WEIGH-IN-MOTION SYSTEMS EVALUATION

FINAL REPORT

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ABSTRACT

This relatively short-term project was initiated in order to perfect installation, operation, and maintenance practices necessary for continued accurate and reliable operation of a computerized Weigh-in Motion system which will be used to gather truck weight data in a long-term study to improve flexible pavement design.

A complete Weigh-in-Motion System installation was made on U. S. Highway 190 near Baton Rouge and operated for approximately three months, during which time 173 trucks varying in weight and number of axles and traveling at various speeds were correlatively checked for total weight against Louisiana Department of Highways enforcement scales located nearby. Accuracy of the system's speed determination capability was checked at the beginning and end of the three-month operating period using a hand-held radar unit as reference.

The goals of the study were attained. Five operators received training and experience in operating, maintaining, and installing the equipment. The accuracy and repeatability of the System was demonstrated by correlative measurements, and the system now stands ready along with a trained crew to be used in the ten-year Louisiana Experimental Base Study.

IMPLEMENTATION

Installation, operation and maintenance procedures which were developed and/or practiced during the course of this study will soon be used in conjunction with a much larger research study intended to improve design and performance criteria for flexible pavements.

The device is available to the Department for other uses and some such uses are being developed.

INTRODUCTION

The Louisiana Department of Highways is conducting a comprehensive study in which information will be collected on response of pavement structure to loaded vehicles. The performance of each pavement structure test section will be compared with traffic loading data in order to derive parameters such as stresses, strains, associated moduli and the life expectancies of base course materials.

Since traffic loading is such an important part of this large and very costly study, it is imperative that accurate, reliable readings be obtained.

The smaller study for which this report is written was initiated to provide a mechanism whereby installation, operation, and maintenance practices necessary for continued accurate and reliable operation of this equipment could be developed and refined. The possibility also existed that successful use of the transducer system could enable the Department to consider its usage in some aspect of weight enforcement or as an aid in assimilating truck weight data obtained in the annually collected loadometer studies.

This report includes a detailed description of the transducer installation and site preparation and an account of all correlative data taken during the study. Also included are accounts of operational difficulties and related problems which arose during the course of the study.

SCOPE

This study was in the strictest sense an equipment evaluation. The scope included the necessary work to develop viable procedures for site preparation and data gathering to be used in future operation of the Weigh-in-Motion system.

EQUIPMENT DESCRIPTION

The Weigh-in-Motion system discussed in this report basically includes a series of load cells and detector loops installed in the roadway and an instrumented trailer containing electronic measuring and recording equipment.

Figure 1 is a drawing showing the various components making up the system and their functional relationships. Two "loop" detectors, a fixed distance apart provide a speed trap for computing speed. Actuation of the vehicle presence detector initiates the weighing and dimensioning program and relates succeeding axles to the transducers. The wheel load transducers containing the aforementioned load cells are powered by the signal conditioning equipment, and their output is amplified so that each signal is compatible with the analog-to-digital converter. Each scale voltage signal is sampled 1,200 times per second by the analog-to-digital converter as it is switched between the scale outputs by the multiplexer. The digital data is processed by the digital controller, and the results may be typed and/or recorded on magnetic tape. Views of the interior of the instrumented trailer are shown in figures 2 and 3.

This equipment is manufactured by Unitech, Inc., of Austin, Texas. Similar models are in use in Texas, Florida and Kentucky. The consenus from users in these states is that the equipment is reasonably trouble-free and correlatable with conventional balance type scales when the load cells and platform are correctly installed and maintained. Platform alignment must be maintained in order to prevent damage and allow continued accurate operation.

