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

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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).

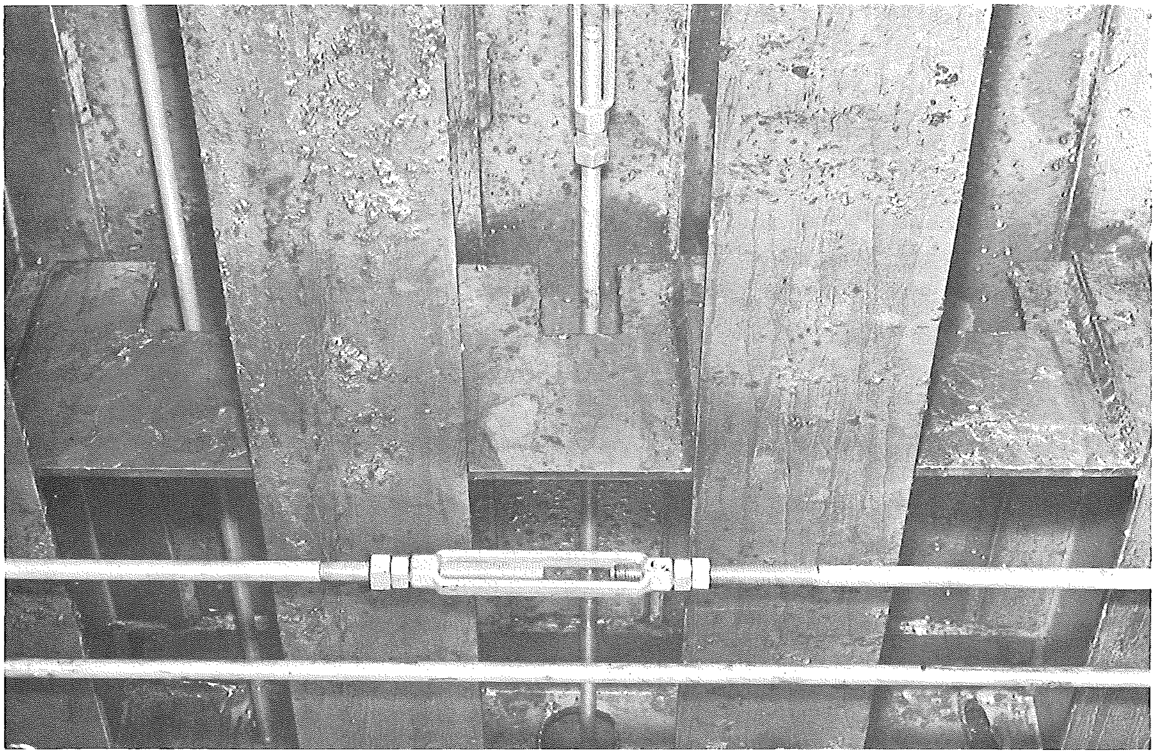


Figure 1. Underside of Platform No. 1 showing diaphragms and longitudinal (top) and transverse (bottom) anchor rods.

