# Methods for Measuring Load Transfer Through Vehicle Tires to the Road Surface

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● THE LOAD TRANSMITTED to the road surface through the tires of a vehicle in motion is 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 at the electronic scale (*1*) near Woodbridge, Virginia, showed that although 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, which suggests that when weighed in motion, a truck is undulating on its springs as it travels along the highway. The axle weight as recorded by the electronic scale would depend on the amplitude of this oscillation and what part of

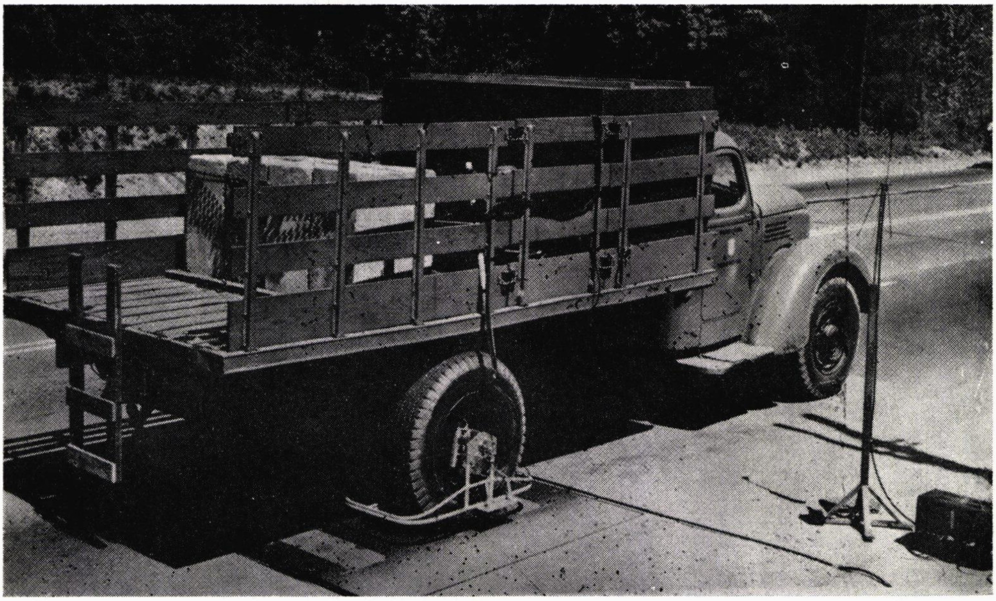

Figure 1. Test truck with experimental apparatus.

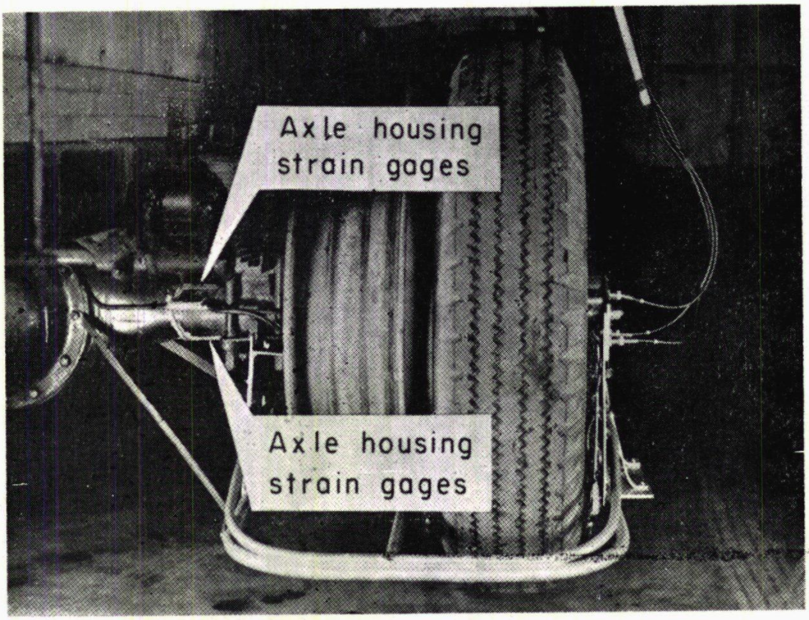


Figure 2. Axle housing strain gage detail.

the oscillation cycle was measured by the scale platform. The amplitude can be controlled somewhat by a smooth pavement surface, but the measured part of the cycle cannot be fixed and the scale platform 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.

