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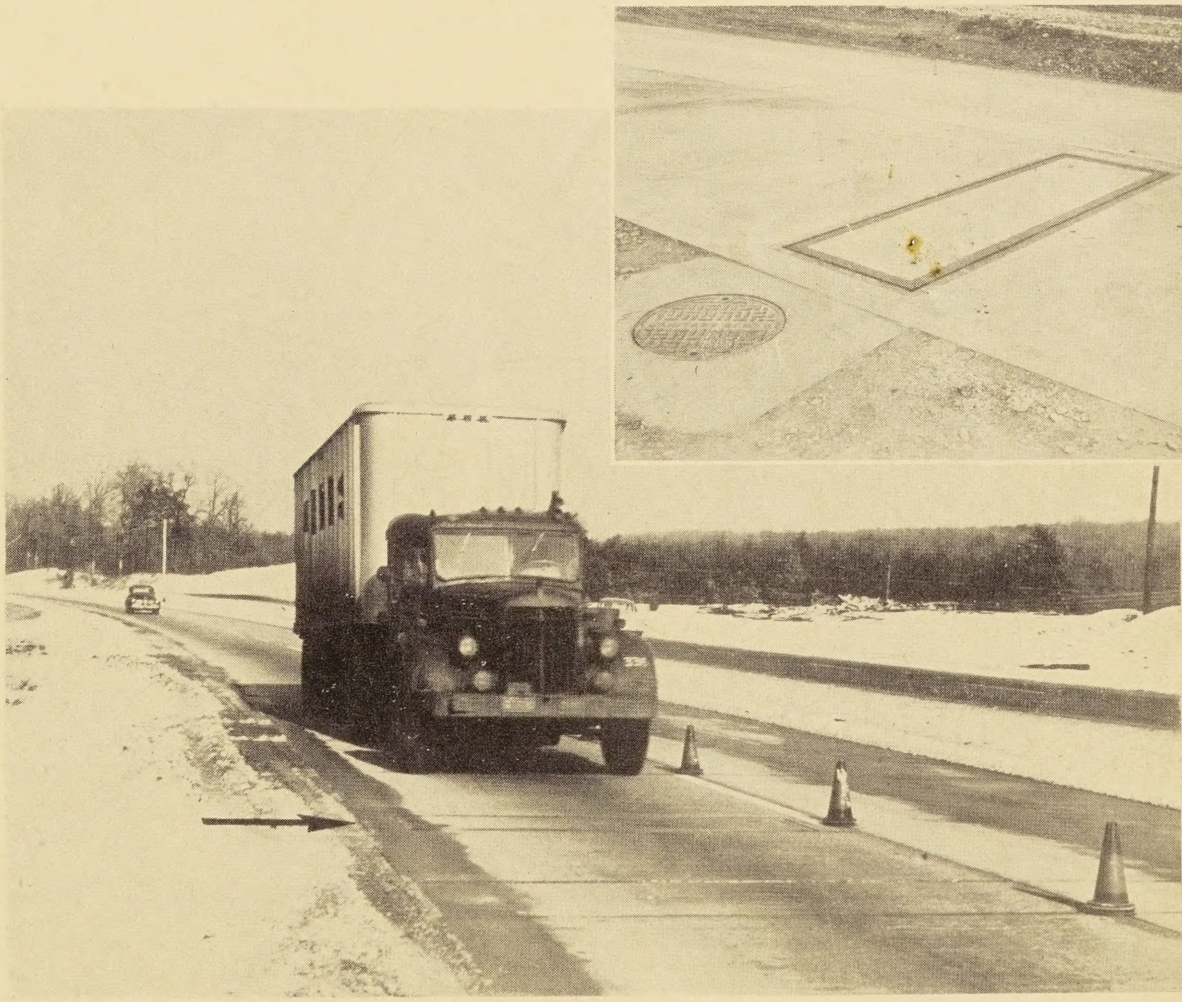

Load cells under a free slab in the pavement, coupled with electronic equipment, measure axle weight, speed, and axle spacing of vehicles in motion

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BUREAU OF PUBLIC ROADS
U. S. DEPARTMENT OF COMMERCE

E. A. STROMBERG, Editor

Weighing Vehicles in Motion

BY

THE HIGHWAY TRANSPORT RESEARCH BRANCH BUREAU OF PUBLIC ROADS

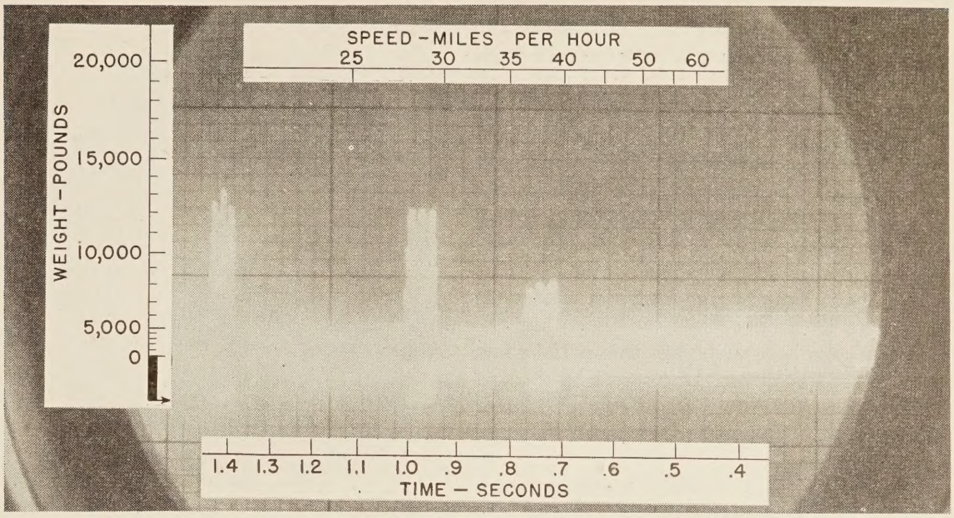


Figure 1.—Oscilloscope pattern of speed, axle-spacing, and axle-weight, with calibrated scales.

Reported by O. K. NORMANN, Chief, Traffic Operations Section, and R. C. Hopkins, Electrical Engineer

Comprehensive information on the gross weights, speeds, axle weights, and axle spacings of trucks traveling the Nation's highways is an important part of the vast body of knowledge necessary for the understanding and solution of our transportation problems. In the use of existing means of obtaining such data, involving portable loadometers and pit scales manned by relatively large crews, trucks must be stopped, and usually only a sample of the total traffic can be weighed and measured.

This article describes the development of an electronic weighing device which can measure axle weights, axle spacings, and speeds of vehicles moving at their normal operating speeds along the highway. The device consists of a narrow, free platform built in the surface of a traffic lane and supported by load cells containing columns to which are affixed groups of wire strain gages. The weight applied to the platform by a vehicle passing over it produces changes in the electrical currents flowing through the strain gages, and these changes, through electronic equipment, are reproduced as a pattern of light on an oscilloscope where they are photographed for record purposes.

A road detector tube, placed on the pavement at a predetermined distance in front of the platform, serves as a timing trigger for the sweep of the light spot across the oscilloscope, and from the recorded pattern not only axle weights but also axle spacings and the speed of the vehicle can be determined.

While the basic theory involved in the operation of this device is not unduly complicated, the experimentation and development work were beset with many electronic and structural problems. Many of these have been solved; others have been overcome in principle but are yet to be effected in practice.

For static weighing, the electronic scale is as accurate as the conventional lever-system pit scale. For highway-planning purposes, the electronic scale in its present stage of development is suitable for determining the frequency of different axle and truck weights, axle spacings, and speeds of vehicles without interfering with their normal operation. For enforcement purposes, through the use of an electronic scale of this type it is possible to cull out trucks with axle weights or total weights approaching or exceeding legal weight limitations.

There is good prospect that the electronic scale will be so improved that its accuracy in weighing vehicles in motion will approach still more closely the accuracy already attained in static weighing. It is also probable that simpler and less costly electronic equipment can be designed, and an oscillograph may prove an adequate substitute for the oscilloscope and recording camera.

KNOWLEDGE regarding the weights of trucks traveling over the Nation's highways is a prerequisite to a thorough understanding of our national transportation problems. Trucks are weighed to obtain information on the tonnage of freight carried by the several vehicle types on the various highway systems, to determine the magnitude and frequency of axle loads for highway design purposes, and to enforce license, tax, and load-limit laws.

At present, weighing trucks for highway planning and design purposes generally involves some sampling process. The most common sampling technique presently employed requires a six-man party equipped with portable loadometers. Such a party can seldom weigh more than 200 trucks per 8-hour day, at a cost of from $100 to $150. Truck operators object to the delay sometimes encountered at a weighing station and frequently use circuitous routes to avoid the station, even though the data obtained are used only for highway planning purposes and no law enforcement is connected therewith.

Common practice in enforcement of legal weight limits requires that, at any enforcement station, all trucks be stopped and weighed, excepting perhaps those obviously empty or of very light weight. Inconvenience and sometimes considerable delay to all operators result, even though only a small percentage are overloaded.

In realization of the widespread need for a scale which can weigh vehicles at their normal highway speeds, the Bureau of Public Roads during the past several years has investigated the possibility of adapting various types of mechanical and electrical devices to this problem. Experimental vehicle-weight recordings were made, using several electronic systems and various weight-sensitive electrical components such as variable resistors of carbon granules, variable capacitors, and strain gages. Of these, the highly perfected resistance-wire strain gage seemed most adaptable to vehicle-weighing requirements.

Electronic scales for weighing stationary objects or materials with an exceedingly high degree of accuracy have been in use for a number of years. Electronic scales are now being used to weigh freight cars while traveling at slow speeds, and to weigh materials in hoppers and ladles or materials picked up by cranes. At the time that the electronic scale described in this article was constructed, however, there was no record of a successful attempt to weigh motor vehicles while traveling at their normal highway speeds.

Basically, the electronic highway scale consists of a free platform built in the surface of a traffic lane and supported by load cells. A small voltage output of the load cells is amplified to operate a recorder which shows the weight of either a static or dynamic load. The load cells employed, and their associated electronic equipment, normally comprise an aircraft weighing kit used by commercial airlines, the Air Force, and the Navy to weigh their planes periodically and determine their centers of gravity. Usually, a plane is jacked up to flight position with a load cell between each of the three jacks and the jack points. Each cell must be capable of measuring within an accuracy of 10 pounds for any weight up to 50,000 pounds. The manufacturer of the kit, Cox and Stevens Aircraft Corporation, Mineola, N. Y., has cooperated in furnishing and adapting these components to the highway scale. Other instruments used for the scale are commercially available.

This report of progress to date discusses the circuitry and physical features of the scale. Also included is a discussion of its present accuracy, the improvements made during the investigation to attain this degree of accuracy, and desirable electronic and structural modifications that will further improve the scale and reduce the complexity of operation.

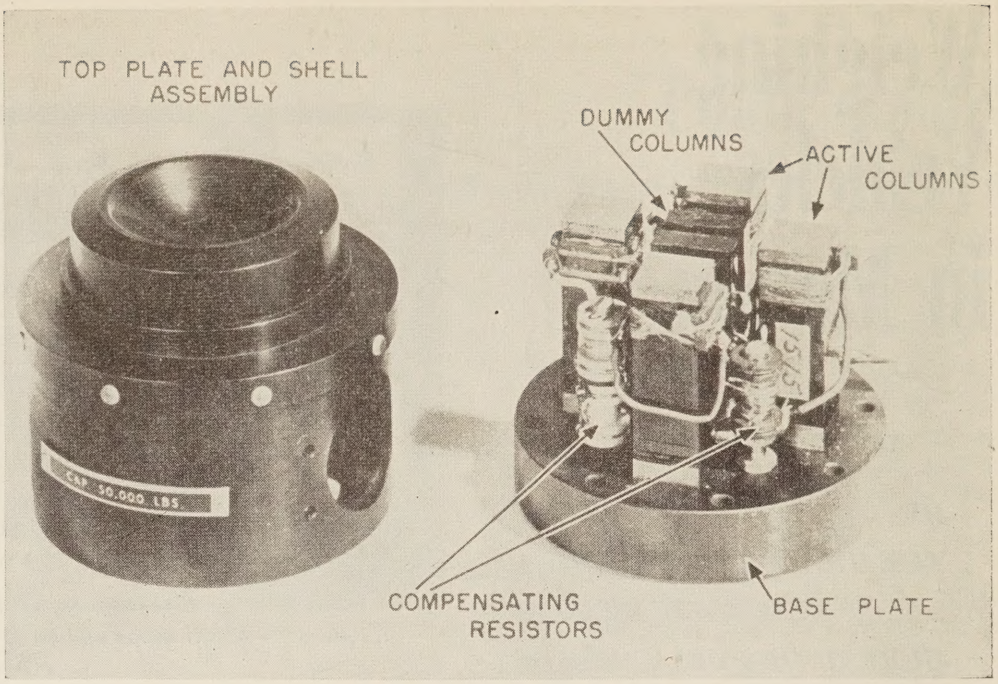


Figure 2.—The load cell.

Conclusions

The results of the tests made to date have been of sufficient scope to justify the following conclusions:

1. For static weighing, electronic scales in proper operating condition are as accurate as the conventional lever-system scales. Based on data obtained from these tests and other sources, electronic scales designed for the purpose for which they are used have a good record for retaining their calibration.

2. For highway-planning purposes, an electronic scale of the type described here is suitable for obtaining data on the frequency of different axle and truck loads, and the gross tonnage on a section of highway, without affecting the normal speeds of trucks. If desired, accurate measurements of vehicle speeds and axle spacings can be obtained at the same time.

3. For enforcement purposes, through the use of a scale of this type it is possible to cull out the trucks with axle loads or total loads which approach or exceed legal weight limits without affecting the normal speeds of most of the trucks. It is estimated, for example, that with a legal axle load of 18,000 pounds and a legal gross load of 50,000 pounds, all the trucks with illegal loads would be included in those which the scale recorded as having axle loads in excess of 16,000 pounds and gross loads in excess of 47,000 pounds. For enforcement purposes the trucks with loads approaching or in excess of the legal limits would have to be weighed statically to obtain a record which would be recognized in court at the present time.

4. There is a good possibility that the accuracy of the scale for weighing trucks in motion will be improved to approach still more closely the accuracy obtained by weighing trucks statically.

Electrical Principles

The electronic highway scale is a straightforward application of simple electrical principles. The experimental instrumentation is very intricate, however, and the circuitry of a practical scale may also be complex, although it need not be complicated in its operation.

The basic electrical principle upon which the electronic scale operates is that the resistance of a conductor is proportional to its length and inversely proportional to its cross-sectional area. The resistance-wire strain gage, usually consisting of several parallel wires connected in series and held solidly in alinement with a special cementing filler, makes use of this principle. When a strain gage is in turn bonded to some structural or mechanical part, a tension of the part in line with the strain gage will lengthen the wires and reduce their diameter, thereby increasing the resistance of the gage. Conversely, a compression of the part will reduce the gage resistance in proportion to the compressing force. The weight-sensitive load cell shown in figure 2 consists of columns to which strain gages have been bonded.

The electrical circuit of a load cell is a resistance network, commonly called a Wheatstone bridge, in which the current flow resulting from an applied voltage is divided equally so that there is no difference in potential at the output terminals. This resistance network consists of several wire strain gages mounted on columns so that compression of the columns deforms strain gages in opposite arms of the Wheatstone bridge, which in turn effects an unbalance in the resistance network, and consequently there is a difference in potential between the output terminals. The value of this potential difference is proportional to the compressing force.

