AUTOMATIC WEIGHING OF VEHICLES IN MOTION AND COLLECTION OF TRAFFIC DATA BY ELECTRONIC METHODS

P. Milliman

Report on Interim Experimental Program Designated "Post Part A"
of a Research Investigation Conducted in Cooperation with
the Bureau of Public Roads, U.S. Department of Commerce

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SYNOPSIS

An interim experimental program is reported, conducted to improve accuracy and durability of the existing system, as installed at the test site for weight and dimension measurement of moving vehicles. In addition to extensive modifications of the system and thorough refurbishing, weight tests were conducted to determine the results of the alterations. Accuracy was significantly improved, when determined by the same method as in Part A, and even further improved when using multiple regression analysis. Platform surface switches and traffic control continue to present problems, but solutions are being evolved.

The following report covers accomplishments of the "Post Part A" experimental program of this research project. To clarify the relationship of this program to the other portions and ultimate objectives of the project, the following condensed outline is presented:

PROPOSAL I Feasibility Study II Final Design, Engineering, Specifications, and Cost III Complete System Installation	July 1960
FEASIBILITY STUDY by Epsco, Inc.	Dec. 1960 to Mar. 1961

The results of the feasibility study indicated that an improvement in program efficiency would result from combination of Parts II and III, and a supplemental proposal was written reorganizing the problem approach:

SUPPLEMENTAL PROPOSAL Part A - Experimental Field Test Program Part B - Automatic Recording and Data Processing Installation	July 1961
PART A by Epsco, Inc.	Sept. 1961 to Mar. 1964

The desired measurement accuracies were not attained in Part A, and thus an extension of the project was proposed, designated "Post Part A," to attempt accuracy and durability improvements.

POST PART A PROPOSAL I Accuracy Improvement II Durability Improvement	Submitted May 1963, Approved Sept. 1963
POST PART A by Michigan State Highway Department	Sept. 1963 to Feb. 1965
SPECIFICATIONS FOR PART B Prepared by Michigan State Highway Department	Sept. 1964
PART B Completion of System by Philco Corp.	Mar. 1965 to Feb. 1966
PART C One Year of Experimental Operation of System by Michigan State Highway Department	1966-67

As this outline indicates, the experimental measurement accuracies originally specified for vehicle axle weights and dimensions were not attained in Part A (performed under contract to the Michigan State Highway Department by Epsco, Inc. of Cambridge, Massachusetts). As a result of this failure to attain what, on the surface, were and still are considered to be reasonable goals, this Post Part A project was initiated. Its primary purpose was improvement, in the areas of accuracy, reliability, durability, and safety, of an already existing measurement system.

Optimism regarding possible results of this interim work was based on observations and experiences of Research Laboratory personnel during Part A and during the Michigan pilot dynamic weighing installation at Fowlerville, in 1959. As a result of the belief that substantial system improvement could be effected by modest expenditure of time and money, a proposal for the required modifications was submitted to the Bureau of Public Roads in May 1963, and returned with approval in September 1963, at which time work began on the project.

Post Part A as originally proposed had two principal goals, both of which placed particular emphasis on those elements of the system relating to vehicle weighing accuracy:

1. To improve the accuracy of system measurements.
2. To improve the overall physical plant condition and operation.

These goals were to be attained through accomplishment of the following specific objectives:

1. To determine and correct the cause or causes of the excessive transverse, longiduinal, and vertical oscillation of the scale platform.

2. To develop a rugged, practical scale surface switch system to replace the existing nondurable system.

3. To develop an effective system of traffic control through the automatic scale installation and around the mechanical scale bypass.

4. To develop a rugged load bearing assembly, incorporating load cell, to provide for vertical adjustment and to eliminate the possibility of side loadings being applied to the cell.

5. To refurblish and improve the physical plant.

The report which follows is of necessity and intent quite brief. It describes the workperformed in Post Part A and the results of that work. The final report for Part B (the next phase of the project) will incorporate all details of the entire program, including plans, specifications, costs, etc. Thus, many details which might be presented here are omitted, due to the likelihood that further modifications are probable.

The distribution of vehicles tested for this report does not represent the usual distribution of traffic for the site. Therefore, the accuracy figures reported here are not those which will be considered binding upon the Part B contractor. These binding specifications will be obtained in the immediate future through a more extensive test series in which a test sample will be taken that will be more representative of the distribution of vehicles normally crossing the site.

SYSTEM AND SITE IMPROVEMENTS

Weighing Accuracy

At the completion of Part A, Research Laboratory personnel felt that Epsco, Inc. had done an excellent job with the electronic instrumentation they had fabricated and installed, but that the physical system (weight and dimension transducers) left much to be desired. It was thought that much of the poor weighing accuracy obtained could be attributed to deficiencies in the scales themselves. For confirmation, a series of tests were performed at the site to determine exactly how the platforms were reacting when impacted by a dynamic load, and after load application. Platform motions were sensed by the load cells and by linear variable differential transformer type motion transducers, and signals were recorded on a high speed oscillograph with galvanometers whose response is essentially flat to 1000 cps.

As a result of these tests it was found that platforms were moving in the horizontal plane as a unit and simultaneously vibrating at their structural resonant frequency in the vertical plane. These motions were combining in such a manner that the load cells under the platform corners were seeing an oscillatory applied load of approximately 60-cps frequency and of an amplitude often exceeding 50 percent of the applied axle load. Consequently, the load cell output signal that the electronic instrumentation was attempting to sample and convert to weight intelligence, consisted of this excessively oscillatory component superimposed over the vehicle dynamic weight signal.

At the completion of these tests all data, together with system structural plans, were turned over to the Laboratory's Structures Unit for analysis and recommendation of structural modifications to resolve the platform vibration problem.

Acting upon these recommendations, a number of physical alterations were performed:

1. Diaphragm stiffeners were positioned and welded between the webs of the platform I-beam stringers (Fig. 1).

2. Flange-to-flange stiffeners perpendicular to the web were added to the I-beams that bear on the load cells, in the area of bearing, to prevent motion of the flange with respect to the web, since the load cells are not positioned directly under the web (Fig. 2).

3. High capacity springs (4000 lb per in.) were procured, and spring mounts and anchors fabricated, for application of platform corner preloads (including platform dead loads) from 5000 to 7500 lb (Figs. 3 and 4).

4. A system of transverse and longitudinal anchor rods was fabricated and installed so as to restrict platform movement in the horizontal plane (Figs. 1, 3, and 5).

5. The load bearing columns under each platform corner, incorporating the load cells, were modified so as to provide vertical adjustment capability and to preclude the possibility of side loadings being applied to the cells (Fig. 2).

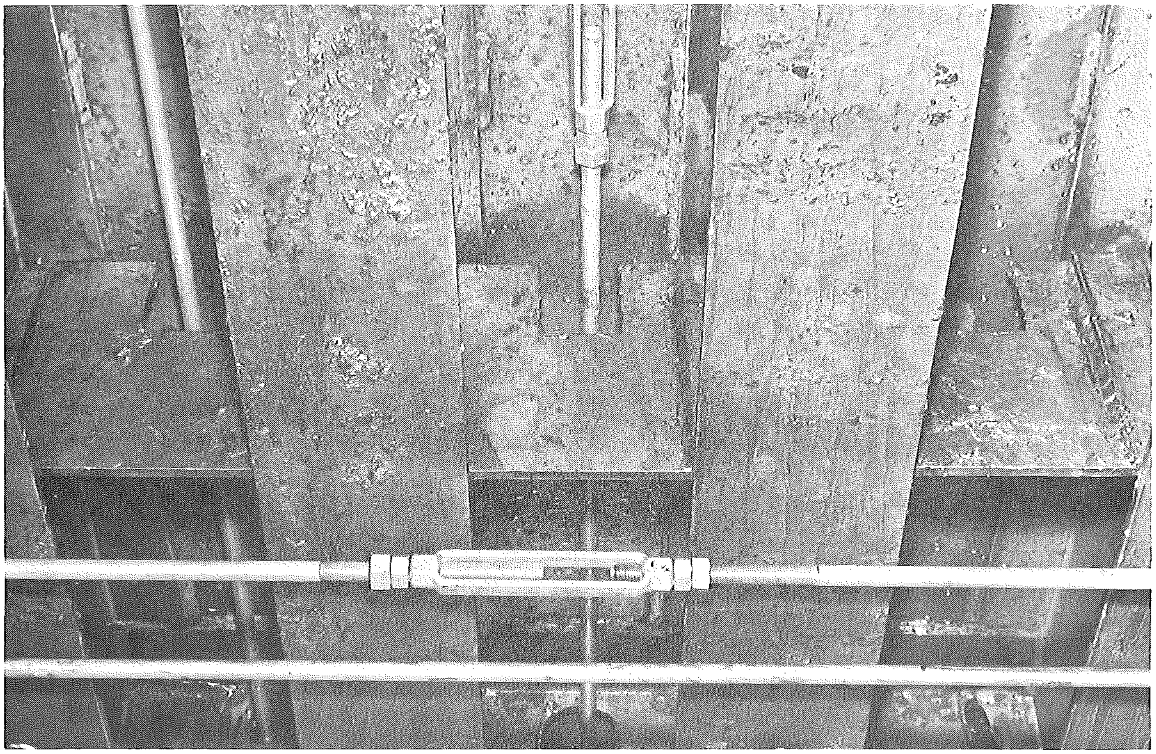


Figure 1. Underside of Platform No. 1 showing diaphragms and longitudinal (top) and transverse (bottom) anchor rods.

