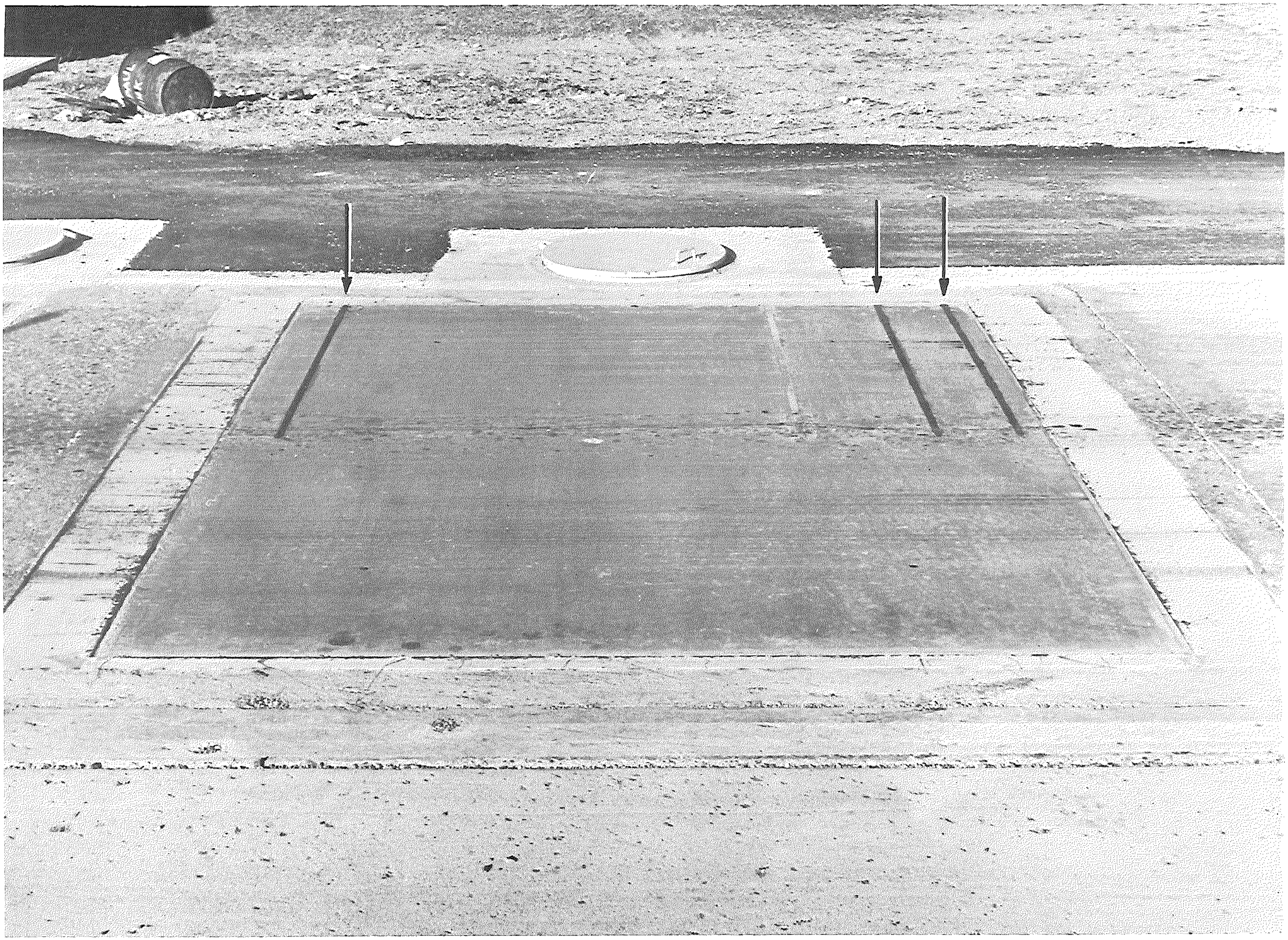


Figure 8. View of the surface of Platform No. 1, showing this platform's three flush-mounted surface switches.