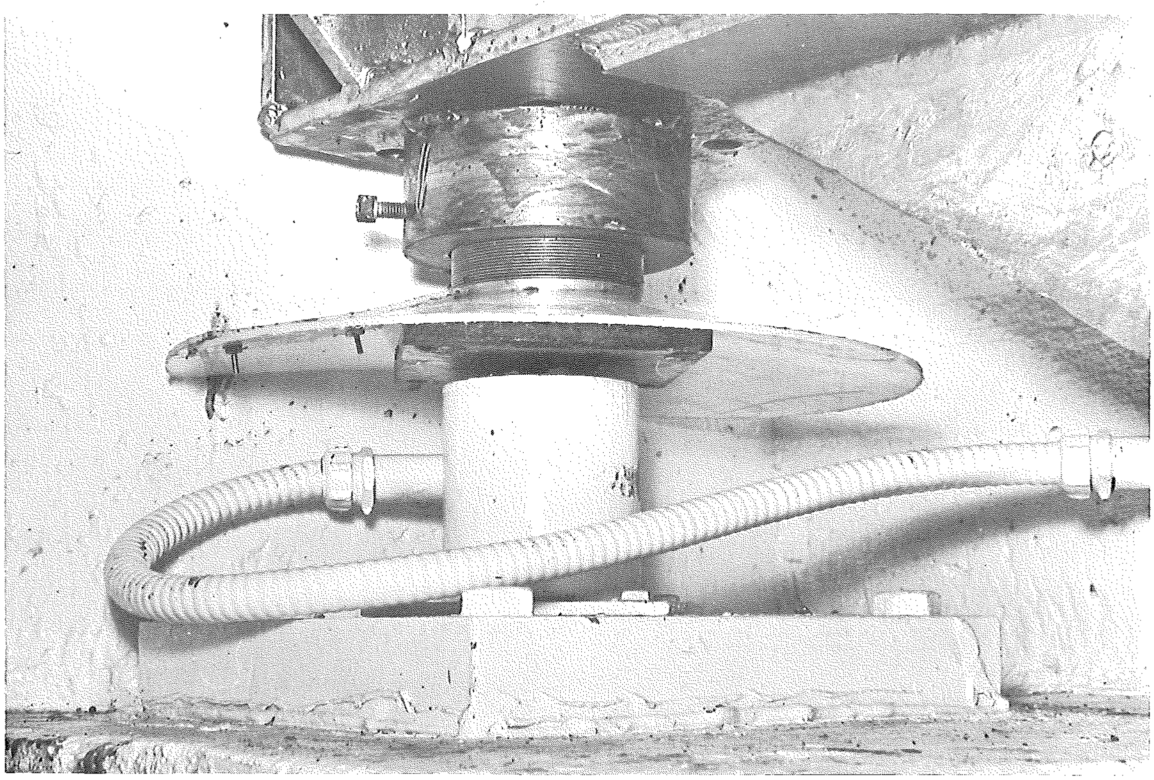


Figure 2. Load column under each corner of each platform consisting (from bottom) of pillar, pillar cap plate, load cell retaining plate, load cell, bearing plate, drip shield, and vertical adjustment jack.

