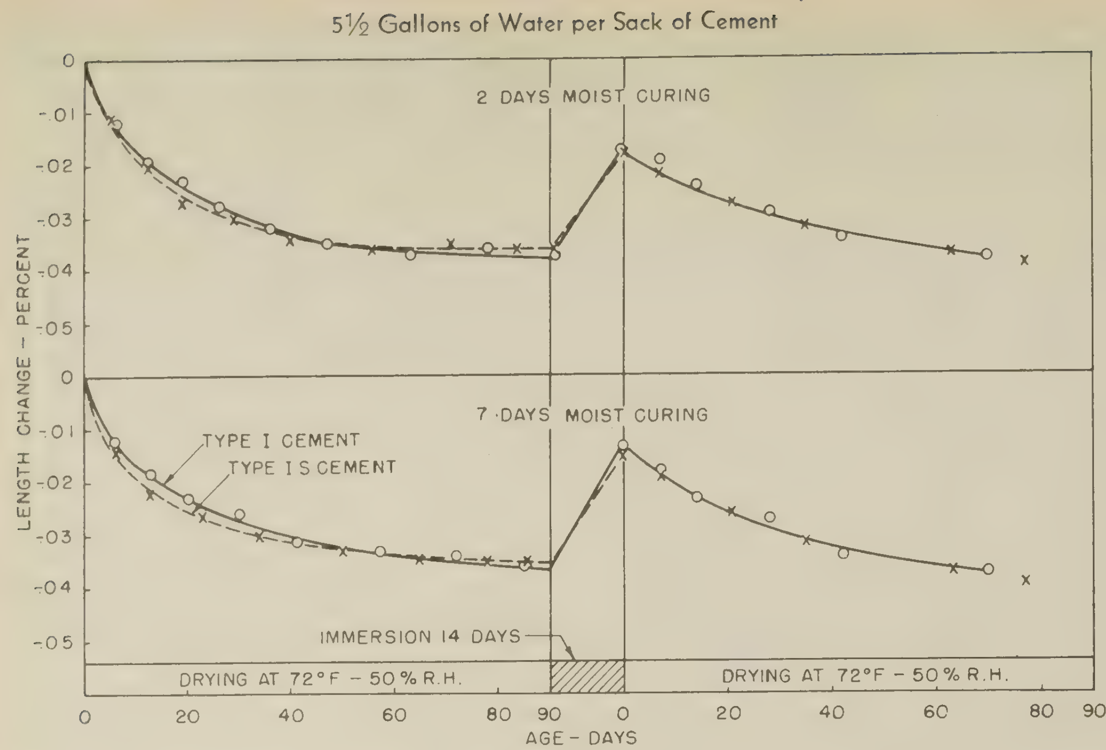

Figure 3.—Comparison of drying shrinkage of portland cement concrete (type I) and portland blast-furnace slag cement concrete (type IS) from 5 sources. (Water-cement ratio: 5½ gallons of water per sack of cement.)

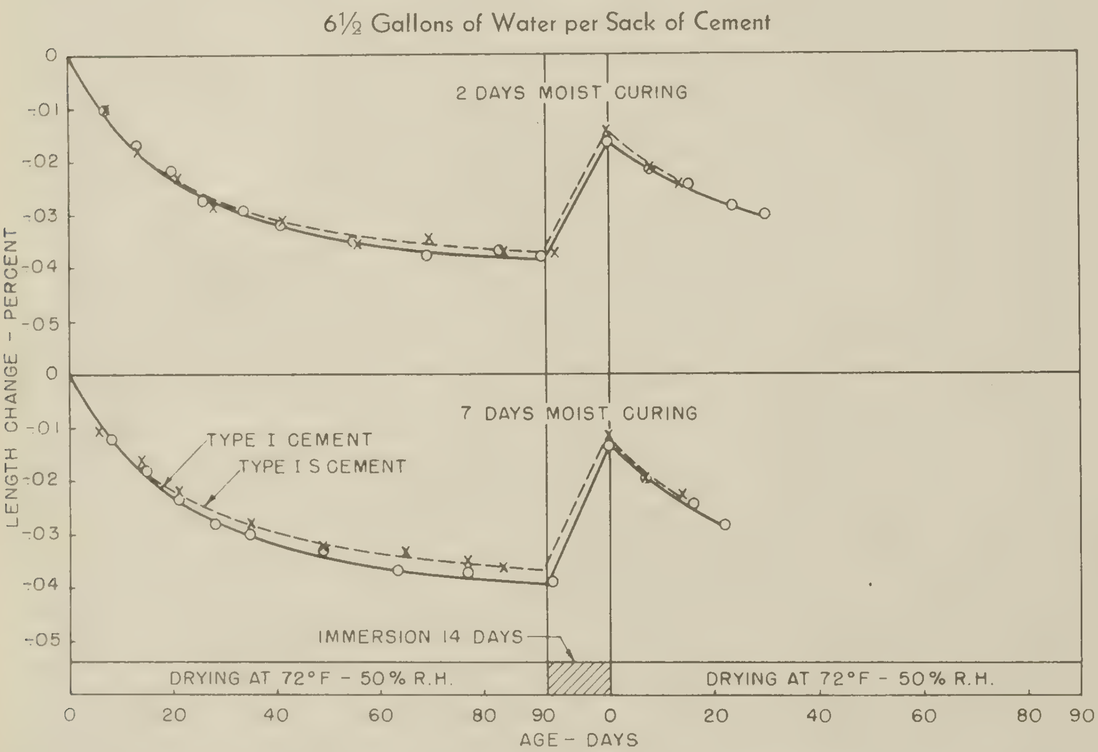

Figure 4.—Comparison of drying shrinkage of portland cement concrete (type I) and portland blast-furnace slag cement concrete (type IS) from 5 sources. (Water-cement ratio: 6½ gallons of water per sack of cement.)

ages of 3 and 7 days, the concretes prepared with portland cement have a higher average modulus than those made with slag cement. At an age of 28 days, the portland cement concretes have a slightly higher average modulus, but at greater ages the reverse is found. All concretes prepared with portland cement from source E, with one exception, have higher moduli than their equivalents prepared with slag cement. However, the moduli for the concretes prepared with slag cement from source E increased with age at a more rapid rate than those for concretes prepared with portland cement from the same source. It is expected that at an age of one year, the moduli for the slag cement concrete will be higher than those for portland cement concrete.

Static Modulus of Elasticity

The static modulus of elasticity was determined on a number of 6- by 12-inch cylinders that were molded from the same batches of concrete used to prepare beams on which the sonic modulus was determined. These concretes containing 7½ gallons of water per sack of cement were tested at an age of 90 days. The results are given in table 9.

It is interesting to note that the difference between the sonic and static moduli for the slag cement concretes is about one-half of that for the portland cement concretes. More extensive data for the static modulus of elasticity will be included in the final report.

Freezing and Thawing Tests

Freezing and thawing tests on concretes prepared with 5½ and 6½ gallons of water per sack of cement are being continued, and the results obtained thus far are shown in table 10. Although the values for N^2 show some slight differences between concretes prepared with the two types of cement, it would probably be desirable to defer consideration of these results until more significant values have been obtained.

Shrinkage Tests

Figures 3 and 4 show the average results of shrinkage tests for concrete prepared with the two types of cement and 5½ or 6½ gallons of water per sack of cement. Some of the specimens tested were moist cured for 2 days; others were moist cured for 7 days prior to the beginning of measurements for shrinkage. The specimens were stored in room air at 72° F. and 50 percent relative humidity for 90 days, and length measurements were made at frequent intervals. The specimens were then immersed in water for 14 days and a second determination of shrinkage made. The differences found to date between concrete specimens prepared with the two types of cement were too small to be significant. It appears that no more concern need be expressed over the shrinkage of concrete prepared with slag cement than over concrete prepared with portland cement, provided the amount of water used is kept within reasonable limits.

Scaling Tests with Calcium Chloride

Concrete slabs prepared with each of the cements for freezing and ice removal tests have been exposed to the atmosphere and subjected to five cycles of freezing and thawing. Although some scaling has already been noted, no qualitative estimates of the effect of the different cements on this scaling can be made.

Relation Between Gross Weights of Motor Trucks and Their Horsepower

BY THE DIVISION OF HIGHWAY TRANSPORT RESEARCH
BUREAU OF PUBLIC ROADS

Reported by CARL C. SAAL, Chief,
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This article discusses the results of a study made in 1950 of the relation between the gross weight and engine horsepower of commercial vehicles. Over 10,000 commercial vehicles, ranging in type from 2-axle trucks to 6- and 7-axle truck combinations, were sampled from the everday traffic in 39 States.

The primary purpose of the study was to develop average values of gross weight-horsepower ratios that could be used in conjunction with the results of studies of travel time, grade-climbing ability, and accelerating ability to estimate time savings to truck operators through more favorable location of highways. A secondary but important purpose was the determination of the impact of proposed minimum performance requirements of gross weight and horsepower on the trucking industry.

Previous studies of hill-climbing ability of commercial vehicles have indicated the futility of attempting to legislate and enforce performance requirements that would materially alleviate congestion caused by the slow-moving vehicles on hills. A minimum requirement in terms of weight and horsepower might be desirable, however, from the standpoint of safer vehicle operation; it is believed that the adoption of such a requirement would result in a better balance between the weight of the vehicle and the capabilities of its brakes, tires, and other components. A minimum requirement would also provide the highway engineer with a fixed base for establishing highway design standards.

For a ratio of 400 pounds gross weight per horsepower, a value commonly accepted as tolerable within the automotive industry and the one used for calculating performance for highway design purposes, the percentages of commercial vehicles in 1950 having weight-power ratios greater than 400:1 were as follows: 3-axle trucks, 10 percent; 2-axle truck-tractors with 1-axle semitrailers, 13 percent; 2-axle truck-tractors with 2-axle semitrailers, 41 percent; and all other combinations, 57 percent.

Comparisons of weight-power ratios by geographical regions and vehicle types show definitely that the ratios increase with the number of axles. It is also evident that weight-power ratios increase substantially with an increase in gross weight, irrespective of vehicle type.

Weight-power ratios, developed from 1955 data collected in a study of braking ability of commercial vehicles, show an overall improvement in performance of at least 10 percent during the period 1950–55.

IN 1950, each State highway department was asked to obtain information in conjunction with the annual loadometer survey that could be used to determine the ratio between gross vehicle weight and engine horsepower for commercial vehicles operating in the everyday traffic. In addition to the data usually recorded, the vehicle make, model, and year model were obtained for trucks and truck combinations at weighing stations located on routes having a heavy concentration of truck traffic.

Data were obtained from all except nine States (Florida, Idaho, Illinois, Kansas, Maryland, Michigan, Pennsylvania, Tennessee, and Wisconsin) and the District of Columbia. This survey of vehicles, selected at random, yielded a total sample of 10,726 vehicles of various types. The data collected in the annual loadometer surveys were supplemented by similar information obtained from brake tests on 782 vehicles in 1949 and 862 vehicles in 1955. The brake test data were used in the present study to investigate the trend in weight-power ratios.

Terminology

Four terms used in this article should be clearly understood. Definitions of the terms follow:

Gross horsepower.—The brake horsepower of the engine, operating without such accessories as fan, air compressor, generator, and muffler, that is available at the clutch or its equivalent.

Net horsepower.—The brake horsepower of the engine, operating with all its normal accessories, that is available at the clutch or its equivalent. It is the gross horsepower minus the horsepower absorbed by such accessories as fan, compressor, muffler, and generator.

Weight-power ratio.—The ratio of the gross weight of the vehicle or combination of vehicles to net horsepower of the powered unit. For example, if the gross weight of a vehicle is 60,000 pounds and the net horsepower is 150, the ratio is 400 pounds per horsepower.