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

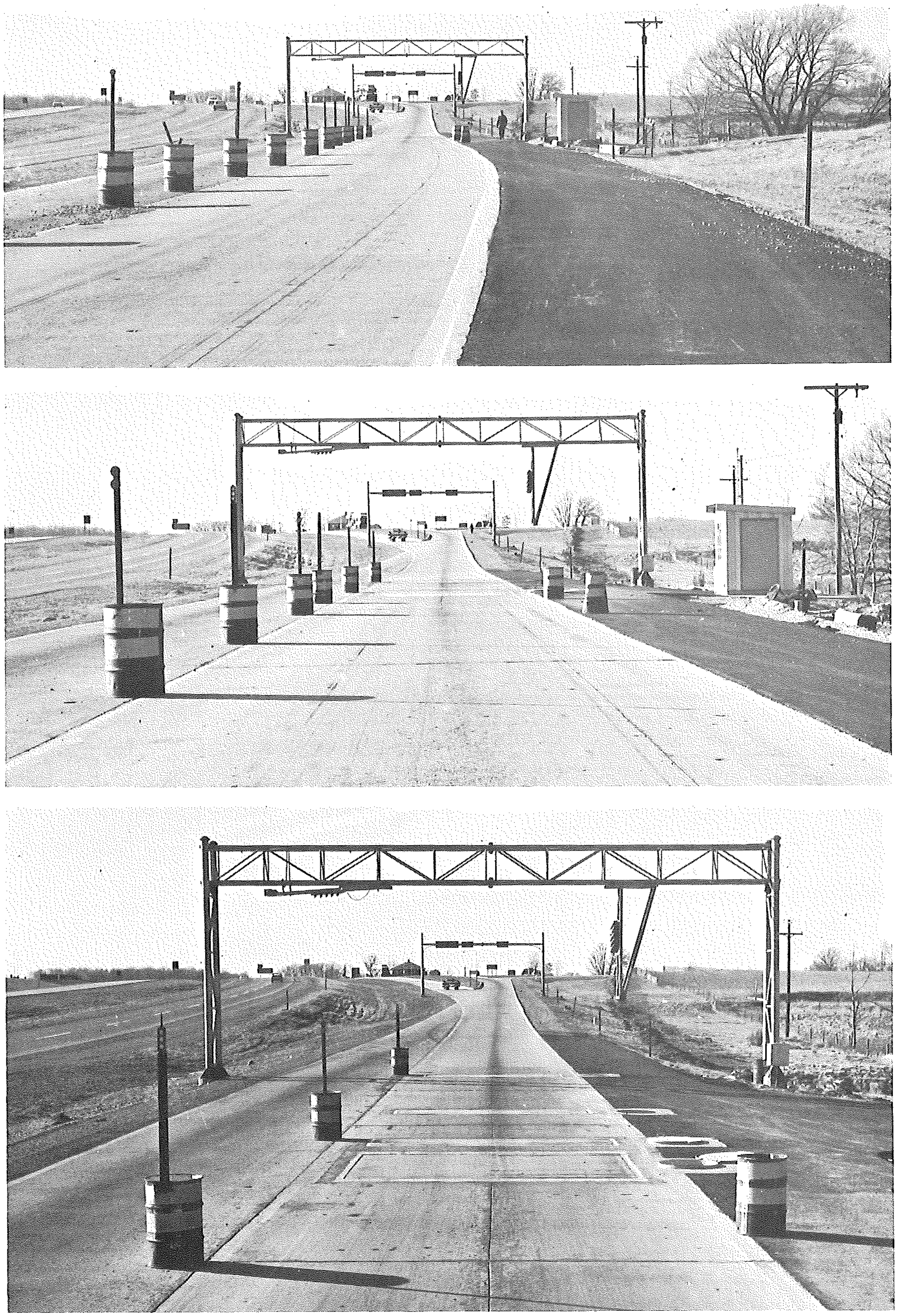


Figure 9. Three views of system as would be seen from approaching vehicle.