Registering Components

To complete the electronic scale, a registering component must be provided and a means of calibrating the compressive forces

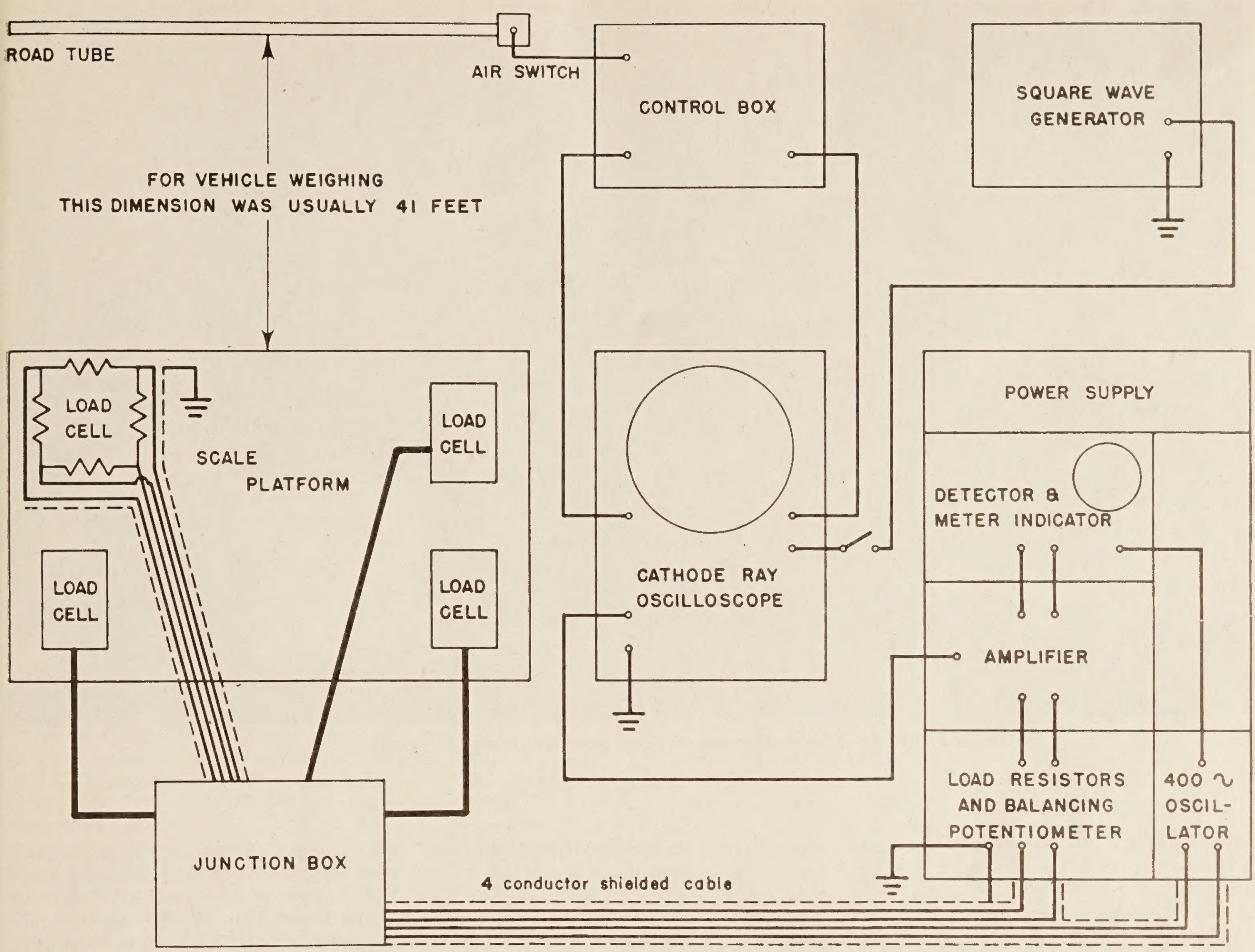


Figure 3.—Block diagram of the electronic scale.

is necessary. The cell output must also be sufficiently amplified to operate the recording device.

The short dummy columns of the load cell (fig. 2) carry no load. Strain gages mounted on these columns serve as the major temperature-compensating components in the cell and eliminate the need for adjustment of calibration with changes in temperature.

Four load cells were used in the experimental scale, as shown in figure 3. Each cell in itself was a complete Wheatstone bridge plus temperature and modulus-compensating resistors. The cells were connected in parallel so that the amplifier input would be a measure of the total unbalance of the four cells. This provided for the accurate indication of any weight, regardless of its position on the platform. A low-voltage 400-cycle current was supplied to the cell input because amplifiers for alternating current are generally more stable electrically than amplifiers for direct current. The cell output was fed through a range-control and calibrating-resistance network to a voltage amplifier and indicating meter. Also, a small voltage from the 400-cycle oscillator was fed directly to a phase-sensitive detector preceding the null-indicating meter so that the direction of the meter deflection showed whether the load was being increased or decreased. The range-control and calibrating-resistance network was composed of precision resistors so connected that known changes in cell unbalance could be directly produced to compensate for platform weight or other dead load on the scale and to calibrate the oscilloscopic presentation. The range-control and vernier potentiometer were also used to rebalance the bridge circuit for static weighing operations.

Weighing vehicles at normal highway speeds was accomplished by connecting an oscilloscope to the output of the second stage of the four-stage voltage amplifier included in the aircraft weighing kit. An oscilloscope contains a cathode-ray tube similar to a television picture tube. The cathode-ray tube in this case had a screen which would retain an image for a short time. A measure of the cells' unbalance was presented on the screen as a pattern which represented the weight for each axle of a vehicle. In addition, a photographic record was made of these transient phenomena.

The horizontal progression of the focused spot of light on the screen of the oscilloscope is called the sweep. The sweep speed is controlled by the rate of charge of a capacitor through a resistor, and only the flatter portions of this charging curve were usable as a time base. It was desirable, therefore, to provide a means for readily choosing a linear portion of the sweep. To accomplish this, a square-wave generator was used. This instrument produces an alternating current which changes from a constant positive value to a constant negative value in zero time as contrasted with the sine-curve wave form of conventional alternating current. The square-wave generator was connected to the Z axis of the

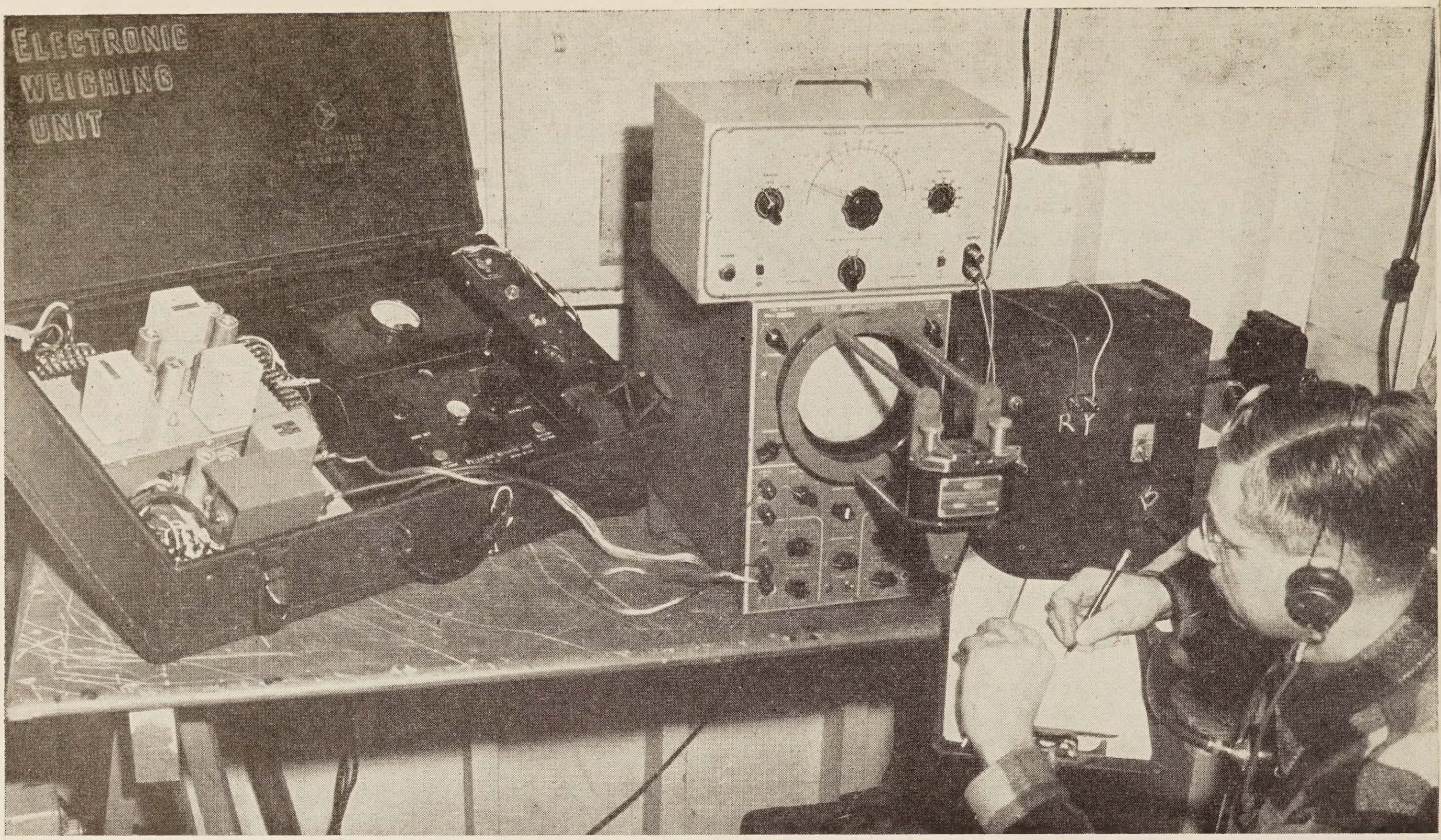


Figure 4.—The oscilloscope and associated electronic equipment in use.

oscilloscope so that chosen time intervals could be shown on the screen by blanking out the beam at a low-frequency rate. This produced a series of equal time dashes on the screen, and the sweep-generator controls could then be adjusted to provide linear time increments throughout the screen width. A rapid change could then be made from a slow sweep speed for recording all axles of a vehicle to a fast sweep speed for single-axle or tandem-axle recording and still provide records with abscissas directly referable to unit time.

To provide a tie between the sweep of the oscilloscope and the progress of a vehicle in the traffic lane, a road detector was used in front of the scale platform. The distance between the road detector tube and the platform was set so that the visible sweep of the oscilloscope coincided with the passage of the vehicle wheels across the scale platform. The front wheels of a vehicle passing over the road tube triggered the sweep circuit in the oscilloscope, permitting the focused spot as seen on the oscilloscope tube to sweep the screen at its predetermined rate.

As each wheel of the vehicle passed over the scale platform, the visible spot was also deflected vertically by a signal from the amplifier of the weighing kit. The amplitude of the vertical deflection was a measure of the axle weight. As the point of origin could be computed and rate of horizontal progression of the spot was known, the position of the weight indication of the front axle also was an indication of the vehicle speed, and the position of the weight indications of succeeding axles showed also a measure of axle spacing.

Operation of Electronic Scale

A typical set-up procedure will best describe the operation of the components of the weighing equipment. The weighing kit, oscilloscope, control box, and square-wave generator were placed conveniently on the bench, generally as shown in figure 4. The shielded cable from the load-cell junction box was connected to the weighing kit and the units were interconnected as shown in the block diagram (fig. 3). The road-detector tube was located at a distance in front of the scale platform, normally 41 feet, which was determined by the range in vehicle speeds. After connecting the air-switch cable to the control box, the set-up was complete.

It was found during the tests that the speed of the focused spot across the screen and the magnitude of its vertical deflection with a given load had a tendency to change during the first half hour of operation. To avoid errors due to changes in calibration because of instrument drift, a half-hour warm-up period was allowed prior to the start of each series of tests. During this warm-up period, the oscilloscope controls were adjusted within their operating range. The Y axis of the oscilloscope was calibrated in pounds by unbalancing the bridge circuit with the load switch in 5,000-pound steps. This method of electrically introducing an artificial load with the factory-calibrated weighing kit eliminated the need for calibrating the oscilloscope scale by placing actual known loads on the platform. The accuracy of this procedure was confirmed by field tests. Usually the Y-position, Y-attenuator, and Y-amplitude controls were set so that a 20,000-pound load caused a vertical deflection of 20 divisions on the screen. Deflection values for other weights were then recorded as shown by the typical weight-calibration record in figure 5.

A weight scale such as that appearing in figure 1 (p. 1) was computed from these weight calibrations. An axle weight is determined from it by alining the arrow at the bottom of the scale with the lowest point of the axle pattern and then reading the weight at the top of the pattern. The distance on the scale from the arrow to the zero reading represents the width of the pattern with no load on the scale.

The purpose of the study and the type of data to be recorded during each study determined the setting of the sweep speed. A two-second sweep time allowed all axles of trucks traveling within the normal range of speeds to be presented on the oscillo-

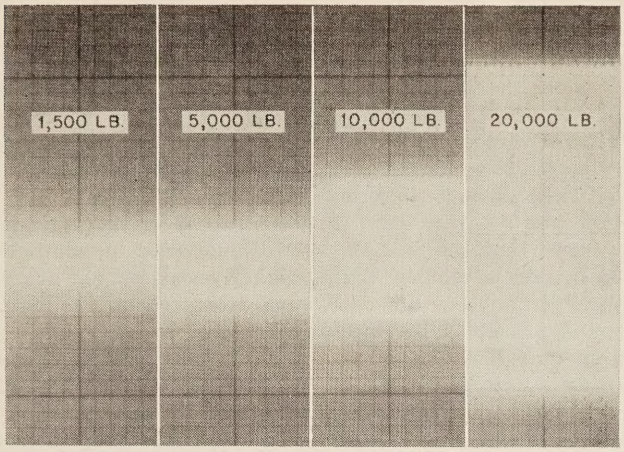


Figure 5.—Patterns of electrically introduced artificial loads for weight calibrations.

then the weight of the axle on the platform.

This experimental scale was constructed entirely with commercially available instruments to test an electronic system for dynamic weighing. No major electrical changes were made in the individual units. The experience gained from the experimental scale now makes it possible to draw general electronic specifications for a scale designed for dynamic weighing which would provide reliability, accuracy, and simplicity of operation.

scope, whereas a one-fifth-second sweep time would permit a detailed presentation of single-axle or tandem-axle weights. An appropriate frequency was then selected on the square-wave generator: 20 cycles per second for the slower sweep and 50 cycles per second for the faster sweep. By observing the number of time marks per inch throughout the width of the oscilloscope screen, a combination adjustment of the sweep range, sweep vernier, X-position, and X-amplitude controls produced the exact linear speed desired.

Figure 6 shows a typical recording made before the final sweep adjustments had been made. Since the spot started its sweep at some point off the visible screen, a known time point was established by recording the axle weights of a passenger vehicle traveling the known distance from the road detector tube to the scale platform at a known speed. Knowing the road-tube spacing, vehicle speed, and the frequency of the equal time pulses, the time and speed scales which appear on figure 1 could be computed.

The weighing kit was provided with a balancing potentiometer which was adjust during the warm-up period to bring the null-indicating meter to center scale when the scale platform was unloaded. At the end of the warm-up period, a slight readjustment of the sweep vernier and the Y-amplitude control prepared the instruments for operation.

Any vehicle for which axle weights were desired could be selected by closing the switch on the control box and opening the camera shutter as the vehicle approached the road tube. After the passage of the vehicle the camera shutter was closed, the film was advanced, and the control-box switch was opened to prepare the instrument for the next vehicle to be recorded. With manual operation of the camera, the complete recording cycle required about 10 seconds. In occasional cases where two trucks were closely spaced, it became necessary to select the one for which data were desired.

A recording of axle weights and spacings and vehicle speed is shown in figure 1. The derivation of the time, speed, and weight scales superimposed on this figure has been previously described. Using these scales, it can be determined from the pattern made by the vehicle that it was traveling 39.5 miles per hour, had axle weights of 7,500 pounds, 12,200 pounds, and 13,300 pounds, and had axle spacings of 13.5 feet and 25.6 feet. The axle spacings were calculated after knowing the time spacings between the axles and their speed.

For static weighing, the road tube, control box, oscilloscope and camera, and square-wave generator were not used. The weighing kit was checked for balance and adjusted by the balancing potentiometer. One axle of the vehicle was run onto the platform, other wheels were trigged, the brakes released, and the null-indicating meter was brought back to center scale by adjusting the weight-indicating dials which were calibrated in pounds. The weight shown on these direct-reading dials was

Recommended Improvements

Some of the more important features that should be included in an improved instrument designed for weighing vehicles in motion which are relatively simple to accomplish are:

1. Redesign of the control box to provide for automatic operation. To accomplish this would require only the addition of one circuit which would reset the sweep trigger when the spot had completed its traverse of the oscilloscope screen.
2. Design of cathode-ray tube circuits specifically for the scale. The oscilloscope now in use is a general-purpose instrument and therefore contains many features not used in conjunction with the highway scale. Also, the present instrument has a greater range of control over the circuits that are used than is desirable. The controls should be reduced to those for spot position, spot intensity, focus, weight calibration, and sweep calibration. The last two mentioned should each have only a single control dial. These should be calibration adjustments rather than complete controls of the amplifier gain and sweep speed now available in the oscilloscope.
3. Automatic operation of the camera, and a large film magazine.
4. Redesign of the weighing-kit circuits to provide a well-shielded oscillator, a stable amplifier with a simple gain calibration and adjustment, and a vacuum-tube de-

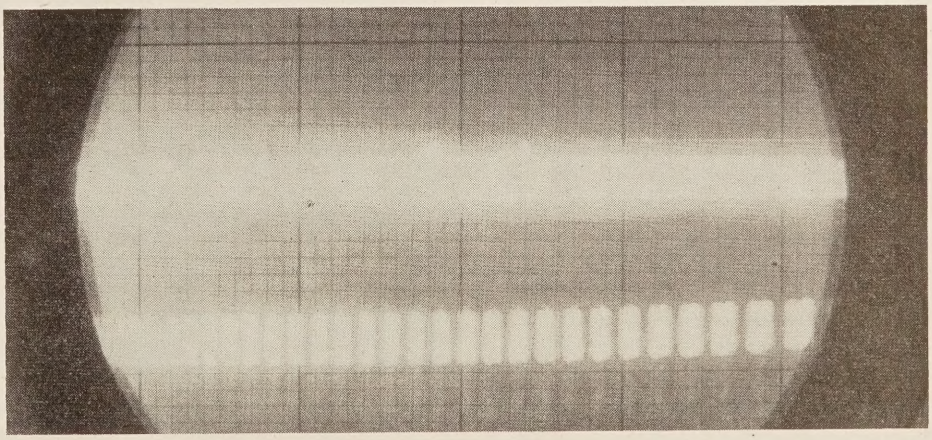


Figure 6.—Pattern produced by an automobile moving 40 miles per hour with 20 time marks per second inserted for speed and axle-spacing calibration.