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 (*2*). Information was also obtained to determine whether the electronic scale is recording 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 US 1 about 1,000 ft south of the Virginia State Official Weighing Station near Woodbridge. The scale was constructed as a cooperative project between the Virginia State Highway Department, a manufacturer of electronic scales, and the Bureau of Public Roads in an effort to improve the accuracy of electronic scales and determine the feasibility of their use in connection with the enforcement of legal weight limits.

The scale has a 7-ft platform in the direction of traffic and extends across the right-hand lane of the 2 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 Highway 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 magnitude and variations in the weight transferred by the tires to the road surface were developed and tested:

1. Axle-housing strain near the spring mounting.
2. The change of bulge or spread of the tire sidewalls directly above the center of contact with the pavement surface.
3. Changes in air pressure within the tire.

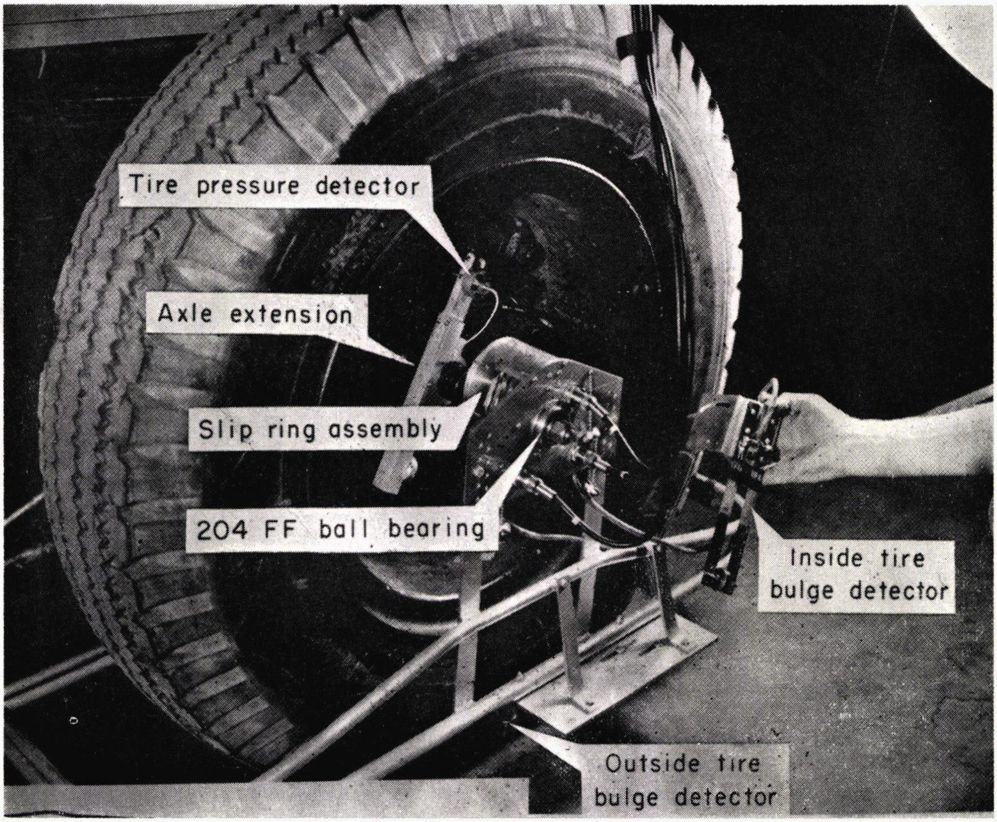


**Figure 3. Tire load detectors.**

The vehicle on which the instruments were mounted for the three types of measurements was a K-7 International single-axle truck with 9:00 x 20 tires (Figure 1). The inside tire on each dual wheel was removed to permit the installation of the detectors and the truck was loaded with four 1,000-lb concrete blocks in a manner to give a 9,000-lb rear-axle load. This produced a tire load of 4,500 lb which is equal to that allowed by the many states having an 18,000-lb single-axle load limit. The right-rear wheel only was instrumented.

The three different means of measuring the wheel load were employed simultaneously. It was not known which of the three methods would prove to be the best. A description of each method follows.