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

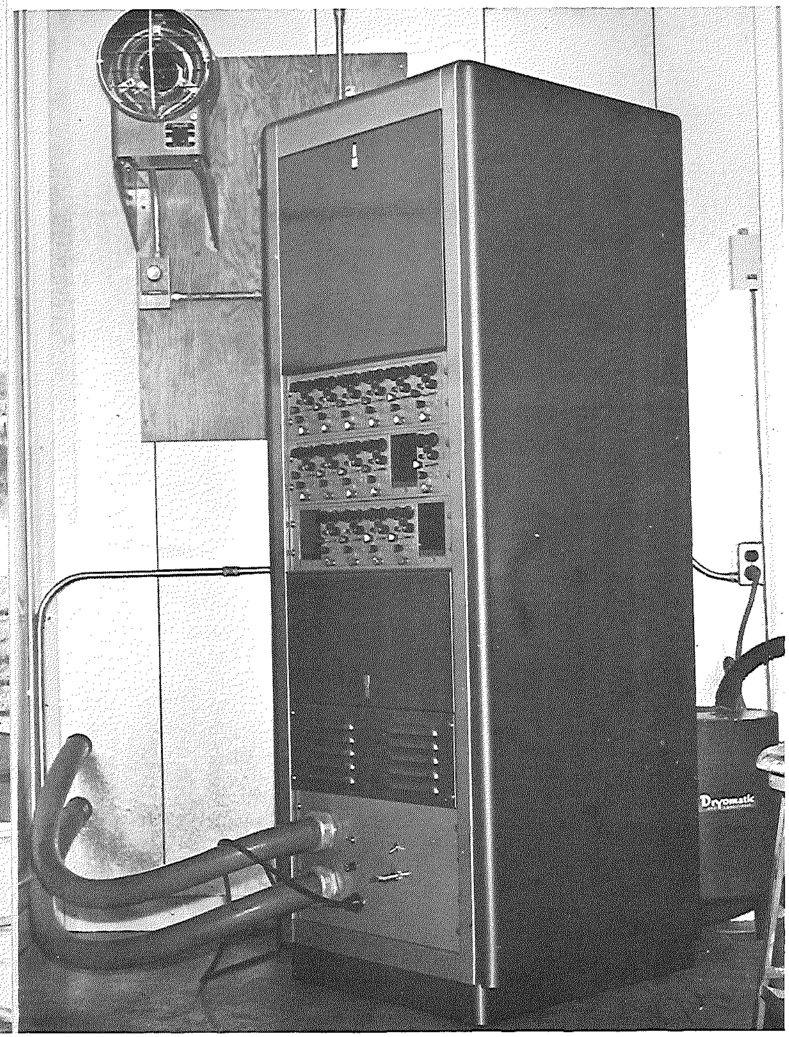