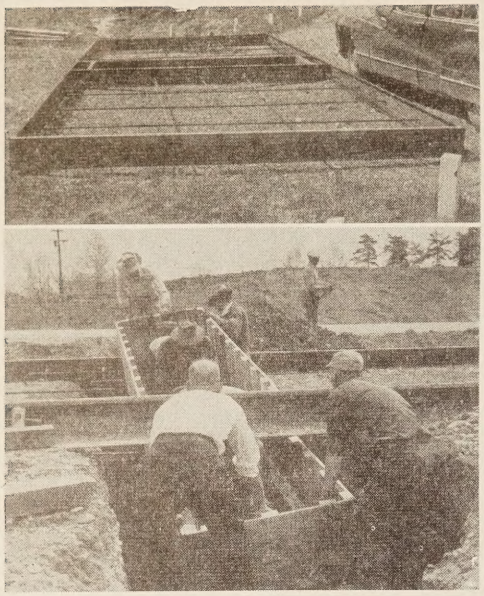


Figure 7.—Above: Steel framework used to form the pavement slab in which the weighing pit was installed. Below: Only an inside form was used for the pit.

tector so that the oscilloscopic presentation of weight is in one direction only from the zero, making for a single scale reading for each axle weight.

5. Possible substitution of a pen or heated-stylus recorder for the cathode-ray oscilloscope and camera.

Several of these design changes are now being incorporated in the present scale. Structural improvements are discussed at the end of the article.

Construction of the Scale

Concurrent with the electronic development, and of equal importance, a program of research was being conducted to determine the most suitable structural and mechanical features of the complete scale.

In April 1951, when it appeared from a number of rather crude preliminary tests that there was a possibility of weighing vehicles in motion by an application of electronic load cells, the last section of concrete pavement on the Shirley Highway, a freeway in Virginia just south of Washington, D. C., was nearing completion. This offered an opportunity to construct an electronic scale for a minimum cost at a location that was ideal for development and test purposes.

With the cooperation of the Virginia State Department of Highways and the contractor, the Williams Construction Company of Norfolk, Va., the Bureau of Public Roads completed the construction of the pit and slab necessary for the installation of the load cells and electrical equipment on May 7, 1951. The exact location of the installation is on the Shirley Highway 1,000 feet north of the intersection with U S 1 near Woodbridge, Va.

The design of the experimental scale was influenced by several considerations which now appear to be either elementary or of slight importance. Since the possibility of recording accurate weights of vehicles in motion seemed rather remote, due to the spring action of the vehicles and impact factors involved, it was obvious that an elaborate installation was not justified. It was necessary, however, that the installation be constructed in such a manner that it would be adequate for an accurate test of the equipment and principles involved. It was also essential that the original installation be designed so that changes could conveniently be made in the electrical equipment and in the suspension of the floating slab, as the investigation progressed, without the need of major changes or reconstruction of the pit located in the roadway. Furthermore, it was desirable that the tests be conducted without unduly interfering with normal traffic operations on the freeway.

The floating slab supported by the load cells, and the pit under the floating slab which provides access to the load cells, were constructed in the right-hand lane of the two lanes used by southbound traffic. The highway carries an average of about 50 dual-tired trucks per hour in each direction, with a fairly uniform flow day and night. Most of the trucks normally use the right-hand lane at the location and are weighed by the Virginia Department of Highways on their conventional lever-system scales located 4 miles to the south. As a check on the accuracy of the electronic

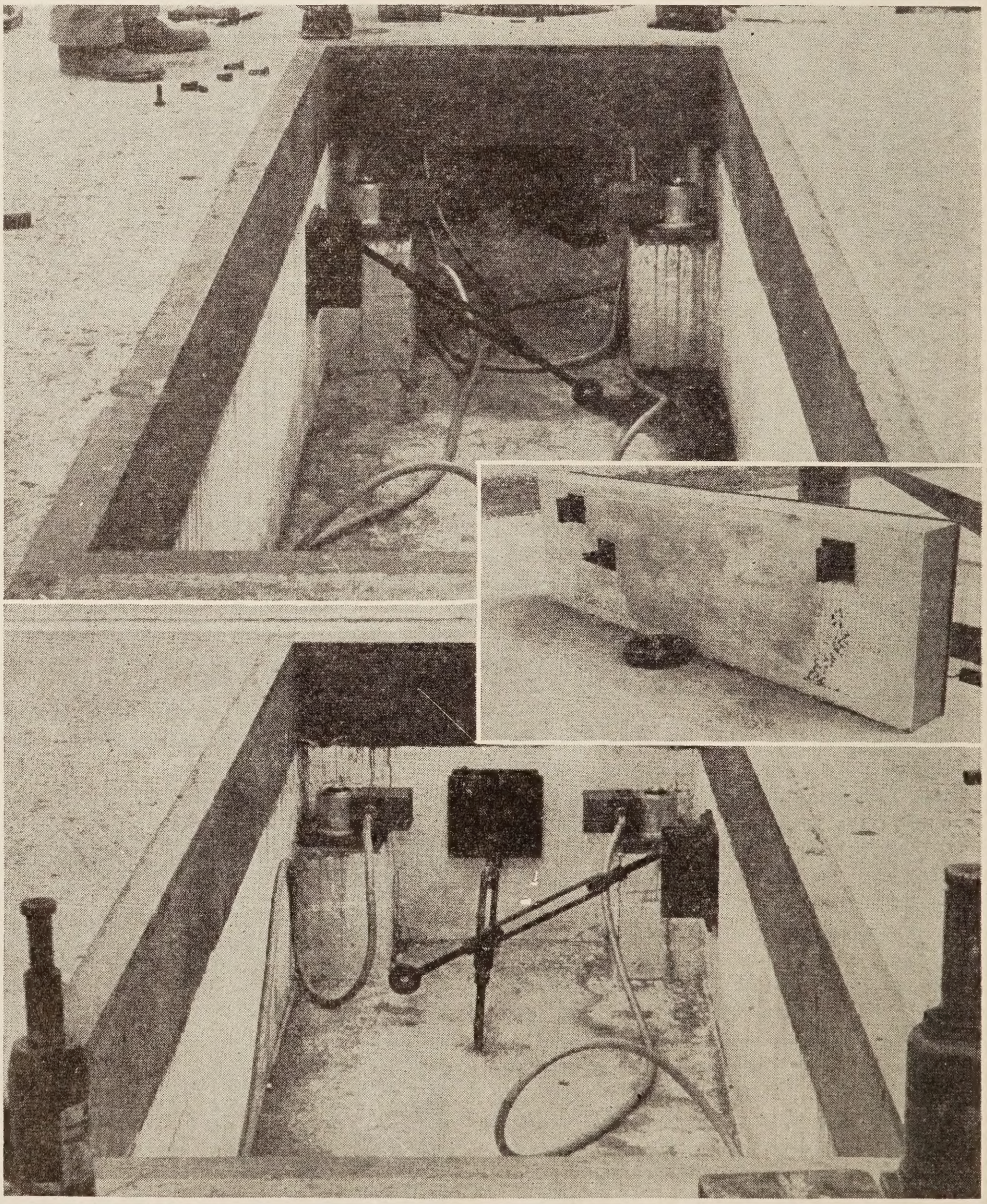


Figure 8.—The completed pit, showing the load cells in place and the turnbuckles attached to the pit brackets. The west end and the access manhole appear in the upper view; the east end is shown below. The floating slab, with the turnbuckle brackets attached to the bottom face, is shown in the inset.

scales for weighing vehicles in motion, the static weights of the trucks were obtained at the lever-system scales.

Maximum possible smoothness of the pavement at the electronic scale was obtained by finishing the surface to the top edge of two 30-foot steel channels rather than to the top of conventional 10-foot concrete forms. A framework of 10-inch channels, as shown in figure 7, was constructed to form the outside dimensions of one concrete slab 30 feet long and 12 feet wide, and the top of the inside walls of the pit. This framework was placed inside the conventional concrete forms and remained in place after the conventional forms were removed. One-inch steel bars spaced about 3 feet apart in both directions were welded to the channel framework to supplement the steel-mesh reinforcing used throughout the project and to assure continued smoothness of the surface at the scale. Extra care was also taken to obtain a smooth surface on the two 30-foot slabs adjacent to the one in which the scale was located.

The pit to accommodate the floating slab and load cells occupied the central 10 feet of the normal 12-foot traffic lane and was 37½ inches wide to allow a three-fourths-inch clearance between the floating slab and the walls of the pit. It would have been desirable to construct the pit for the entire 12-foot lane width, but this would have introduced additional construction difficulties that did not seem warranted for this investigation. The 36-inch width for the floating slab was selected to obtain the maximum size on which the weight of not more than one axle of a vehicle would be present at any one time. The clear distance between tire-contact areas on dual axles approaches a minimum of 3 feet. The thickness of the floating slab was 12 inches. It was reinforced with 12-inch steel channels weighing 35 pounds per foot which had been welded together to form the outside dimensions. The ends of 1-inch reinforcing rods spaced about 2 feet apart were also welded to the channels in addition to the two layers of wire mesh.

The depth of the pit was 30 inches. This dimension was limited by the elevation of the bottom of the drainage ditch of the roadway. A greater depth for the pit would have been desirable if natural drainage from the bottom of the pit could have been provided. The bottom and walls of the pit were 12 inches thick. They were poured integrally with the surface of the rest of the 30-foot slab. Access to the pit with the floating slab in place was through a manhole located on the shoulder, as shown in the cover illustration.

Two steel angle brackets were fastened on the long side of the pit and one on the short side, and corresponding brackets were bolted to the under side of the floating slab. These brackets were connected with tie bars and turnbuckles, to hold the slab in proper horizontal position. After the slab was installed a ¾- by 1-inch rubber strip was placed in the space between the slab and the walls of the pit.

The location of the four load cells and the turnbuckles for adjusting the tie bars that held the floating slab in its proper horizontal position is shown in figure 8. The cover illustration shows a view of the completed installation as it appeared on the surface of the road.

Initial Tests of Accuracy

A loaded two-axle dump truck was used in the first series of tests to determine the accuracy of the scale. The static weight of

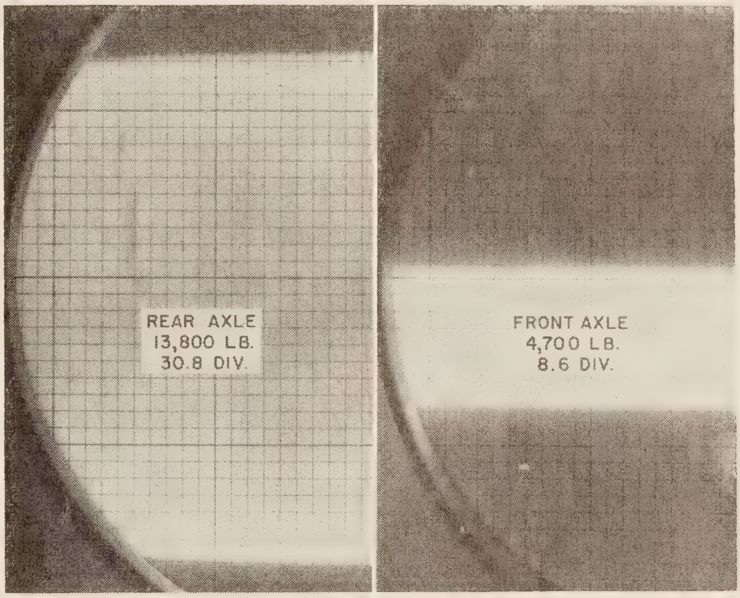


Figure 9.—Static weight pattern for a two-axle truck.

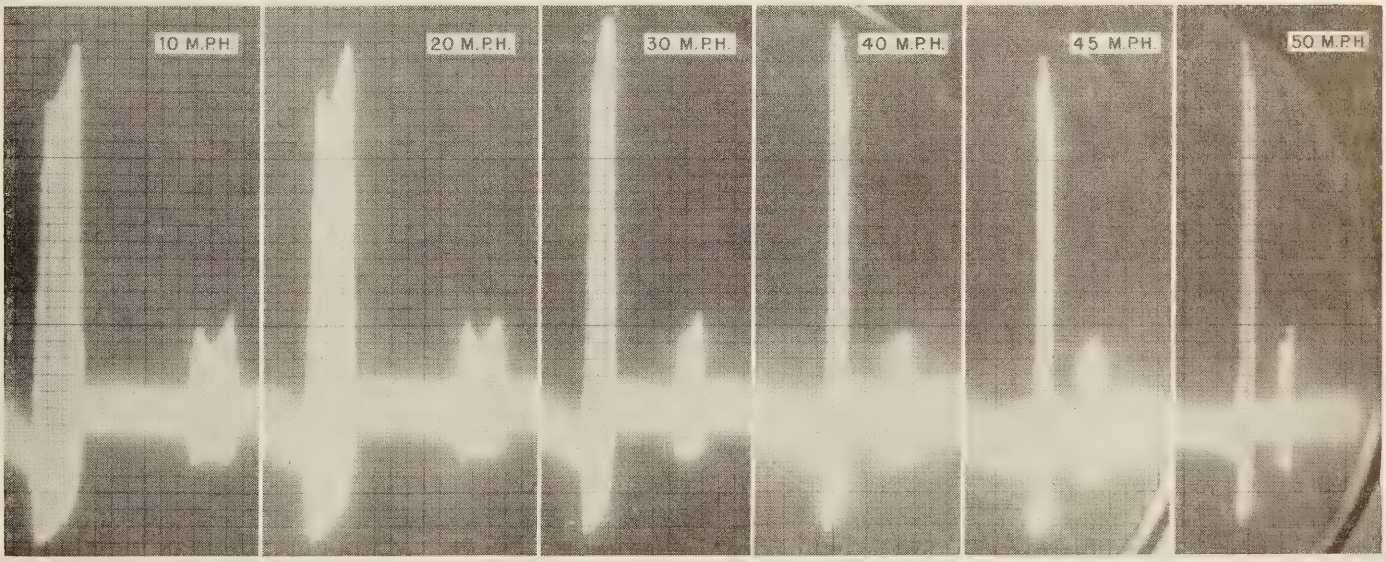


Figure 10.—Weight patterns for various speeds of the truck weighed statically in figure 9.

Table 1.—*Recorded weights of two-axle truck at various speeds*

Speed	Based on longest vertical oscillation				Based on extremes of pattern			
	Front axle		Rear axle		Front axle		Rear axle	
	Recorded weight	Error [1]	Recorded weight	Error [1]	Recorded weight	Error [1]	Recorded weight	Error [1]
M.p.h.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*
0	4,700	....	13,800	....	4,700	....	13,800	....
10	4,800	+100	12,800	−1,000	4,950	+250	13,850	+50
20	4,600	−100	12,700	−1,100	4,750	+50	13,500	−300
30	4,700	0	13,400	−400	4,750	+50	13,900	+100
40	4,300	−400	13,700	−100	4,300	−400	13,800	0
45	4,750	+50	13,300	−500	4,750	+50	13,300	−500
50	4,900	+200	13,200	−600	4,900	+200	13,200	−600

[1] Deviation from static weight.

each axle of the truck was obtained first on the electronic scale and then on the conventional lever-system scale. The oscilloscope pattern of the static weight for each axle while the truck was standing on the electronic scale is shown in figure 9. It is possible to vary the magnitude of the vertical deflection of the oscilloscope spot for a given load by turning the Y-amplitude dial. For example, it is possible to change the adjustment so that one division of the grid on the screen will represent 10 pounds, 10,000 pounds, or any load between 10 and 10,000 pounds. During this series of tests the Y-amplitude was adjusted so that the pattern for the load of the heavier axle of the truck covered most of the screen. This permitted the recorded weights as obtained from the patterns to be read with a greater precision than if a smaller scale were used to represent the same weight.