*Axle-Housing Strain Method*

Four strain gauges 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 gauges were cemented to the rear axle housing just inside the spring mount, two gauges on top and two on the bottom (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 gauges 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 instru-

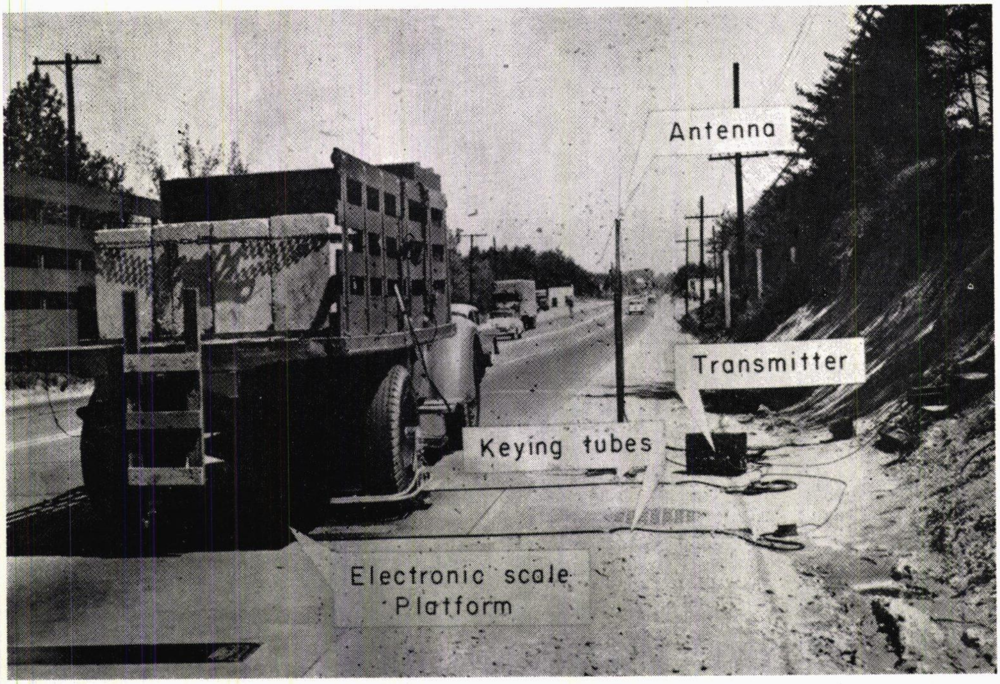


**Figure 4. Truck on electronic scale.**

ments recorded a corresponding change in strain, giving a calibration curve.

Although this is a simple means of recording the change in wheel load and worked very well in this study, there are 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 because it would have practically no vertical motion or acceleration.

Another complicating factor is the addition of the second wheel of a dual assembly, which 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. 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.

### *Bulge or Spread of Tire Sidewalls Method*

Another method of determining wheel load changes was suggested by Endres and Bombard (*3*). As the load changes 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 similar manner as the axle-housing strain, with the addition of rotating the wheel between each change in load to allow the sidewall to attain its normal deflection for the given load as it would with the vehicle in motion.

The instrument used to measure the tire sidewall deflection was built in the Bureau of Public Roads laboratory (Figure 3) and consisted of two 1/16- x ¾-in. pieces of spring steel, 9½ in. long, riveted to a ¼- x 3- x 3-in. aluminum plate. The two pieces of spring steel were spaced ¾