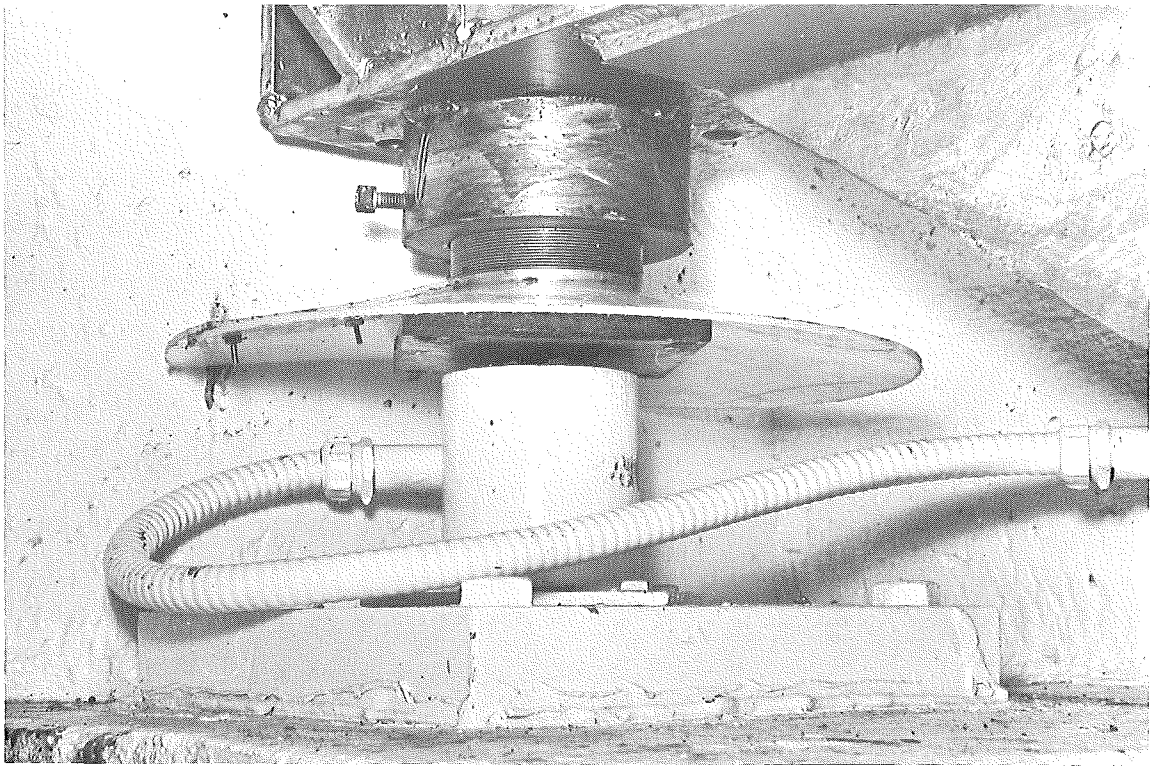


Figure 2. Load column under each corner of each platform consisting (from bottom) of pillar, pillar cap plate, load cell retaining plate, load cell, bearing plate, drip shield, and vertical adjustment jack.

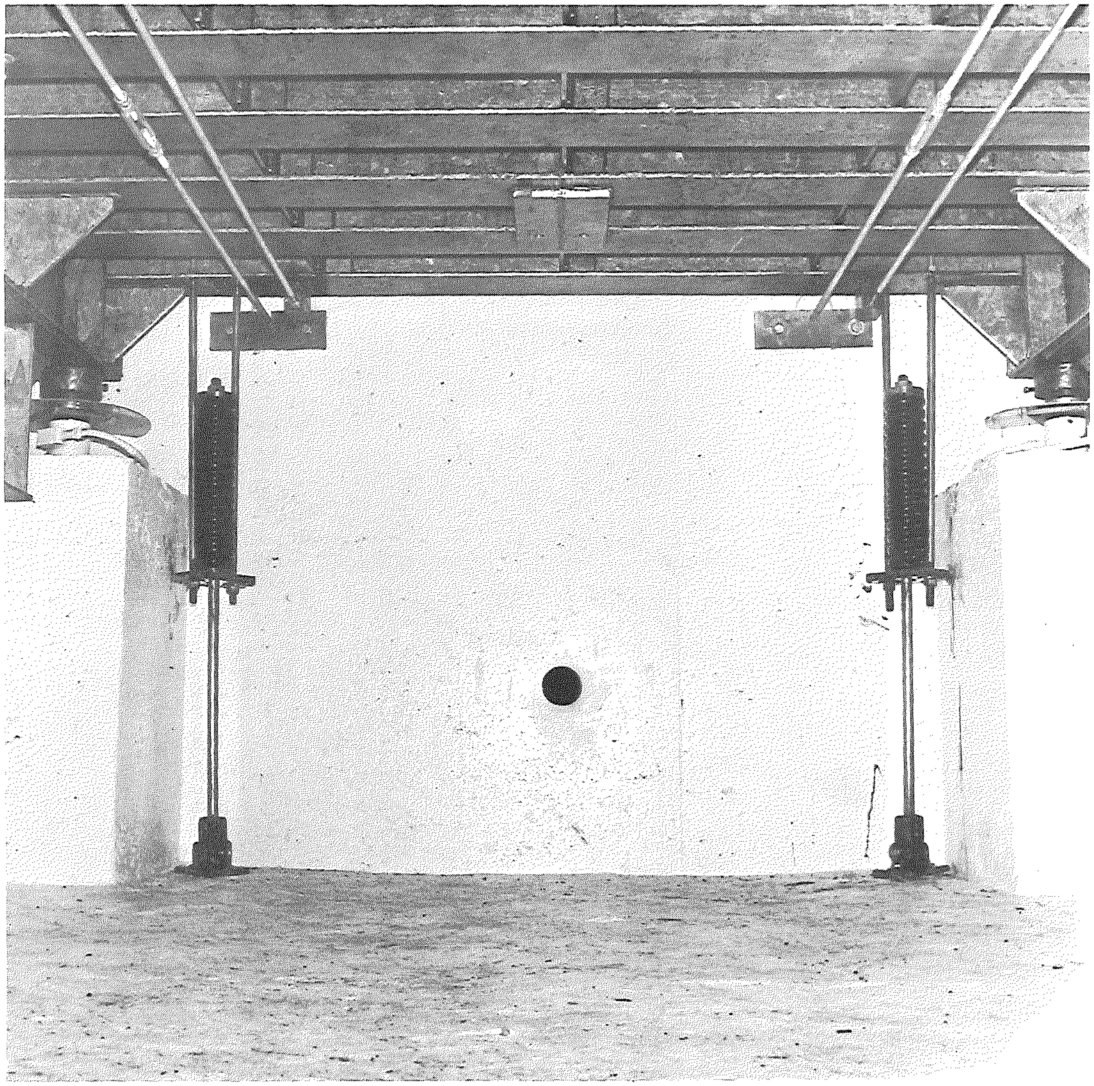


Figure 3. Interior of Pit No. 1 showing hold-down springs, transverse anchor rods, and load columns.

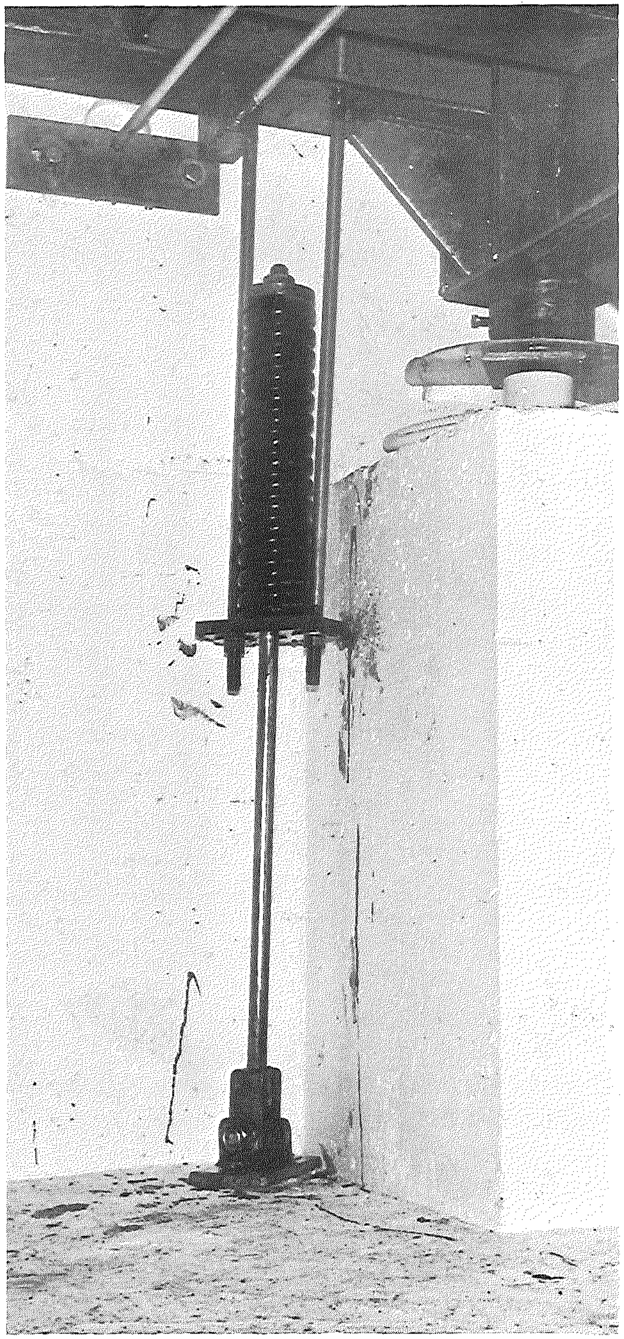


Figure 4. Closeup view of 4000-lb per in. hold-down spring and its mountings.