After obtaining the static-load pattern, a series of weight patterns was obtained as the truck crossed the electronic scale at different speeds, ranging from 10 to 50 miles per hour. These patterns are shown in figure 10. The difference between the magnitude of the static-load pattern for each axle, measured vertically, and the magnitude of each pattern while the truck was in motion is a direct measure of the error in the recorded axle weights. Table 1 shows the recorded weights of the truck traveling at various speeds as obtained by translating the oscilloscope patterns into axle loads.

There was some question during these initial tests as to whether the recorded weights were represented by the magnitude of the extremes of the axle-weight patterns or by the magnitude of the longest vertical lines of the patterns. One set of figures in table 1 is based on the longest vertical lines within the patterns, whereas the other set of figures is based on the extreme magnitudes of the patterns. In this test, the weights that are based on the extremes of the patterns correspond more closely with the static weights than those that are based on the longest vertical lines. This did not hold true in subsequent tests. Generally, the weight represented by the longest vertical line of a pattern corresponds more closely with the static weight than the weight represented by the extremes of the pattern. In either case, the maximum difference between the static weight and the recorded weight while the vehicle was in motion was 400 pounds for the front axle, a difference of 8.5 percent. For the rear axle, the maximum error was 1,100 pounds or 8.7 per cent in the one case and 600 pounds or 4.4 percent in the other case. Most of the errors shown in table 1 are within the precision with which it is possible to read the magnitude of the oscilloscope patterns.

Major Errors in Dual-Axle Weights

It should be noted that there is no consistent increase or decrease in error with an increase in the speed of the vehicle. A number of tests of this type were made, using two-axle trucks, during the period that improvements and adjustments were being made in the electrical equipment and in the procedures being developed for conducting more comprehensive studies of normal traffic using the highway. Similar results were obtained in all of these tests, there being no indication that a greater error was likely to occur at one particular speed than at another speed. Many minor improvements were made in the equipment during this period, but attempts to increase the accuracy by minor changes in the electrical apparatus were not successful. The

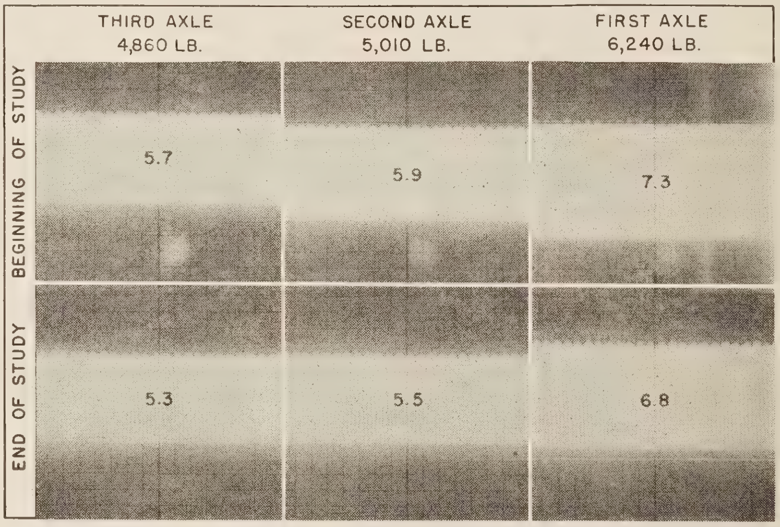


Figure 11.—Static weight patterns for a three-axle truck at the beginning and end of the study. The figures in the pattern bands indicate their widths in divisions.

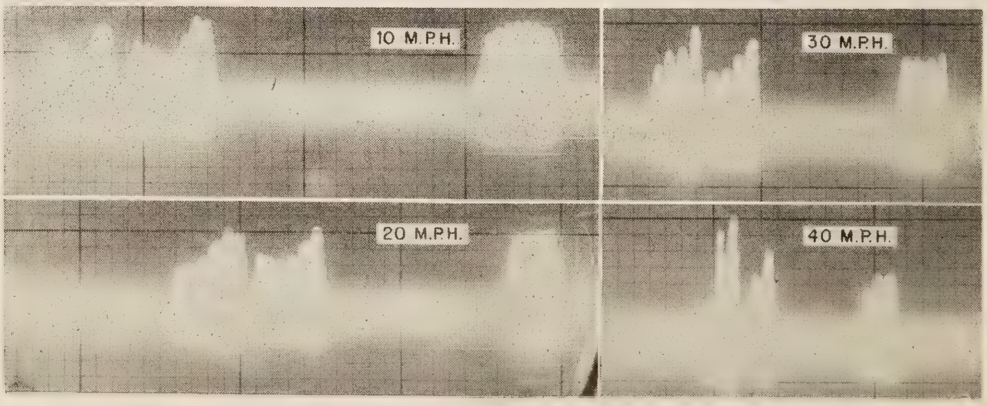


Figure 12.—Weight patterns (with unequal dead weights on load cells) for various speeds of the truck weighed statically in figure 11.

use of equipment built especially for weighing vehicles in motion rather than the present equipment, which was a combination of instruments already available commercially, appeared to be the only way in which a greater accuracy could be attained. The results obtained, however, appeared to be sufficiently accurate to justify a more extensive test on the large variety of truck types using the highway.

The results of the initial tests, in which trucks using the highway were weighed by the electronic scale as they passed the study location and were again weighed statically on the conventional lever-system scale, showed that extremely high errors were obtained for trucks with dual axles. To determine whether speed had any effect on the magnitude of the error in the weight of dual axles, a series of tests similar to the initial tests on two-axle trucks was conducted on a three-axle single-unit truck. The patterns obtained for the three-axle truck when it was operated at various speeds are shown in figures 11 and 12.

Figure 11 shows the static weight patterns for each of the three axles at the beginning of the study and also at the end of the study. The difference between the magnitudes of the patterns at the beginning of the study and at the end of the study illustrates the drift of the calibration when tests are started without allowing a half-hour warm-up period.

Figure 12 shows the patterns obtained as the three-axle truck crossed the scale at 10, 20, 30, and 40 miles per hour. Translating these patterns into weight measurements resulted in the data shown in table 2. It may be seen that the speed of the truck had no consistent effect on the accuracy of the recorded weights for the first axle, the errors in each case being within the precision with which the magnitude of the recorded patterns can be measured. The results for the second axle (table 2) show a marked increase in the magnitude of the error with an increase in speed of the truck. This is also true for the errors in the recorded weight of the third axle. The errors for the third axle at the higher speeds are considerably greater than the errors for the second axle.

Table 2.—*Recorded weights of three-axle truck at various speeds*

Speed	First axle		Second axle		Third axle	
	Recorded weight	Error [1]	Recorded weight	Error [1]	Recorded weight	Error [1]
M.p.h.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*
0	6,240	....	5,010	....	4,860	....
10	6,500	+260	6,700	+1,690	6,500	+1,640
20	6,450	+210	6,900	+1,890	6,800	+1,940
30	6,250	+10	7,350	+2,340	8,550	+3,690
40	6,150	−90	7,700	+2,740	9,850	+4,990

[1] Deviation from static weight.

Improvements in Slab Suspension

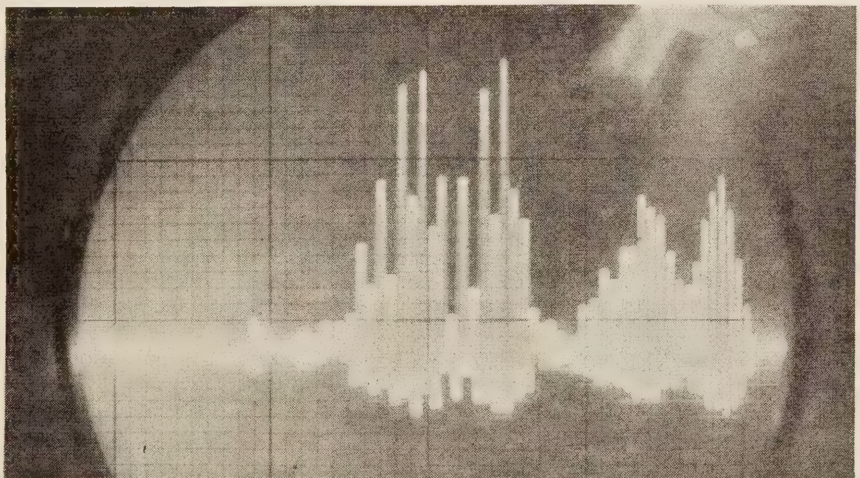
Some horizontal and vertical movement of the floating slab as the truck passed over it was noticed during the period in which the series of tests on the three-axle truck was conducted. The movement of the slab appeared to be causing impacts which were transmitted to the load cells. The impacts were definitely greater as the second and third axles went over the scale than with the passage of the first axle of a truck, especially at high truck speeds.

It may be seen from figure 12 that the appearance of the patterns for the second and third axles of the truck is quite different from the appearance of the patterns for the first axle, especially at the high speeds. It seemed desirable, therefore, to obtain more detailed pictures of the weight patterns. Figure 13 is such a picture of a pattern for the dual axle of a semitrailer traveling 53 miles per hour. It was obtained by increasing the horizontal speed of the oscilloscope spot as it swept across the screen. In this case, the spot moved across the screen in one-fifth of a second and the dual axle was on the 3-foot scale platform for only one-tenth of a second. To obtain such a weight pattern approximately centered on the oscilloscope screen requires split-second timing. The oscilloscope spot, which starts its sweep off the screen, must be triggered so that the one-tenth-second weight pattern falls within the one-fifth-second visible sweep time.

Each vertical deflection of the oscilloscope spot may be seen as a separate line in figure 13. The spot traveled up and down at the rate of 400 oscillations per second, the magnitude of its vertical travel being controlled by the weight on the load cells. It therefore appeared, from a study of figure 13, that the load cells were being subjected to extremely rapid changes in load, possibly caused either by a horizontal movement of the slab, by a rocking of the slab on its four supports, or by vibrations in the slab, produced by the first axle of the tandem, that were still remaining at the time the second axle passed.

Complete elimination of any vibratory movement of the floating slab, both vertically and horizontally, seemed desirable. The horizontal movement was eliminated by welding the turnbuckle tie bars to the brackets on the under side of the slab and on the walls of the pit. Previously these tie bars had been pin-connected and the pins had developed some play, although originally they were tight enough to require that they be driven in place.

It is extremely difficult to place an object as rigid as the slab on four supports and be certain that each support carries a fair share of the load. Repeated trials showed that a difference of as little as two- or three-thousandths of an inch in the height of one support was sufficient to cause the slab to rock and produce an impact which would result in a pattern similar to the one shown in figure 13. With the help of the company which manufactured the load cells and weighing kit, a system was developed whereby the static load of the floating slab on each cell could be determined. This made it possible to obtain approximately the same dead weight on each load cell.



WEIGHT	2 ND AXLE	1 ST AXLE
FROM PATTERN	22,000 LB.	15,000 LB.
CORRECT	12,700 LB.	12,700 LB.

Figure 13.—Weight pattern for a dual axle traveling 53 miles per hour, with the floating slab not resting uniformly on the load cells (oscilloscope sweep at high speed).

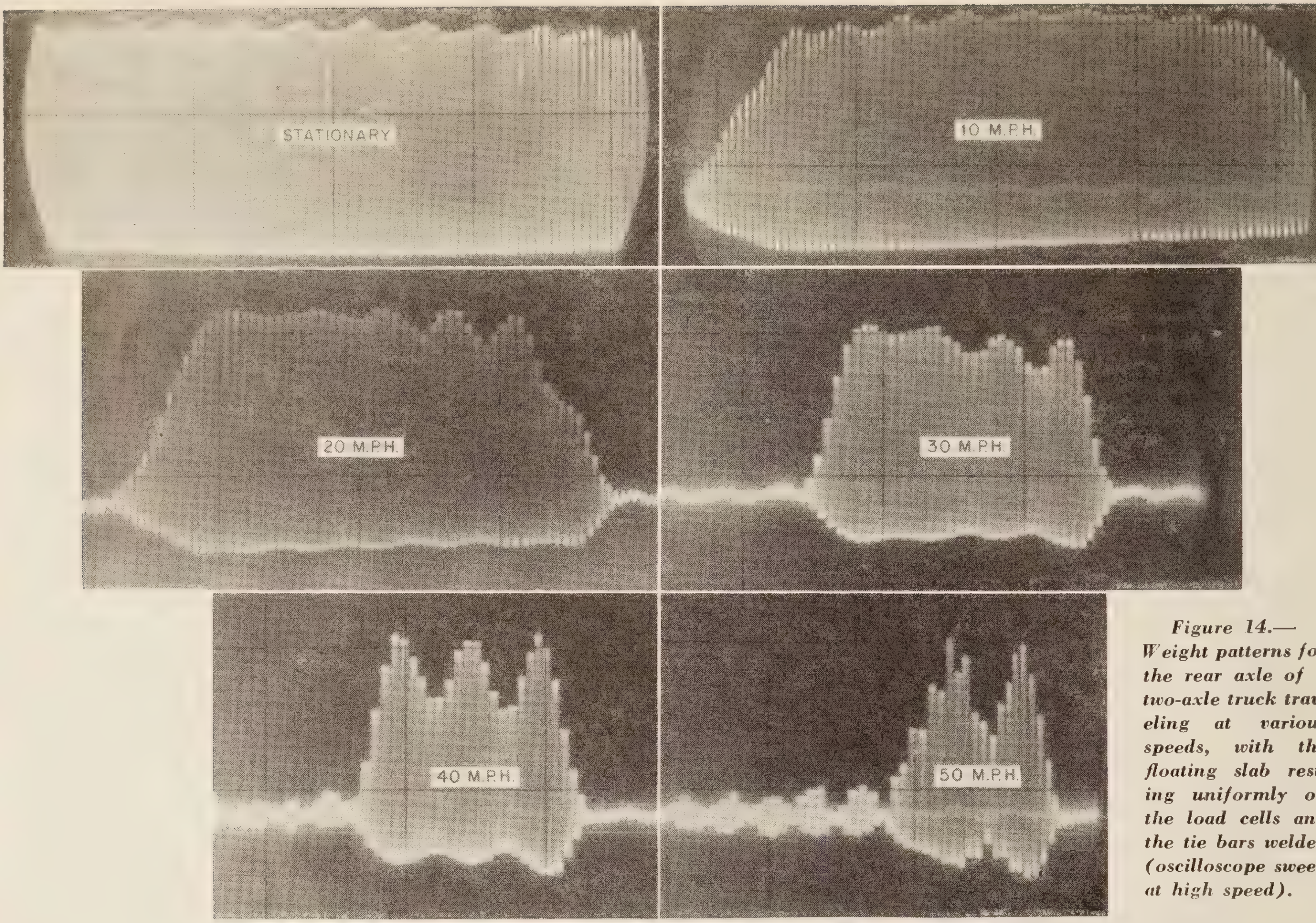


Figure 14.—Weight patterns for the rear axle of a two-axle truck traveling at various speeds, with the floating slab resting uniformly on the load cells and the tie bars welded (oscilloscope sweep at high speed).

Weight adjustments were made by grinding the bearing surface on top of the load cells rather than by the use of shims.

After the bearing points of the floating slab on the load cells had been adjusted so that each cell carried approximately the same portion of the total weight of the slab, which was about 5,000 pounds, and the horizontal tie bars had been welded, patterns similar to those shown in figure 14 were obtained. All of the separate patterns shown in figure 14 were made by the rear axle of a single-unit truck. Other patterns made by dual axles were similar, and none had the extremely ragged appearance of the pattern shown in figure 13. There are, however, several characteristics of these patterns which as yet have not been explained.

It may be noted that while the truck was stationary the pattern has a scalloped appearance at the top. This same repetition rate of the scallops is found in the pattern of weights of moving vehicles and appears to remain constant regardless of the speed of the vehicle. It apparently occurs at a frequency of about 60 cycles per second, corresponding with the frequency in the oscillation of the alternating current used to operate the electrical equipment. The magnitude of the peaks and valleys, however, increased with an increase in the speed of the vehicle. It may seem that the recorded load should be determined by using an average of the magnitude of the vertical lines at the peaks and at the valleys. This was not the case, however, since it can be seen from figure 14 that the length of the vertical lines at the peaks of all the patterns remains fairly constant regardless of speed, being about 16 divisions of the scale in all cases.

It is interesting to note that the zero line immediately to the left of the weight pattern increases in width with an increase in the speed of the vehicle. This increased width is undoubtedly caused by vibrations in the slab immediately after an axle had passed over it. It is also interesting to note that the peaks caused by the vibrations of the slab are four or five oscillations apart, which indicates that the frequency of vibration of the slab was 80 to 100 cycles per second. This frequency does not correspond with the frequency of the valleys and peaks in the load pattern.

Dual-Axle Weight Errors Continue

With the floating slab resting uniformly on the four load cells and with the tie bars welded in position, a series of tests was made of the accuracy of the scale by weighing vehicles as they passed the study location. Under normal operation about half of the trucks passing the location have all tires on the 10-foot platform. To increase the data obtained in a given period and eliminate the need of weighing trucks (at the lever-system scale) which did not have all tires on the electronic scale, rubber cones were placed on the center line of the pavement used by southbound vehicles. Most of the weight recordings were then usable data for comparison with weights obtained at the lever-system scale. Any trucks passing with one or more tires off the scale were indicated by a transverse placement detector and their records eliminated from further consideration.