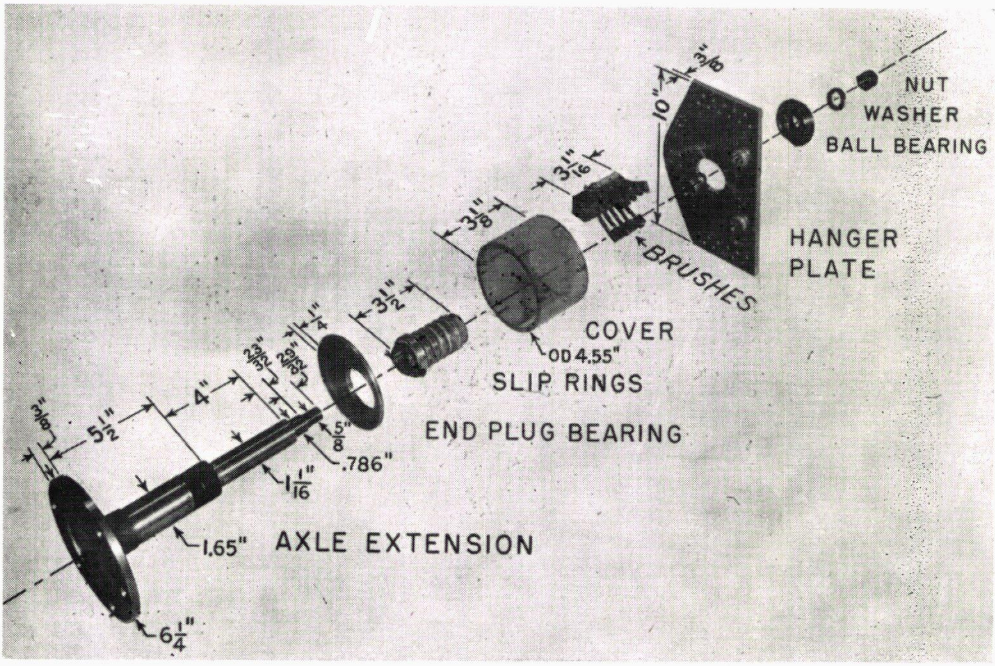


**Figure 5. Slip ring assembly.**

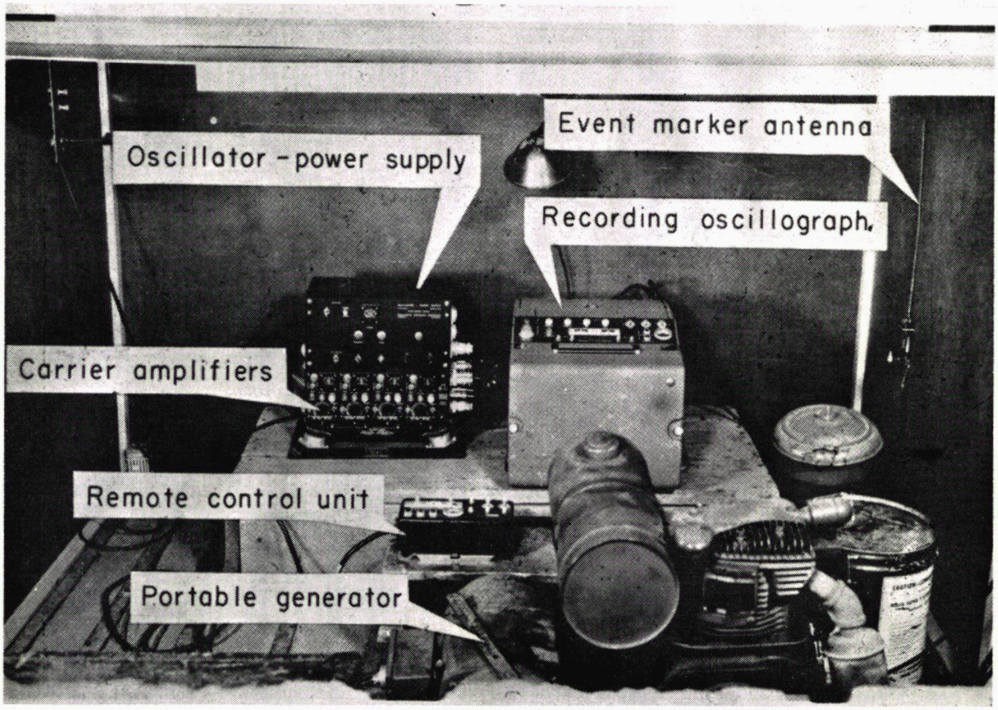


**Figure 6. Recording instruments and generator.**

in. 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 sidewall, any deflection of the sidewall would cause the spring steel straps to bend. Strain gauges 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 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 ¼- x 4- x 12-in. horizontal aluminum plate. 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 sidewall. A framework, made by bending ¾-in. thinwall 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. This framework was rectangular in shape with rounded corners and encircled the wheel.