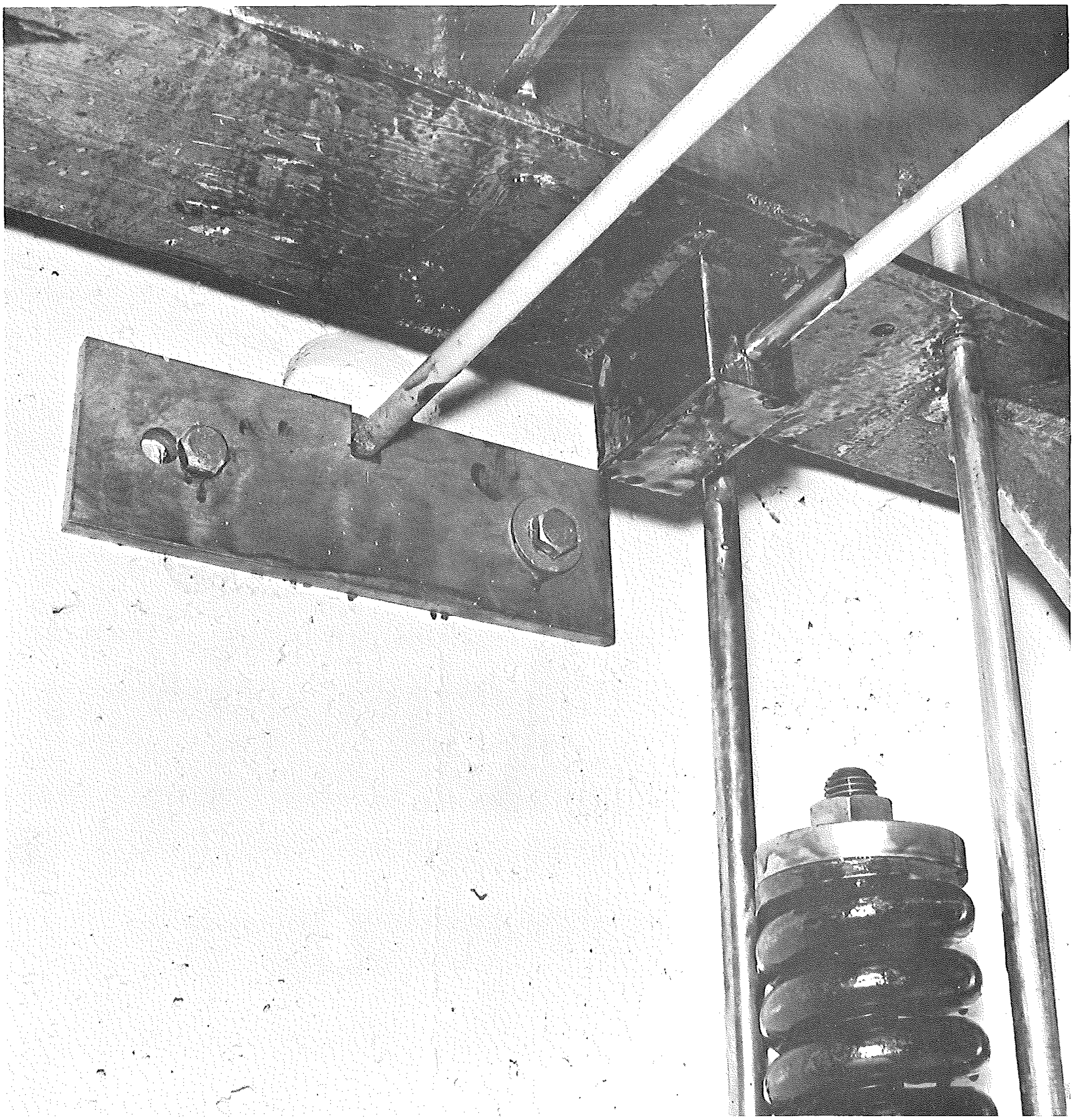


Figure 5. Platform transverse anchor rods showing one wall anchor and one rod-to-platform attachment block.

Because of the extreme inefficiency which would have resulted by performing this work on a piecemeal, one-scale-at-a-time basis, it was decided to integrate the scale accuracy-oriented modifications with the many other system modifications required. Consequently, the system was not in a condition for dynamic accuracy tests until all other alterations and modifications had been completed.

The tests performed to determine dynamic weighing characteristics and accuracy of the four scales utilized two special State Highway Department test vehicles and approximately 250 trucks from the traffic stream normally traversing the scale installation. Single axle loads of these 250 vehicles ranged from 4 to 19 kips, and tandem axle loads from 8 to 32 kips. Most trucks analyzed traveled over the scales at 20 to 50 mph. All records taken were of analog type so that a clear picture of signal characteristics could be obtained.

For the purposes of these tests it was decided to take weights on single and 4-ft tandem axles only, excluding steering axles, tridems, walking beams, other special types, and those which present difficulties in static weighing such as air suspension and liquid carriers.

Calibrations were established for all scales prior to testing as follows:

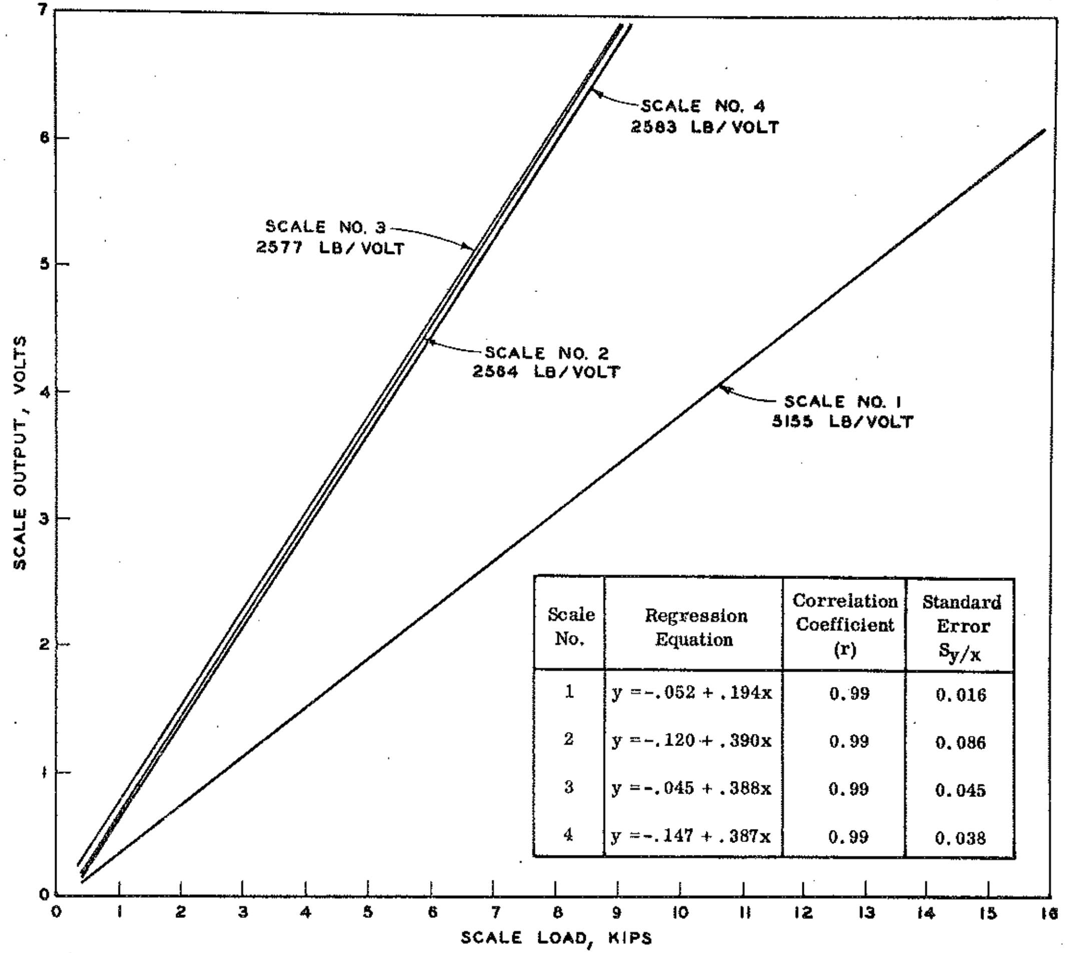
1. The 16 load cell power supply outputs were adjusted, using a digital voltmeter to an indicated accuracy of ± 0.01 v (i.e., 4.99 to 5.01 v for the cells of Scale No. 1, and 9.99 to 10.01 v for the cells of Scales 2, 3, and 4).

2. The tare voltage output of each cell was balanced to 250 μv resulting in a combined scale (four cells) output of 1 mv. This voltage was then amplified by a factor of 1000 in the DA-102 amplifier to give a tare voltage signal of 1.0 v. The purpose of this voltage was to preclude the possibility of the scale signal going negative when the platform was vibrating.

3. To complete calibration, the relationship between applied load and scale voltage output was determined by stopping axles on the electronic scale platforms, making precise recordings of the resulting scale output voltages, and then statically weighing these axles on the mechanical scales. The resulting relationships are shown in Fig. 6.