Rate of rise and fall.—The total rise and fall for any section of highway divided by the length of section in hundreds of feet If the total rise and fall is 640 feet and the length of section is 20,000 feet, then the rate of rise and fall is 3.2 feet per 100 feet. It is not to be confused with the percent of grade. It is equivalent to the average percent of grade only when either the rise or fall is 100 percent of the total rise and fall.

Purpose of Investigation

The principal objective of the survey was to provide frequency distributions and average values of weight-power ratios that could

Table 1.—Cumulative frequency distribution of weight-horsepower ratios of 2-axle, 6-tire trucks weighed in the 1950 loadometer study

Region	Number of vehicles	Percentage of 2-axle, 6-tire trucks with weight-horsepower ratios less than—							Average ratio
		100	150	200	250	300	350	400	
New England	795	33.8	68.4	84.0	95.3	99.1	100.0	----	135
Middle Atlantic	100	22.0	59.0	73.0	91.0	97.0	100.0	----	154
South Atlantic (North)	170	40.6	62.9	80.0	92.9	99.4	100.0	----	139
South Atlantic (South)	336	47.3	66.3	82.1	93.4	99.1	100.0	----	131
East North Central	74	62.1	87.8	93.2	98.6	100.0	----	----	106
East South Central	330	45.8	70.0	82.7	94.8	99.1	99.7	100.0	130
West North Central	538	25.6	53.8	75.4	93.2	99.2	100.0	----	152
West South Central	769	33.7	73.5	90.2	97.7	99.4	100.0	----	129
Mountain	206	24.8	53.9	74.8	88.4	96.6	100.0	----	156
Pacific	324	35.2	70.4	82.7	96.3	99.7	100.0	----	133
United States total	3,642	35.1	66.5	82.8	94.8	99.0	99.9	100.0	135

Table 2.—Cumulative frequency distribution of weight-horsepower ratios of 2-axle truck-tractors with 1-axle semitrailers weighed in the 1950 loadometer study

Region	Number of vehicles	Percentage of 2-axle truck-tractors with 1-axle semitrailers having weight-horsepower ratios less than—											Average ratio
		100	150	200	250	300	350	400	450	500	550	600	
New England	900	------	5.3	22.5	35.7	55.8	77.7	90.8	97.9	99.3	99.9	100.0	281
Middle Atlantic	290	0.3	2.4	15.2	27.6	39.0	56.9	76.6	90.7	97.6	98.3	98.6	324
South Atlantic (North)	217	1.9	8.0	20.1	33.1	50.3	74.0	90.3	98.2	99.1	100.0	------	288
South Atlantic (South)	467	.2	4.5	22.7	34.0	52.0	80.0	93.1	97.4	100.0	------	------	281
East North Central	118	------	5.1	17.8	30.5	46.6	72.0	89.8	97.4	99.1	100.0	------	295
East South Central	306	1.0	6.9	30.4	39.9	55.9	76.5	91.8	97.7	99.3	100.0	------	274
West North Central	755	------	2.2	11.9	21.7	34.0	57.3	82.5	92.7	98.0	99.6	99.7	325
West South Central	601	1.7	6.7	29.7	44.8	53.8	70.6	86.1	95.9	99.4	99.9	99.9	281
Mountain	198	.5	6.6	13.2	27.3	48.5	70.7	86.4	93.0	98.5	99.5	100.0	302
Pacific	48	10.0	26.0	70.0	74.0	82.0	90.0	92.0	98.0	98.0	100.0	------	208
United States total	3,900	.7	5.3	21.6	33.8	49.1	70.8	87.6	95.8	99.0	99.7	99.8	294

Table 3.—Cumulative frequency distribution of weight-horsepower ratios of truck combination units with 4 or more axles weighed in the 1950 loadometer study

Region	Number of vehicles	Percentage of combination units with 4 or more axles having weight-horsepower ratios less than—										Average ratio
		150	200	250	300	350	400	450	500	550	600	
New England	110	0.9	12.7	20.9	33.6	50.0	68.2	79.1	90.9	93.6	95.4	352
Middle Atlantic	131	------	5.3	16.8	27.5	37.4	57.3	81.7	93.9	97.7	98.5	367
South Atlantic (North)	168	1.2	14.3	19.7	32.8	52.4	72.0	86.9	95.8	97.0	97.6	342
South Atlantic (South)	85	2.4	17.7	31.8	47.1	65.9	75.3	87.1	93.0	97.7	97.7	316
East North Central	97	3.1	14.4	25.7	29.8	35.0	43.3	55.7	69.1	77.3	87.6	416
East South Central	79	5.0	27.8	36.7	44.3	54.4	69.6	82.3	92.4	94.9	100.0	323
West North Central	916	.2	6.3	16.4	25.4	36.5	52.4	67.7	82.3	91.9	96.2	386
West South Central	347	2.3	13.0	25.1	30.9	40.1	52.8	73.8	88.8	95.7	97.4	344
Mountain	597	.8	8.9	21.1	31.8	39.5	53.5	65.3	79.2	90.9	97.1	381
Pacific	152	1.3	8.5	33.5	37.4	42.7	54.6	69.1	78.3	94.1	98.0	364
United States total	2,682	1.1	9.9	21.4	30.5	41.0	55.8	71.0	84.2	92.8	96.6	371

be correlated with the results of other studies of travel time, grade-climbing ability, and accelerating ability of trucks. For example, the results of this study may be used in conjunction with the relations established between travel time and weight-horsepower ratios in a previous article [1] in order to estimate the savings in time that accrue to truck operators

[1] *Time and gasoline consumption in motor truck operation as affected by the weight and power of vehicles and the rise and and fall in highways*, by Carl Saal. Highway Research Board Research Report No. 9-A, February 1950.

Table 4.—Summary of average weight-horsepower ratios and gross weights for single-unit trucks

Region	2-axle, 4-tire			2-axle, 6-tire			3-axle		
	Number of vehicles	Average ratio	Average weight	Number of vehicles	Average ratio	Average weight	Number of vehicles	Average ratio	Average weight
New England	119	73	5,700	795	135	12,500	39	227	21,800
Middle Atlantic	-----	-----	-----	100	154	15,300	21	290	27,900
South Atlantic (North)	5	67	5,600	170	139	12,700	53	262	25,500
South Atlantic (South)	3	87	7,300	336	131	11,900	3	209	17,000
East North Central	2	47	5,800	74	106	9,300	6	117	11,000
East South Central	6	78	6,900	330	130	11,500	51	185	16,800
West North Central	8	108	8,600	538	152	12,100	28	332	30,300
West South Central	52	73	6,100	769	129	11,400	13	240	25,100
Mountain	9	67	5,800	206	156	13,800	19	271	32,100
Pacific	35	76	6,100	324	133	11,800	30	232	26,400
United States total	239	75	6,000	3,642	135	12,100	263	244	24,100

Table 5.—Summary of average weight-horsepower ratios and gross weights for truck-tractors with semitrailers

Region	2-axle truck-tractor with 1-axle semitrailer			2-axle truck-tractor with 2-axle semitrailer			3-axle truck-tractor with 2-axle semitrailer		
	Number of vehicles	Average ratio	Average weight	Number of vehicles	Average ratio	Average weight	Number of vehicles	Average ratio	Average weight
New England	900	281	36,500	109	347	48,700	1	865	77,400
Middle Atlantic	290	324	40,000	131	367	49,300	-----	-----	-----
South Atlantic (North)	217	288	33,000	165	342	45,100	2	264	48,000
South Atlantic (South)	467	281	31,100	85	316	39,300	-----	-----	-----
East North Central	118	295	29,500	55	367	39,600	2	585	63,000
East South Central	306	274	28,300	78	322	39,200	1	357	40,000
West North Central	755	325	32,400	773	385	46,100	141	395	51,200
West South Central	601	281	27,400	339	341	42,100	8	484	67,900
Mountain	198	302	31,600	215	327	43,000	290	421	58,800
Pacific	48	208	21,000	41	344	41,100	38	372	53,700
United States total	3,900	294	31,600	1,991	357	44,500	483	411	56,300

through more favorable location of a highway.

A secondary but important purpose was to provide means for determining the impact of proposed minimum performance requirements on the trucking industry. In this phase, the results may be used to find the percentage of vehicles that would be affected by the 450-pound gross weight per net horsepower performance requirement recently enacted in Pennsylvania. This may also be done in the case of a requirement expressed in x miles per hour on a y percent grade, since hill-climbing ability is proportional to the ratio. A ratio of 450 is roughly equivalent to 20 miles per hour on a 2½-percent grade.

If performance requirements are to be enacted, the use of a weight-power ratio instead of a grade-climbing ability expression is recommended. A weight-power ratio does not impose limitations on vehicle design and operation and may be practically enforced by weighing the vehicle.

A performance requirement should not be predicated on the idea that it would eliminate the congestion that results from slow-moving vehicles on hills. The results of hill-climbing studies [2] conducted by the Bureau of Public Roads and the Arizona Highway Department have shown the futility of trying to legislate and enforce a requirement that would materially alleviate congestion. It is believed that the eventual solution must be preceded by the recognition of the following conditions: (1) The operating characteristics of freight

[2] *Hill-climbing ability of motor trucks*, by Carl C. Saal. Public Roads, vol. 23, No. 3, May 1942. *Survey of uphill speeds of trucks on mountain grades*, by Wm. E. Willey. Proceedings of the Twenty-Ninth Annual Meeting of the Highway Research Board, 1949, pp. 304–310; also *Truck congestion on uphill grades*, Highway Research Board Bulletin 104, 1955, pp. 21–33.

Table 6.—Summary of average weight-horsepower ratios and gross weights for trucks with trailers and truck-tractors with semitrailers and trailers

Region	2-axle truck with 2-axle trailer			5-axle combinations of trucks with trailers and truck-tractor-semitrailers and trailers			6- and 7-axle combinations of trucks with trailers and truck-tractor-semitrailers and trailers		
	Number of vehicles	Average ratio	Average weight	Number of vehicles	Average ratio	Average weight	Number of vehicles	Average ratio	Average weight
South Atlantic (North)	-----	-----	-----	-----	-----	-----	1	467	56,000
East North Central	11	532	60. 100	27	459	53,400	2	368	62. 500
West North Central	1	340	62,300	-----	-----	-----	1	384	70,300
Mountain	7	373	42,800	61	365	51,700	24	430	62,300
Pacific	1	422	43,500	48	366	50,500	24	384	53,100
United States total	20	461	53,300	136	384	51,600	52	406	58,100

Table 7.—Summary of average weight-horsepower ratios and gross weights for 2-axle trucks with 2-axle trailers and combination vehicles with 5 or more axles

Region	Number of vehicles	Average ratio	Average weight
New England	1	865	77,400
South Atlantic (North)	3	332	50,700
East North Central	42	480	56,100
East South Central	1	357	40,000
West North Central	143	394	51,400
West South Central	8	484	67,900
Mountain	382	412	57,600
Pacific	111	373	52,100
United States total	691	407	55,400

Table 8.—Variation of weight-horsepower ratios and gross weights for all commercial vehicle types

Region	Number of vehicles	Average weight-power ratios for gross weights (in 1,000 pounds) ranging from—									Average weight-power ratios
		3.0 to 9.9	10.0 to 19.9	20.0 to 29.9	30.0 to 39.9	40.0 to 49.9	50.0 to 59.9	60.0 to 69.9	70.0 to 79.9	80.0 to 89.9	
New England	1,963	86	155	216	275	336	387	434	574	--------	212
Middle Atlantic	542	93	160	214	306	370	404	446	474	--------	302
South Atlantic (North)	613	88	158	231	312	354	431	436	--------	460	257
South Atlantic (South)	894	84	166	242	320	357	467	--------	--------	--------	227
East North Central	297	85	163	252	338	424	488	566	643	--------	282
East South Central	772	95	162	252	342	372	434	454	--------	--------	210
West North Central	2,245	92	172	250	342	390	455	495	538	597	308
West South Central	1,782	91	162	243	356	400	461	498	585	634	221
Mountain	1,029	88	163	240	284	363	408	471	521	573	316
Pacific	589	88	158	218	280	371	439	471	508	--------	201
United States total	10,726	89	162	237	320	368	433	475	532	568	253

and passenger vehicles are definitely dissimilar; (2) the two classes cannot be designed to approach similarity in the foreseeable future without grave injustice to one or both; (3) the public interest requires that highways provide adequately for both classes of vehicles; and (4) by appropriate highway design, both can be provided for without undue interference in their movement over the highways.