A second framework of ½-in. tubing was placed above the ¾-in. framework. It had the same general shape as the latter, but the sides were raised 4 in. at the center to make it more rigid. The two frameworks 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 protrude about 3 in. beyond the plane of the tire sidewall (Figure 4). 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 of 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 was hung. Through this bearing, the framework was rigidly supported even though the axle extension rotated with the wheel. A sidewall bulge detector 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 (Figure 2). Electrical cables from the gauges on the bulge detectors were wired to sockets in the hanger plate so that the cables leading to the recording equipment could 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. A ½-in. 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 for the detectors used to measure the deflection of the sidewalls was obtained by a laboratory test calibration of the bulge detectors using a micrometer screw to move the roller of the detector through a 1-in. range. A greater displacement was not tried because the original ½ in. ± ½ in. was thought to be sufficient to record the expected range in the bulge, and 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 for the roller. Furthermore, that part of the tire in contact with the roller had to be trued because the plane of the tire sidewall was not exactly perpendicular to the axis of rotation. Otherwise, the wobble of the tire sidewall would have been recorded and could not have

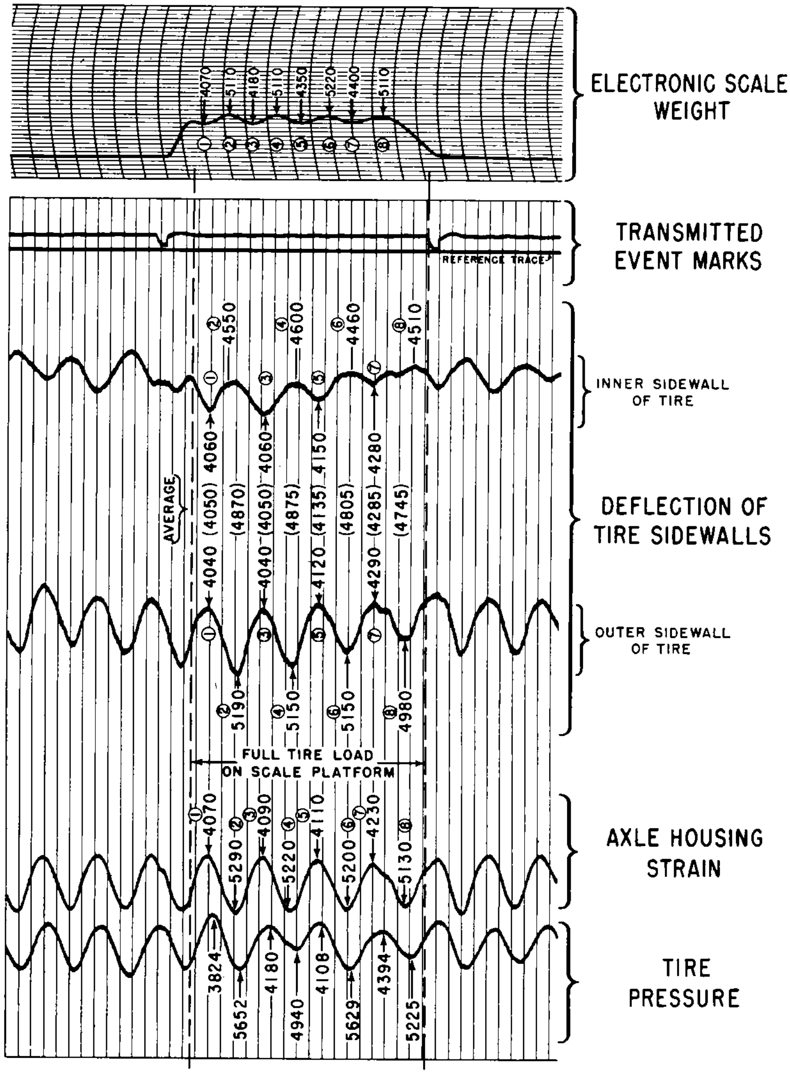


**Figure 7. Oscillograms of wheel load measurements.**

been distinguished from actual sidewall deflection due to a change in the load on the tire.

Using an emery wheel in a fixed position while the jacked-up truck wheel was rotating, a smooth and true path was provided 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 in. Some slight imperfections remained, however, and undoubtedly accounted for some error in the recordings.