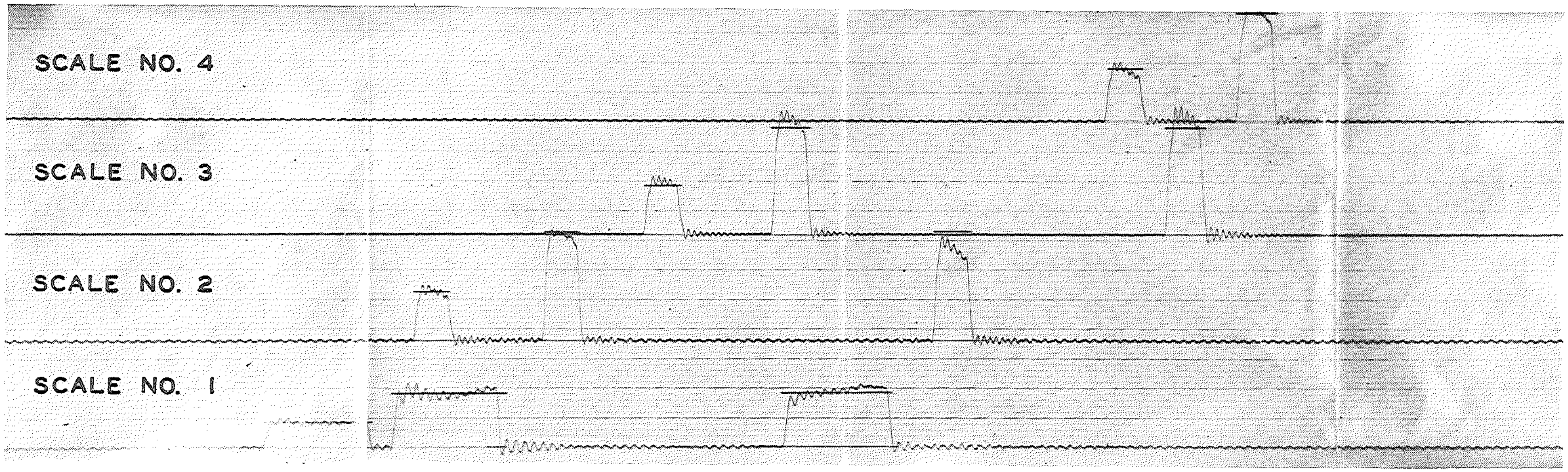
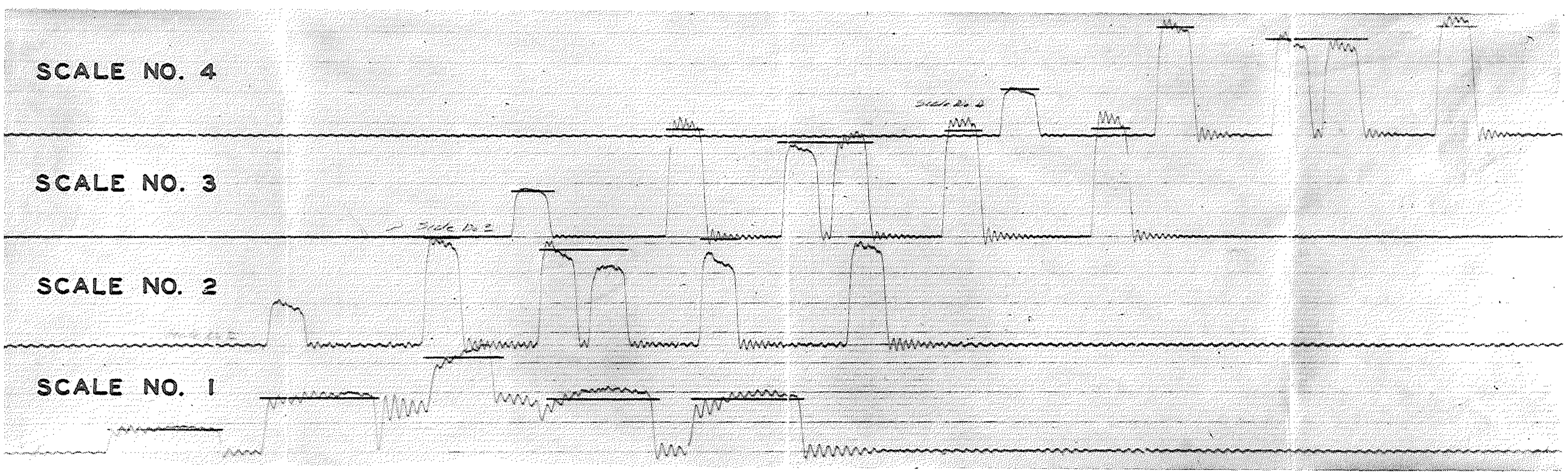