The Weigh-in-Motion (WIM) system instrumented trailer was accepted by Department personnel at the assembly plant in Austin, Texas in early August, 1974. Before the equipment was transported to home station, three Department employees, including the principal and co-principal investigators for this study received two days of training in operation,

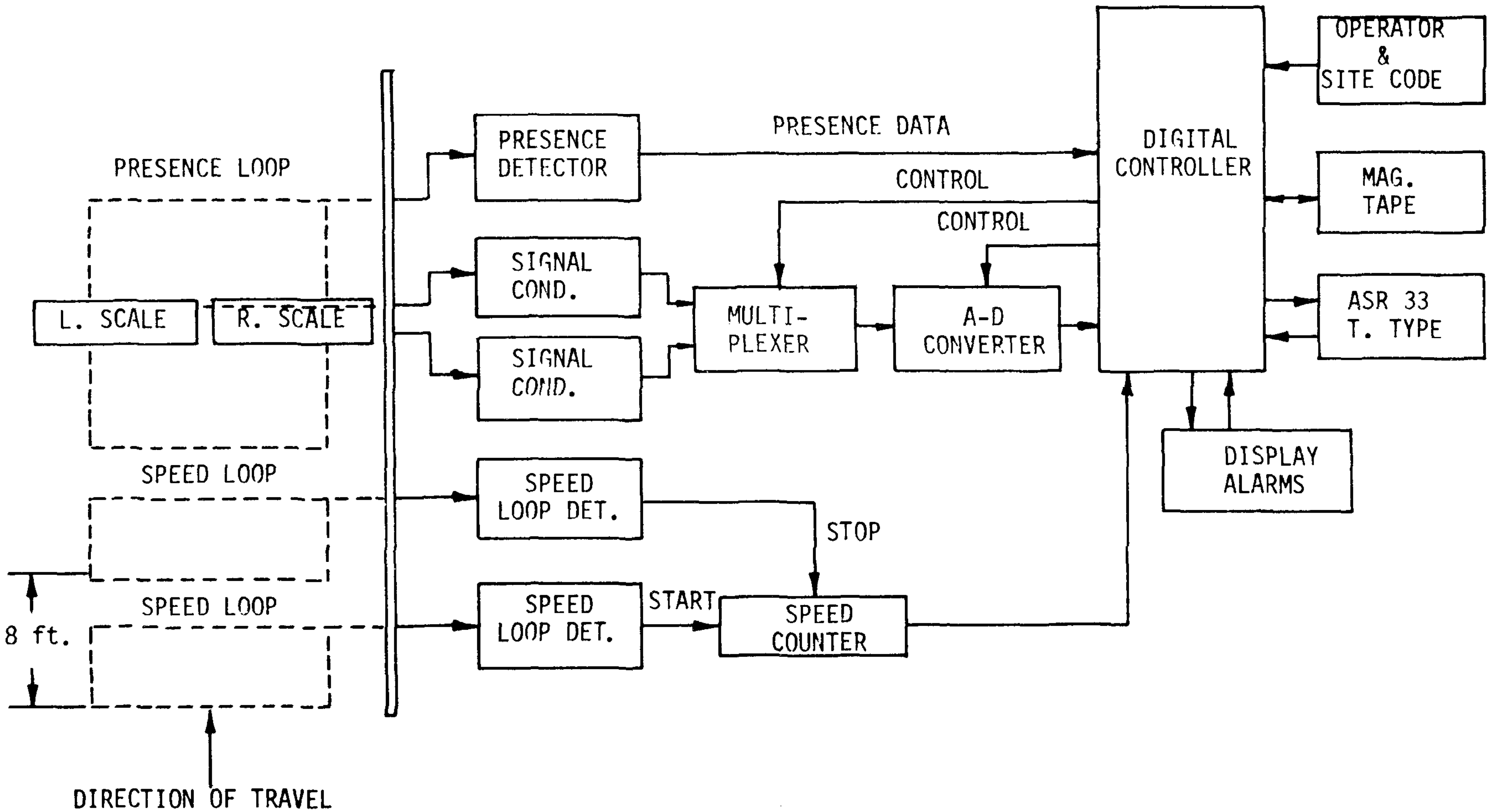

Figure 1

Weigh-in-Motion (WIM) System Components and Functional Relationships

Figure 2
WIM Trailer Interior View - Operator Position

Figure 3

WIM Trailer Interior View - Tape Transport and Teletype theory and care of the equipment. Four weeks later a factory representative came to Baton Rouge to supervise transducer installation and site preparation. In the interim period, research personnel gained experience by operating the equipment with the "vehicle simulator," a device designed to create electronic stimuli comparable to that produced by an actual roadway hookup.