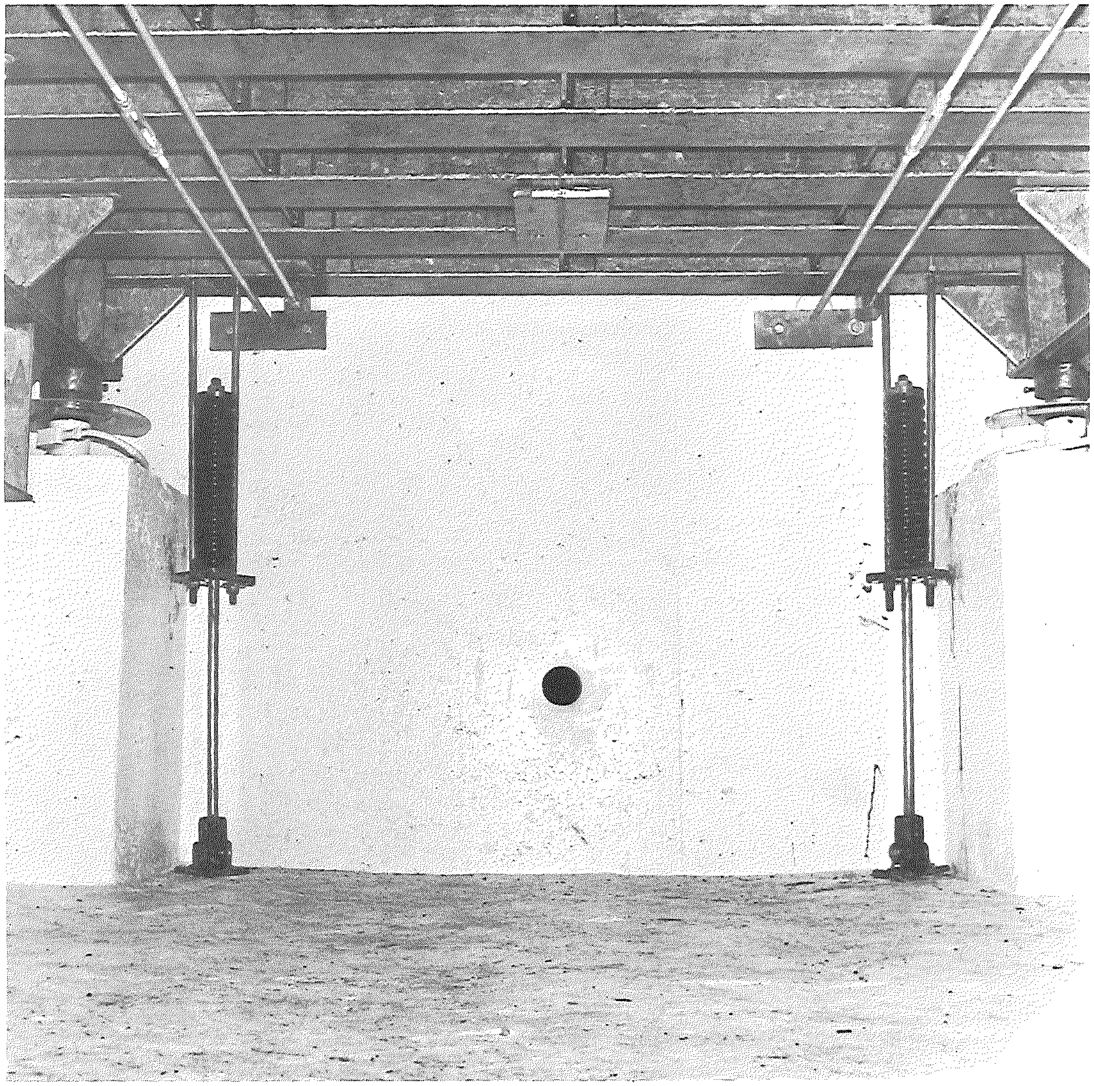


Figure 3. Interior of Pit No. 1 showing hold-down springs, transverse anchor rods, and load columns.