Test procedure consisted of selecting a vehicle as it approached the system, recording its normal-speed passage over the scales, and then stopping it at the mechanical scale for a very careful static weighing. Utilizing this procedure some 140 single axles and a similar number of tandems were measured.

In addition to the tests just described, it was felt that the system's repetition ability should be evaluated. To this end, the two Department trucks, one with a near legal limit single axle (16.25 kips) and the other with a near legal limit tandem axle (31.85 kips) each made 20 recorded runs across the scales at a controlled speed of approximately 35 mph.



Scale No.	Regression Equation	Correlation Coefficient (r)	Standard Error $S_{y/x}$
1	y =-.052 + .194x	0.99	0.016
2	y =-.120 + .390x	0.99	0.086
3	y =-.045 + .388x	0.99	0.045
4	y =-.147 + .387x	0.99	0.038

Figure 6. Electronic scale calibrations.

Dimensional Accuracy

The dimensional accuracy obtained by the infrared curtains of Part A was initially limited by the fact that the sensors were spaced at 3-in. intervals. In addition, height and width measurement were adversely affected by the fact that vehicle bounce, flapping tarps, etc. tend to bias height readings to the high side, and vehicle "crab," a common vehicle characteristic, also tends to bias width readings to the high side. These tendencies are predictable and for height and width were substantiated by the results of Part A. However, length measurements as determined in Part A were disappointing in that the method used in their determination would have been predicted to produce very good results. It consisted simply of summing the spacing between the extreme axles of a given vehicle and the front and rear overhangs of that vehicle. And considering that axle spacing was the system's most accurate measurement, averaging about 75 percent of the total length measurement, the large errors that occurred suggested either an error in the computer program or length transducer problems. A study of these two possible error sources indicated that the computer program was correct, and thus the trouble probably involved the transducers of the infrared system. The problem was believed to involve variations in the rise and decay times among different cells. This has not yet been confirmed by experiment because of the concentration of effort on the weighing system. The problem, therefore, reamins to be resolved. However, the proposal for Part B submitted by Philco Corp. describes experiments performed by them which appear to indicate that the infrared cells used in Part A are satisfactory for their intended purpose.

Physical mountings for the infrared components of the height measuring system were modified and re-installed in an attempt to determine the feasibility of establishing an operative curtain with beams on 1-in. centers as shown in Fig. 7. Upon attempting to align the light sources and sensors it was found that the light sources focused poorly and gave a very large, irregular shaped spot which impinged upon a number of sensors at one time, and was thus completely unsatisfactory. This dictated either modifying or obtaining new light sources, but before anything could be accomplished in this area the proposals for Part B had been received and in each case the prospective contractor proposed complete re-engineering of the infrared system. Therefore, any intervening work by the Laboratory would probably be of little or no value. As a result of this proposed re-engineering, Bureau of Public Roads personnel recommended that this portion of Post Part A be abandoned and that recommendation was accepted.

Platform Surface Switches

The nine vehicle-actuated switches located in the platform surfaces--three in Platform No. 1 (Fig. 8), and two each in Platforms Nos.

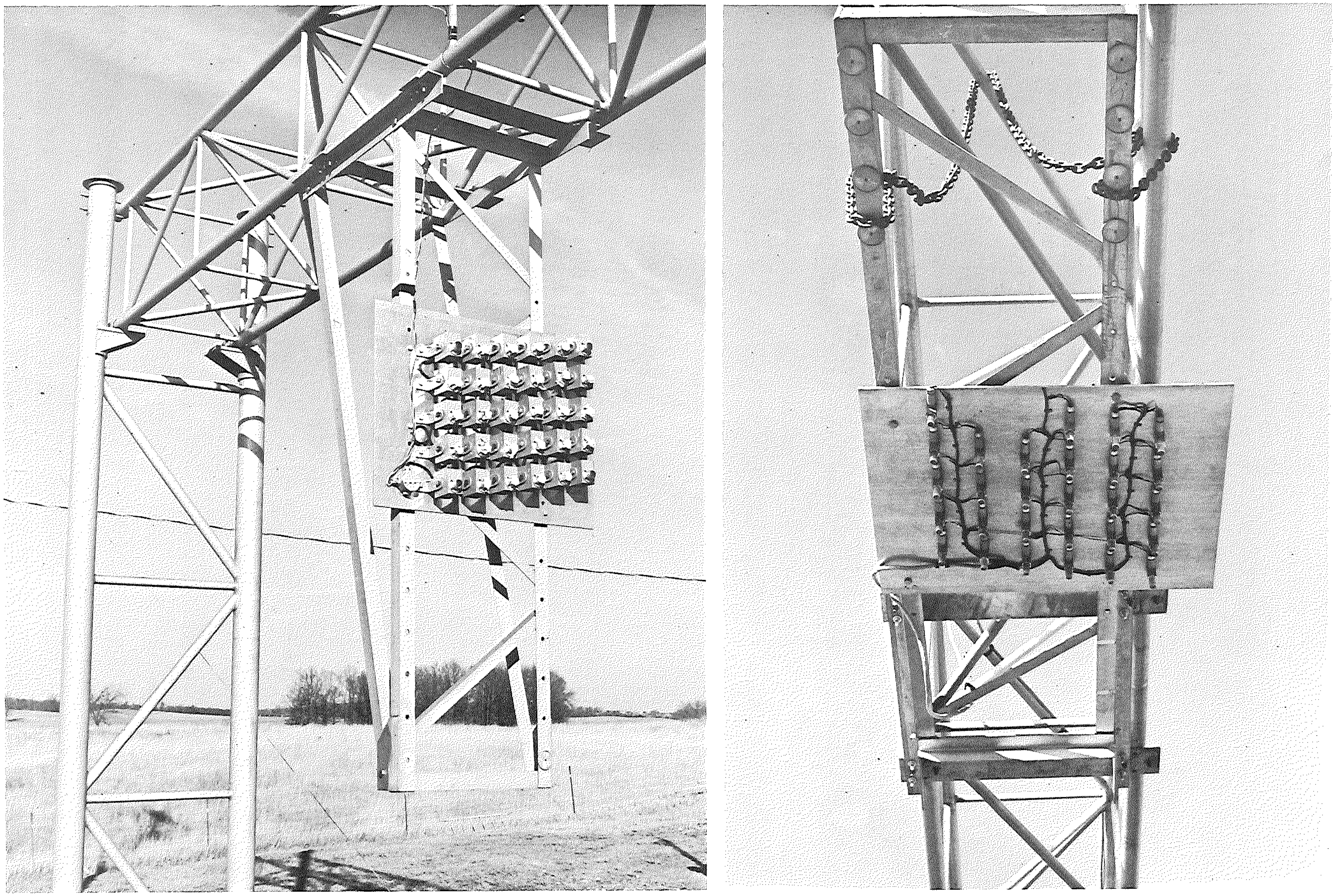


Figure 7. Modified infrared height array with sources (left) and detectors (right, in retracted position) on 1-in. centers.