METHOD OF PROCEDURE

Site Preparation

General

Figure 4 shows the site which was chosen for installation of the Weigh-in-Motion System as preparation was underway. Such factors as pavement smoothness, number of trucks passing, availability of parking space and power, and proximity of Department Weight Enforcement scales were considered in the choice. The site was located in a rural area of U. S. Highway 190, about three miles (4.8km) west of Baton Rouge.

The pavement of this location is made up of an original concrete roadway and two asphalt overlays. This heavy bulk of existing material was an apparent advantage since the unit's load cell and chassis assembly required very little readjustment during a fifteen-month period in which the site remained functional.

Figure 5 through 20 show various stages in the three and one half day installation and site preparation. These pictures, together with figure 1 in the introduction section, will serve to illustrate the following description of the site preparation activities. A ten step summary of same is included at the end of the Site Preparation section.

Layout and Excavation

Laying out locations for the chassis-load cell assembly and the three detector loops was the first stage in site preparation.

Red and blue lumber crayons and a metal straightedge were used in marking the locations according to the prescribed configuration of the transducer manufacturer. Activity relating to this can be seen in figures 5 and 6.

Figure 4

Site Chosen for WIM Installation

Figure 5
Laying out Location for Detector Loops and Load Cell Assemblies

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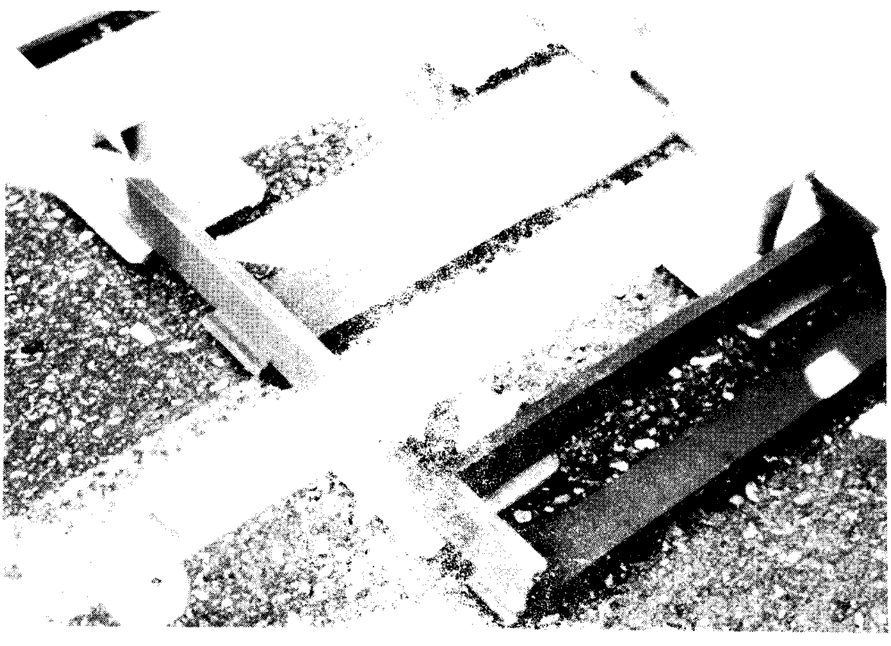
Loops [illegible]



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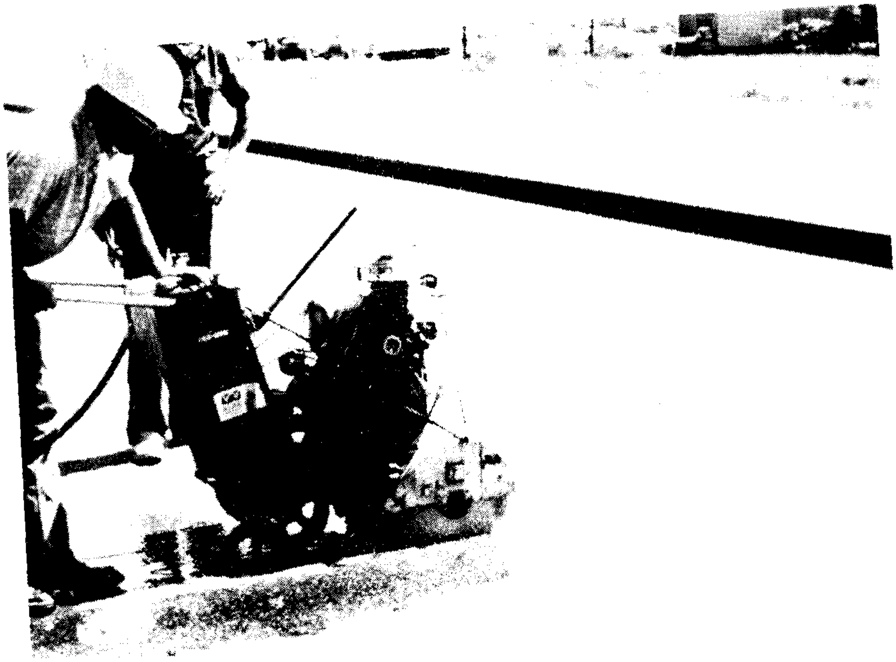