A minimum performance requirement in terms of weight and power is believed to be desirable. However, this position is based primarily on the belief that the adoption of such a requirement would result in a better balance between the weight of a vehicle and the capabilities of its brakes, tires, and other components. An improved balance between design capacities of such components and gross vehicles weights should result in safer vehicle operation. It would also give the highway engineer a fixed base for establishing highway design standards to accommodate both freight and passenger vehicles efficiently.

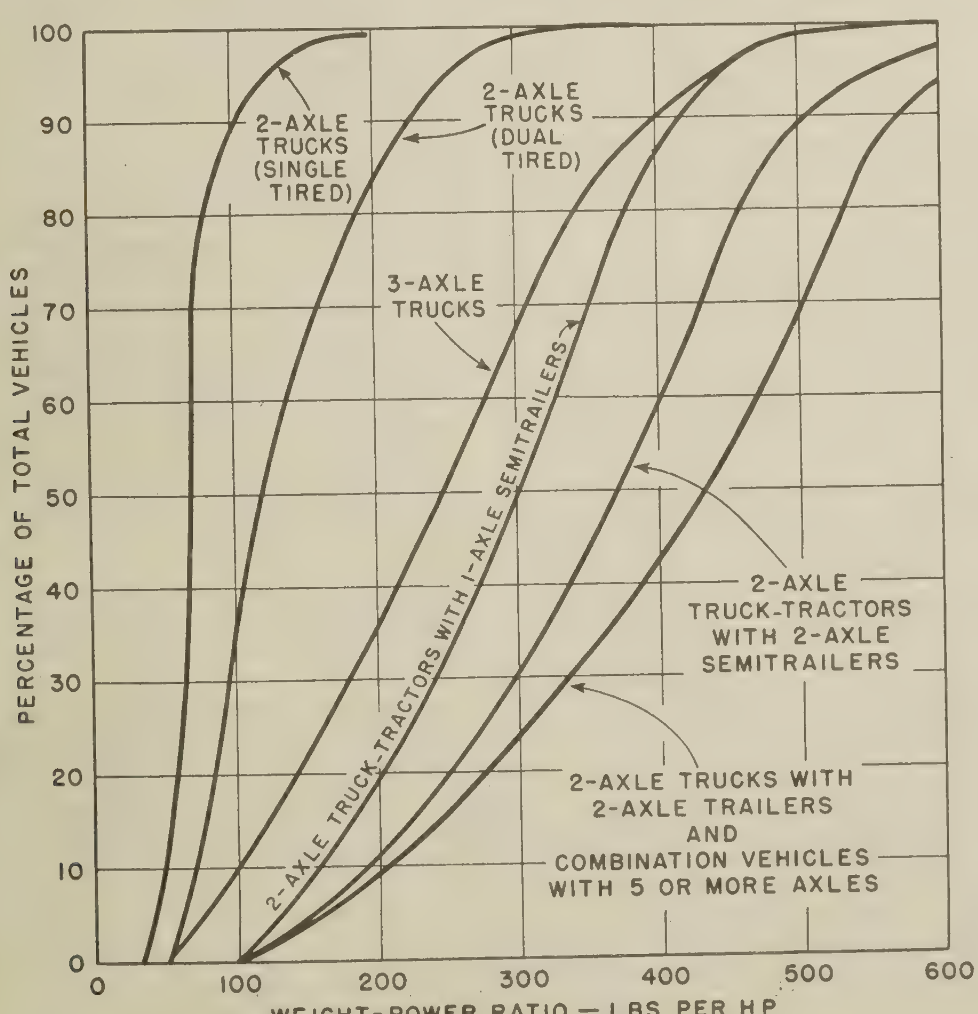

Figure 1.—Cumulative frequency distributions of weight-power ratios for commercial vehicles weighed in the 1950 loadometer study.

Vehicle Type Code

In some instances it is convenient to describe vehicle types by the codes generally used. Each digit indicates the number of axles of a vehicle or of a unit of a vehicle combination. A single digit, or the first digit of a group symbol, represents a single-unit truck, and if followed by an "S," it represents a truck-tractor. The "S" designation, of course, represents a semitrailer. A digit without an "S," in the second or third position in a group symbol, represents a full trailer.

2 =2-axle single-unit truck
3 =3-axle single-unit truck
2-S1 =2-axle truck-tractor with 1-axle semitrailer
2-S2 =2-axle truck-tractor with 2-axle semitrailer
3-S2 =3-axle truck-tractor with 2-axle semitrailer
2-2 =2-axle truck with 2-axle trailer
2-3 =2-axle truck with 3-axle trailer
3-2 =3-axle truck with 2-axle trailer
3-3 =3-axle truck with 3-axle trailer
2-S1-2=2-axle truck-tractor with 1-axle semitrailer and 2-axle trailer
2-S2-2=2 axle truck-tractor with 2-axle semitrailer and 2-axle trailer
2-S2-3=2-axle truck-tractor with 2-axle semitrailer and 3-axle trailer
3-S1-2=3-axle truck-tractor with 1-axle semitrailer and 2-axle trailer

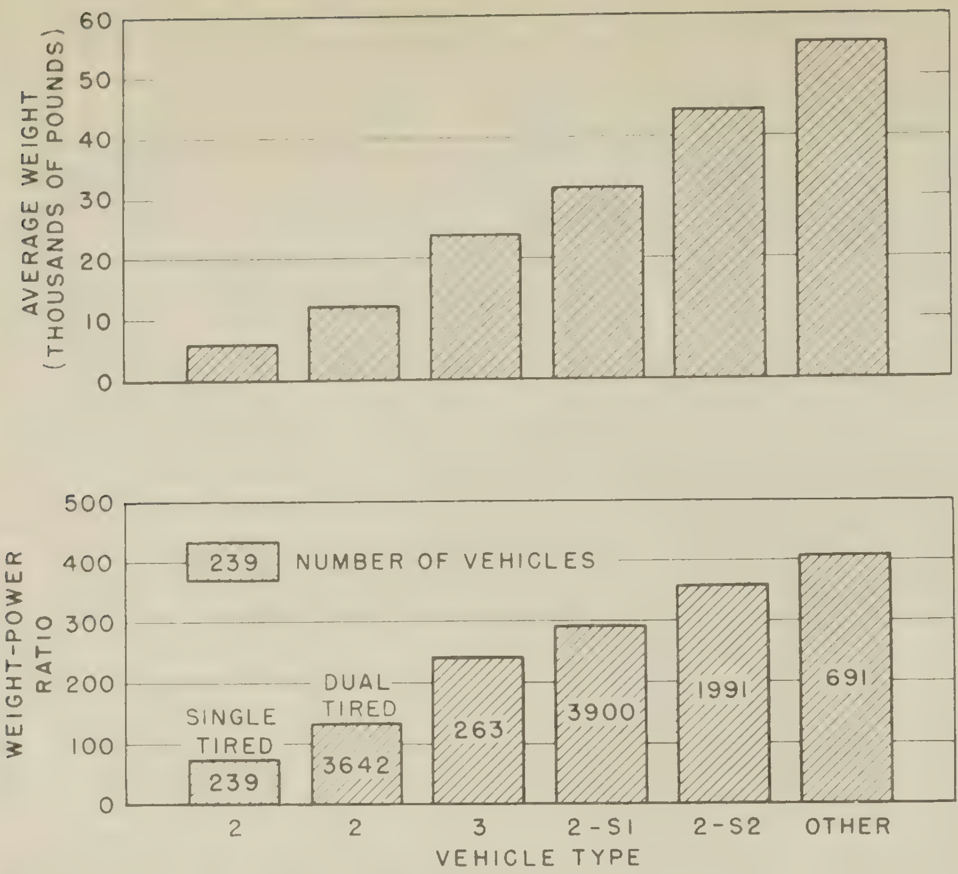

Figure 2.—Average weight-power ratios and gross weights for commercial vehicles weighed in the 1950 loadometer study.

Procedure Followed

The first step in the analysis was the determination of the net horsepower for each of the vehicles sampled. This was accomplished by using vehicle specifications, furnished by individual manufacturers and the Automobile Manufacturers Association, in conjunction with the make and model recorded in the field. In those instances, where it was possible to find only the gross horsepower, the net horsepower was assumed to be 90 percent of that value. The weight-power ratio was then calculated by dividing the gross weight by the net horsepower.

The next step was to group the sample data according to vehicle type. This step was followed by further subdividing the sample for each vehicle type by geographical regions. These regions, omitting the States not reporting, were composed as follows:

New England.—Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont. *Middle Atlantic.*—New Jersey and New York. *South Atlantic (North).*—Delaware, Virginia, and West Virginia. *South Atlantic (South).*—Georgia, North Carolina, and South Carolina. *East North Central.*—Indiana and Ohio. *East South Central.*—Alabama, Kentucky, and Mississippi. *West North Central.*—Iowa, Minnesota, Missouri, Nebraska, North Dakota, and South Dakota. *West South Central.*—Arkansas, Louisiana, Oklahoma, and Texas. *Mountain.*—Arizona, Colorado, Montana, Nevada, New Mexico, Utah, and Wyoming. *Pacific.*—California, Oregon, and Washington.

When the sample had been sorted by vehicle type and region, three types of analyses were made. Frequency distributions of weight-power ratios grouped in class intervals of 50 pounds gross weight per horsepower were first made for each vehicle type by region and total sample. Then the average weight and ratio were determined for each vehicle type by region and total sample. A third analysis was made to determine the relation existing between the ratio and gross weight. This was accomplished by distributing the vehicles by type and geographical region into class intervals of 10,000 pounds gross weight and by calculating an average ratio for each class interval.

Results of Survey

The cumulative frequency distributions of the weight-power ratios by regions are shown in table 1 (p. 233) for the 2-axle, 6-tire trucks; in table 2 for the 2-axle truck-tractors with 1-axle semitrailers; and in table 3 for combination vehicles with 4 or more axles. Also shown in this series of tables are the average ratios and the number of vehicles in the sample. The 2-axle, 4-tire trucks and the 3-axle trucks are not considered because of the small sample in most regions.

A summary of the cumulative frequency distributions for the several types of vehicles is shown in figure 1. For a ratio of 400 pounds gross weight per horsepower, a value commonly accepted as tolerable within the automotive industry and the one used for calculating performance for highway design purposes, the cumulative percentages of vehicles having ratios less than 400 pounds per horsepower were as follows: 100 percent for both 2-axle, 4- and 6-tire trucks, 90 percent for 3-axle trucks, 87 percent for 2-axle truck-tractors with 1-axle semitrailers, 59 percent for 2-axle truck-tractors with 2-axle semitrailers, and 43 percent for all the other combination vehicles. The comparison in figure 1 indicates that the hill-climbing and accelerating ability of commercial vehicles vary considerably for the different vehicle types. This dissimilarity in power characteristics is analogous with braking ability [3] for the various types of commercial vehicles selected from the everyday traffic.