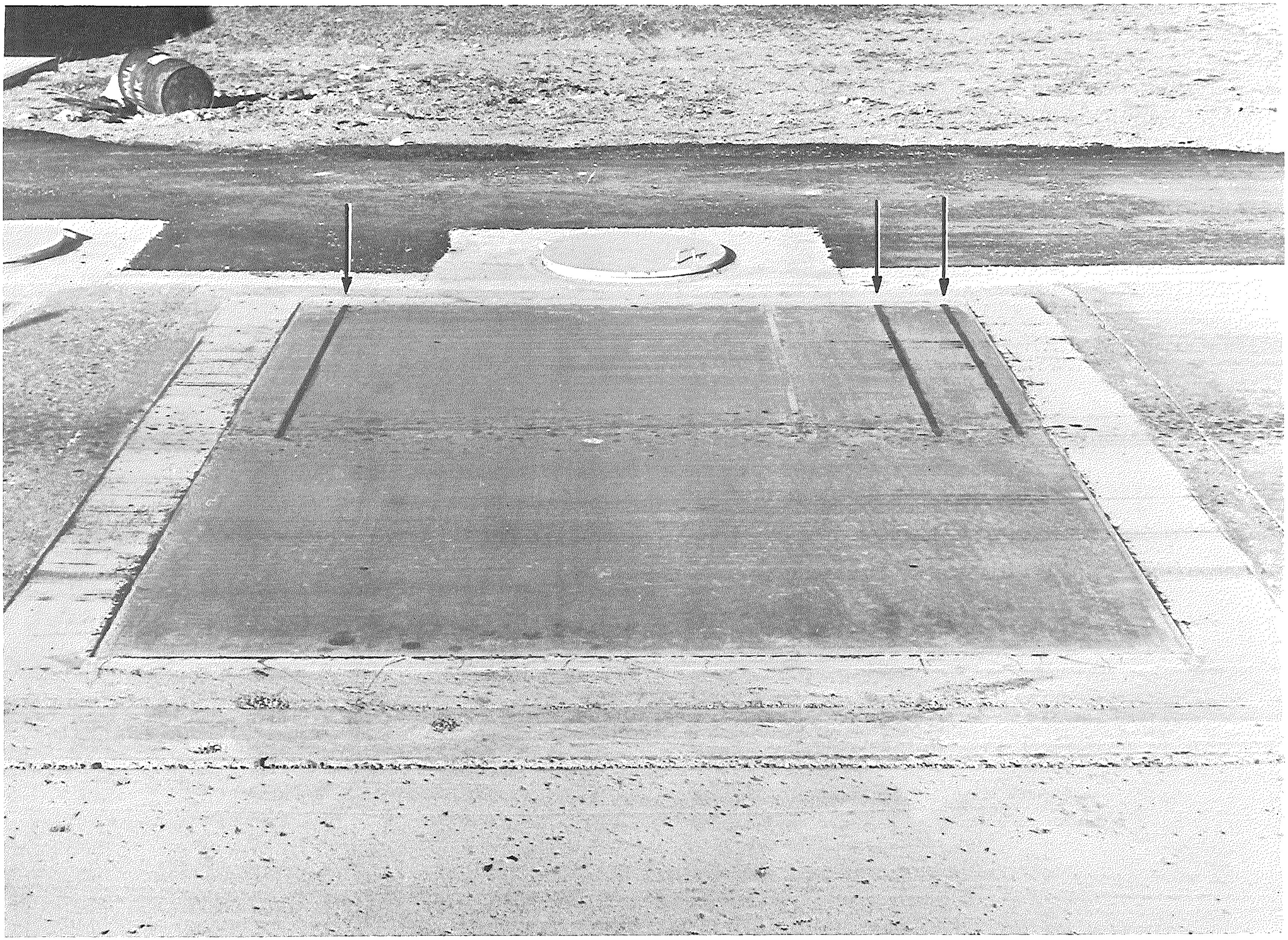


Figure 8. View of the surface of Platform No. 1, showing this platform's three flush-mounted surface switches.

2, 3, and 4--are the only information source for calculating vehicle axle spacings and also provide part of the information necessary to compute vehicle axle weights and lengths. They are therefore indispensible to the system.

During Part A work, Epsco, Inc. experienced considerable difficulty with their tapeswitch installations in that moisture penetrated into the switch mechanism in spite of all precautions and no embedding material was ever found that would satisfactorily maintain a bond to the switch slots under truck traffic and in all weather conditions.

To resolve these problems Laboratory personnel contacted the Tapeswitch Corp. (the only known manufacturer of this type of switch) to obtain if possible hermetically sealed units, and the Laboratory's Materials Research Section was requested to obtain the best embedding material available. Tapeswitches obtained were sealed in a neoprene tube, supposedly moisture proof, and a quantity of a polysulphide-rubber type joint seal (designated PRC 3000) was poured which purportedly had excellent adhesive and cohesive properties.

Using these materials and adhering closely to the recommended procedures for their use, the nine switches were re-installed. At present, four months after installation, all switches in the small platforms have failed. Variable open condition resistances of from a few hundred to a few thousand ohms have been observed, indicating the presence of moisture between the switch elements.

The only difference between these six switches and the three in Platform No. 1, which so far have performed perfectly, is that the machined slots in that platform are somewhat deeper and thus possibly afford better protection to the switches, rendering them less vulnerable to crushing action of vehicle tires traversing their surfaces.

This problem area is as yet unresolved, but plans are underway to deepen the slots of Platforms Nos. 2, 3, and 4, and also to install an experimental, low-movement, treadle-bar-type switch in one slot. Regardless of the outcome of these experiments, work will continue until a satisfactory switching system is achieved, since the system cannot operate without them.

Traffic Control

Laboratory personnel have little experience in traffic control, and consequently after a number of conferences to define the problem it was turned over to the Department's Traffic Division for recommendations.

Traffic personnel have studied the problem, visited the site a number of times, and are presently engaged in preparation of plans and specifications for signs, delineators, etc. to take care of this matter. Current appearance of the site is shown in Fig. 9.

System Modification and Refurbishing

Laboratory and field work performed in modifying and refurbishing the system was far too extensive and involved to attempt detailed description in this report. Nearly every component of the physical system was affected, with the following achievements:

1. A small, insulated, steel building (Fig. 10) was erected beside the scales as an enclosure for Post Part A and Part B electronics and as the junction of all wiring going to the scalehouse.

2. All electronic components except the load cells were moved from the pits to this enclosed shelter and mounted in a vertical rack cabinet (Fig. 11). All infrared components except sources and cell were also moved to the enclosure.

3. All temporary wiring of Part A was replaced with permanent, earth burial or conduit enclosed cables. Enclosed junction boxes were provided and new wiring charts prepared.

4. The pits were completely reworked to lessen the severity of their internal environment and to adapt them to the redesigned platform mounts and anchors. A pit interior is shown in Fig. 3.

5. Platforms were stiffened, all machining necessary for the redesigned supports and anchors was performed, and they were completely corrosion-proofed.

ANALYSIS AND DISCUSSION OF WEIGHT TEST DATA

Data Analysis

The weighing test procedures previously described generated approximately 250 analog traces requiring reduction and analysis by the Laboratory's Data Processing Unit. Two typical examples are shown in Fig. 12. The mechanics of data reduction and analysis consisted of taking readings from valid portions of the traces (wheel completely on

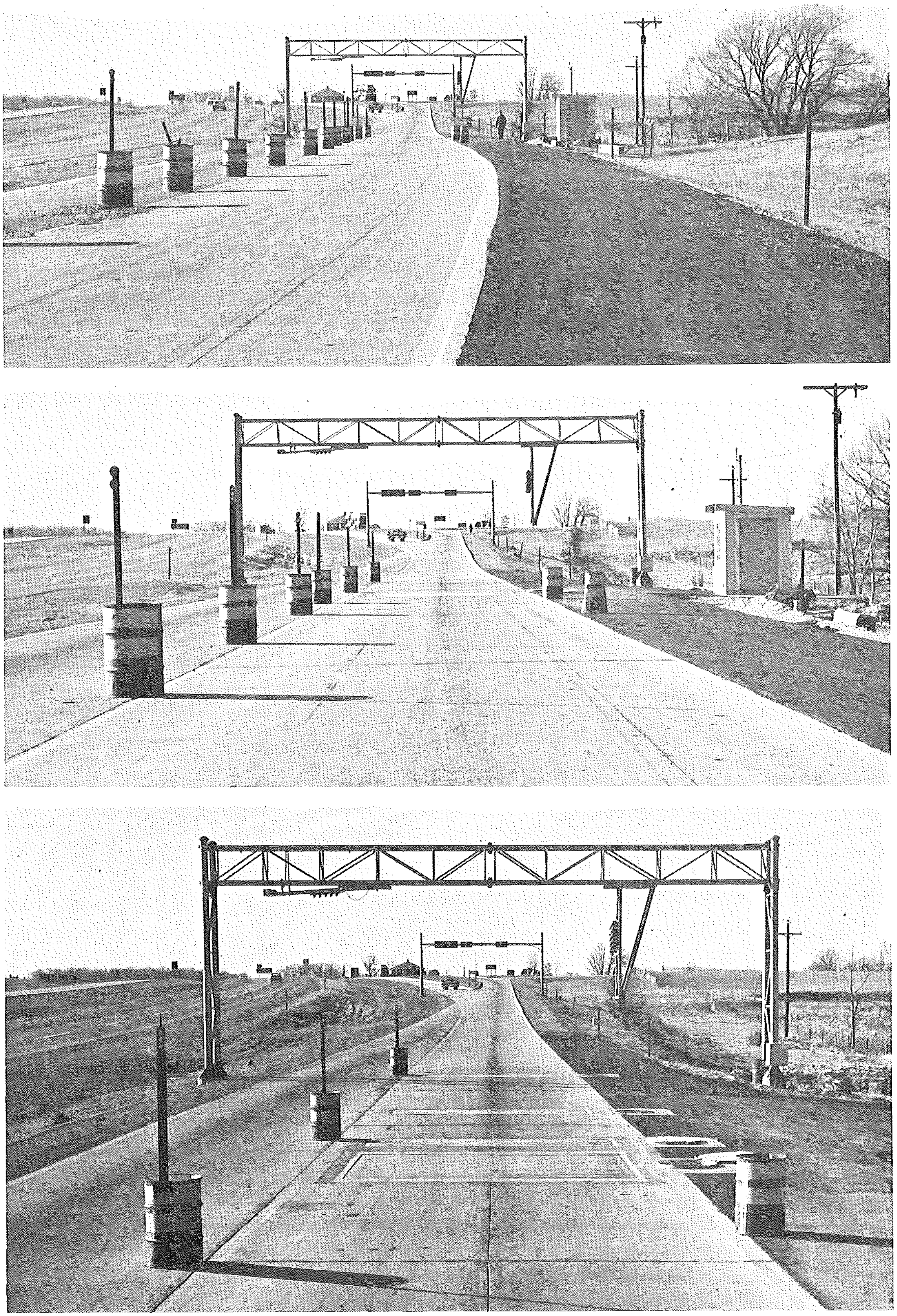


Figure 9. Three views of system as would be seen from approaching vehicle.