*Changes in Tire Air Pressure Method*

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

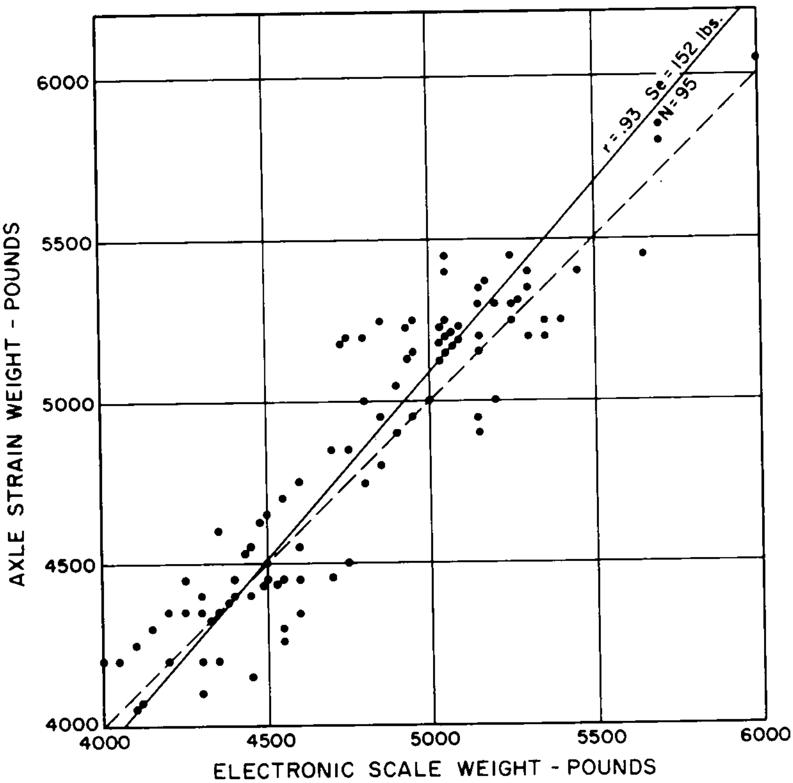


Figure 8.

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 Corporation pressure pickup gage type 4-311,-0-50 psi (gage) was used to record pressure changes (Figure 3). A hole was drilled in the valve stem of the tire tube and a short piece of ⅛-in. 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 diaphram was parallel with the axis of rotation of the truck wheel, thus, minimizing the effect of angular and vertical accelerations on the diaphram. The tire was inflated to a pressure of 55 psi (gage) when cold.

The pressure pickup is of the unbonded strain gauge 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 slip-ring assembly of five rings was built for this purpose (Figure 5). 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

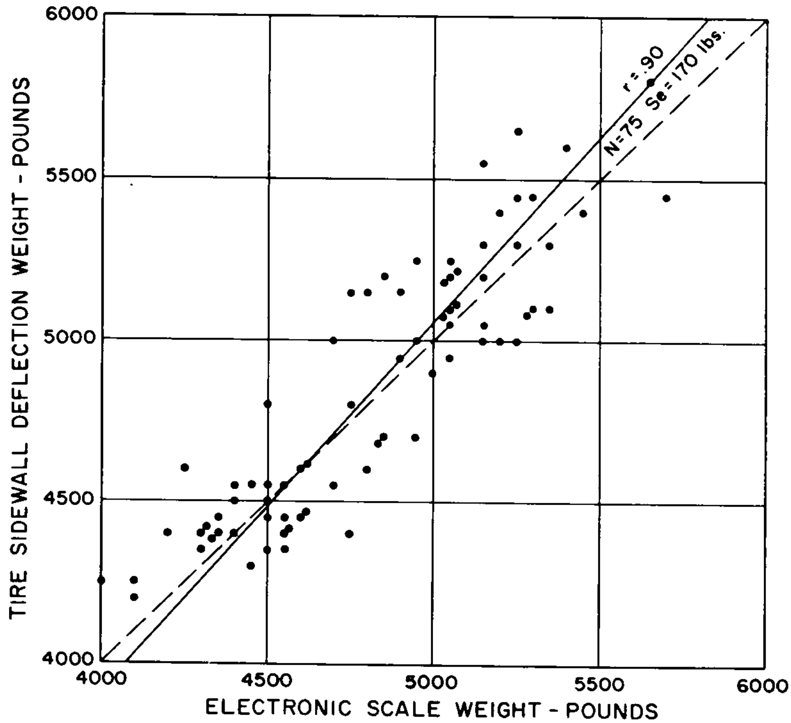


Figure 9

provided for the slip-ring assembly to keep dust and other foreign matter out.