Tables 4–7 give the average ratios and weights for each vehicle type by geographical regions. National totals by vehicle types are

[3] *Braking performance of motor vehicles*, by Carl C. Saal and F. William Petring. Published by the Bureau of Public Roads, 1954.

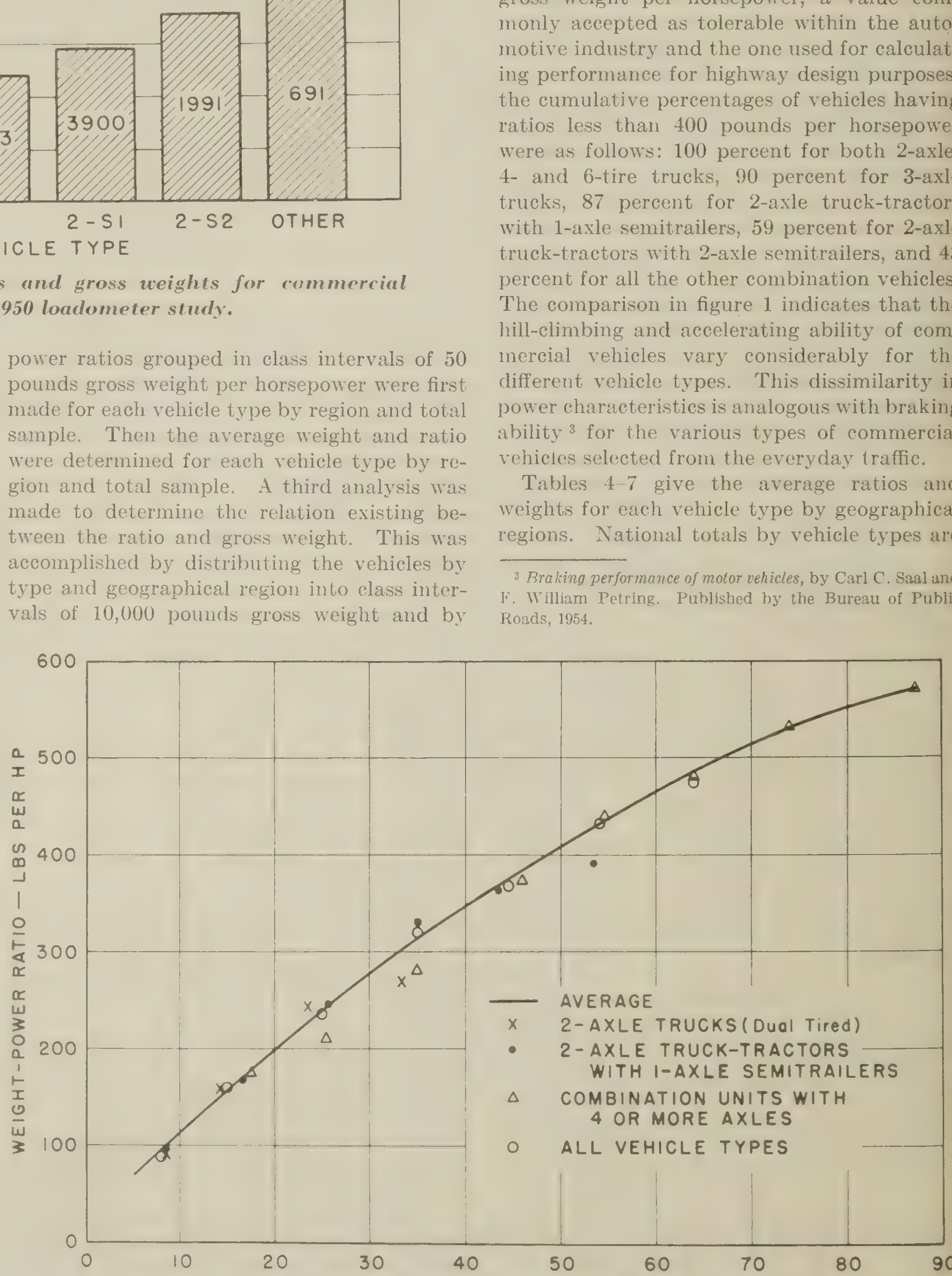

Figure 3.—Relation of weight-power ratios and gross weights for commercial vehicles weighed in the 1950 loadometer study.

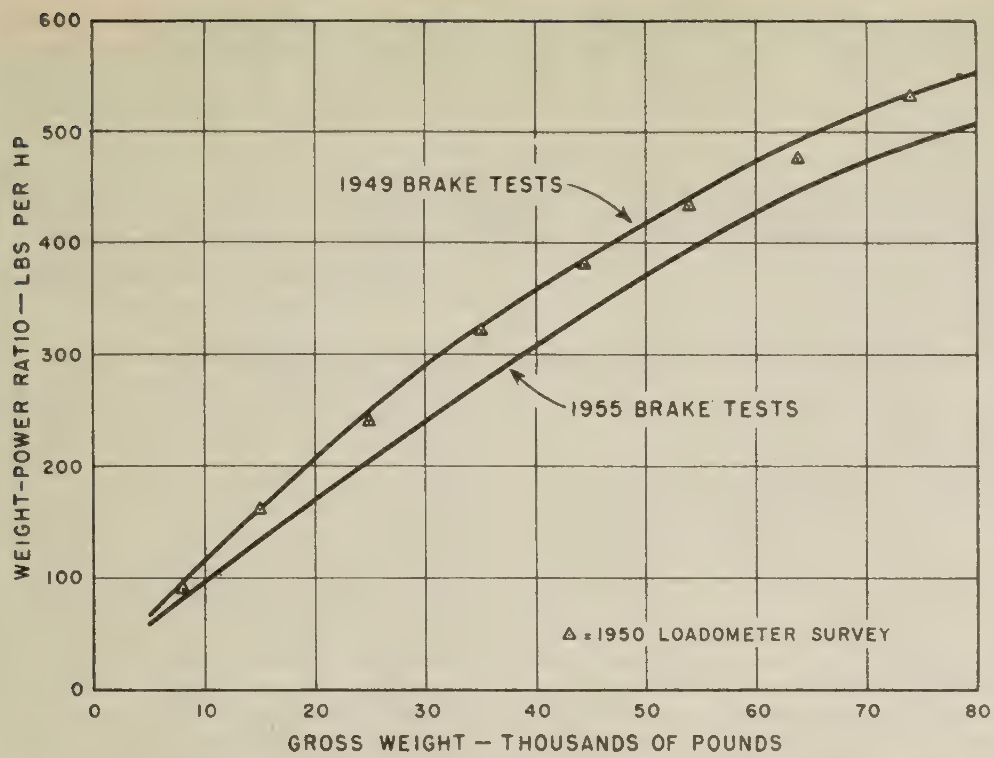

Figure 4.—Trends in weight-power ratios from 1949 to 1955, based on average data for all commercial vehicle types.

compared in figure 2. This presentation of the data emphasizes again the wide variation in performance that may be expected of the various vehicle types. There is a definite increase in weight-power ratios with an increase in the number of axles.

The data in table 8 show that the ratios increase with an increase in gross weight. It is further indicated in figure 3 that the same relation exists, irrespective of vehicle type.

Trend in Ratios

The levels of performance indicated by the ratios presented thus far in this article are on the conservative side for two reasons. It is rather common for a commercial truck manufacturer to have several optional engine sizes for a particular chassis model. The model of the engine installed was sometimes difficult for the weighing party to determine, and where there was any doubt, the net horsepower for the smallest engine size was used in computing the ratio. A second reason for the conservative evaluation is the age of the data which were collected over 5 years ago. During this period there has been a decided upward trend in net engine horsepower which has been offset to some extent by an increase in gross vehicle weights.

In studies conducted by the Arizona Highway Department,[4] it was reported that the crawl speed of heavily loaded over-the-road combinations climbing a 6-percent grade increased from 7 miles per hour in 1948 to 12.5 in 1952, an improvement of about 78 percent. However, the data from the brake tests shown in figure 4 indicate that the ratios have probably not decreased in this proportion for the country as a whole, although there has been an appreciable improvement.

[4] See footnote 2, p. 234.

The curves in figure 4, which are similar to the one presented in figure 3, were plotted from data recorded at a location in Maryland, Michigan, and California. The points in figure 3, which represent the average ratios for all vehicles sampled in 1950, are also plotted in figure 4 (triangular symbols). It is apparent that the average ratios derived from the 1950 loadometer study follow closely the curve for the 1949 brake test data.

The improvement in ratios indicated by figure 4 amounts to about 15 percent in the average ratio for gross weights ranging from 10,000 to 40,000 pounds. Above that weight, the improvement decreases to about 8 percent for a gross weight of 80,000 pounds. It may be stated that the improvement, which represents a decrease in the ratio, averages at least 10 percent.

Table 9 compares the 1950 average ratios for the various vehicle types with those obtained from the 1949 and 1955 brake test samples of vehicles. In general, there is close agreement between the 1949 and 1950 values as was the case in figure 4. This is indicated by the rather small variation, except in a few instances, between the percentage improvement from 1949 to 1955 and from 1950 to 1955. The exceptions occur where the samples were very small. The overall improvement between 1949 and 1955 was about 12 percent, which checks closely with that estimated from the curves plotted in figure 4.

Another check on the trend in weight-power ratios was made by comparing the 1950 and 1955 percentile values obtained from cumulative frequency distributions of the ratios for the various types of vehicles. A comparison of 15-, 50-, and 85-percentile values read from figure 1 for 1950 and figure 5 for 1955 indicated that the overall improvement was negative in the case of 2-axle, 6-tire trucks; very slight for 3-axle trucks, 2-axle trucks with

Table 9.—Comparison of average weight-power ratios by vehicle types for 1949, 1950, and 1955

Vehicle type [1]	Number of vehicles			Average weight-power ratios			Percentage improvement in weight-power ratios	
	1949	1950	1955	1949	1950	1955	1949–55	1950–55
Single-unit trucks:								
2-axle, 4-tire	19	239	99	81	75	57	30	24
2-axle, 6-tire	275	3,642	272	142	135	142	-------	−5
3-axle	38	263	67	227	244	231	−2	5
Truck-tractors with semitrailers:								
2–S1	228	3,900	117	291	294	264	9	10
2–S2	87	1,991	145	369	357	301	18	16
3–S2	46	483	57	422	411	348	18	15
Other truck combinations:								
2–2	8	20	17	405	461	331	18	28
2–3, 3–2, and 2–S1–2	51	136	71	394	384	418	−6	−9
3–3, 2–S2–2, and 3–S2–2	30	52	17	434	406	416	4	−2
Total vehicles	782	10,726	862	----	----	----	-------	-------
Weighted averages	----	------	----	260	253	228	12	10

[1] For an explanation of code, see p. 235.

Table 10.—Example for determining daily time savings by using weight-power ratios calculated for different gross vehicle weight groups

Gross vehicle weight		Number of vehicles	Weight-power ratio [1]	Composite travel time [2]			Time saved per vehicle	Total time saved
Class interval	Average			Route A	Route B	Savings		
1,000 lbs.	*Pounds*			*Min./mile*	*Min./mile*	*Min./mile*	*Minutes*	*Hours*
5–14.9	9,800	545	100	1.40	1.25	0.15	15.0	136
15–24.9	19,600	485	170	1.75	1.40	.35	35.0	284
25–34.9	29,300	176	240	2.10	1.60	.50	50.0	146
35–44.9	41,000	111	310	2.40	1.75	.65	65.0	120
45–54.9	48,300	91	350	2.65	1.85	.80	80.0	121
55 and over	59,900	32	410	2.95	2.10	.85	85.0	45
Total	------	1,440	------	------	------	------	------	852

[1] Weight-power ratios from fig. 3 multiplied by 0.88.
[2] Rate of rise and fall: Route A, 3.7; Route B, 2.3. Each route was 100 miles long.