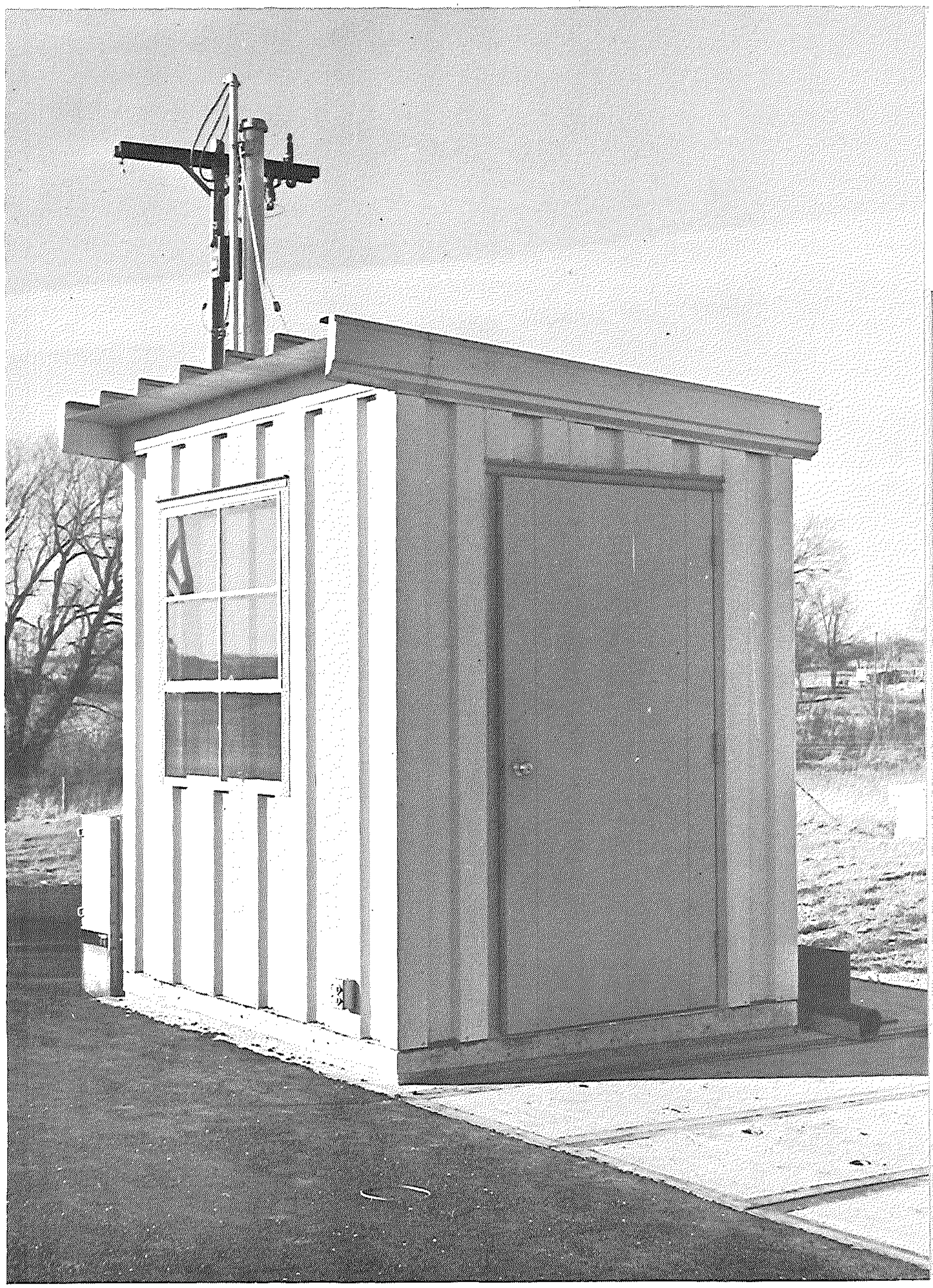
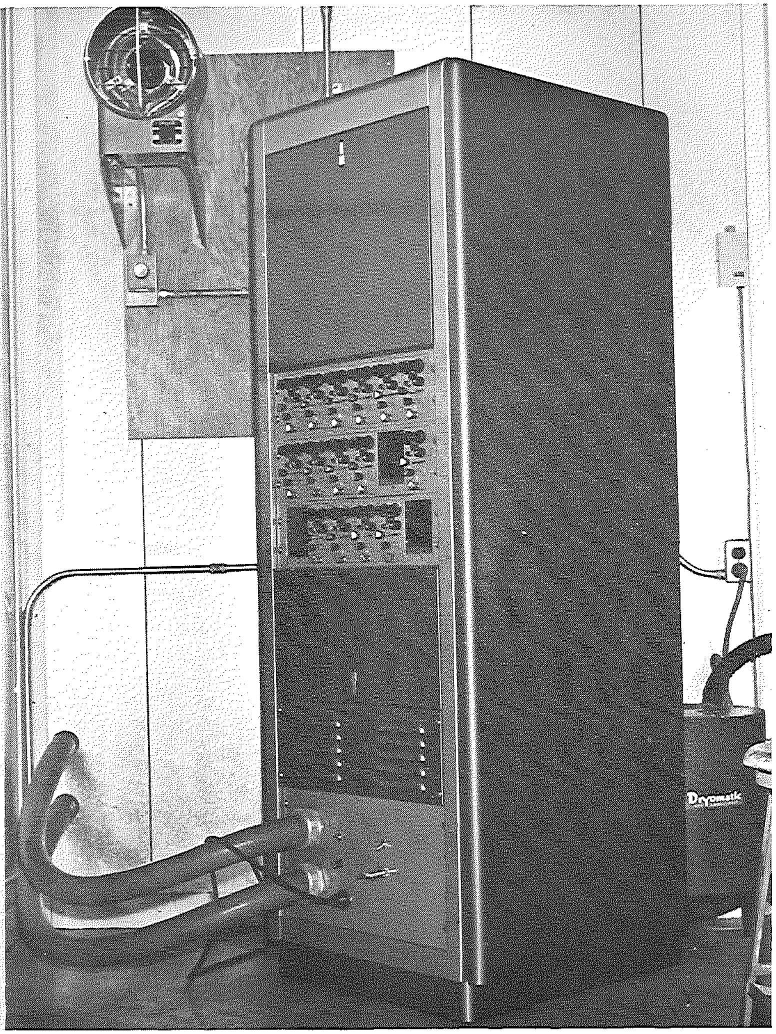
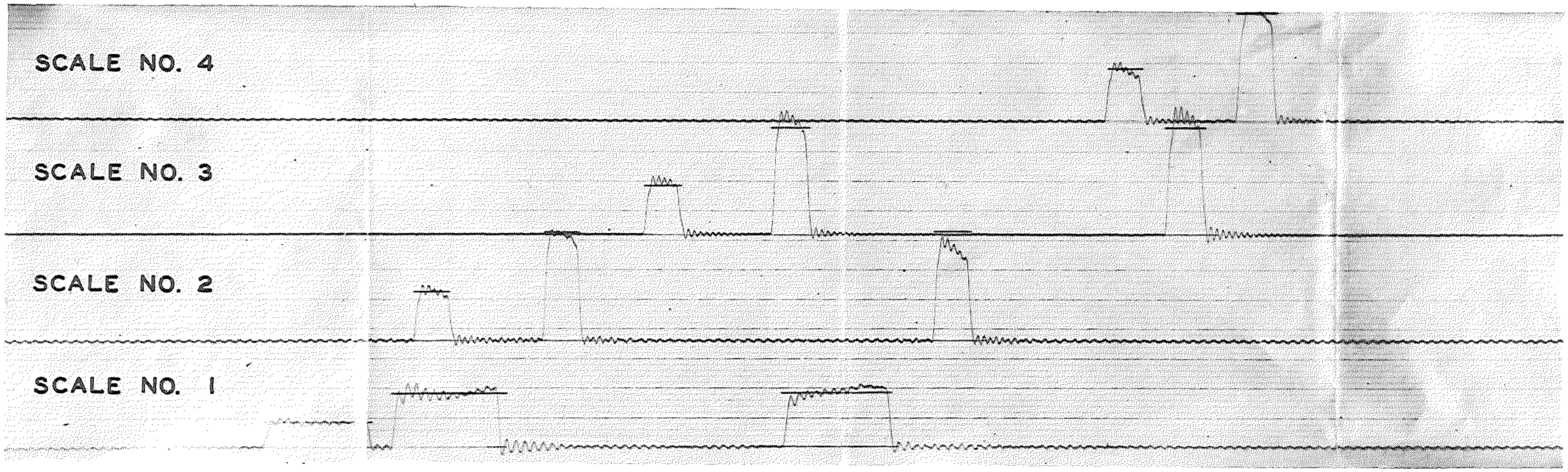


Figure 10. Shoulder enclosure erected to house electronic components removed from pits and truss junction box, and additional Part B equipment.

Figure 11. Interior of shoulder enclosure showing rack cabinet housing load cell power supplies and infrared system electronics.