During the first of a series of tests employing vehicles that normally passed the study location, trucks were slowed to 10 miles per hour for a short period and to 20, 30, and 40 miles per hour for other periods to obtain a range of speeds. During the final period of the test, the trucks were permitted to operate at their normal speeds. Figure 15 shows results of these tests.

In figure 15, the weight of each axle as shown by the oscilloscope pattern of the electronic scale is plotted against the actual weight of each axle as recorded at the lever-arm scale. When the plotted point falls on the 45-degree line, there is no difference between the two weight recordings. For some of the axles the plotted points fall on or near the line, but in other cases, especially for some of the dual axles, the plotted points fall off the 45-degree line a distance which represents more than 2,000 pounds. There is, however, fair similarity between the recorded weights at the two scales.

Based on the weights indicated by the lever-arm scale, table 3 shows the variation in the average error of the electronic scale for various vehicle speeds. The difference between the weight of an individual axle as recorded by the electronic scale while trucks were moving at their normal speeds and its weight as recorded statically on the lever-arm scale was, on an average, about 600 pounds for single axles and for the first axle of dual axles. The average error for the second axle of dual axles was 2,300 pounds. On a percentage basis, these errors amount to 6.5 percent for single axles, 4.4 for the first of dual axles, and 16.7 for the second of dual axles. At other speeds, the errors in some cases were higher than at normal speeds and in some cases lower, there being no consistency in the effect of speed.

The errors shown in table 3, which was just discussed, are average values for individual axles. Some of the weights recorded by the electronic scale were higher and some were lower than the weights as recorded at the lever-system scale. If the cumulative weight of all trucks recorded at the one scale is compared with the cumulative weight of the same trucks at the other scale, the errors are much lower, as shown in table 4. For example, table 4 shows that if it is desired only to obtain the total tonnage on the highway during the study period, the results obtained by the electronic scale would, on an average, be

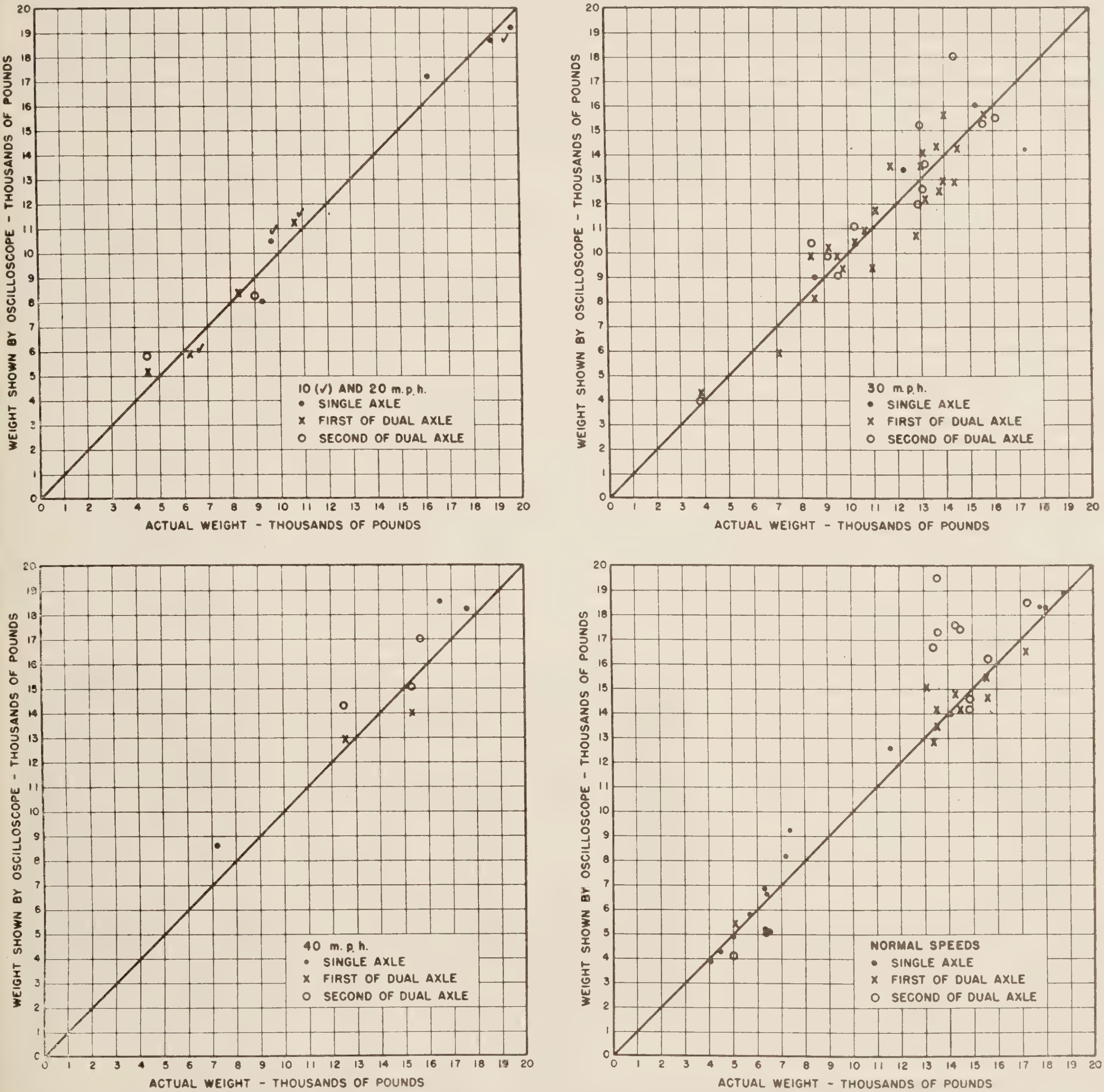


Figure 15.—Accuracy of electronically recorded axle weights of trucks operating at various speeds.

Table 3.—*Average absolute errors in recorded axle weights for trucks at various speeds*[1]

Speed of trucks	Error in pounds			Error in percent		
	Single axles	Dual axles		Single axles	Dual axles	
		First	Second		First	Second
10 m.p.h.	500	450	....	3.5	5.3	....
20 m.p.h.	915	325	1,025	5.6	5.1	16.0
30 m.p.h.	1,350	878	1,050	9.1	7.4	9.0
40 m.p.h.	1,333	850	1,100	9.8	6.1	7.6
Normal	612	600	2,300	6.5	4.4	16.7
Weighted average	815	755	1,517	6.9	6.3	12.2

[1] Based on total of 96 axle weights.

Table 4.—*Average algebraic error in recorded weights for trucks at various speeds*

Speed of trucks	Single axles		Dual axles	
	Lb.	*Percent*	*Lb.*	*Percent*
10 m.p.h.	+300	2.1	+50	0.6
20 m.p.h.	−5	.0	+675	10.1
30 m.p.h.	−250	1.7	+275	2.4
40 m.p.h.	+1,333	9.8	+258	1.8
Normal	+82	.9	+905	7.1
Weighted average	+166	1.5	+482	4.2

166 pounds higher for each single axle and 482 pounds higher for each dual axle than the results at the lever-arm scale. The total weight of all single axles as recorded by the electronic scale with the trucks in motion was 1.5 percent higher than their static weight recorded at the conventional lever-arm scale. The corresponding figure for dual axles was 4.2 percent.

High Truck Speeds

The normal speeds of trucks were higher at the electronic scale than on the average highway. Figure 16 shows that 74.3 percent of the trucks exceeded 45 miles per hour and 40 percent exceeded 50 miles per hour, with 2 percent in the 65–70–mile range. The average speed was 48.4 miles per hour. These are the speeds that the trucks were traveling when their weights were recorded by the electronic scale, except during special tests when the trucks were purposely slowed by special signs and police-officer control.

Vibrations in the slab appeared to be causing erroneous weight recordings for axles that crossed the scale immediately behind other axles. These vibrations were the aftermath of the suddenly applied wheel loads. Support by an additional load cell placed under the center of the slab would have reduced the bending moments produced by the loads and probably reduced the magnitude of the vibrations. This, however, would have required changes in the design and calibration of the weighing kit since it had already been modified from a single-cell unit to one for use with four load cells (but not five).

As an alternative to an additional support, vertical bolts extending through the floating slab and securely anchored to the bottom of the pit were installed at the center and at each end of the floating slab. Tightening the nuts on the bolts against the top of the slab permitted the load cells and the slab to be preloaded. Tension up to 6,000 pounds could be applied to each of the three bolts. Preloading the slab would change its vibration period, thus permitting additional data to be obtained for a study of the vibration problem.

After a load had been applied with the bolts, the weight-recording instruments were adjusted to show a zero load with no truck on the scale. With a truck axle of a known weight on the scale, however, the weight as shown by the scale dials was less than the actual weight of the axle by the amount that the tension in the bolts was reduced due to the additional bending of the slab. For example, a truck having a weight of 18,000 pounds when there was no tension on the bolts showed an indicated reading of 14,600 pounds on the dials when there was an initial load of 4,200 pounds on the center bolt and no load on the end bolts. Likewise, with 5,000 pounds on the center bolt and 6,000 pounds on each end bolt, the dials showed a reading of only 10,400 pounds for the 18,000-pound axle weight. It was therefore necessary to calibrate the scale each time that a change was made in the tension placed in the bolts to preload the slab.

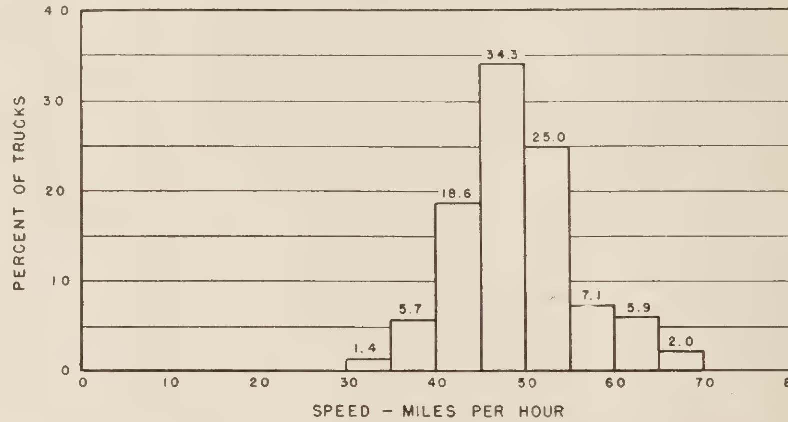
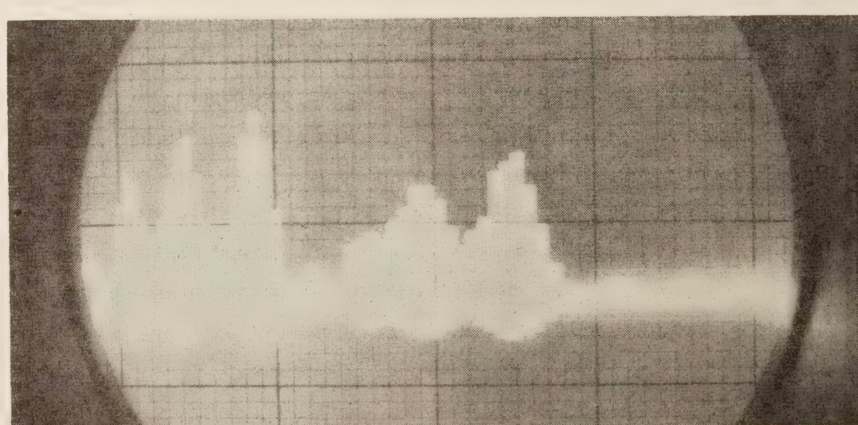


Figure 16.—Normal operating speeds of trucks at the electronic scale location.



2ND AXLE	1ST AXLE	WEIGHT FROM PATTERN
14,500 LB.	11,200 LB.	MAXIMUM PEAK
12,600 LB.	9,100 LB.	CENTER PEAK
9,200 LB.	9,200 LB.	CORRECT

Figure 17.—Weight pattern of a dual axle traveling 45 miles per hour, with no preloading of the floating slab.

Preloading Improved Accuracy

The preloaded scale was calibrated by recording the static weights of several axles on both the electronic and lever-arm scale immediately prior to each test in which vehicles in motion were weighed. This procedure was necessary to eliminate the effects of temperature changes which affect the amount of tension in the bolts.

Tests following the addition of the bolts showed that the preloading produced smoother oscilloscope weight patterns and a greater accuracy in the weighing of vehicles in motion. Figure 17 shows the weight pattern recorded for a dual axle on a truck traveling 45 miles per hour when the slab was not preloaded. Figure 18 shows the same information for another truck, also traveling about 45 miles per hour, when the slab was preloaded 2,500 pounds by the center bolt.

In figure 17, each division of the vertical scale represents 1,000 pounds. The peak of the pattern for the first axle represents a load of 11,200 pounds, or 2,000 pounds more than the correct weight of the axle. The peak of the pattern for the second axle represents a load of 14,500 pounds, or 5,300 pounds more than the correct weight of the axle. Examination of the pattern shows that the correct weights of the axles are represented by the second peak in the pattern for the first axle, and by the third peak in the pattern for the second axle. This relation did not always hold true, however, and while it was generally possible for someone familiar with the shape of the patterns to estimate the weight of axles with a high degree of accuracy by using a little judgment, a satisfactory scale must show consistent results without involving personal opinion.

The shape of the pattern in figure 18 and other patterns made with the slab preloaded by applying tension on the bolts was generally less erratic than the patterns made without preloading the floating slab. All, however, were not as uniform as those of figure 18, nor did the weights correspond as closely with the correct weight of the axles. The patterns continued to show peaks of the same frequency regardless of the load on the bolts, apparently proving that the major peaks and valleys were not caused by vibrations of the slab or by impact loads produced by the trucks.

The effect that preloading had on the accuracy of the scale for weighing trucks traveling at their normal speeds is shown by figure 19. Prior to the tests during which these data were obtained, the bearing plates of the load cells were not adjusted so that each cell carried the same portion of the dead weight of the slab. The adjustment was omitted because it was one purpose of the test to determine whether preloading of the slab and cells would eliminate the need of such an adjustment. The results as shown by the upper chart in figure 19 are therefore more erratic than those of figure 15, which were obtained with the best possible adjustment of the bearing plates.

A study of the results shown in figure 19 indicates that there was a definite improvement in the accuracy of the scale when the slab was preloaded. A few erratic results were obtained, however, especially for the second axle of the dual axle shown in the lower left-hand chart of figure 19 for which a weight of 10,800 pounds was recorded while its correct weight was 17,800 pounds. It is believed that in this case one tire of the axle was not on the scale as the truck passed the study location. This would have been called to the attention of the scale operator had the lateral placement detector been in use during this test. Such an occurrence was so rare after the rubber cones were placed on the lane line that use of the placement detector was considered unnecessary.

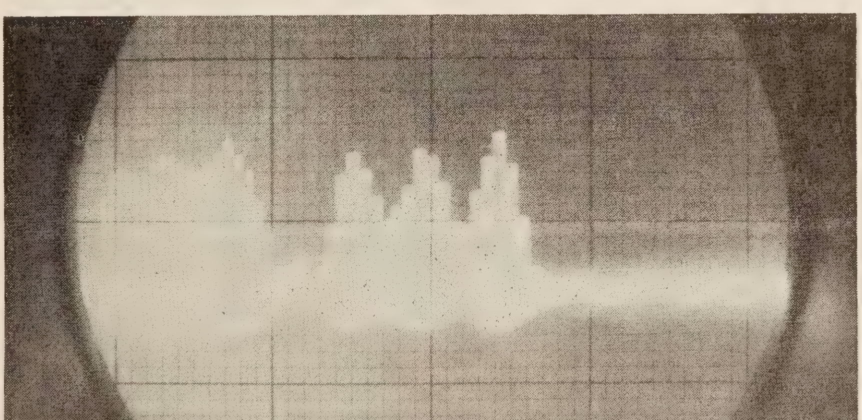
The average errors of the electronic scale with and without preloading of the slab are shown in tables 5 and 6. In table 5, the average errors in the recorded weights of individual axles are shown. Preloading the slab by placing either a tension of 4,200 pounds on the center bolt or 5,000 pounds on the center bolt and 6,000 pounds on each of the end bolts reduced the magnitude of the errors, measured in pounds, by an average of about 50 percent. Measured as a percentage of the actual weight, preloading the slab cut the errors in the recorded

Table 5.—*Effect of preloading of floating slab on average absolute errors in recorded weights of individual axles*

Load on floating slab	Single axles			Dual axles					
				First			Second		
	No.	Error		No.	Error		No.	Error	
		Lb.	*Percent*		*Lb.*	*Percent*		*Lb.*	*Percent*
No preloading	45	1,213	14.3	13	1,442	15.3	13	2,246	23.9
4,200 pounds on center bolt	17	767	7.2	6	592	4.9	6	928	7.2
5,000 pounds on center bolt; 6,000 pounds on each end bolt	29	625	5.5	10	790	6.0	11	1,140	8.7

Table 6.—*Effect of preloading of floating slab on average algebraic error in recorded total weights for all axles*

Load on floating slab	Single axles			Dual axles					
				First			Second		
	No.	Error		No.	Error		No.	Error	
		Lb.	*Percent*		*Lb.*	*Percent*		*Lb.*	*Percent*
No preloading	45	686	8.1	13	242	2.6	13	1,731	18.3
4,200 pounds on center bolt	17	21	.2	6	541	4.5	6	728	5.7
5,000 pounds on center bolt; 6,000 pounds on each end bolt	29	63	.6	10	−400	3.0	11	−195	1.5



2ND AXLE	1ST AXLE	WEIGHT
13,800 LB.	14,100 LB	FROM PATTERN
13,600 LB. *	13,600 LB *	CORRECT

* ½ OF TOTAL

Figure 18.—Weight pattern of a dual axle traveling 45 miles per hour, with preloading of 2,500 pounds at the center of the floating slab.

weights of individual axles by at least half and in most cases by considerably more than half of what they were without preloading the slab.