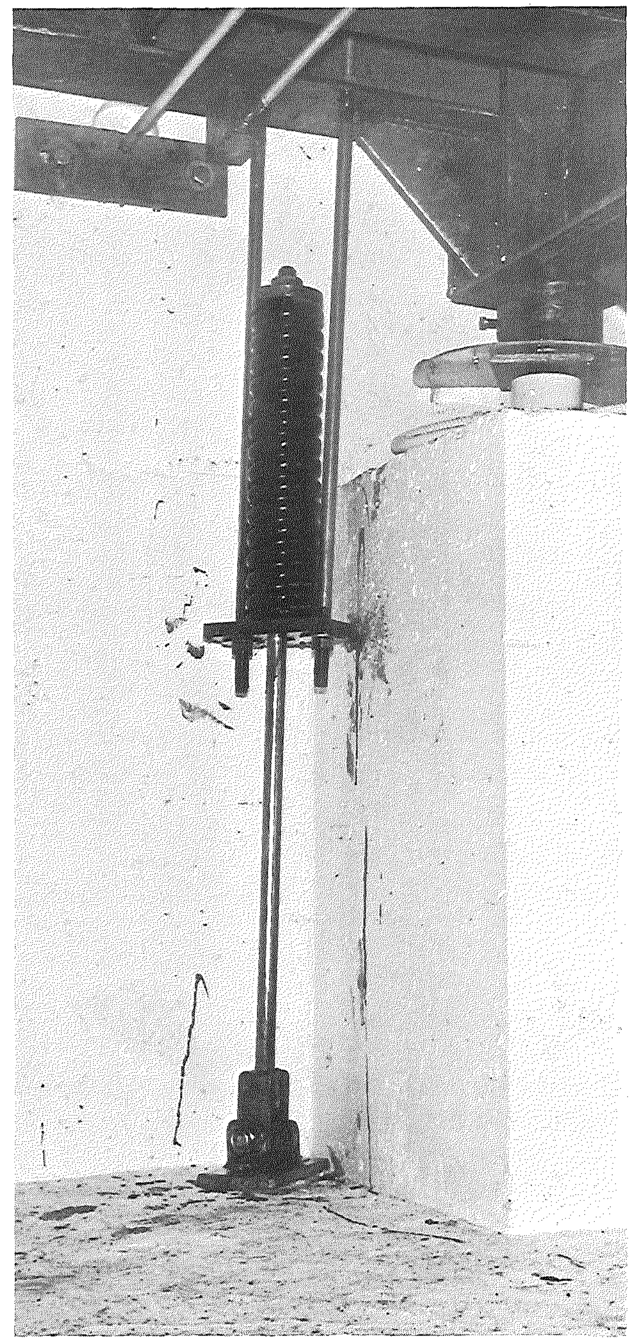


Figure 4. Closeup view of 4000-lb per in. hold-down spring and its mountings.

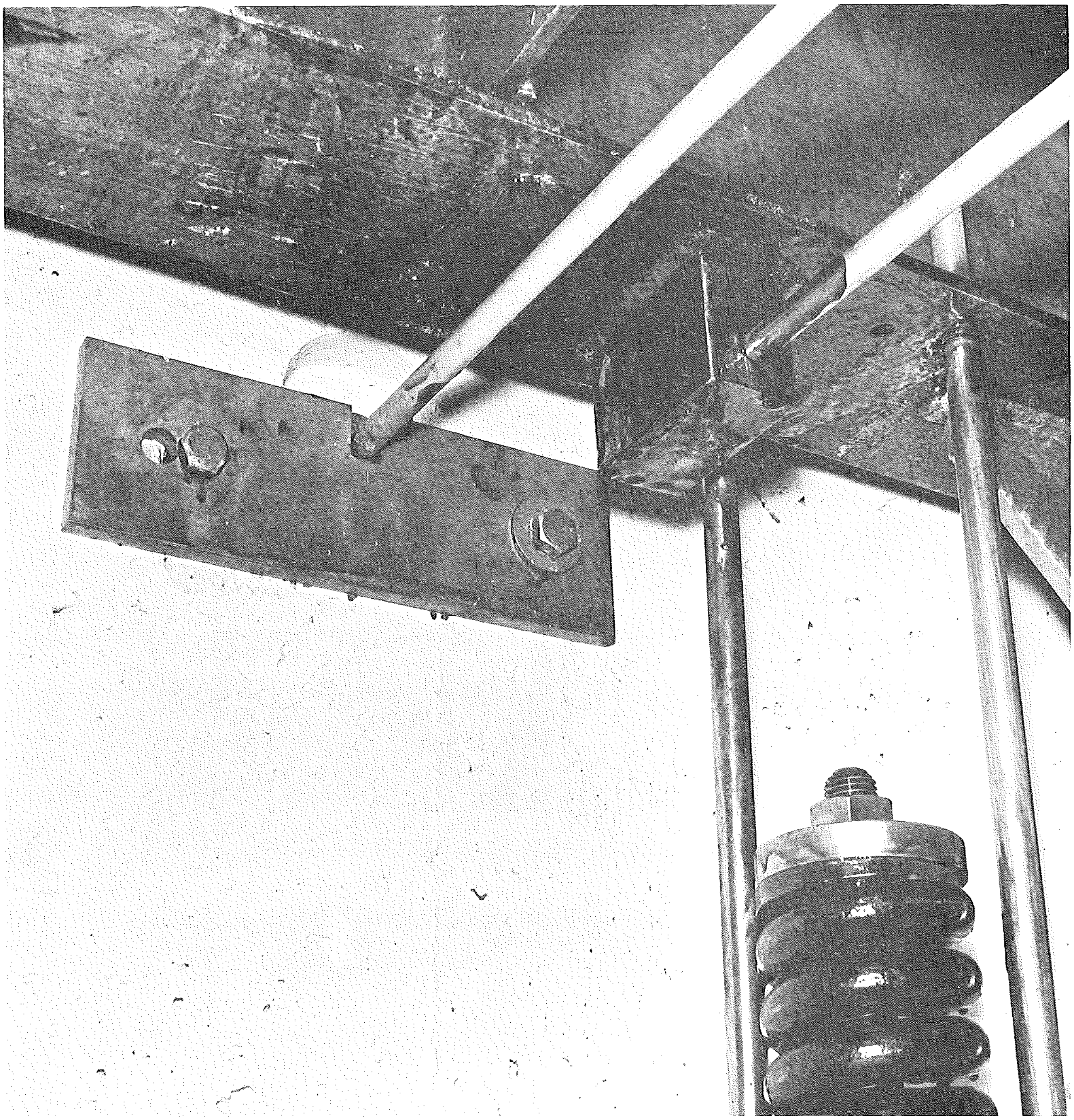


Figure 5. Platform transverse anchor rods showing one wall anchor and one rod-to-platform attachment block.