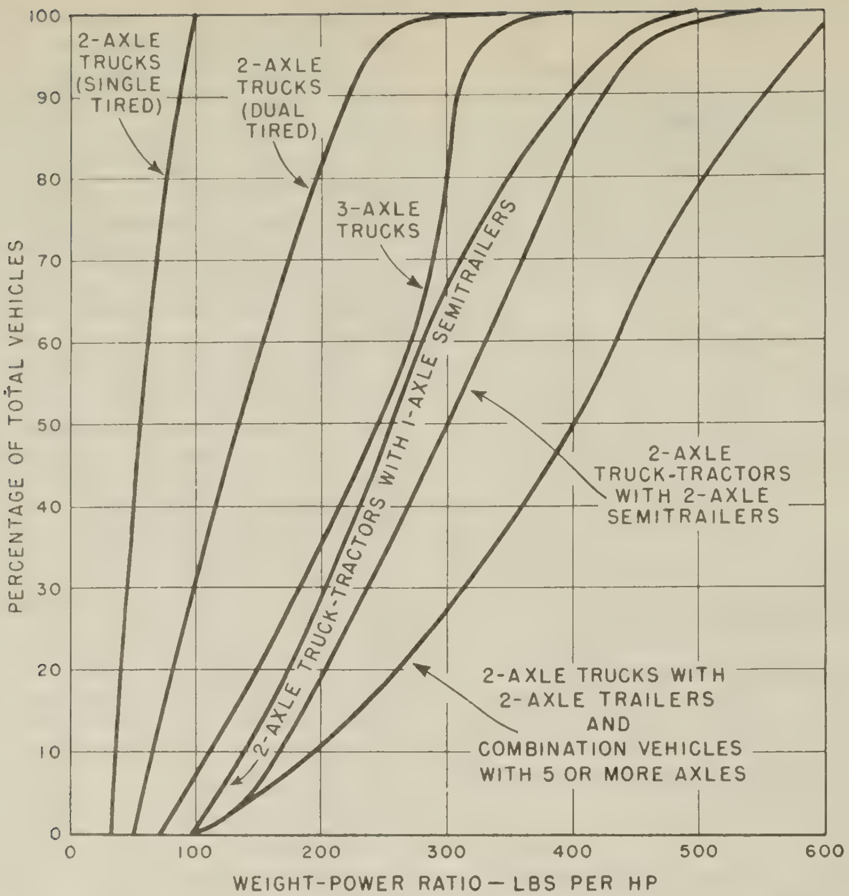

Figure 5.—Cumulative frequency distributions of weight-power ratios for commercial vehicles weighed in the 1955 brake test study.

Table 11.—Example for determining daily time savings by using average values of weight-power ratios for the different vehicle types

Vehicle type	Number of vehicles	Weight-power ratio [1]	Composite travel time [2]			Time saved per vehicle	Total time saved
			Route A	Route B	Savings		
Single unit trucks:			*Min./mile*	*Min./mile*	*Min./mile*	*Minutes*	*Hours*
2-axle, 6-tire	694	120	1.50	1.35	0.15	15.0	173
3-axle	70	215	2.00	1.55	.45	45.0	52
Truck combinations:							
2-axle truck-tractor with 1-axle semi-trailer	338	260	2.25	1.70	.55	55.0	309
2-axle truck-tractor with 2-axle semi-trailer	338	315	2.45	1.80	.65	65.0	366
Total	1,440	------	------	------	------	------	900

[1] Average weight-power ratios from tables 4 and 5 multiplied by 0.88.
[2] Rate of rise and fall: Route A, 3.7; Route B, 2.3. Each route was 100 miles long.

Table 12.—Percentage of vehicles weighed in the 1955 brake tests that could not meet indicated performance levels

Vehicle type	Percentage of vehicles with weight-power ratios greater than—					
	250:1	300:1	350:1	400:1	450:1	500:1
Single-unit trucks:						
2-axle, 6-tire	3	1	--------	--------	--------	--------
3-axle	48	21	2	--------	--------	--------
Truck combinations:						
2-axle truck-tractor with 1-axle semi-trailer	53	34	20	10	2	--------
2-axle truck-tractor with 2-axle semi-trailer	66	50	34	17	5	1
All other combinations	82	73	62	50	35	22

2-axle trailers grouped with combinations of 5 or more axles; and appreciable for 2-axle, 4-tire trucks and 2-axle truck-tractors with 1- and 2-axle semitrailers. The greatest improvement among the combination vehicles was observed for 2-axle truck-tractors with 2-axle semitrailers.

Time Savings Computed from Weight-Power Ratios

If the normal distribution of vehicle weights is known for a given route, the time savings that might accrue to commercial vehicles through the improvement of the existing route or the construction of a route on another location may be computed by using ratios selected from the curve in figure 3. An example of the computations involved is contained in table 10 for two routes, each 100 miles in length, but with different rates of rise and fall, 3.7 against 2.3. The weight-power ratios were taken from the curve in figure 3 for the average weight of the group and then corrected to present conditions by multiplying by the factor 0.88. The midpoint of the group may be used instead of the average gross weight. The travel time in minutes per mile for Routes A and B was then read from the chart on page 54 of the Highway Research Board Research Report No. 9–A [5] for the given ratio and the respective rate of rise and fall. The total time saved was obtained by first multiplying the difference between the travel times for Routes A and B by the length in miles to compute the savings per vehicle, and then multiplying that value by the daily number of vehicles in the particular weight group.

When the distribution of commercial vehicles by weight is not known, the travel time may be estimated in a similar manner by using the average values of the ratios contained in tables 4–7 and the number of vehicles by type obtained from a visual traffic classification survey. The example in table 11 shows how this can be accomplished. The classification of vehicles by type is for the same sample of vehicles used to demonstrate the previous method.

Impact of Performance Requirements

The percentage of the vehicles sampled in 1955 that could not meet various levels of performance is shown in table 12. The percentages were determined from figure 5. It appears from this tabulation that a value of 400 pounds gross weight per horsepower is tolerable for highway design purposes. It is also evident that a performance requirement of less than a 400:1 ratio would affect a sizable number of combination units, especially those with more than 4 axles.

[5] See footnote 1, p. 234.

The Efficiency of Public Transit Operation in the Utilization of City Streets

BY THE DIVISION OF HIGHWAY TRANSPORT RESEARCH BUREAU OF PUBLIC ROADS

Reported [1] by WILLIAM P. WALKER, Highway Transport Research Engineer, and ROY A. FLYNT, Georgia State Highway Planning Engineer

In this study, a comparison is made of the relative efficiencies of public transit vehicles and private automobiles in utilizing street space and transporting people. The operation of buses, streetcars, and automobiles was investigated in Washington, D. C., and trolley coaches and automobiles in Atlanta, Ga. An additional phase of the study included the comparison of bus and automobile operation on a section of the Atlanta Expressway.

Three factors were considered in evaluating the efficiencies of the various modes of travel: the speed of the vehicle, the space occupied by the vehicle in the traffic stream, and the number of persons traveling per vehicle.

The results of the study show that buses operating in Washington, D. C., were 3.7 times as efficient as automobiles on downtown streets, 4.6 times as efficient in intermediate areas, and 2.6 times as efficient in outlying areas. Streetcar versus automobile operation was observed in the downtown area of Washington only, and it was found that streetcars were 1.8 times as efficient as automobiles.

Trolley coaches in Atlanta, Ga., were found to be 6.3 times as efficient as automobiles on downtown streets, 8.7 times as efficient in intermediate areas, and 6.3 times as efficient in outlying areas. A comparison of bus and automobile operation on the Atlanta Expressway indicated that buses were 7.2 times as efficient as automobiles.

MASS TRANSPORTATION is recognized as a highly desirable if not essential component of the overall transportation scheme in urban centers. In recent years public transit systems have experienced a decline in patronage, while the number of persons using privately owned automobiles has represented an increasingly larger percentage of the people transported over city streets. The overcrowding of streets is often attributed to this decline in public transit patronage, and fears have been expressed that cities, and more particularly their transit companies, are facing economic ruin unless the trend is arrested. Subsidization has been proposed, and in several cases, it has been resorted to as a means of maintaining public transit service.

The purpose of the street system is to serve the public, and decisions as to how this service can be most satisfactorily and economically provided rest with the highway user, taken collectively. The increased use of private automobiles at the expense of transit patronage is merely a registration of highway-user attitudes. However, the expansion in automobile usage has thus far taken place on streets that have undergone only minor change or improvement through the years and the outlay for capital improvements of street systems has not approached the rate of growth of private automobile usage.

Large capital expenditures for street improvement are a prerequisite to the unabated growth of vehicular traffic. When the proportionate share of these costs is levied upon the private automobile user, the preference which he has thus far exhibited might be altered somewhat.

A thorough investigation of the economics of public transit versus private automobile usage of city streets would be very far-reaching and would cover all of the various aspects of user costs, convenience and comfort factors, time savings or losses, and other operational economies. As one phase of an economic investigation, the present study has for its purpose a comparison of the relative efficiencies of public transit vehicles and private automobiles in utilizing street space and transporting people.

A Standard for Measuring Efficiency

Any measure of efficiency must consider the space occupied per person in the moving traffic stream, and the length of time that the space is occupied in traveling a given distance. Space per person may be expressed as the space occupied in the traffic stream by a vehicle of a particular type, divided by the number of persons carried by the vehicle. The length of time that the space is occupied may be determined by dividing the distance traveled by the overall speed of the vehicle. Thus, for comparing efficiencies of different modes of transportation, there are three elements to be considered for each type of vehicle if conclusive results are to be obtained. These are the speed of the vehicle, the space occupied by the vehicle in the traffic stream, and the carried load. These three variables were investigated for automobiles, buses, and streetcars in the Washington, D. C., metropolitan area, and for automobiles and trolley coaches in Atlanta, Ga.

Conclusions

The investigations reported here are exploratory in nature, and the interpretations placed upon the results are based on operating conditions as they actually occurred during the periods studied. Recognition might well be taken of the fact that operating conditions are subject to change and that the rates at which people are transported in various types of vehicles do not in any sense represent the maximum number of people that could be transported under hypothetical operating conditions. For example, in no instance was the potential capacity of the streetcar-track lane fully utilized by public transit vehicles although the routes studied were the most heavily traveled in the city; and one site, with 113 streetcars in one hour, approached what is considered the limit in numbers that can use a street in one direction. More people could have been transported by streetcars without any further encroachment upon the street space, but this could happen only if more people wished to avail themselves of this mode of transportation, and if more streetcars were made available for their use.

In the case of automobiles, the potential capacity of the street space was more fully utilized by vehicles at most of the study sites than was the case for streetcars. Automobiles were operating at only one-third their passenger capacity, however. To hypothesize

[1] This article was presented at the 36th Annual Meeting of the Highway Research Board, Washington, D. C., January 1957.

that more streetcars could operate over a single track (if there were people to ride on them) merely invites a parallel hypothesis that more people could band together as group riders in automobiles if they should so choose. For current operations, comparisons as made in this article would seem to be founded on as firm a basis as any that might be conceived. On this premise the following conclusions are drawn for peak-hour operations.

1. In Washington, D. C., buses were 3.7 times as efficient as automobiles on downtown streets, 4.6 times as efficient in intermediate areas, and 2.6 times as efficient in outlying areas. On a freeway, buses in Atlanta, Ga., were 7.2 times as efficient as automobiles.