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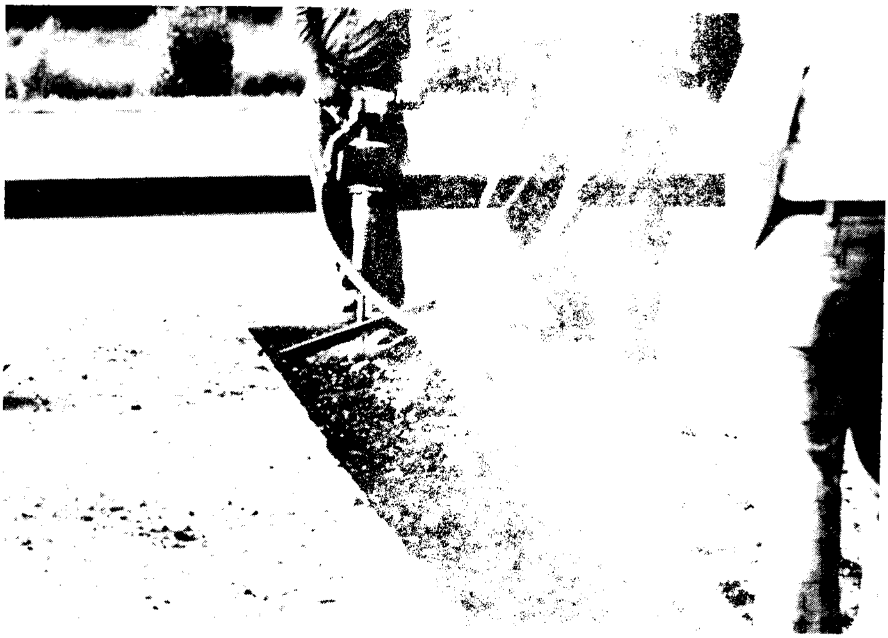