Table 6 shows that when the slab was preloaded the total weight of all axles recorded while the trucks were traveling at their normal speeds was remarkably close to their total static weight. With a tension of 5,000 pounds on the center bolt and 6,000 pounds on each end bolt, the cumulative errors were plus 0.6 percent for the single axles, minus 3.0 percent for the first of the dual axles, and minus 1.5 percent for the second of the dual axles. These are well within the limits of precision necessary for such highway-planning purposes as a determination of gross tonnage of trucks traveling over a highway.

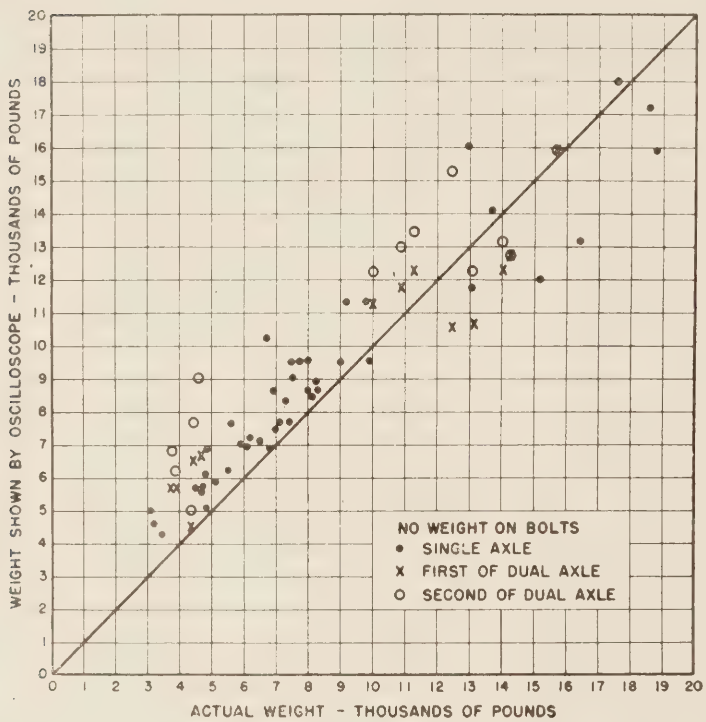
A factor which may have resulted in charging errors to the electronic scale improperly, throughout these studies, was the assumption that both axles of a dual axle carried the same weight whenever separate readings were not taken at the lever-system scale. For 63 percent of the dual axles, the second axle weighed more than the first axle, according to the lever-arm scale. The reverse was true for the other 37 percent. Table 7 shows the magnitude of the differences in weight between the two axles of the duals. The difference in four cases was about 4,000 pounds. Since separate weights were obtained at the lever-system scale for less than 50 percent of dual axles weighed at the electronic scale, the assumption that equal weights were carried on both axles of a dual axle when they were not weighed separately probably caused many of the major indicated errors of the electronic scale.

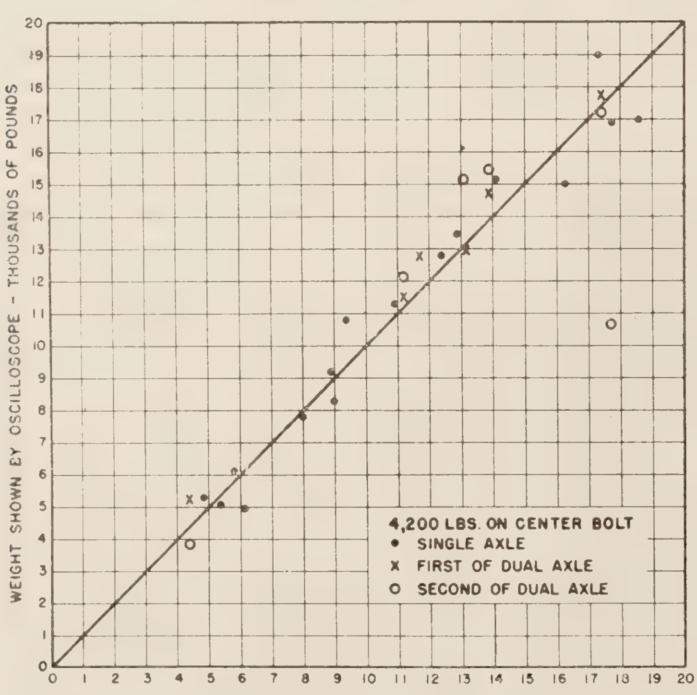
Table 7.—*Distribution of weight differentials between the two axles of duals*

Difference in weight	Number of dual axles
Pounds	*Percent*
Under 500	30.6
500 to 999	18.4
1,000 to 1,999	32.6
2,000 or more	18.4

Other Improvements Tried

While it is realized that the method used for preloading the slab would not be satisfactory for a practical scale because frequent recalibration would be required, the method did provide a means of studying the causes of inaccuracies. For a practical installation, additional load cells to measure the tension in the bolts should be connected in parallel with the present cells. This would eliminate the need for recali-





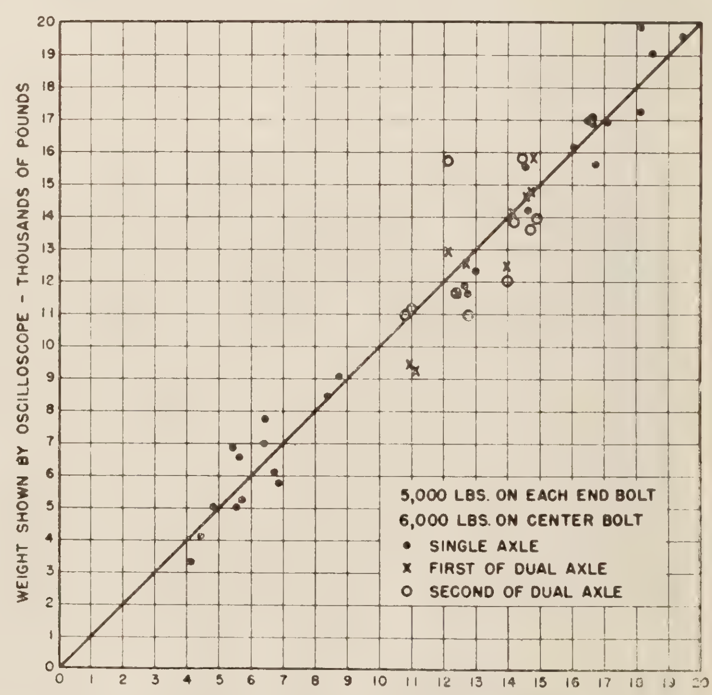


Figure 19.—Accuracy of electronically recorded axle weights, with no preloading of the floating slab (above), with preloading at the center, and with preloading at the center and both ends.

brating the instrument with changes in temperature.

As a further effort to improve the scale's accuracy, the electrical circuits were changed to include an integrator. Basically, the purpose of the integrator is to smooth the pattern by reducing the magnitudes of the valleys and peaks, and to change the behavior of the oscilloscope spot so that the load deflections are only in the one direction. This makes it possible to calibrate the screen so that each horizontal line represents a certain load, thereby eliminating the need for measuring the total length of the ordinate of a weight-pattern. Figure 20 shows a calibration pattern using the integrator, and figures 21 and 22 show typical weight patterns for trucks when the integrator was used. The accuracy of the scale using the integrator was not always as good, however, as figures 21 and 22 indicate. The results obtained during its use, as shown by figure 23, are too limited to use as a basis for determining whether or not the integrator helped to improve the accuracy of the scale.

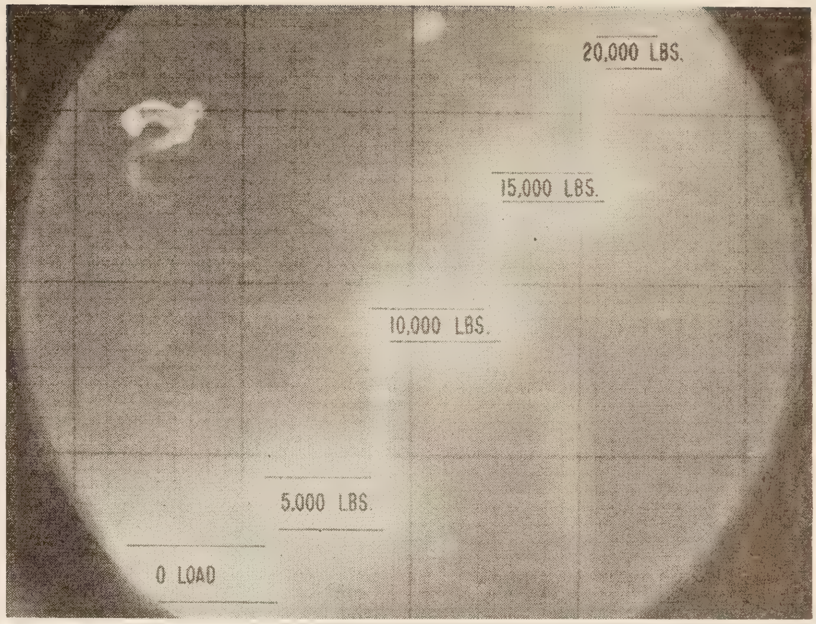
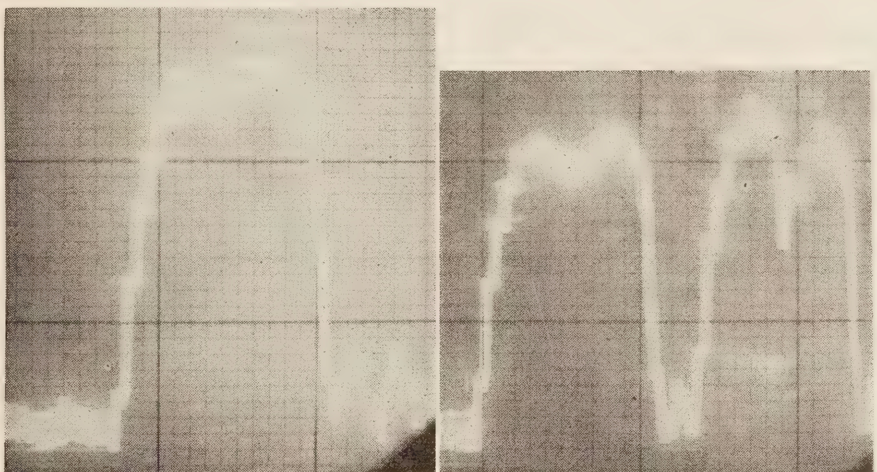


Figure 20.—Weight calibration pattern with an integrator used in the circuit.



SINGLE AXLE	WEIGHT	DUAL AXLE FIRST	DUAL AXLE SECOND
14,000 LB.	FROM PATTERN	12,700 LB.	13,550 LB
14,200 LB.	CORRECT	13,200 LB. *	13,200 LB. *

* ½ OF TOTAL

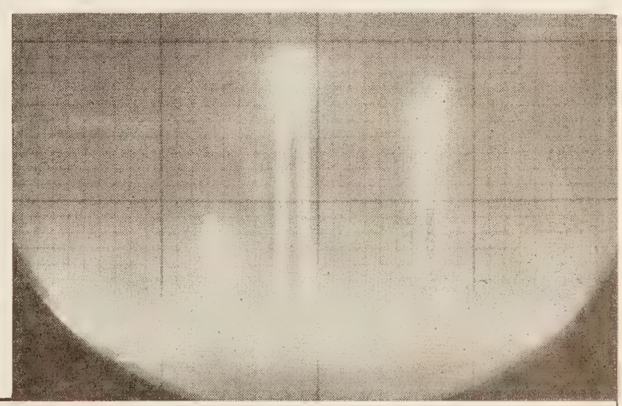
Figure 21.—Weight patterns for a single axle and a dual axle, using the integrator (oscilloscope sweep at high speed).

In the latest change made on the scale, an oscillograph was substituted for the oscilloscope as the recording instrument. The advantages or disadvantages of this change cannot be determined without further tests. The oscillograph does, however, have one important advantage—a permanent record is obtained immediately without the need of taking a picture or developing a film. The type of record made by the oscillograph is shown in figure 24, and the data recorded during its use are shown in figure 25. Since the oscillograph had not been calibrated to show the load in pounds, figure 25 is useful only to show the uniformity of the results. They appear to compare favorably with results obtained with the oscilloscope.

Speed and Axle Spacings Measured

The equipment used for electronic weighing also permits the recording of vehicle speeds and axle spacings at the same time. Figures 26 and 27 show the accuracy in axle spacings obtained with the electronic weighing equipment.

More accurate measurements of axle spacings were possible after the square-wave generator was available to insert time marks on the screen than without the generator. The average error in measuring axle spacings was 0.5 foot without using the generator and 0.4 foot with the generator. These figures are based on the assumption that the manual measurements of axle spacings were correct to the nearest tenth of a foot. It is highly probable, how-



AXLE NUMBER	1	2	3
WT FROM PATTERN	- 4,600	10,600 LBS.	9,350 LBS.
CORRECT WEIGHT	- 4,600	10,680 "	9,360 "

Figure 22.—Weight pattern for a three-axle truck, using the integrator (oscilloscope sweep at normal speed).

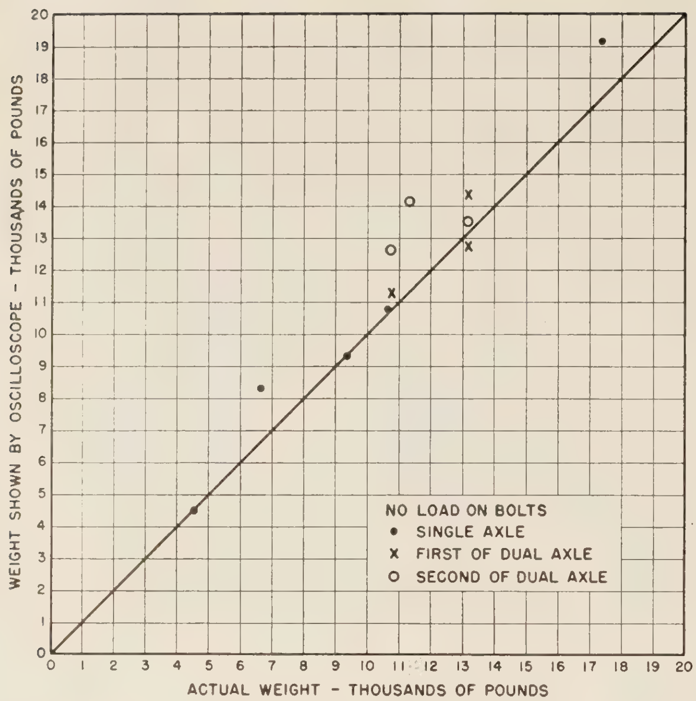


Figure 23.—Accuracy of electronically recorded axle weights, using the integrator.

ever, that the results obtained electronically are more accurate than those obtained manually. Great care was not taken in the manual measurements because it was not expected that the electronic measurements made while the trucks were traveling at their normal speeds would be accurate to within less than one foot.

Design Improvements

The results and observations presented in this progress report are those that have been obtained to date. The scale is now being modified both structurally and electrically to embody several of the features that the tests thus far have shown to be desirable. Electronic improvements have already been discussed in the description of the circuitry.

The major change being made in the structural design involves the location of the load cells. In the original design, the load cells were nearly 10 feet apart in the transverse direction of the roadway. The tread width of the heavier trucks is approximately 8 feet, measured from outside to outside of tires. The centers of the loads transmitted to the pavement by the two sets of dual tires on one axle are thus about 6 feet apart.