2. In Atlanta, trolley coaches were 6.3 times as efficient as automobiles on downtown streets, 8.7 times as efficient in intermediate areas of the city, and 6.3 times as efficient in outlying areas.

3. In Washington, streetcars were 1.8 times as efficient as automobiles on downtown streets.

4. The efficiencies of public transit vehicles in Washington, as derived in this investigation, cannot be compared directly with those in Atlanta because of differences in the operation of automobiles in the two cities. Automobiles in Washington traveled faster and carried more passengers than automobiles in Atlanta.

Bus Operation on City Streets

The investigation of bus operation included studies of travel speeds and of passengers carried by buses in normal operation during various periods of the day, and of the effect that buses have on street capacity. The speed and loading studies covered a number of bus lines in the Washington metropolitan area. Observers posted on buses compiled complete records showing the number of persons on board between stops, the number of persons boarding and alighting at each stop, the travel time between stops, the length of time spent in loading and unloading operations, and the cause and duration of delays.

The study extended over a period of 5 days, Monday through Friday, during the spring of 1950. Information was obtained on 283 bus trips (one way) divided about equally between the morning rush period, the afternoon rush period, and the off-peak or base period. Thirteen operating routes were studied.

Average carried load

The average number of passengers carried by buses during peak and off-peak periods are summarized in table 1. These buses were inbound during the morning peak period and outbound during the afternoon peak. The number of persons shown is the average per bus, weighted according to passenger-miles traveled.

Operating speed

The travel time for buses and automobiles during peak and off-peak periods is also shown in table 1. The data include minor traffic delays and delays resulting from traffic signals, and they represent the travel time for vehicles that were inbound during the morning peak period and outbound during the afternoon peak.

Travel time for automobiles was determined by driving a test car over the routes included in the study of buses. On each of these routes, nine trips were made with a test car driven at a speed which the driver thought was representative of the average speed of traffic. Three trips were made during the morning rush hour (not necessarily on the same day), three during the afternoon rush period, and three during the off-peak period.

Space occupied

In the study of the effect that buses have on street capacity, the maximum rates of traffic flow (possible capacities) for selected intersections in the Washington metropolitan area were determined by counting the number of vehicles entering each intersection from one of its approaches when the traffic demand was equal to or greater than the capacity of that approach. The traffic count for each signal cycle was classified as to the extent of interference by buses; that is, no interference, interference by one bus, by two buses, and so forth. The capacity of the intersection approach without bus interference was compared with its capacity with bus interference, and a determination was made of the number of automobiles displaced by one bus in the traffic stream. Satisfactory data were obtained for 16 intersection approaches—11 on major streets and 5 on minor streets. This study was conducted in June 1953.

The amount of space in a traffic stream that a bus occupies varies with the street width, the number of passengers loading and unloading, the gradient of the street, parking conditions, and a number of less important factors. The 11 major streets on which studies were conducted ranged in width from 40 to 60 feet. All of the intersection approaches except one had near-side bus stops and the one exception had a far-side stop. None of the study sites was in the central business district although some were on the fringe of the downtown area. Most of the locations were in intermediate-type areas with a few being in the outlying suburban districts. Parking was not permitted during rush hours on any of the major streets during the course of the studies and all bus traffic followed a straight course (no turns at intersections).

The interchange of passengers at the bus stops was only moderately heavy. Studies were conducted during morning and afternoon hours of peak traffic movement, and during the off-peak periods as well. With such a notable variation in the conditions at the various study sites, a corresponding variation in results was to be expected. On the average major street, one bus was found to have a displacement equivalent to 3.3 automobiles, as shown in table. 1. The range in the passenger-car equivalent of one bus was from 2.1 to 6.0. On the 5 minor streets, the average bus was found to be equivalent to 1.6 automobiles with a range from 1.0 to 1.9. An appreciable difference was observed in the bus equivalent between morning and afternoon study periods on the major streets, the former being about one and one-half times the latter on an average.

The disparity between the morning and afternoon values is presumed to be a result of differences in the conditions at the study sites and not a result of any difference in the characteristics of bus operations for the two time periods. The average of the values for morning and afternoon travel on major streets is used in subsequent comparisons of vehicle efficiencies.

For automobiles, the space per vehicle in the traffic stream has been taken as unity for purposes of this analysis. The other two variables—travel time and the average carried load—were determined by field investigation. The average number of persons per automobile was 1.97.

Relative efficiencies

Table 2 compares automobiles with buses in their travel time, carried load, space per vehicle in the traffic stream. and relative efficiencies. Travel time, carried load, and space per vehicle as shown in table 2 under the heading of "major streets" are average values for the morning peak hour in the inbound direction and the afternoon peak hour in the outbound direction. The relative efficiencies for the two types of transportation, automobiles and buses, are shown using the automobile as unity as a basis for comparison. In the down-

Table 1.—Average number of passengers carried by buses, average travel time for buses and automobiles, and average number of automobiles displaced by one bus

Variables	Time of day			
	Morning peak period (inbound)	Afternoon peak period (outbound)	Peak-hour average (inbound and outbound)	Off-peak period average (inbound and outbound)
Average number of persons per bus:				
Downtown areas	30.1	48.5	39.3	28.5
Intermediate areas	47.1	53.4	50.2	31.4
Outlying areas	25.6	36.0	30.8	16.8
Average travel time for buses:				
Downtown areas ... minutes/mile	10.1	9.2	9.6	9.6
Intermediate areas ... do	6.2	6.5	6.4	5.8
Outlying areas ... do	5.2	5.4	5.3	4.3
Average travel time for automobiles:				
Downtown areas ... do	5.8	6.2	6.0	6.2
Intermediate areas ... do	3.9	3.9	3.9	3.7
Outlying areas ... do	2.8	3.1	3.0	2.9
Number of automobiles displaced by one bus:				
Major streets	3.9	2.7	3.3	---------
Minor streets	1.6	1.7	1.6	---------

Table 2.—Relative efficiencies of automobiles and buses in the utilization of street space and movement of people during peak hours of traffic on major streets and on an urban freeway

Variables	Major streets			Urban freeway
	Downtown areas	Intermediate areas	Outlying areas	
Travel time (minutes per mile):				
Automobiles	6.0	3.9	3.0	1.8
Buses	9.6	6.4	5.3	2.4
Carried load (persons per vehicle):				
Automobiles	2.0	2.0	2.0	1.7
Buses	39.3	50.2	30.8	27.9
Space per vehicle (automobile units):				
Automobiles	1.0	1.0	1.0	1.0
Buses	3.3	3.3	3.3	1.7
Relative efficiency:				
Automobiles	1.0	1.0	1.0	1.0
Buses	3.7	4.6	2.6	7.2

town area, 39.3 passengers in one bus occupy as much space in the traffic stream as 6.6 passengers in 3.3 automobiles, a ratio of 5.95 to 1 in favor of the bus. These bus passengers occupy their space 1.62 times as long as the automobile occupants in traveling any given distance, so the efficiency of the bus is thereby reduced by the speed differential in the ratio of 1 to 1.62, or to 62 percent. The resultant efficiency of the bus in the downtown area during peak hours is 3.7 times that of the average automobile. In the intermediate area the bus is 4.6 times as efficient as the automobile, and in the outlying area it is 2.6 times as efficient as the automobile.

Bus Operation on Freeways

The average load and rate of travel for diesel-powered buses while operating in express service on a freeway were determined as one part of a study of public transit operation in Atlanta, Ga., in 1955. The bus route traverses the northeast leg of the Atlanta Expressway system, which is a freeway with full control of access. There are no intermediate bus stops between the point where the route enters the freeway in the residential district and the point of exit in the downtown area.

During the morning peak period, the average bus on the expressway carried 31.3 passengers and traveled at the rate of one mile in 2.5 minutes. During the afternoon peak period the average load was 24.5 passengers, and the rate of travel was one mile in 2.4 minutes. For the morning and afternoon periods combined, the average express bus carried 27.9 passengers and the average rate of travel was one mile in 2.4 minutes.

Automobiles using this portion of the Atlanta Expressway carried an average of 1.7 persons during the morning and afternoon peak periods and traveled at the rate of one mile in 1.8 minutes.

The number of buses in service on this route was too small to permit a reliable determination of the space occupied by a bus in a stream of expressway traffic. The Shirley Memorial Highway in Arlington, Va., a freeway in the Washington, D. C., metropolitan area, afforded a more satisfactory location for comparing the space occupied by an automobile with that occupied by a bus.

An extensive study by the Bureau of Public Roads revealed that for any given volume of traffic the average bus on the Shirley Memorial Highway occupies a time-gap in the traffic stream which is 1.7 times that for the average automobile. The study covered the operation of 658 buses and more than 75,000 automobiles.

Relative efficiencies

By using the travel time and carried load for automobiles and buses as found on the Atlanta Expressway, and the space occupied by a bus as found on the Shirley Memorial Highway, buses on freeways were found to be 7.2 times as efficient as automobiles in the utilization of freeway space and in the transport of people. The data are summarized in the last column of table 2.

Trolley-Coach Operation

The procedures used in making studies of bus operation on major streets in Washington, D. C., were employed in a study of trolley coaches in Atlanta. The study was made in February and March of 1955 and the results are summarized in table 3. The results of studies at 11 intersections are included. The similarity between the displacement of trolley coaches on major streets in Atlanta and of gasoline-powered buses on major streets in Washington, as shown in table 1, is very striking. Trolley coaches as well as buses seem to reduce the capacity of major streets to a considerably greater extent during the morning period of peak traffic movement than during the afternoon peak. It would seem to be more than happenstance that both buses and trolley coaches were found to contribute more to congestion in the morning than during the afternoon, but the reason for this is not clear. As in the case for buses, the average of the morning and afternoon values for the space occupied by trolley coaches on major streets is used in comparing vehicle efficiencies.

At the time that trolley coaches were carrying the number of passengers shown in table 3, automobiles using the same streets in Atlanta were carrying an average of 1.7 people. The average travel times for automobiles on these same streets are shown in table 3.

Relative efficiencies

The relative efficiencies of trolley coaches and automobiles, based on the three variables of travel time, persons per vehicle, and space occupied per vehicle, are shown in table 4. The figures given are average values for morning and afternoon peak periods. In the downtown area, for example, trolley coaches are shown as being 6.3 times as efficient as automobiles. Their speed is 0.7 that of automobiles; their load is 28.7 times that of automobiles; and their space in the traffic stream is 3.3 times that of an automobile. In the intermediate area the trolley coach is 8.7 times as efficient as the automobile, and in the outlying area the relative efficiency of the trolley coach is 6.3, the same as in the downtown area.