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Placement o

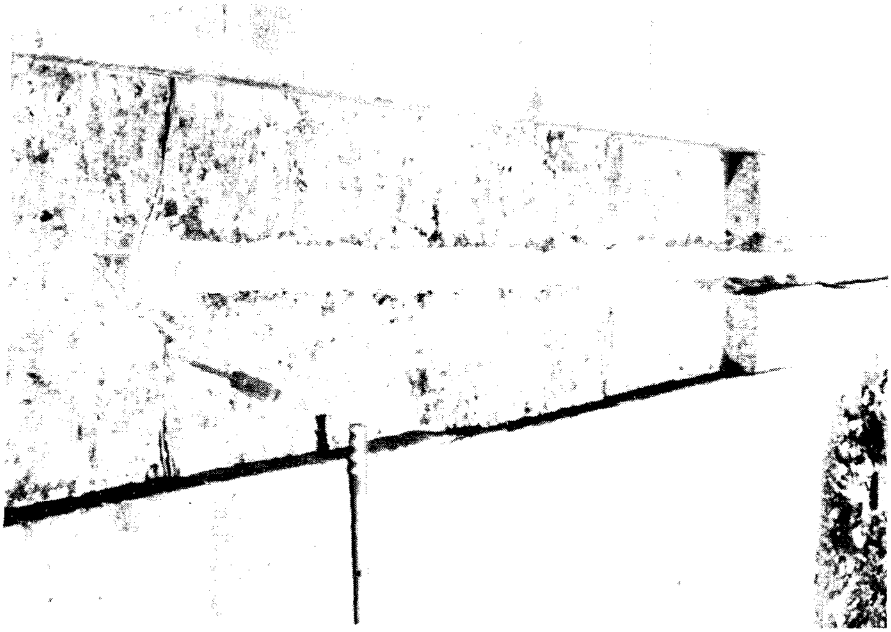


Figure 12
Prepared Transducer Pit with
Drain Tube and Sand Bedding

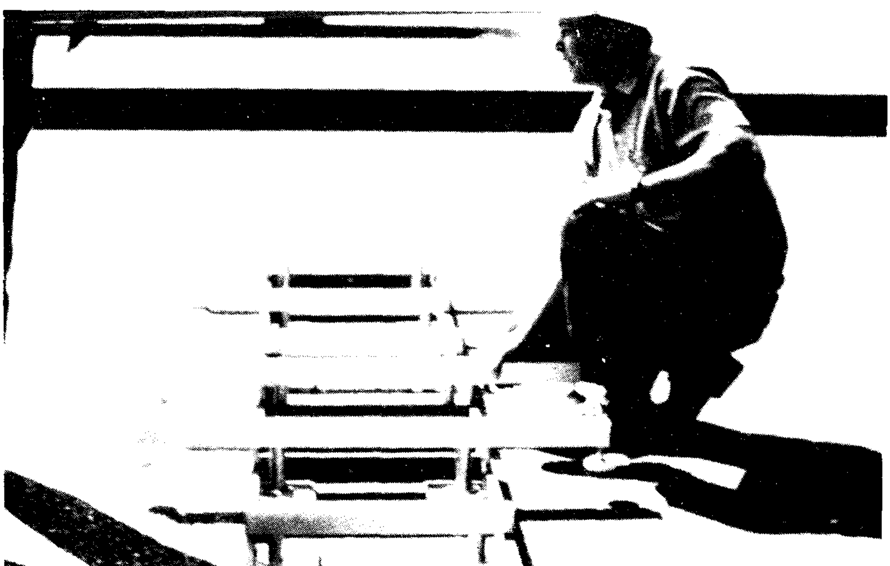
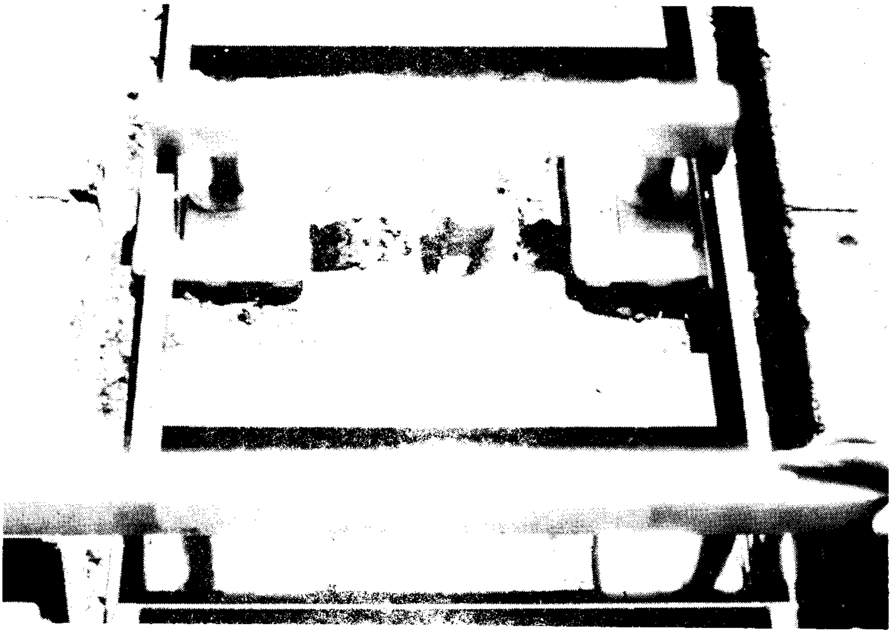


Figure 13
Frame and Bearing Pads in Place
Prior to Application of Bonding and Filler