Calibration of the pressure pickup was accomplished by comparing the pressure pickup oscillogram with the maximum and minimum weights 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 slip rings stationary and with them in rotation. The plotted points of comparison show some scatter due to normal imperfections in the slip rings and brushes used. The use of high quality instrument-type slip rings 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.

The recording instruments for the three tests were mounted on the forward end of the truck bed (Figure 6). The recording oscillograph (using mirror galvanometers) 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 placed on the truck bed just behind the instrument shelter. The shelter was built of 3/16-in. tempered pressed fiber panels which provided protection from the elements and darkened the space so that the operator could better see the viewing screen on the oscillograph. The rear panel of the instrument shelter was removed (Figure 6) to allow 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

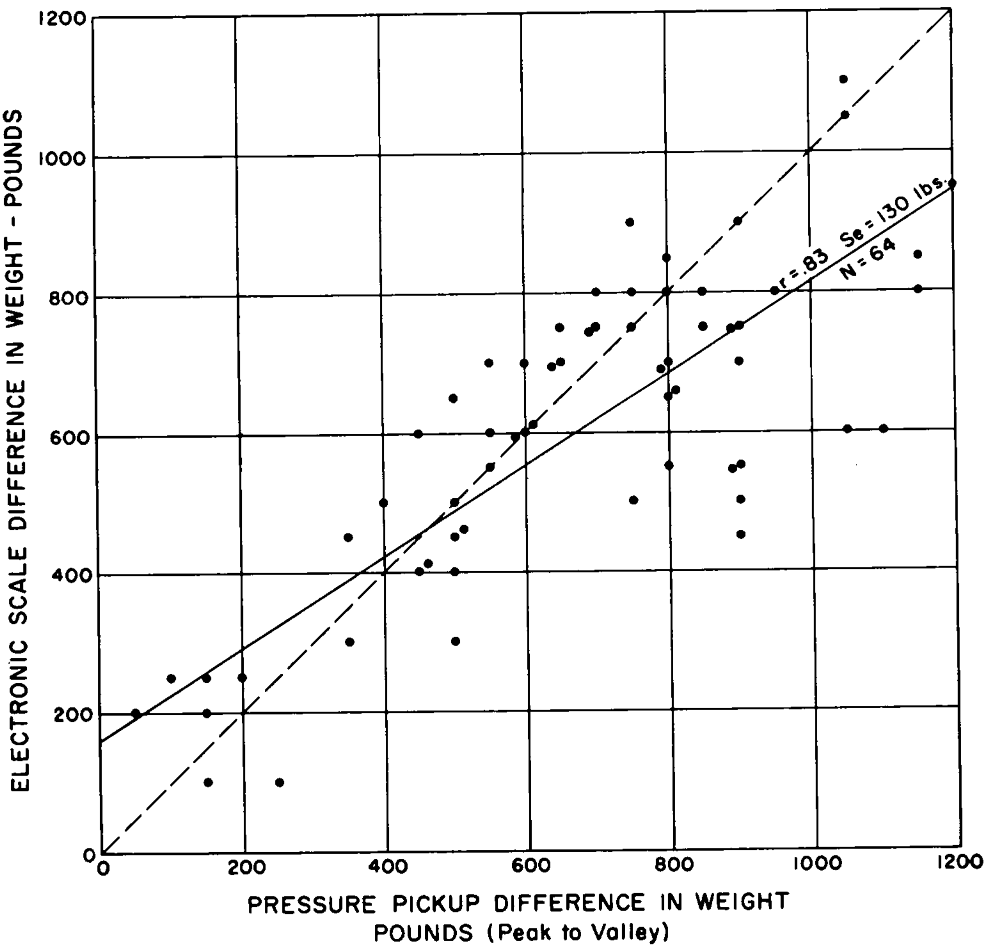


Figure 10.

wheel and axle weights were obtained by weighing at the nearby official weighing station. Only the right side of the vehicle passed over the platform because only the right-rear wheel was instrumented.

Pneumatic detectors were placed at the beginning and end of the scale platform to synchronize the recording of axle strain, tire bulge, and tire pressure with the wheel weight as recorded by the electronic scale. The air switches of these detectors keyed a radio transmitter (Figure 4).

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. The signal was rectified by a germanium diode whose output was connected to one of the galvanometers in the oscillograph. This made a pip on the oscillogram every time a pneumatic detector was depressed by a tire. The oscillogram of the wheel load measurements was thus marked so that it could be directly compared with the oscillogram of the electronic scale weight.