Streetcar Operation

The procedure for studying streetcar operation differed in several respects from that employed for buses and trolley coaches. The major difference, however, was that vehicles and passengers were counted as they passed fixed points along the routes rather than by having observers on the vehicles. The majority of the study sites chosen were in the downtown business district, with the remainder being in the area immediately adjacent thereto. Study sites were selected at loading platforms where automobiles and streetcars were each allotted a specific portion of the street separate and distinct from that available to the other. Attempt was made to choose locations where conditions were most highly favorable for public transit operations,

Table 3.—Average number of passengers carried by trolley coaches, average travel time for trolley coaches and automobiles, and average number of automobiles displaced by one trolley coach

Variables	Time of day			
	Morning peak period (inbound)	Afternoon peak period (outbound)	Peak-hour average (inbound and outbound)	Off-peak period average (inbound and outbound)
Average number of persons per trolley coach:				
Downtown areas	50.4	47.0	48.7	28.5
Intermediate areas	51.7	52.5	52.1	28.3
Outlying areas	38.9	40.1	39.5	19.4
Average travel time for trolley coaches:				
Downtown areas ......minutes/mile	10.7	12.2	11.4	9.8
Intermediate areas ......do	5.6	6.4	6.0	5.2
Outlying areas ......do	4.2	4.3	4.3	3.7
Average travel time for automobiles:				
Downtown areas ......minutes/mile	8.2	8.6	8.4	6.7
Intermediate areas ......do	5.3	5.9	5.6	4.2
Outlying areas ......do	3.7	4.2	3.9	3.2
Number of automobiles displaced by one trolley coach:				
Major streets	4.0	2.6	3.3	----------
Minor streets	3.8	3.8	3.8	----------

Table 4.—Relative efficiencies of automobiles and trolley coaches and automobiles and streetcars (downtown areas only) in the utilization of street space and movement of people during peak hours of traffic on major streets

Variables	Automobiles and trolley coaches operating in—			Automobiles and streetcars operating in downtown areas
	Downtown areas	Intermediate areas	Outlying areas	
Travel time (minutes per mile):				
Automobiles	8.4	5.6	3.9	6.0
Trolley coaches	11.4	6.0	4.3	----------
Streetcars	----------	----------	----------	11.0
Carried load (persons per vehicle):				
Automobiles	1.7	1.7	1.7	2.0
Trolley coaches	48.7	52.1	39.5	----------
Streetcars	----------	----------	----------	50.8
Space per vehicle (automobile units):				
Automobiles	1.0	1.0	1.0	1.0
Trolley coaches	3.3	3.3	3.3	----------
Streetcars	----------	----------	----------	7.6
Relative efficiency:				
Automobiles	1.0	1.0	1.0	1.0
Trolley coaches	6.3	8.7	6.3	----------
Streetcars	----------	----------	----------	1.8

that is, along the most heavily traveled and highly patronized transit routes. A total of 10 sites were studied and, with one exception, these sites happened to be on important automobile routes. However, transit traffic was the primary consideration governing their selection.

Studies were conducted during morning and afternoon hours of peak traffic on four weekdays in April 1952. Information collected consisted of a simple count of vehicles in each category and the number of persons in each vehicle. Traffic in the direction of the heavier movement only was counted and the field data were summarized for each signal cycle (80 seconds). From this study a comparison was made of the space occupied by streetcars and automobiles and the load carried by vehicles of each type.

Travel time

For the purpose of measuring streetcar travel time, three streets were selected and these were either within or adjacent to the central business district of Washington.

Travel time for streetcars was determined by observers working in pairs on the three streetcar lines. The observers were stationed several blocks apart and each recorded the exact time of day that every streetcar passed his station, together with the identification number painted on the side of the car. Later, the records for the two observers were compared, and the elapsed time for each streetcar to traverse the known distance between the observation points was computed. Data were collected for 750 streetcars covering approximately 450 vehicle-miles of travel. The average travel time during periods of peak traffic was found to be 11.0 minutes per mile.

The rate of travel for automobiles, as measured in the study of bus operation and as shown in table 1, is used in comparing automobile and streetcar operation.

Average load carried

A summation of data for the heaviest hour of traffic at each of the 10 study sites shows that 690 streetcars and 9,126 automobiles were observed. The 690 streetcars transported 35,070 passengers, whereas automobiles carried a total of 17,932 passengers including drivers. Average carried loads were 50.83 persons for streetcars as against 1.97 for automobiles. The average streetcar carried 25.8 times as many people as the average automobile.

Space per vehicle

The space occupied by the average vehicle of each type may be measured by dividing the number of vehicles per hour by the width of street available to that type of vehicle. At the average site, 4.7 streetcars per hour per foot of width availed themselves of the space allotted to them, that is, the width of the car-track lane to the center of the street and including the loading platform. The average number of automobiles utilizing the space between the curb and platform was 35.9 per hour per foot of street width. For operating conditions as they occurred during the week of the study, the average streetcar occupied 7.6 times as much space in the traffic stream as the average automobile.

Relative efficiencies

The procedure for calculating the relative efficiencies of automobiles and streetcars is the same as that followed in comparing automobiles and buses. Relative efficiencies of streetcars, as compared with automobiles, together with values of the variables used in developing these efficiencies, are shown in the last column of table 4. The streetcar is shown as being 1.8 times as efficient as the automobile in downtown Washington. Data were not obtained for other areas of the city.

Efficiencies of Public Transit Vehicles and Automobiles Summarized

The operation of each of three types of public transit vehicles has been compared with automobiles that were using the same or similar streets during approximately the same period of time. The three variables used in the comparison were travel time, number of passengers, and space occupied in the traffic stream. The resulting efficiencies, based on the three variables, are summarized in the upper portion of table 5.

Figures in table 5 cannot be used to compare transit vehicles in one city with transit vehicles in another city because the automobiles, which were used as a standard for comparison, varied in their operation on different types of streets, and more particularly between cities. Automobiles in Atlanta, for example, traveled slower and carried fewer passengers than automobiles in Washington. It is primarily for this reason that trolley coaches in Atlanta show a higher efficiency than buses in Washington. The inference should not be drawn that trolley coaches would be almost twice as efficient in Washington as buses.

As another precaution, table 5 should not be interpreted as meaning that automobiles could be substituted for transit vehicles in the numbers shown in the table with the result that the same total number of persons could be transported by automobile alone as are presently being moved by transit vehicles and automobiles combined.

Fewer people could be transported in automobiles alone than can be moved on a street by automobiles in combination with transit vehicles. but this smaller number of people would reach their destinations in a shorter length of time. If the concern is with

Table 5.—Relative efficiencies of various types of vehicles in the utilization of street space and movement of people

Mode of travel	Downtown areas	Intermediate areas	Outlying areas
RELATIVE EFFICIENCIES CONSIDERING TRAVEL TIME, PERSONS PER VEHICLE, AND SPACE PER VEHICLE			
Automobiles	1.0	1.0	1.0
Buses (major street operation)	3.7	4.6	2.6
Buses (freeway operation)	----------	7.2	----------
Trolley coaches	6.3	8.7	6.3
Streetcars	1.8	----------	----------
RELATIVE AMOUNT OF SPACE OCCUPIED BY ONE PERSON			
Automobiles	1.00	1.00	1.00
Buses (major street operation)	.17	.13	.21
Buses (freeway operation)	----------	.10	----------
Streetcars	.30	----------	----------
RELATIVE EFFICIENCIES CONSIDERING PERSONS PER VEHICLE AND SPACE OCCUPIED PER VEHICLE			
Automobiles	1.00	1.00	1.00
Buses (major street operation)	5.95	7.60	4.67
Buses (freeway operation)	----------	10.00	----------
Streetcars	3.38	----------	----------

absolute numbers of persons that can be moved on a street without regard to rate of travel, then the transit vehicle enjoys a much greater advantage than is reflected in table 5. The space in the traffic stream which a person occupies while traveling in various types of vehicles is a more reliable measure of the number of people that can be moved past a point by vehicles of each type. The middle portion of table 5 shows the relative amount of space in the traffic stream a person occupies while traveling in automobiles, buses, and streetcars.

Translated into relative efficiencies of street-space utilization, the reciprocals of the figures for space occupied by one person are shown in the lower portion of table 5. As previously mentioned, a direct comparison cannot be made between trolley coaches and buses or streetcars because trolley coach operation is related to automobile operation in Atlanta, whereas bus and streetcar operation is related to automobile operation in Washington.

Acknowledgments

This investigation is a product of the joint efforts of several agencies. The studies of travel time and passengers carried by trolley coaches and automobiles in Atlanta were performed by personnel of the Georgia State Highway Department, with the cooperation of the Atlanta Transit Company in the selection of routes and the furnishing of riders' passes to those engaged in the study. Field work for a determination of the space occupied by trolley coaches in the traffic stream was performed by the Traffic Engineering Department of the City of Atlanta.

Field work for the bus study in Washington, D. C., was performed by Bureau of Public Roads personnel with the assistance of personnel furnished by the Capital Transit Company. Participation by that Company included the services of five observers under the supervision of the Company's Research and Planning Department. The Company also participated in establishing procedures for the study and provided riders' passes to all engaged in the study. The Washington-Virginia-Maryland Coach Company of Arlington, Va., supported the study by furnishing free fares to observers operating on their lines.

Highway Statistics, Summary to 1955

Highway Statistics, Summary to 1955, a general historical summary of factual information dealing with highways, their use, and financing, is now available. The new publication may be purchased from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., at $1 a copy.

This 150-page bulletin brings together under one cover a comprehensive statistical review of highway development in the United States through 1955, and includes all of the data presented in a previous compendium, "Highway Statistics, Summary to 1945," and most of the material published since then in the "Highway Statistics" annual bulletins.

The material is presented in four major groupings. The motor-fuel section includes analysis of motor-fuel consumption, tax rates, and tax receipts. The section on motor vehicles includes tables on motor-vehicle registrations and operators' licenses, their fee schedules, and the revenues received therefrom and from motor-carrier taxes; also included in this section are travel, loading, and speed data. The highway finance section covers the disposition of highway-user imposts, receipts and expenditures for highways, and highway debt; because of the interest in the subject, data for toll facilities are segregated. Although the local finance historical series are not presented separately in this bulletin, combined State and local government finance data are reported in several series of tables. The mileage section reports road and street mileage existing, and the mileage built each year, classified by system and by type. The section on Federal aid includes tables on Federal excise taxes and on Federal-aid funds, construction, and system mileage.

U. S. GOVERNMENT PRINTING OFFICE: 1957

A list of the more important articles in PUBLIC ROADS may be obtained upon request addressed to Bureau of Public Roads, Washington 25, D. C.

PUBLICATIONS of the Bureau of Public Roads

The following publications are sold by the Superintendent of Documents, Government Printing Office, Washington 25, D. C. Orders should be sent direct to the Superintendent of Documents. Prepayment is required.

ANNUAL REPORTS

Work of the Public Roads Administration:
1941, 15 cents. 1948, 20 cents.
1942, 10 cents. 1949, 25 cents.

Public Roads Administration Annual Reports:
1943; 1944; 1945; 1946; 1947.
(*Free from Bureau of Public Roads*)

Annual Reports of the Bureau of Public Roads:
1950, 25 cents. 1953 (out of print). 1956, 25 cents.
1951, 35 cents. 1954 (out of print).
1952, 25 cents. 1955, 25 cents.

PUBLICATIONS

Bibliography of Highway Planning Reports (1950). 30 cents.

Braking Performance of Motor Vehicles (1954). 55 cents.

Construction of Private Driveways, No. 272MP (1937). 15 cents.

Criteria for Prestressed Concrete Bridges (1954). 15 cents.

Design Capacity Charts for Signalized Street and Highway Intersections (reprint from PUBLIC ROADS, Feb. 1951). 25 cents.

Electrical Equipment on Movable Bridges, No. 265T (1931). 40 cents.

Factual Discussion of Motortruck Operation, Regulation, and Taxation (1951). 30 cents.

Federal Legislation and Regulations Relating to Highway Construction (1948). Out of print.

Financing of Highways by Counties and Local Rural Governments: 1931–41, 45 cents; 1942–51, 75 cents.

First Progress Report of the Highway Cost Allocation Study, House Document No. 106 (1957). 35 cents.

General Location of the National System of Interstate Highways, Including All Additional Routes at Urban Areas Designated in September 1955. 55 cents.

Highway Bond Calculations (1936). 10 cents.

Highway Bridge Location, No. 1486D (1927). 15 cents.

Highway Capacity Manual (1950). $1.00.

Highway Needs of the National Defense, House Document No. 249 (1949). 50 cents.

Highway Practice in the United States of America (1949). 75 cents.