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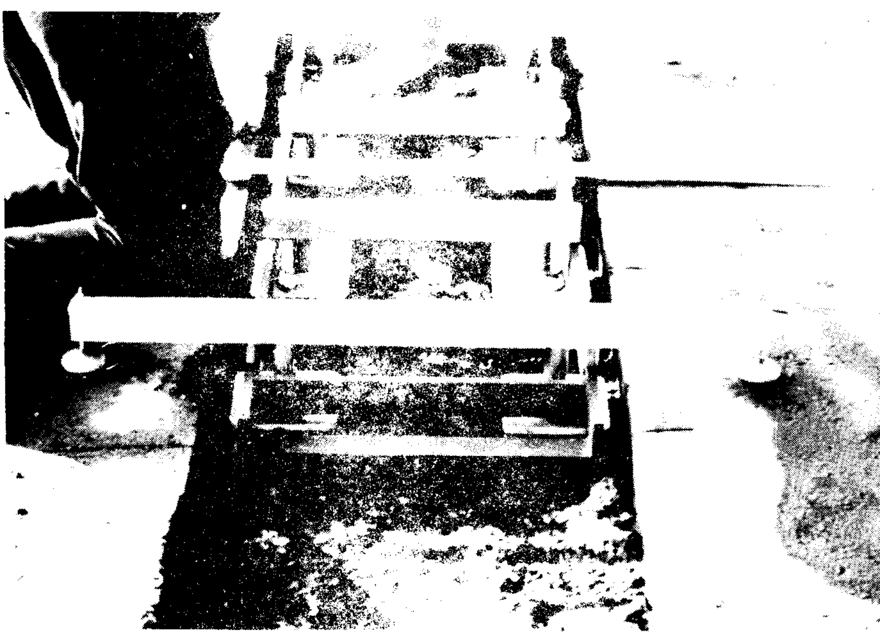
Place Prior ... and Filler



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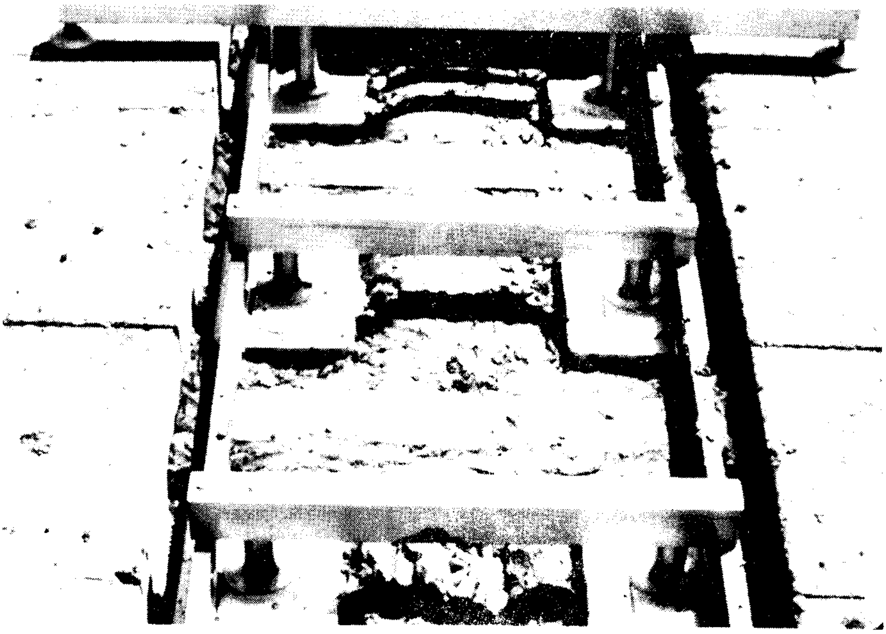