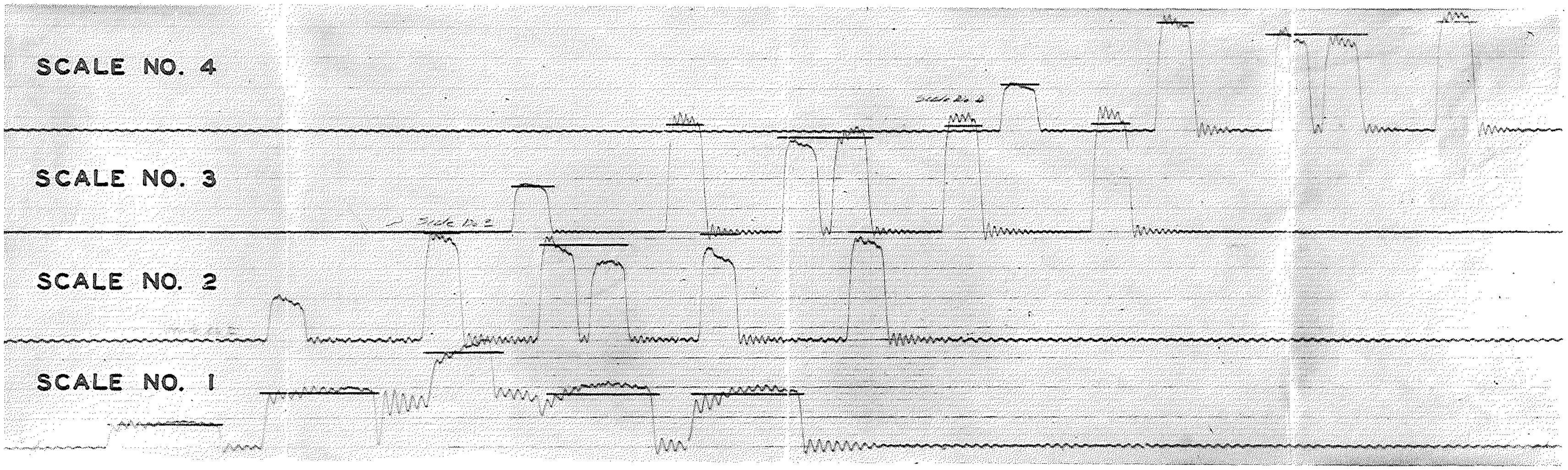




TEST DATA (Record No. 13)
Date: 12-16-64

Vehicle Class: 2S1
Speed: 36.5 mph

Axle Loads (Static): 8,270-lb steering, 18,000-lb drive, and 18,000-lb semitrailer



TEST DATA (Record No. 19)
Date: 12-16-64

Vehicle Class: 2S2-2
Speed: 29.8 mph

Axle Loads (Static): 7,500-lb steering, 17,620-lb drive, 31,650-lb semitrailer, 17,550-lb trailer 1, and 17,730-lb trailer 2

Figure 12. Typical examples of electronic scale traces. Short horizontal lines indicate static weights, for comparison with dynamic weights shown by trace.

scale) by means of a strip chart reader, converting the resulting punched paper tape to punched paper cards, and then, after writing the program and punching a program deck, running these decks on the Michigan State University CD 3600 Computer.

To perform a data reduction identical to that of the Part A (Epsco) study would have required reading of weight samples from the traces every 1.2 milliseconds. However, this was not practical at this time because of the paper speed used when recording the traces, and it was decided to take readings at some practical multiple of 1.2 milliseconds. The multiple used was eight, or one sample every 9.6 milliseconds.

Two methods of analysis were used in determining electronic weights and the system's accuracy. The first, identical to that used by Epsco in Part A except for the sampling increment, consists simply of calculating the arithmetic average of the 9.6-millisecond increment electronic weight samples of each axle on each scale, and then combining the four scale weights into one average. These average electronic weights were then paired with their corresponding mechanical scale static weights in a regression analysis to produce a regression equation and standard error of estimate of the relationship between electronic and static weights.

It was desired to present accuracy ranges at the high confidence level of 99 percent (meaning that 99 out of 100 samples will fall within the specified range). The accuracy ranges specified here represent 2.58 standard errors (assuming data to be normally distributed). In other words, the product of one standard error and 2.58 establishes the limits about the regression line within which 99 percent of all test samples will occur.

The second analytical method is somewhat different, and represents an apparently successful attempt to improve system precision by computing individual scale weighting coefficients on the basis of a large number of axles. Then using the coefficients so determined, individual vehicle axle weights may be predicted on the basis of the electronic scale outputs. This constitutes a "multiple regression" and requires solution of an equation of the form $\underline{y} = \underline{aX_1} + \underline{bX_2} + \underline{cX_3} + \underline{dX_4} + \underline{e}$, where $\underline{X_1} \ldots \underline{X_4}$ represent electronic weights for a given axle on Scales 1 through 4, respectively, and the coefficients $\underline{a}$, $\underline{b}$, $\underline{c}$, and $\underline{d}$ control the magnitude of each scale's contribution to the final computed and reported weight of this axle. The equation's constant $\underline{e}$ represents and corrects for any apparent fixed bias in the combined scale system.

The coefficient computed for a given scale is a measure of that scale's reliability in predicting static axle weights; i.e., the output of a scale with a high coefficient, even though possibly biased toward high or low weights, is characterized by a consistent (low scatter) relationship with static weight. A low coefficient indicates a much less reliable relationship (large scatter) between electronic and static weight. Therefore, in the final calculation of any given axle's weight the indicated electronic weights from the scale or scales found most reliable are heavily weighted and those from less reliable scales are less heavily weighted in proportion to their reliability.

The specified system accuracies based on the multiple regression method are then determined in the same manner as in the first method. The Y values resulting from solution of the multiple regression equation are paired with their static values, and a simple two-variable linear regression analysis is performed. This produces the straight-line equation of the relationship, the standard error of estimate, and with proper conversion (2.58 standard errors) the system accuracy at the 99-percent confidence level.

The scatter plots of Figs. 13 and 14 appear to indicate that further accuracy refinement might be realized by separating the weights into bands and analyzing them on that basis. To determine the effects of such an approach, single and tandem axle weights were both separated into three ranges, spanning the full range from zero to the maximum load encountered. Results of this work are given in Tables 1 and 2 and discussed next.

Discussion of Test Results

Results of the Post Part A modifications and improved analytical procedures are summarized in Table 1. The two outlined boxes under the heading "Single Axles" and the two under "Tandem Axles" set forth the comparative results of Part A and Post Part A for the case of unweighted arithmetic mean analysis as used in Part A. It can be seen that a very definite error reduction (3.7 percent) has been effected for single axle weighings, and although the reduction for tandems (1.1 percent) is less it still represents a significant system improvement.

The other Table 1 figures give results of the multiple regression analysis, the weight band analysis, and application of both these analytical methods to a select group of very heavy single and tandem axles (near or over legal limit in each case), plus the results of a series of repetitions of two particular axles, one single and one tandem.

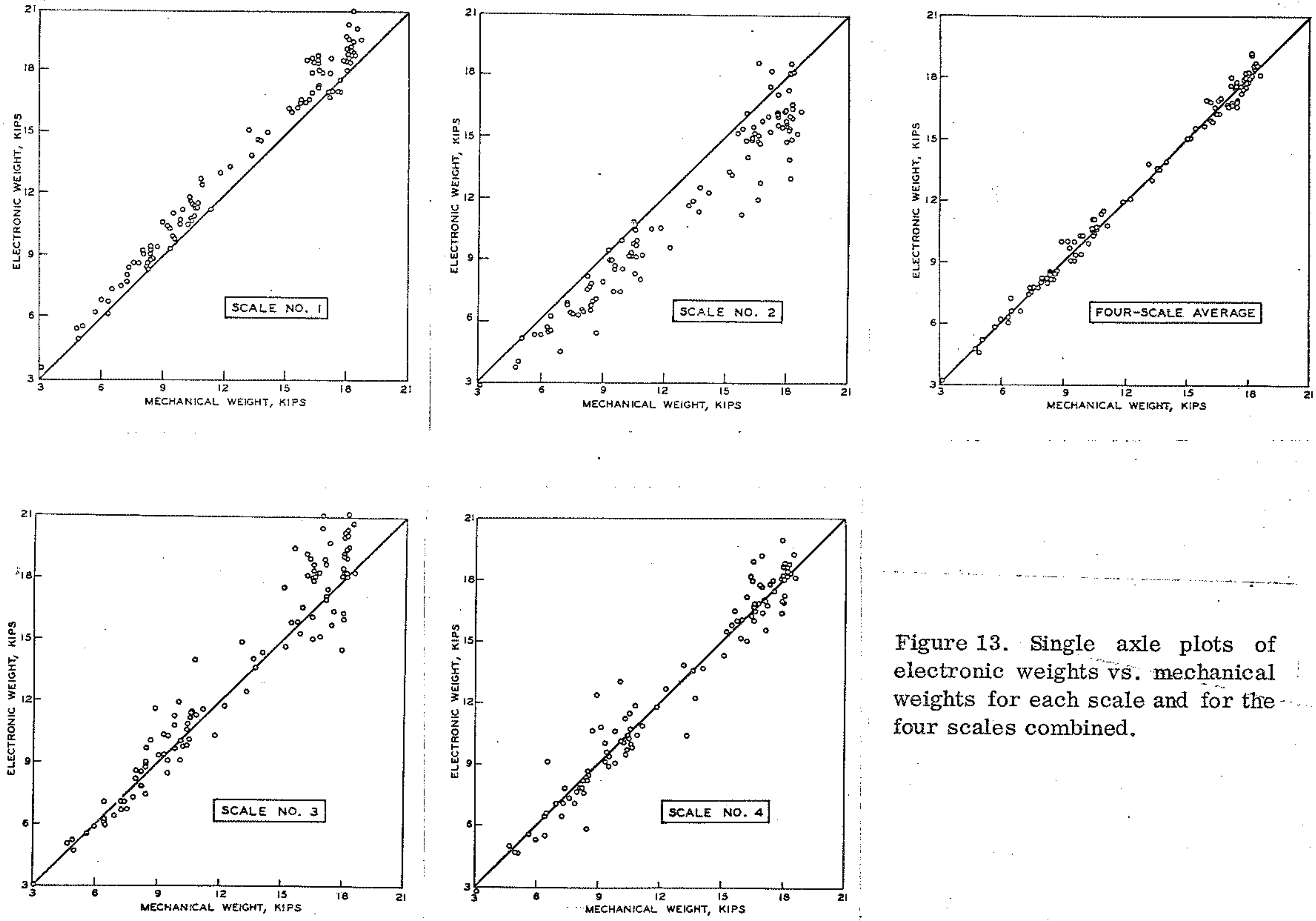


Figure 13. Single axle plots of electronic weights vs. mechanical weights for each scale and for the four scales combined.