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:

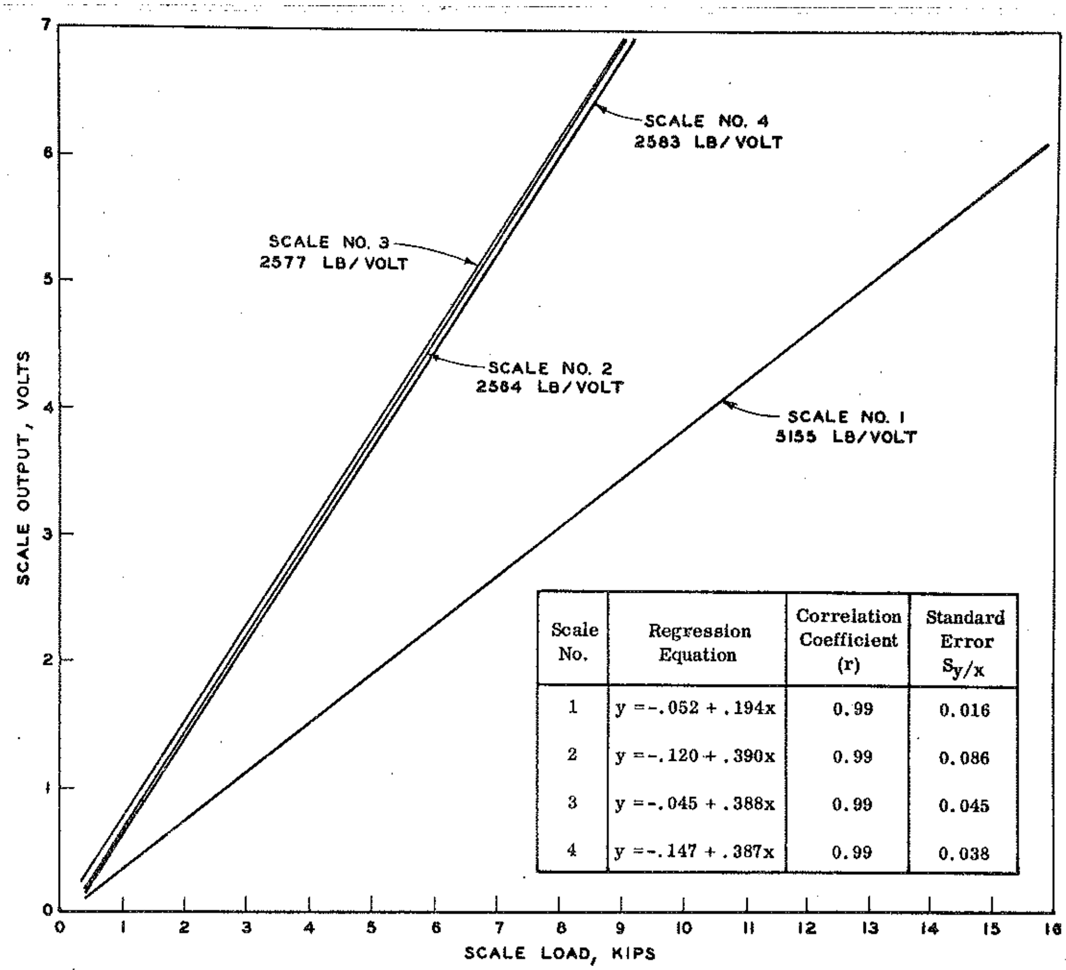
1. The 16 load cell power supply outputs were adjusted, using a digital voltmeter to an indicated accuracy of $\pm$ 0.01 v (i.e., 4.99 to 5.01 v for the cells of Scale No. 1, and 9.99 to 10.01 v for the cells of Scales 2, 3, and 4).