Figure 16
Transducer Pi[illegible] Working-in of
Quick-se[illegible] Cement

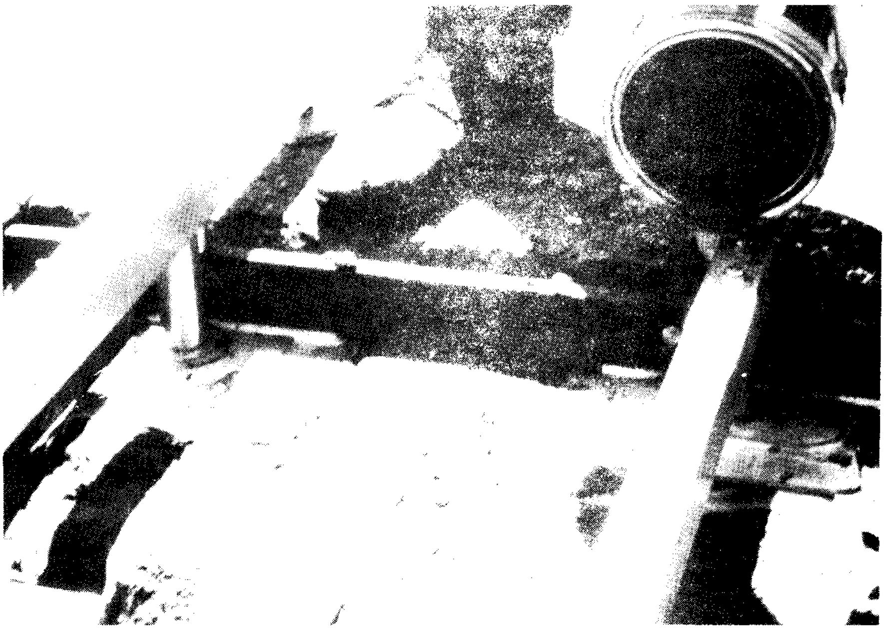


Figure [illegible]
Addition of [illegible] Voids
under [illegible]