Locating the load cells so that they are directly under the tires should practically eliminate the bending moments in the slab and the resulting vibrations. In the modified design, the load cells are being placed 6¼ feet apart.

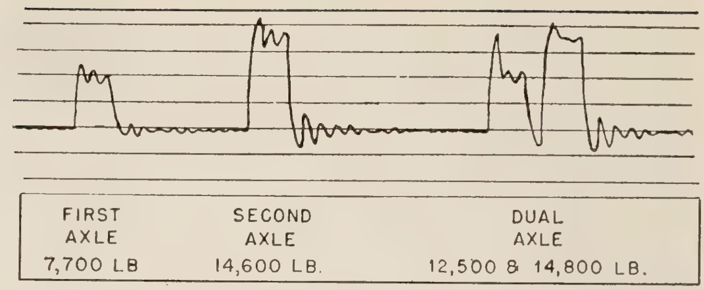


Figure 24.—Oscillograph recording of axle weights of a four-axle tractor-semitrailer.

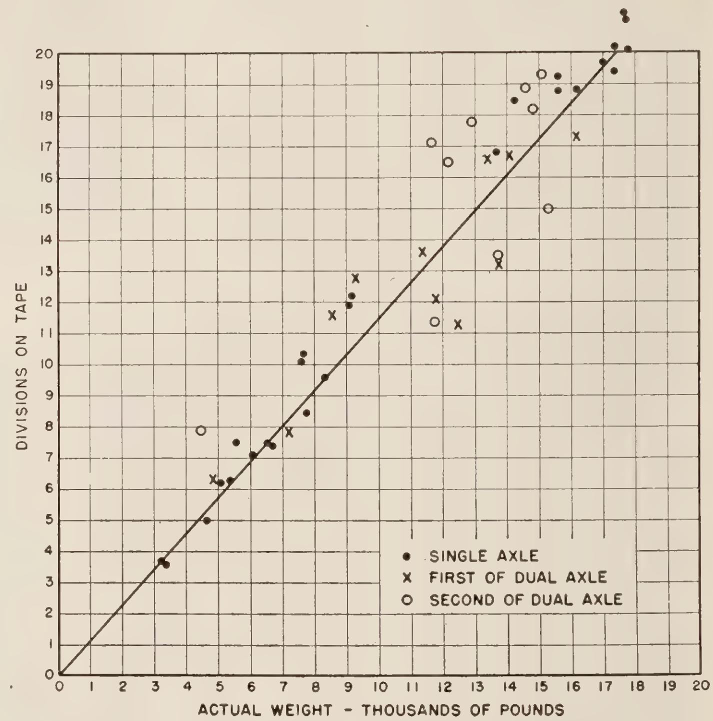


Figure 25.—Uniformity of oscillograph recordings of axle weights.

Tie bars to prevent any horizontal movement of the floating slab are also being located at the surface of the pavement. These will supplement those already installed, which are about 15 inches below the surface. There are other changes that would be desirable but which cannot be incorporated in the present scale without rebuilding the entire pit and slab. For example, three-point suspension, which is entirely feasible, might ultimately be adopted should too-frequent adjustment of the bearing plates in a four-point suspension system be found to be necessary.

One essential improvement which has not been mentioned is the waterproofing of the load cells. The load cells used in these tests were housed in a supposedly waterproof jacket with a bag of silica gel to dehumidify the air within the jacket. On two occasions a cell was replaced because the jacket became filled with water. At the end of the tests, three of the jackets were filled with water and the fourth was damp. Moisture, of course, destroys the accuracy of resistance-wire strain gages. It is probable that some water in the cell jackets penetrated the water-resistant coatings of the strain gages and introduced undetected errors before a saturation of the gages, which caused obvious errors, made it necessary to replace the cells. Those now being installed are moistureproof in themselves, and should serve satisfactorily.

With the changes that are now being made, there is reason for confidence that the electronic scale will provide a means of obtaining data for highway planning and permit enforcement of legal limits at low costs and without inconveniencing the large majority of truck operators who load properly.

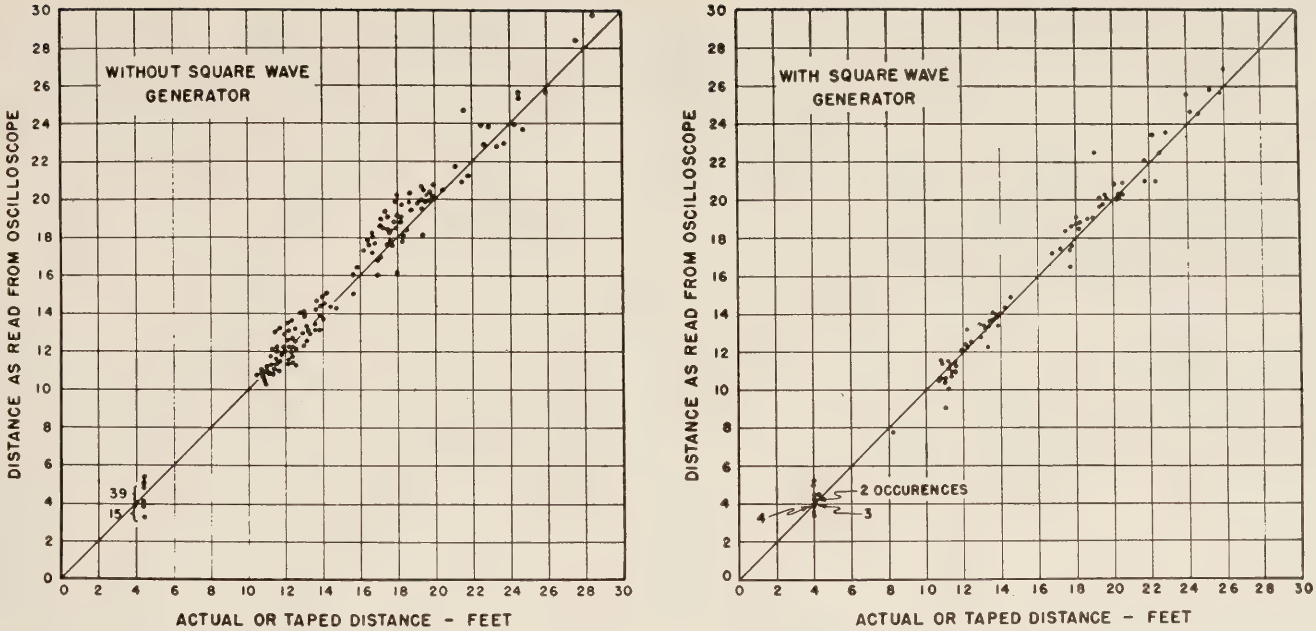


Figure 26.—Accuracy of electronically recorded axle spacings, with and without the square-wave generator.

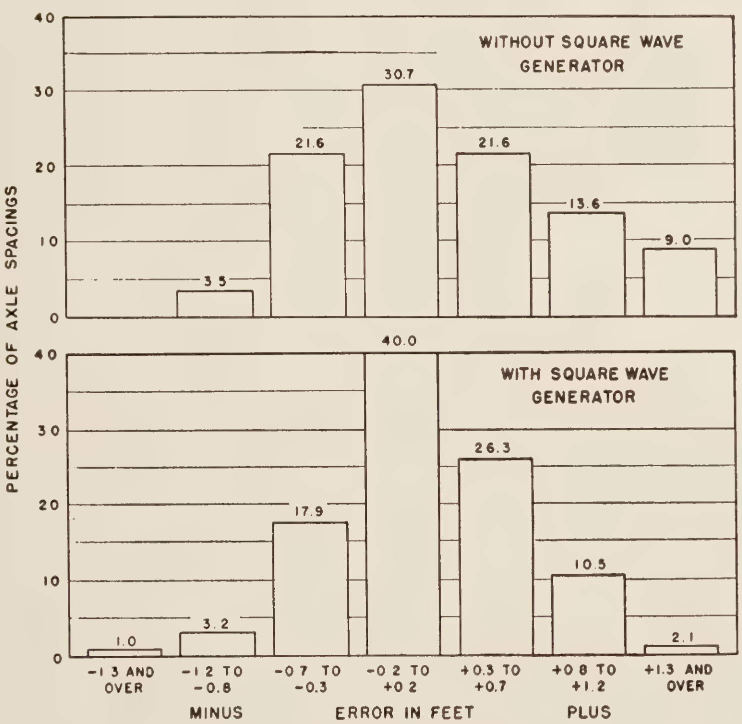


Figure 27.—Errors in electronically recorded axle spacings, at normal road speeds.

HIGHWAY STATISTICS, 1950

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Weathering Tests on SR-4 Strain Gages

BY THE PHYSICAL RESEARCH BRANCH
BUREAU OF PUBLIC ROADS

Reported by E. G. WILES
Highway Physical Research Engineer

The use of SR–4 strain gages to determine strains in steel bridges is important in highway research. For such work it is desirable that the gages be attached and protected so that not only can they be used when first installed to record strain caused by loads, but also re-used for a similar purpose at some later time, possibly after a relatively long period of time has elapsed. Tests of several commercial materials, reported in this article, demonstrate that some of them will serve satisfactorily for cementing and weatherproofing the gages for at least 3½ years.

PREPARATORY to a test program in which strains caused by different types and magnitudes of vehicular loads on highway bridges are to be determined, two questions needed to be answered: Can SR-4 electrical resistance strain gages be maintained in working condition over a period of a few days when exposed to severe weather conditions; and can they be maintained over longer periods of time and re-used when needed for additional tests on the same structure? In answer to these questions, the limited study reported here shows that SR-4 strain gages can be satisfactorily weatherproofed so as to record faithfully even after long periods of exposure to the weather.

Method of Test

Although other work has been done on this problem, the rather simple means adopted to determine the effectiveness of the gages and certain combinations of cements and weatherproofing materials have not been previously described in the literature.

In July 1948, 24 type A-3 SR-4 electrical resistance strain gages were installed in pairs on opposite sides, in the center of each of twelve ¼- by 2- by 14-inch cold-rolled steel bars. Different kinds of cements, weatherproofing materials, and installation techniques were used, varying from no covering over the gages to a rather heavy combination of coverings. The bars were then exposed to the weather.

At periodic intervals, to determine whether or not the gages were functioning, each steel bar was supported as a simple beam with a 12-inch span length and a fixed load was applied at the third points. Strain measurements were made at no load and again under the load condition, and the strain difference computed. Since the same loading was used throughout the tests, the strain difference remained relatively constant in all cases where the gages were performing properly.

Preparation of Specimens

The cold-rolled steel bars used as specimens were first cleaned and painted. Areas for the gages and for bearings for third-point loading and support were kept free from paint during painting operations by covering with pieces of cellulose tape. The tape was removed after the paint dried.

For identification purposes, bars were stamped A, B, C, etc., through L and, in order that bars might be kept in the same position when exposed, a letter T (for top) was marked on one side of each bar.

The gages were of the electrical resistance type and were purchased commercially. The gage wire was a cupro-nickel alloy and was cemented to a thin paper backing which made possible easy application to a test specimen. The effective gage length was thirteen-sixteenths of an inch. The resistance of each gage was approximately 120 ohms and the gage factor, which is the ratio of unit change in resistance to unit change in length, was determined by calibration by the manufacturer as 2.05 ± 1 percent.

Before installing the gages, the surface of the metal was sandpapered and then washed with carbon tetrachloride and acetone. Three kinds of cement were used to attach the gages to the steel bars, as follows:

Fourteen gages, on specimens A, D, F, G, H, K, and L, were attached by SR-4 cement purchased from the Baldwin-Lima-Hamilton Corporation as part of a kit of cementing materials.

Six gages, on specimens B, E, and I, were attached with Duco household cement purchased locally in Washington, D. C., in a tube.

Four gages, on specimens C and J, were attached with HO cement furnished by the Celanese Plastics Corporation. On specimen J, the heat from two 250-watt infrared lamps was concentrated on the gages for 20 minutes after gage application.

Pairs of stiff lead wires, 24-gage (0.020-inch diameter) phosphor bronze, were soldered to and at right angles with the gage pigtails. Pieces of adhesive tape were used as insulation between the lead wires and the steel bar. Additional tape over the wires held them parallel and against the surface of the insulating tape. Lead wires from the top and bottom gages extended out from opposite edges of the bar 1½ inches beyond and perpendicular with the edge.

After 4 days the gages were coated with the different types of weatherproofing material, except for gages on specimens A, B, and C, which were left uncoated.

Gages on specimens D and J were coated with approximately one-sixteenth-inch thickness of melted Petrosene A wax purchased from the Baldwin-Lima-Hamilton Corporation. On specimen J, over this wax coating was placed another coat of approximately one-eighth-inch thickness of Ozite B heated to 400° F. This material was purchased from the G. and W. Electric Specialty Company.

Gages on specimen E were coated with approximately one-sixteenth-inch thickness of vaseline from available stock. Gages on specimens F and G were covered with Dow-Corning silicone ignition sealing compound about one-sixteenth-inch thick: Gages on specimen F were covered with C24 compound and those on specimen G with C28 compound.

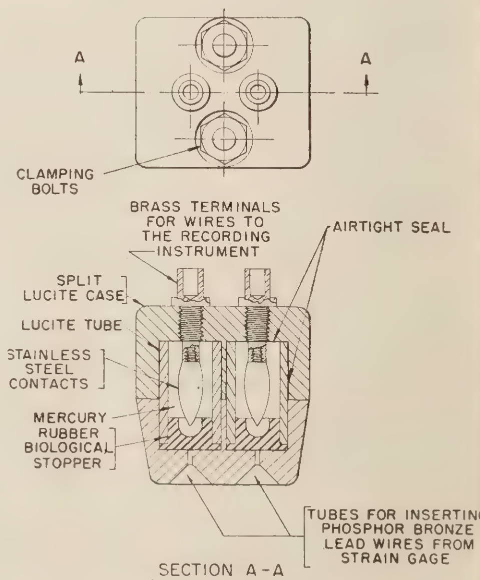

Figure 1—Mercury connector.

Gages on specimen H were coated with approximately one-sixteenth-inch thickness of melted ceresin wax purchased on Government contract from the J. T. Baker Chemical Company. Gages on specimen I were first coated with about one-sixteenth-inch thickness of Ozite A heated to 400° F., followed by a wrapping of electrician's rubber tape and a second wrapping of friction tape. This top surface was then covered with another coating of Ozite A.

Gages on specimen K were covered with approximately one-eighth-inch thickness of Fenox No. 3005 furnished by the Bakelite Corporation. Gages on specimen L were covered with Short Stop, a dry-sealing insulator purchased from Buchanan Associates, Inc.

The materials used for adhesives and for weatherproofing in these tests were selected because they seemed to have possibilities for these purposes. Similar materials, produced by other manufacturers, might have been equally as effective as those covered in this report. Furthermore, some of the materials that were tested and found to be unsatisfactory were not produced for this use by their manufacturer; consequently their failure is not an indication of poor quality.

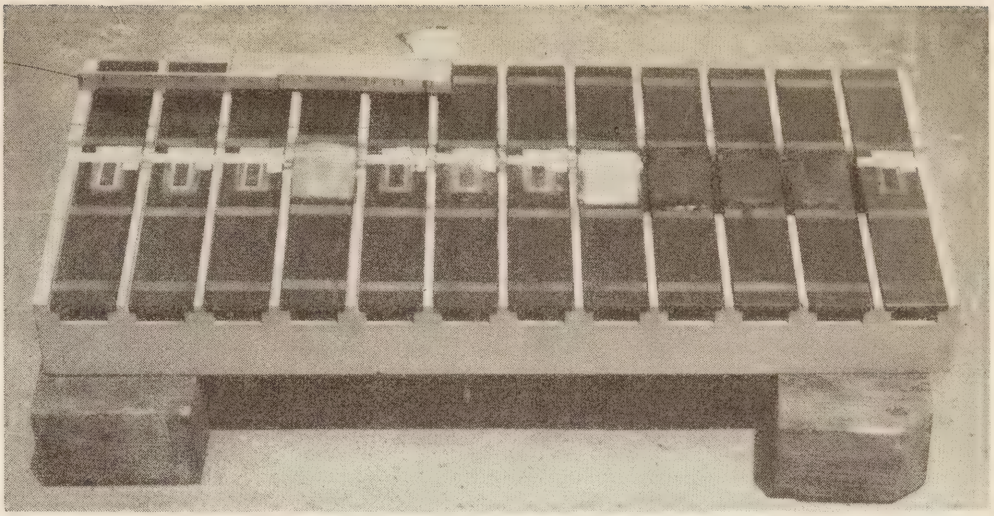

Figure 2.—Appearance of gages at beginning of weathering tests.