Figure 11. Interior of shoulder enclosure showing rack cabinet housing load cell power supplies and infrared system electronics.



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 $y = aX_1 + bX_2 + cX_3 + dX_4 + e$, where $X_1 \ldots X_4$ represent electronic weights for a given axle on Scales 1 through 4, respectively, and the coefficients a, b, c, and d control the magnitude of each scale's contribution to the final computed and reported weight of this axle. The equation's constant 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 $\underline{Y}$ 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.

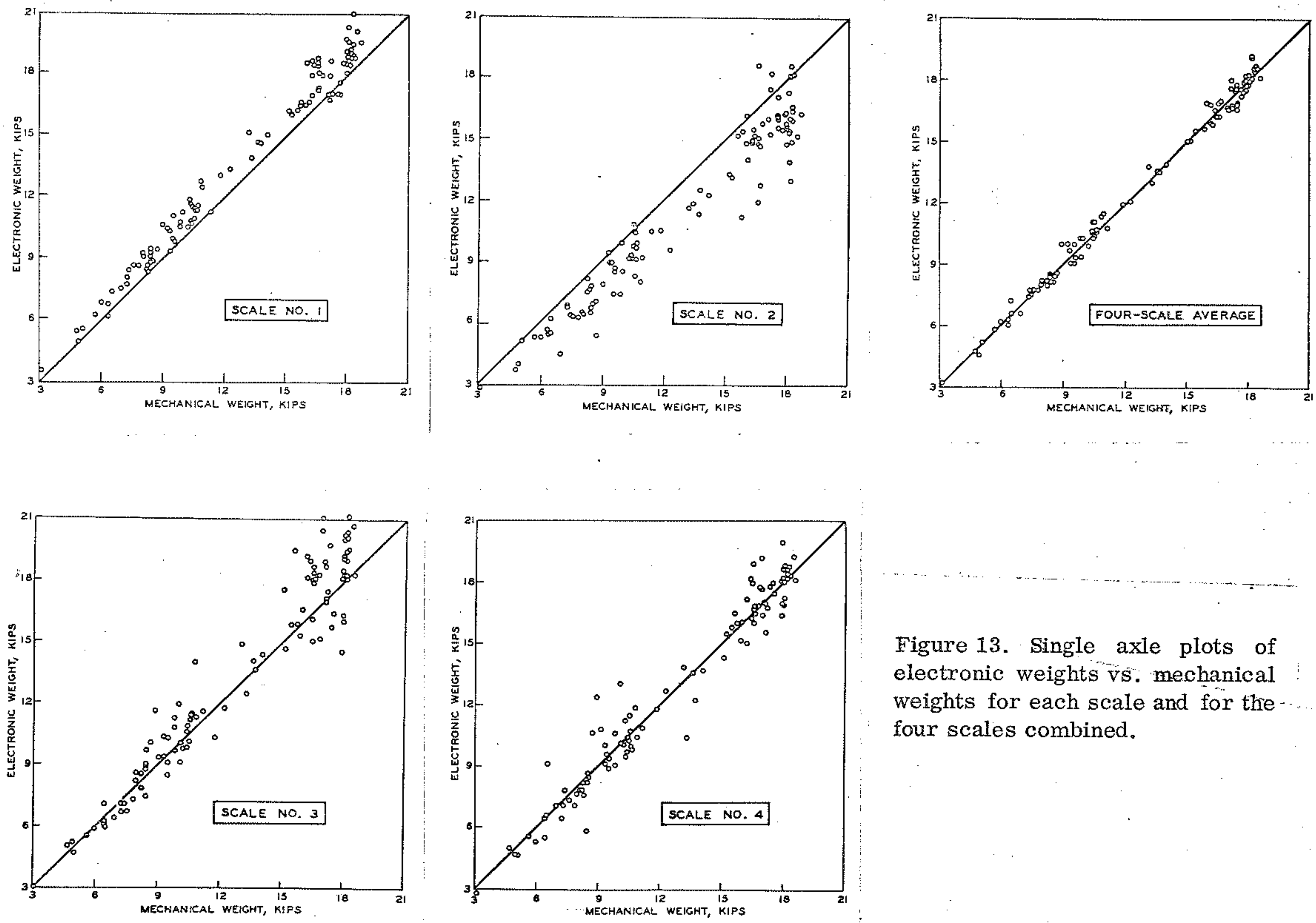


Figure 13. Single axle plots of electronic weights vs. mechanical weights for each scale and for the four scales combined.