During trial runs across the scale platform, 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. Consequently, the load was

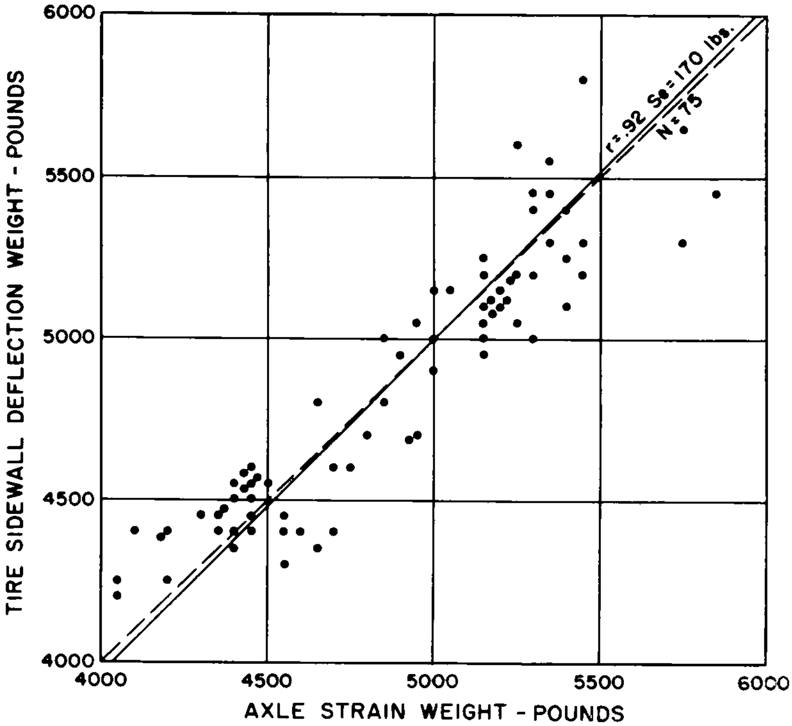


Figure 11.

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 lb.

At creep speed the load was oscillated through 6 or 6½ cycles while the wheel was crossing the 7-ft scale platform. At 10 mph, 1 or 1½ cycles were recorded; and at 20 mph, about ½ cycle was recorded. Speeds above 20 mph 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 mph were made across the scale platform.

Figure 7 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.

The data taken from the oscillogram were plotted to show the correlation between the three methods of wheel load measurement with the electronic scale. The correlation is also shown between the weight as derived from axle-housing strains and that derived from tire sidewall deflections (Figures 8, 9, 10, and 11). The static wheel load was 4,750 lb. These data were recorded while the truck was being artificially oscillated. The lines shown in Figures 8, 9, and 10 are the computed statistical regression lines, used to predict the weight recorded by the electronic scale from any of the other three recordings. The line on Figure 11 is the relationship between weights as shown by the axle-housing strain and the tire sidewall bulge.

The 45-deg line (dashed) represents a hypothetical line of perfect correlation on which all plotted points would fall if there were no difference 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. N on the graphs indicates the number of samples or observations.

Figures 8 and 9 show that the correlation is good, indicating 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 down the open highway without the man providing 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 on the rougher surfaces, and the higher frequencies occurred on the smoother surfaces.

Figure 10 shows that the correlation between the differences in weights as recorded by the pressure pickup compared with the electronic scale was less than for the other two methods probably because of the changing circuit constant of the slip-ring assembly. Calibration of this random change showed it to be equal to about 225 lb maximum, which would account for much of the observed error in this method.

Figure 11 shows that there was a high correlation between the weights as recorded by the axle-housing strain and the tire sidewall deflection.

Three means are being considered to improve the performance of the pressure pickup for future studies: 1. better quality slip rings; 2. differential-type pressure pickup (5 psi differential) which should give a strong signal output compared to any slip-ring noise; and 3. rotating pressure slip joint to eliminate the electrical slip rings between the pressure transducer and the recording equipment.

## CONCLUSIONS

1. The most practical of the three methods for measurements 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 make the other two methods less desirable. It is possible by incorporating refinements to record, continuously 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. The load transfer characteristics of the many different suspension systems now in common use on the undercarriage of trucks can now be compared.

4. Differences in weight of more than 5 percent between the static axle weight and the weight 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.

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