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.

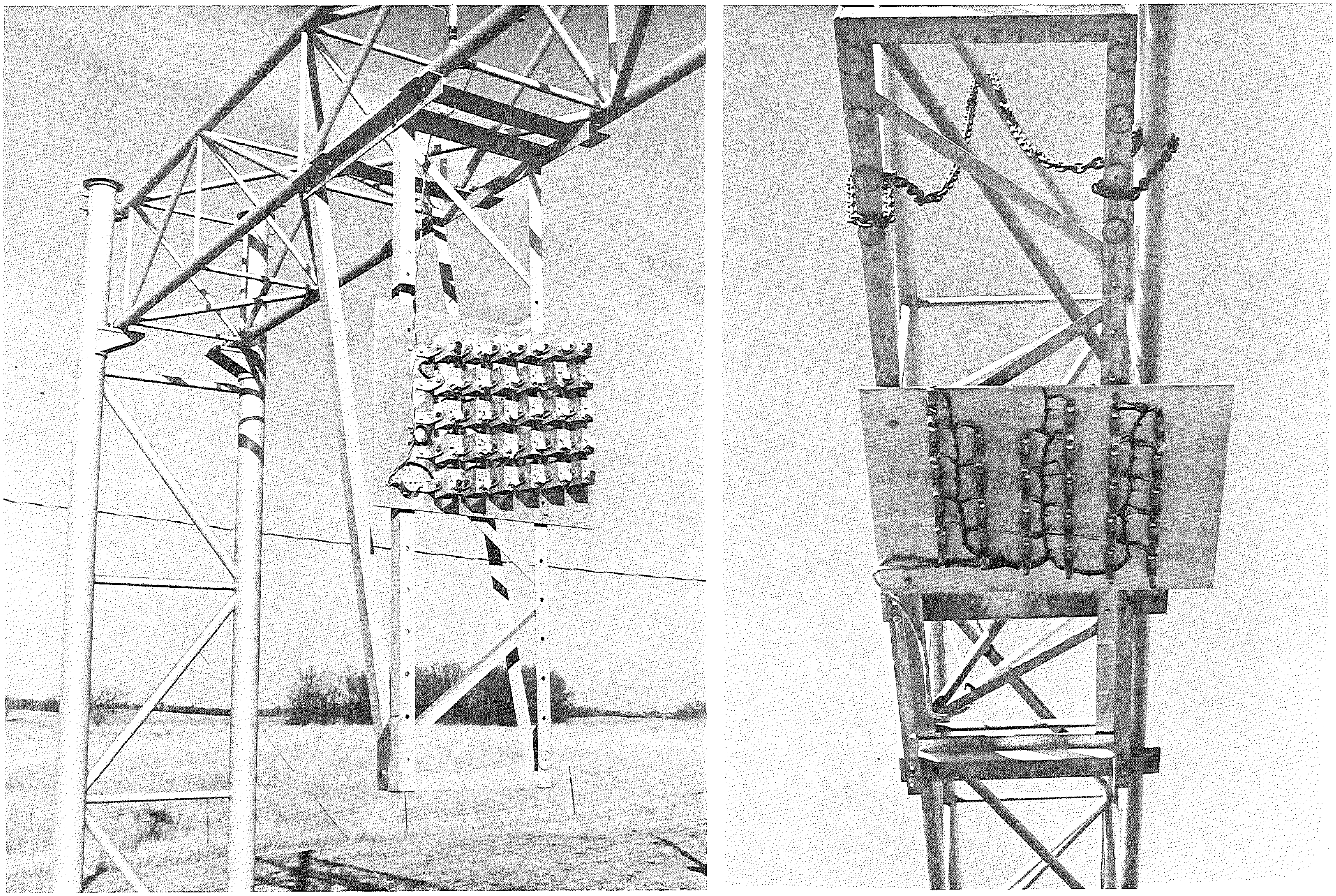


Figure 7. Modified infrared height array with sources (left) and detectors (right, in retracted position) on 1-in. centers.