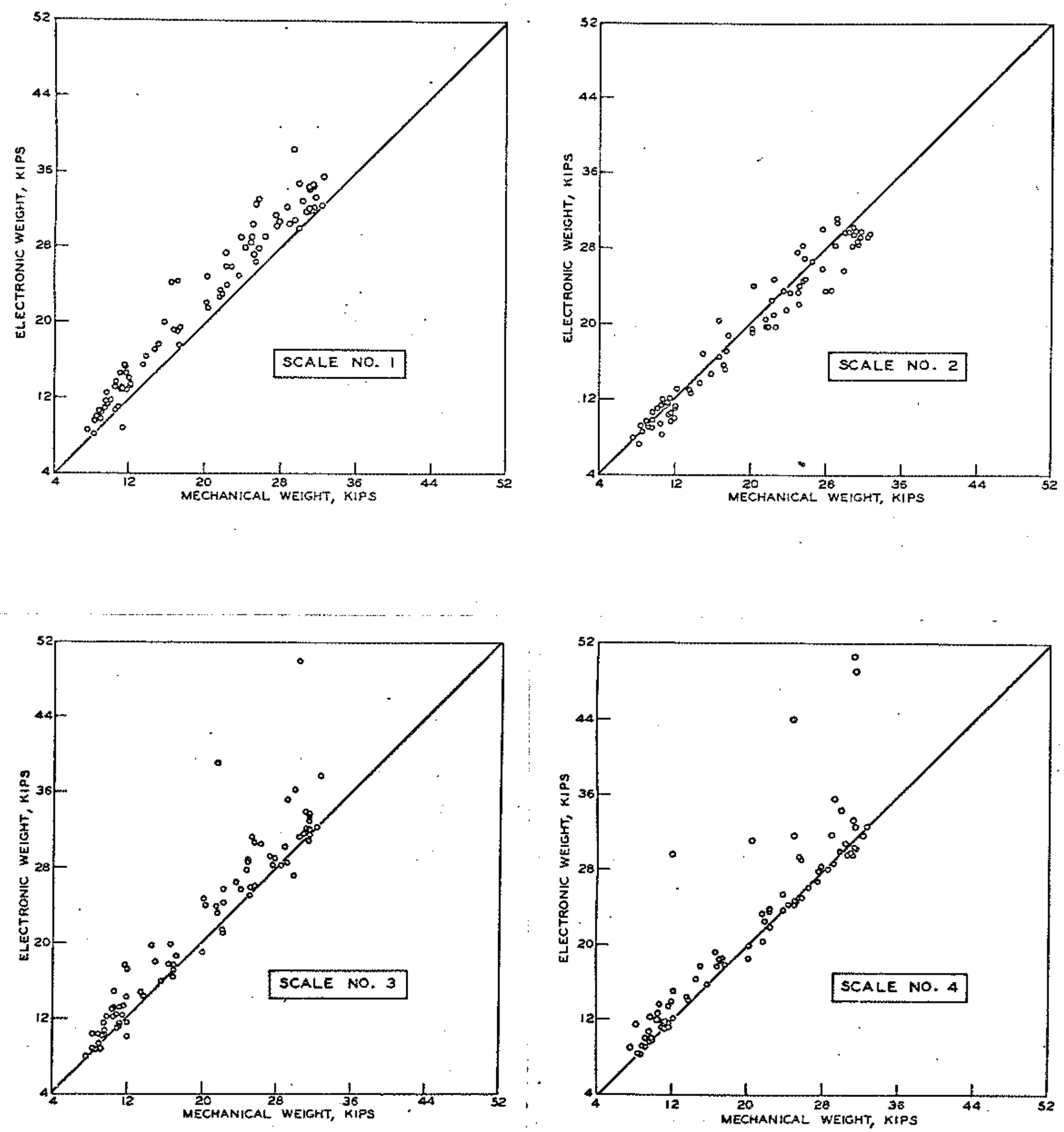


Figure 14. Tandem axle plots of electronic weights vs. mechanical weights for each scale and for the four scales combined.

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.