Highway Statistics (annual):
1945 (out of print). 1949, 55 cents. 1953, $1.00.
1946, 50 cents. 1950 (out of print). 1954, 75 cents.
1947, 45 cents. 1951, 60 cents. 1955, $1.00.
1948, 65 cents. 1952, 75 cents.

Highway Statistics, Summary to 1955. $1.00.

Highways in the United States, *nontechnical* (1954). 20 cents.

Highways of History (1939). 25 cents.

Identification of Rock Types (reprint from PUBLIC ROADS, June 1950). 15 cents.

Interregional Highways, House Document No. 379 (1944). 75 cents.

Legal Aspects of Controlling Highway Access (1945). 15 cents.

Local Rural Road Problem (1950). 20 cents.

Manual on Uniform Traffic Control Devices for Streets and Highways (1948) (*including 1954 revisions supplement*). $1.25.
Revisions to the Manual on Uniform Traffic Control Devices for Streets and Highways (1954). *Separate*, 15 cents.

PUBLICATIONS (Continued)

Mathematical Theory of Vibration in Suspension Bridges (1950). $1.25.

Needs of the Highway Systems, 1955–84, House Document No. 120 (1955). 15 cents.

Opportunities in the Bureau of Public Roads for Young Engineers (1955). Out of print.

Parking Guide for Cities (1956). 55 cents.

Principles of Highway Construction as Applied to Airports, Flight Strips, and Other Landing Areas for Aircraft (1943). $2.00.

Progress and Feasibility of Toll Roads and Their Relation to the Federal-Aid Program, House Document No. 139 (1955). 15 cents.

Public Control of Highway Access and Roadside Development (1947). 35 cents.

Public Land Acquisition for Highway Purposes (1943). 10 cents.

Public Utility Relocation Incident to Highway Improvement, House Document No. 127 (1955). 25 cents.

Results of Physical Tests of Road-Building Aggregate (1953). $1.00.

Roadside Improvement, No. 191MP (1934). 10 cents.

Selected Bibliography on Highway Finance (1951). 60 cents.

Specifications for Aerial Surveys and Mapping by Photogrammetric Methods for Highways, 1956: a reference guide outline. 55 cents.

Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects, FP–57 (1957). $2.00.

Standard Plans for Highway Bridge Superstructures (1956). $1.75.

Taxation of Motor Vehicles in 1932. 35 cents.

Tire Wear and Tire Failures on Various Road Surfaces (1943). 10 cents.

Transition Curves for Highways (1940). $1.75.

MAPS

State Transportation Map series (available for 39 States). Uniform sheets 26 by 36 inches, scale 1 inch equals 4 miles. Shows in colors Federal-aid and State highways with surface types, principal connecting roads, railroads, airports, waterways, National and State forests, parks, and other reservations. Prices and number of sheets for each State vary—see Superintendent of Documents price list 53.

United States System of Numbered Highways. 28 by 42 inches, scale 1 inch equals 78 miles. 20 cents.

Single copies of the following publications are available to highway engineers and administrators for official use, and may be obtained by those so qualified upon request addressed to the Bureau of Public Roads. They are not sold by the Superintendent of Documents.

Bibliography on Automobile Parking in the United States (1946).

Bibliography on Highway Lighting (1937).

Bibliography on Highway Safety (1938).

Bibliography on Land Acquisition for Public Roads (1947).

Bibliography on Roadside Control (1949).

Express Highways in the United States: a Bibliography (1945).

Indexes to PUBLIC ROADS, volumes 17–19 and 23.

Title Sheets for PUBLIC ROADS, volumes 24–28

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Official Business

STATUS OF FEDERAL-AID HIGHWAY PROGRAM

AS OF AUGUST 31, 1957

(Thousand Dollars)

STATE	UNPROGRAMMED BALANCES 1/	ACTIVE PROGRAM											
		PROGRAMMED ONLY			CONTRACTS ADVERTISED, CONSTRUCTION NOT STARTED			PROJECTS UNDER WAY			TOTAL		
		Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles
Alabama	$73,689	$35,109	$26,938	331.5	$12,740	$8,380	126.9	$74,331	$46,178	836.1	$122,180	$81,496	1,294.5
Arizona	34,659	19,060	17,247	117.4	5,143	3,912	64.9	26,941	22,694	159.6	51,144	43,853	341.9
Arkansas	51,028	32,461	23,549	472.7	15,489	9,224	140.1	46,360	30,677	511.5	94,310	63,450	1,124.3
California	156,907	30,800	19,039	218.6	17,411	13,437	17.3	411,602	215,384	336.7	459,813	247,860	572.6
Colorado	51,429	20,516	14,781	166.3	9,498	7,311	96.9	47,333	33,058	277.0	77,347	55,150	540.2
Connecticut	55,929	2,480	1,260	3.4	11,625	8,623	5.7	32,876	20,423	39.4	46,981	30,306	48.5
Delaware	31,956	2,530	1,293	14.7	2,538	1,481	10.0	15,052	8,306	62.1	20,120	11,080	86.8
Florida	60,033	37,651	25,927	427.7	16,830	13,029	35.3	43,459	24,973	226.8	97,940	63,929	689.8
Georgia	105,462	49,958	31,285	568.9	11,286	5,975	70.8	90,623	51,728	864.0	151,867	88,988	1,503.7
Idaho	48,377	18,025	13,089	144.8	1,952	1,426	18.7	18,573	12,879	202.1	38,550	27,394	365.6
Illinois	128,474	90,221	62,619	549.2	66,545	52,784	90.6	153,528	107,999	780.1	310,294	223,402	1,419.9
Indiana	146,797	24,193	13,187	147.0	15,966	8,270	184.3	50,802	32,024	234.5	90,961	53,481	565.8
Iowa	62,902	41,751	35,692	275.5	10,628	6,809	124.1	69,577	44,444	1,655.3	121,956	86,945	2,054.9
Kansas	56,024	42,289	34,856	746.9	7,327	4,721	119.6	51,346	31,618	1,374.3	100,962	71,195	2,240.8
Kentucky	93,196	8,112	4,140	81.6	10,490	6,057	49.2	51,232	34,924	260.7	69,834	45,121	391.5
Louisiana	69,437	43,589	27,192	212.0	14,072	8,873	75.8	53,166	29,336	317.8	110,827	65,401	605.6
Maine	44,957	9,442	5,031	80.3	1,322	665	19.5	18,796	9,996	106.7	29,560	15,692	206.5
Maryland	29,209	29,950	17,431	87.0	15,252	10,188	18.1	63,270	43,312	215.5	108,472	70,931	320.6
Massachusetts	79,603	36,667	24,002	31.8	49,499	33,050	32.8	63,096	34,590	49.1	149,262	91,642	113.7
Michigan	115,868	66,917	51,161	446.6	32,602	18,239	75.1	111,198	76,560	601.0	210,717	145,960	1,122.7
Minnesota	74,620	15,933	13,694	176.4	4,830	3,288	38.1	102,986	72,005	1,651.9	123,749	88,987	1,866.4
Mississippi	48,144	30,118	21,238	566.6	22,090	18,047	129.5	51,608	32,736	821.5	103,816	72,021	1,517.6
Missouri	97,607	27,342	16,651	1,024.8	7,974	5,725	34.6	127,265	81,489	1,392.7	162,581	103,865	2,452.1
Montana	72,776	11,168	7,861	238.8	6,489	4,394	75.9	42,637	30,971	314.3	60,294	43,226	629.0
Nebraska	79,498	15,898	8,861	246.5	7,384	4,195	97.6	43,407	25,289	1,224.1	66,689	38,345	1,568.2
Nevada	43,146	13,483	12,601	46.0	984	823	14.0	21,547	18,670	190.1	36,014	32,094	250.1
New Hampshire	21,341	10,542	7,973	28.4	1,717	1,500	.6	21,083	13,705	68.6	33,342	23,178	97.6
New Jersey	103,923	9,498	5,484	65.6	23,859	19,227	11.8	58,322	37,534	49.8	91,679	62,245	127.2
New Mexico	39,348	3,733	2,527	39.2	3,704	2,790	51.2	37,873	31,716	225.5	45,310	37,033	315.9
New York	215,349	43,127	29,022	67.4	60,917	34,718	80.8	479,209	288,615	551.7	583,253	352,355	699.9
North Carolina	105,021	35,803	24,657	326.9	6,924	4,783	50.8	84,735	50,549	949.9	127,462	79,989	1,327.6
North Dakota	42,960	20,943	16,013	963.0	2,681	1,929	49.5	28,509	18,016	1,170.7	52,133	35,958	2,183.2
Ohio	107,765	100,680	68,910	176.1	31,476	21,768	45.4	198,055	131,594	285.1	330,211	222,272	506.6
Oklahoma	60,091	45,301	34,480	443.6	15,255	11,057	65.5	56,432	33,543	562.8	116,988	79,080	1,071.9
Oregon	48,948	10,564	7,685	39.2	9,540	7,350	42.0	44,537	33,073	262.1	64,641	48,108	343.3
Pennsylvania	155,455	90,675	58,397	194.0	75,637	59,630	93.1	213,344	131,256	363.5	379,656	249,283	650.6
Rhode Island	19,365	5,734	3,140	11.0	4,764	3,570	4.9	31,571	22,215	16.6	42,069	28,925	32.5
South Carolina	52,616	40,065	28,897	369.1	3,713	3,040	22.8	38,337	22,394	738.2	82,115	54,331	1,130.1
South Dakota	42,081	27,428	21,512	345.4	1,512	845	62.5	28,567	19,451	736.9	57,507	41,808	1,144.8
Tennessee	65,510	61,856	47,721	343.4	14,864	8,695	48.0	81,350	48,423	652.5	158,070	104,839	1,043.9
Texas	226,761	22,930	13,876	350.6	59,746	45,083	283.5	179,752	118,317	1,649.0	262,428	177,276	2,283.1
Utah	42,442	15,218	12,496	114.7	1,523	1,135	2.0	18,584	14,632	211.5	35,325	28,263	328.2
Vermont	25,433	2,113	1,161	23.2	2,981	2,683	1.9	18,802	12,889	57.5	23,896	16,733	82.6
Virginia	58,400	48,283	37,002	170.1	24,164	16,076	64.6	54,964	36,125	277.9	127,411	89,203	512.6
Washington	68,897	15,821	10,978	123.1	3,453	2,610	31.3	53,853	37,798	294.2	73,127	51,386	448.6
West Virginia	48,819	47,057	33,505	86.0	3,507	1,784	13.6	32,369	16,614	78.6	82,933	51,903	178.2
Wisconsin	101,790	27,015	17,965	308.2	10,160	6,252	84.0	65,772	38,781	512.6	102,947	62,998	904.8
Wyoming	23,082	13,116	10,343	48.9	8,674	7,564	48.2	42,380	33,213	367.3	64,170	51,120	464.4
Hawaii	7,539	7,260	3,630	15.6	71	36		4,138	1,985	7.9	11,469	5,651	23.5
District of Columbia	30,552	7,990	6,552	2.9	2,913	1,801	1.9	17,603	13,856	2.0	28,506	22,209	6.8
Puerto Rico	16,690	3,835	1,390	9.0	1,146	557	1.8	18,899	8,967	59.6	23,880	10,914	70.4
Alaska	13,645	4,238	4,234	58.8	3,042	3,042	113.7	8,668	7,160	275.4	15,948	14,436	447.9
TOTAL	3,655,550	1,476,488	1,040,175	12,146.4	755,909	528,451	3,040.8	3,800,319	2,394,684	25,132.3	6,032,716	3,963,310	40,319.5

1/ Includes funds authorized for the fiscal year 1959 apportioned August 1, 1957.