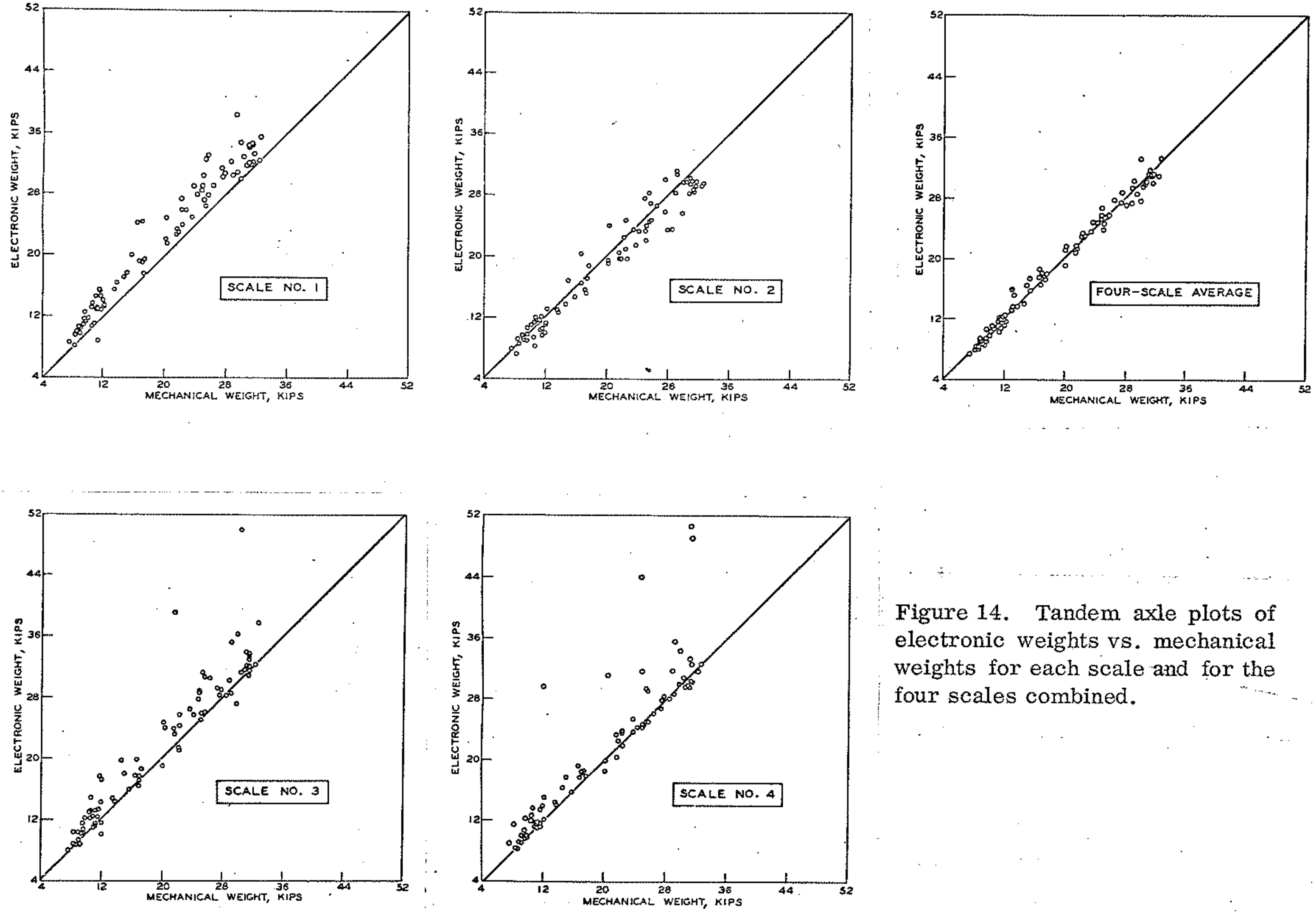


Figure 14. Tandem axle plots of electronic weights vs. mechanical weights for each scale and for the four scales combined.

The multiple regression analysis can be seen to result in significant accuracy improvement in every instance of its use, thereby indicating its superiority as a method of analysis for this study. The relative merit of weight band separation is somewhat less conclusive in the single axle analysis, except for the 0-to-9 kip range where there is significant improvement. In the tandem axle analysis considerably more improvement appears throughout the whole range, except for the higher error of the over-24-kip band as opposed to the full range error. Results of this weight band analysis, although not too conclusive, are sufficiently encouraging to indicate the value of exploring the matter further.

The next category of Table 1 to be considered concerns the two groups of near-legal-limit axles. These groups were examined because of the nature of the accuracies specified for Part B of this study (to be performed by Philco Corp.), where the allowable error specified for both single and tandem axles is given as a percentage of the maximum legal load. Very good accuracy can be seen to have been achieved in both the single and tandem cases, and again the efficacy of multiple regression analysis is demonstrated.

The final tabulation of Table 1 presents the results of the repetitive tests with the two Department vehicles. In this area, predictably, are found the lowest errors of any test grouping, and the effects of multiple regression analysis are most dramatically demonstrated, there being zero error for the 37 dynamic weighings at the 100-percent confidence level.

In Table 2 the multiple regression equation coefficients of the weight band analysis are presented and the value of one standard error of each coefficient is also included. The purpose of this chart is threefold: 1) it defines the magnitude of the contribution of each scale for each weight band and axle type used, 2) by means of the coefficient standard errors it presents a measure of the reliability of each coefficient, and 3) it gives the magnitude of the system (four-scale) bias, in pounds, for each weight band, and a measure of the certainty of this fixed bias by virtue of its standard error. This table also points out the influence or lack of influence of different scales in different weight bands. Contributions of a given scale may vary markedly for different weight bands or different axle types. Large variations of fixed bias occur in different weight bands and for different axle types.

TABLE 1

ERROR COMPARISONS BEFORE AND AFTER POST PART A MODIFICATIONS

Two Methods of Computing Weight: Unweighted Arithmetic Mean and Multiple Regression

	Axle Load Range	Before Post Part A	After Post Part A	
		Unweighted Arithmetic Mean	Unweighted Arithmetic Mean	Multiple Regression
SINGLE AXLES	0 to 9 kips	---	---	760 lb
	9 to 16 kips	---	---	920 lb
	16 kips and over	---	1420 lb	940 lb
	Full Range (all axles combined)	1900 lb (or 10.4% of 18 kips)	1210 lb (or 6.7% of 18 kips)	950 lb (or 5.3% of 18 kips)
	Special Group: 25 heavy single axles from traffic stream	---	1410 lb (or 7.8% of 18 kips)	810 lb (or 4.5% of 18 kips)
	Special Group: 18 repetitions of one 16.26-kip single axle (Department truck)	---	796 lb (or 4.4% of 18 kips)	Zero Error
TANDEM AXLES	0 to 16 kips	---	---	1370 lb
	16 to 24 kips	---	---	1900 lb
	24 kips and over	---	---	2300 lb
	Full Range (all axles combined)	2600 lb (or 8.1% of 32 kips)	2260 lb (or 7.0% of 32 kips)	2200 lb (or 6.9% of 32 kips)
	Special Group: 23 heavy tandem axles from traffic stream	---	2080 lb (or 6.5% of 32 kips)	1264 lb (or 4.0% of 32 kips)
	Special Group: 19 repetitions of one 31.85-kip tandem axle (Department truck)	---	1190 lb (or 3.7% of 32 kips)	Zero Error

TABLE 2
MULTIPLE REGRESSION SCALE COEFFICIENTS
OF THE EQUATION $y = aX_1 + bX_2 + cX_3 + dX_4 + e$
AND ESTIMATED STANDARD ERRORS S OF THESE COEFFICIENTS

Scale No.	Constants and Their Standard Errors*	Single Axles				Tandem Axles			
		0-9 kips	9-16 kips	>16 kips	Full Range	0-16 kips	16-24 kips	>24 kips	Full Range
1	a	0.65	0.63	0.38	0.60	0.23	0.17	0.27	0.25
	S	0.10	0.12	0.07	0.05	0.06	0.06	0.09	0.04
2	b	0.20	0.30	0.13	0.23	0.19	0.42	0.14	0.21
	S	0.09	0.07	0.04	0.03	0.06	0.10	0.08	0.05
3	c	0.14	0.03	-0.02	0.03	0.36	0.42	0.13	0.34
	S	0.09	0.07	0.04	0.03	0.06	0.10	0.09	0.05
4	d	-0.05	0.04	0.19	0.13	0.03	-0.05	0.36	0.21
	S	0.06	0.09	0.06	0.04	0.06	0.12	0.09	0.06
	e	110	-270	5500	-60	1300	100	-500	-960
	S	300	400	1200	120	400	1500	1700	230

* a, b, c, d = coefficients
S = standard errors
e = bias constants

CONCLUSIONS

The work of Post Part A can be said to have been generally successful, despite the fact that some of the target problem areas, such as surface switches and traffic control, still remain to be resolved. The following conclusions result from this experimental program:

1. The system's accuracy has been significantly improved over that of Part A.

2. An improved analysis method (multiple regression) has been experimented with and found to be superior to the unweighted arithmetic mean method as used in Part A. Further work in this area is indicated, especially with regard to analysis on the basis of discrete weight bands in conjunction with multiple regression.

3. The complete installation has been renovated, modified, and refurbished so that it should have a long, relatively trouble-free life expectancy.