Mercury Connectors

Special mercury connectors were constructed to connect the phosphor-bronze lead wires to a suitable recording instrument. The connectors were a modification of an existing design[1] and were particularly suitable because of their low and constant contact resistance. The two principal modifications of these connectors were the use of stainless-steel bullet-nosed tips at the terminal ends in the mercury wells, to aid in making direct contact with the phosphor-bronze wires after they have been pushed into the wells; and the use of cross-slitted rubber biological stoppers as diaphragms, to hold back the mercury. No. 18 solid copper insulated wires connected the mercury connectors to the recording instrument. A drawing of the modified connectors, as used on these tests, is shown in figure 1.

The ends of the stiff phosphor-bronze lead wires connected to the gages and extending out from the edge of the bar are guided into the bottom of the tubes through the small inverted funnels. By holding the wires firmly and giving a slight push, the ends of the wires can be forced through the rubber biological stoppers and into the mercury wells. After readings are obtained the lead wires are withdrawn. The rubber diaphragms close behind the wires and prevent mercury from escaping.

[1] *Improved techniques and devices for stress analysis with resistance wire gages*, by W. V. Bassett, H. Cromwell, and W. E. Wooster. Proceedings of the Society for Experimental Stress Analysis, vol. III, No. 2. p. 76.

Weathering Tests

The steel bars on which the gages were mounted were placed horizontally on a wooden rack, as shown in figure 2, and exposed to prevailing weather conditions on the flat roof of a building near Washington, D. C. One gage on each bar was exposed face up to the elements and the other gage of the pair was face down towards the roof. The rack was blocked up so that air could circulate freely under and around the gages. The conditions of exposure of pairs of these gages simulated those to which gages might be exposed when mounted on horizontal bridge members. Observations were made initially at intervals of a few days, later at weekly intervals, and at present the observations are being made at intervals of approximately a month.

Figure 3.—Equipment for making strain measurements.

Strain Measurements

On days when strain measurements were to be made, the rack full of bars was brought into the laboratory a few hours in advance in order that they might adjust themselves to laboratory temperature conditions. In no case were bars brought in when it was raining or when it appeared that rain was imminent. At first, unpainted places on the bars, left for the load and support bearings, were coated with grease to prevent rusting. The attempt at rust prevention was not successful, however, and after the first few weeks no further care was given these surfaces. This had no apparent effect on the test results.

Initially an SR-4 Wheatstone bridge control box was used to measure strains, but 40 days after the beginning of the tests a type K strain indicator was purchased and it has been used since.

Table 1.—*Materials and service lives of SR-4 strain gages in weathering tests*

Specimen No.	Cement	Weatherproofing material	Service life	
			Top gage	Bottom gage
			Days	*Days*
A	SR-4	None	224	186
B	Duco	None	224	116
C	HO	None	224	116
D	SR-4	Petrosene A wax	1,300+	1,300+
E	Duco	Vaseline	441	441
F	SR-4	DC 4 ignition sealing compound C 24	186	580
G	SR-4	DC 4 ignition sealing compound C 28	224	818
H	SR-4	Ceresin wax	257	257
I	Duco	Ozite A, rubber tape, friction tape, Ozite A	1,300+	1,300+
J	HO	Petrosene A wax, Ozite B	1,300+	1,300+
K	SR-4	Fenox No. 3005	1,300+	1,300+
L	SR-4	Short Stop	25	1,300+

As previously mentioned, the bar was deflected as a simple beam under loads applied at the third points of the span length. Figure 3 shows the equipment used for applying load and for measuring strains. A total load of 212 pounds was supported by a chain hoist, until after the bar had been positioned on the supports, and an initial no-load reading obtained on the strain indicator. The load was then lowered until supported completely by the steel bar. A yoke moving in guides kept the third-point loading device and the suspended weights in position. The weights, attached by a hooked rod to the yoke, can be seen under the table. An opening in the center of the table gave sufficient clearance for the yoke, supporting the weights, to move freely. The type K indicator is at the left while a Leeds and Northrup type S testing set, used for measuring resistances of the gages, is shown at the right. More recently a Simpson model 260 volt-ohm-milliammeter has been used for a more rapid checking of the gage resistances.

In order to prevent any difference between the two mercury terminals from affecting the strain readings, the upper strain gages were always connected to one terminal while the bottom gages were always connected to the other. These mercury terminals, in turn, were always connected correspondingly to the same terminal posts on the strain-measuring equipment.

By having the gage on the tension side of the beam serve as one arm of a Wheatstone bridge and the gage on the compression side serve as an adjacent arm of the same bridge, temperature compensation was provided and the strain magnitude measured was the total for the two gages, or double that of either the tension or compression value. For the conditions described the combined strain measured was approximately 1,400 microinches. Normally, gages would record this amount of strain throughout their service life. Failure of gages was indicated by a marked change from this value.

If failure occurred in the top gage of a beam being loaded, the mercury terminal normally used to connect to it was connected instead to the top gage on another bar. This second bar was not loaded, but was placed adjacent to the loaded one and used solely to compensate for temperature changes. A similar procedure was followed in case a bottom gage failed. In these instances only one gage was deformed by the load and consequently the strain recorded was approximately 700 microinches.

Service Life

Now, after approximately 3½ years of exposure, it is of interest that pairs of gages on four bars and the bottom gage on one additional bar are still functioning satisfactorily. A tabulation showing the different types of cements, the weatherproofing, and the service life for all of the specimens is shown in table 1.

The six gages on three bars that had no special weatherproofing had surprisingly long service lives, from 116 to 224 days. The bottom gages failed first in each case.

The appearance of the top gages on these bars after failure to record strain is shown in figure 4. Moisture, corrosion, and temperature changes caused the gages eventually to peel away from the surface of the bar and no longer respond to deformation caused by load. They indicate the gage resistance of approximately 120 ohms with a very slight increase in strain under load because a small part of their effective gage length is still in contact with the bar.

Of the four pairs of gages still functioning satisfactorily, thus showing effective weatherproofing, Petrosene A wax and Ozite, either singly or in combination, were used on three pairs (on specimens D, I, and J). Heat is required to melt and apply both of these materials, Petrosene being a microcrystalline wax and Ozite a bituminous compound. For laboratory installations the use of these materials is not a problem. For field installations, however, heating the materials to proper temperatures and applying them to gages, especially on the underside of bridge members, might be difficult.

The other material that has proved to be effective in weatherproofing a pair of gages (on specimen K) is Fenox No. 3005, an electrical sealing compound. It is slightly tacky and adheres readily to the metal surface surrounding the gages. It is of putty-like consistency and can be applied with a spatula or the fingers and heating is not required. Exposure does not appear to have changed its properties.

The bottom gage on the beam (specimen L) that is still recording strain has a coating material different from any of the above. This material, known as Short Stop, forms a varnishlike coating, and has continued to give satisfactory weathering protection on the bottom gage, in spite of the fact that the top gage on this same bar was the first one to fail. It is a matter of conjecture as to whether this failure was inherent in the gage itself or caused by some deterioration of the weatherproofing material. For more positive results in tests of this kind more than one specimen of each type of weatherproofing should be included. However, it is indicated by these tests that SR-4 gages mounted on steel can be weatherproofed and will record satisfactorily after long periods of exposure to all of the usual weather conditions.

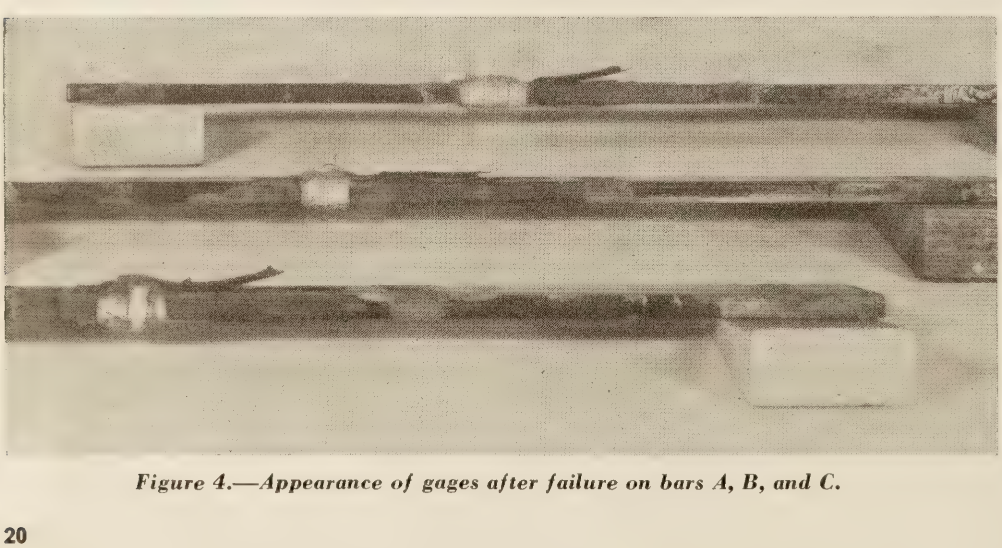

Figure 4.—Appearance of gages after failure on bars A, B, and C.

Acknowledgments

The author wishes to thank various individuals and companies for their helpfulness in giving information and, in some instances, samples of material for installing and weatherproofing strain gages.

Appreciation is expressed also to personnel at the David Taylor Model Basin, the National Bureau of Standards, and the Engineer Research and Development Laboratories, who furnished some information regarding installation and weatherproofing of gages.

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STATUS OF FEDERAL-AID HIGHWAY PROGRAM

AS OF FEBRUARY 29, 1952

(Thousand Dollars)

STATE	UNPROGRAMMED BALANCES	ACTIVE PROGRAM											
		PROGRAMMED ONLY			PLANS APPROVED, CONSTRUCTION NOT STARTED			CONSTRUCTION UNDER WAY			TOTAL		
		Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles
Alabama	$16,924	$22,548	$11,644	400.6	$5,339	$2,700	102.8	$20,512	$10,302	401.1	$48,399	$24,646	904.5
Arizona	1,246	7,513	5,426	179.6	1,130	806	13.1	7,701	5,334	118.7	16,344	11,566	311.4
Arkansas	8,370	7,323	4,045	292.3	6,284	3,107	216.4	12,290	6,341	333.5	25,897	13,493	842.2
California	6,452	53,020	20,492	204.6	12,722	6,531	38.6	66,593	31,775	241.4	132,335	58,798	484.6
Colorado	6,828	4,712	2,602	112.9	3,049	1,709	61.4	11,708	6,375	233.9	19,469	10,686	408.2
Connecticut	6,848	4,470	2,285	9.7	1,099	548	1.0	12,248	6,368	19.7	17,817	9,201	30.4
Delaware	2,221	6,385	2,693	31.7	329	234	7.0	3,199	1,594	31.2	9,913	4,521	69.9
Florida	9,034	11,090	5,714	192.5	8,914	4,723	173.7	16,360	8,140	310.4	36,364	18,577	676.6
Georgia	12,645	11,283	5,771	264.0	11,106	5,049	115.6	30,036	14,962	472.4	52,425	25,782	852.0
Idaho	7,134	9,970	6,240	269.8	2,703	1,719	79.3	3,162	2,069	73.6	15,835	10,028	422.7
Illinois	15,894	63,171	34,386	485.6	20,855	10,444	171.2	63,518	32,077	488.8	147,544	76,907	1,145.6
Indiana	18,212	33,770	17,470	174.9	9,260	5,114	72.2	17,744	8,982	195.4	60,774	31,566	442.5
Iowa	4,262	17,194	9,019	652.0	11,923	5,972	383.3	13,982	6,967	569.5	43,099	21,958	1,604.8
Kansas	11,867	11,495	5,598	1,125.8	3,176	1,565	262.0	16,079	8,414	639.2	30,750	15,577	2,027.0
Kentucky	9,323	15,052	8,058	218.2	7,405	3,673	185.6	11,279	5,693	159.0	33,736	17,424	562.8
Louisiana	7,106	16,587	7,942	86.2	8,613	3,905	81.9	20,165	10,102	169.4	45,365	21,949	337.5
Maine	4,562	5,923	3,333	30.0	1,742	867	10.6	7,308	3,707	62.8	14,973	7,907	103.4
Maryland	8,821	3,200	1,517	55.8	2,493	1,721	.7	9,517	4,443	25.3	15,210	7,681	81.8
Massachusetts	8,247	8,860	4,563	13.9	3,388	1,491	12.5	49,924	24,198	40.1	62,172	30,252	66.5
Michigan	7,097	36,550	18,239	542.1	8,865	4,444	140.4	51,949	22,439	275.0	97,364	45,122	957.5
Minnesota	9,214	14,584	7,484	1,405.3	5,240	2,613	291.5	20,641	11,309	638.7	40,465	21,406	2,335.5
Mississippi	10,870	10,364	5,352	336.4	3,410	1,672	121.6	18,456	9,610	466.9	32,230	16,634	924.9
Missouri	14,064	30,003	15,144	704.3	15,030	7,794	287.3	36,699	19,188	576.1	81,732	42,126	1,567.7
Montana	10,788	12,289	7,338	415.6	4,286	2,741	78.2	15,371	9,044	223.8	31,946	19,123	717.6
Nebraska	13,211	12,280	6,424	485.3	7,924	3,940	199.7	15,777	7,826	511.1	35,981	18,190	1,196.1
Nevada	7,116	2,756	1,996	83.4	1,972	1,650	44.6	3,266	2,708	134.8	7,994	6,354	262.8
New Hampshire	3,199	2,790	1,581	17.1	1,077	537	6.3	5,828	2,902	40.0	9,695	5,020	63.4
New Jersey	5,870	10,632	5,196	34.3	11,345	5,672	4.3	24,849	12,100	20.5	46,826	22,968	59.1
New Mexico	3,328	7,010	4,487	253.7	1,551	1,001	40.6	12,170	7,783	270.4	20,731	13,271	564.7
New York	48,444	72,364	37,858	144.1	26,218	12,002	141.5	90,690	41,475	277.9	189,272	91,335	563.5
North Carolina	8,662	22,773	11,074	548.9	7,007	3,229	110.2	19,557	9,823	376.3	49,337	24,126	1,035.4
North Dakota	3,416	11,939	6,149	1,253.9	5,887	2,939	551.5	7,689	3,885	630.2	25,515	12,973	2,435.6
Ohio	18,061	34,711	17,284	175.6	14,739	7,071	74.4	68,429	34,877	234.9	117,879	59,232	484.9
Oklahoma	9,789	9,256	5,295	137.9	7,387	3,866	118.1	17,870	9,532	172.5	34,513	18,693	428.5
Oregon	2,045	7,088	4,277	119.9	3,205	1,816	86.1	15,534	8,635	159.7	25,827	14,728	365.7
Pennsylvania	18,831	35,513	17,757	37.3	7,169	3,578	9.4	68,775	34,136	191.2	111,457	55,471	237.9
Rhode Island	1,576	5,713	2,856	43.0	2,153	1,077	13.2	17,817	9,163	12.5	25,683	13,096	68.7
South Carolina	5,173	12,338	6,639	387.9	2,916	1,505	149.6	12,592	6,284	257.9	27,846	14,428	795.4
South Dakota	1,849	10,633	6,129	827.6	4,057	2,444	253.8	12,282	7,062	661.3	26,972	15,635	1,742.7
Tennessee	8,405	12,258	5,746	339.7	11,512	5,486	215.1	25,270	12,032	292.4	49,040	23,264	847.2
Texas	25,672	6,145	2,950	241.2	12,231	6,157	453.8	53,921	27,964	658.5	72,297	37,071	1,353.5
Utah	3,928	5,184	3,933	93.5	2,976	2,205	78.6	4,185	3,009	55.8	12,345	9,147	227.9
Vermont	1,577	5,408	2,917	63.9	826	417	9.5	5,504	2,736	36.0	11,738	6,070	109.4
Virginia	11,545	15,789	7,819	331.3	7,345	3,699	156.1	21,082	10,510	336.3	44,216	22,028	823.7
Washington	9,108	6,045	2,354	110.1	2,896	1,192	24.6	20,092	10,462	108.6	29,033	14,008	243.3
West Virginia	6,939	11,944	6,032	115.3	2,778	1,388	28.2	11,058	5,524	116.8	25,780	12,944	260.3
Wisconsin	8,074	31,375	16,281	627.7	9,699	4,994	126.6	17,263	8,695	392.9	58,337	29,970	1,147.2
Wyoming	2,522	3,659	2,476	68.8	1,905	1,241	26.5	5,727	3,703	134.6	11,291	7,420	229.9
Hawaii	2,811	5,791	2,598	12.5	25	13	.1	11,656	4,662	33.9	17,472	7,273	46.5
District of Columbia	6,396	2,894	1,447	.7				3,252	1,819	.9	6,146	3,266	1.6
Puerto Rico	5,806	10,972	5,254	56.9	979	446	4.4	9,672	4,443	32.2	21,623	10,143	93.5
TOTAL	461,382	792,616	407,164	14,815.3	316,140	160,707	5,834.7	1,118,248	563,183	12,916.0	2,227,004	1,131,054	33,566.0