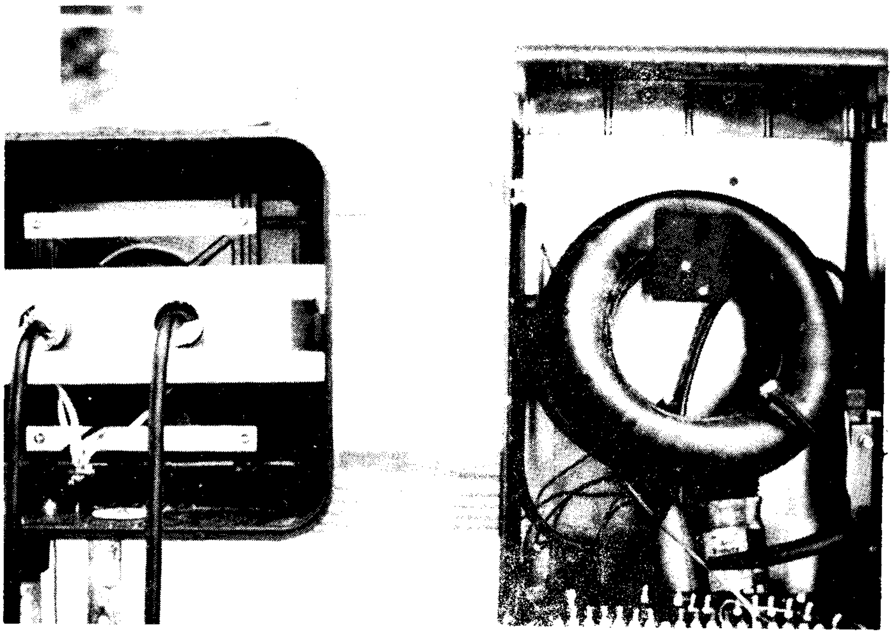


Figure
Completed Load

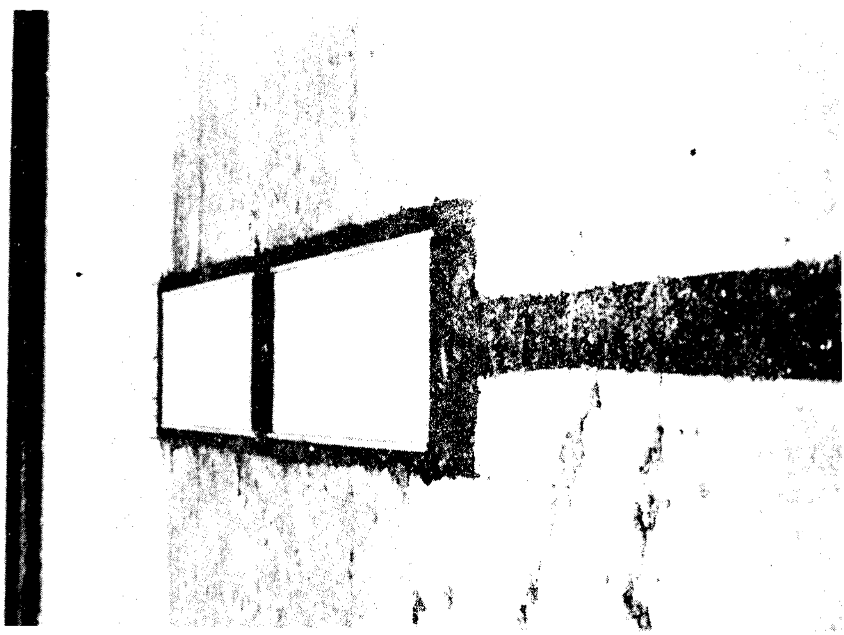


Figure
Interior View
Junction

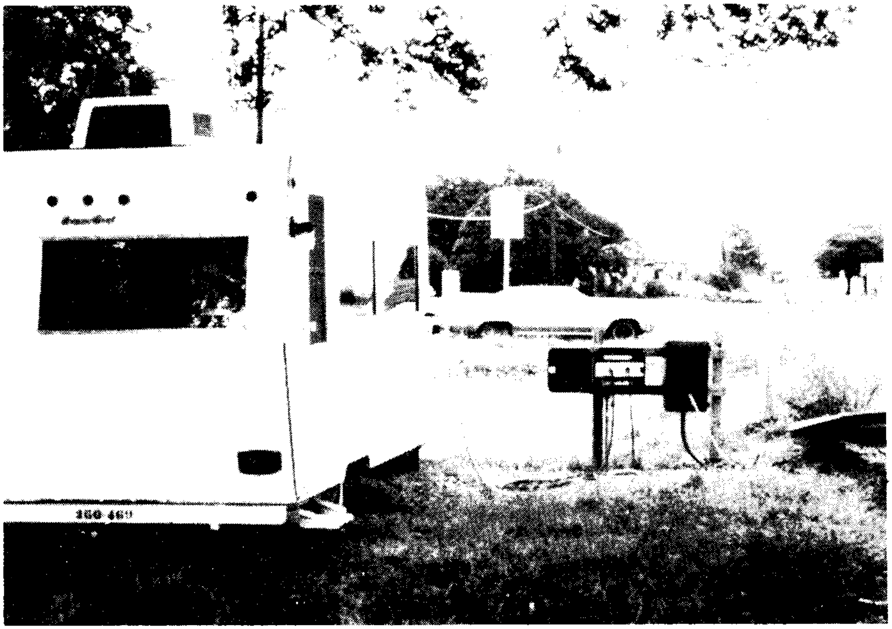


Figure 20
Weigh-in-Motion Equipment
Trailer in Operation at Site

The load cell frame was set in position over the spot at which its pit was to be excavated. Lines were drawn on the pavement around its perimeter so that the resulting rectangle was approximately 2 inches (5.1 cm) larger on each side than the outside of the frame (see figure 7). This was done so that hot mix could be tamped around the frame to "blend" it into the roadway and provide alignment space and a smooth transition between existing pavement and the metal load plates which covered the load cells.

Cuts were made along the chalked outlines of the transducer pit with a pavement saw as shown in figure 8. These cuts were made to a depth of 3 to 3-1/4 inches (7.6-8.3 cm). Somewhat deeper cuts were made down the center of the transducer area and extended across the shoulder to provide an appropriate passageway for transducer and loop detector wires as well as a drain tube to carry water out of the pit. Additional saw cuts were made across the outline of the transducer area to expedite removal of the pavement with an air hammer. The saw cuts through which the presence loop wires traversed the pit were also cut at this time.

Two different bit sizes were used in the air hammer. The smaller one is shown in figure 9 and is being used to remove material from what will later be the subtrench for the drain tube and wiring connections.

The remainder of the cuts required for placement of the loop detectors was then made, and the wire making up the loops was pushed into the saw cuts. This wire placement is shown in progress in figure 11. The two turns of wire making up the presence loop were of necessity exposed along the area in which they crossed the transducer pit near the bottom, but there was relatively little danger of physical damage to them after the frame was installed. The two wire leads which terminated each loop were routed into the passageway with additional saw cuts and across same to the junction box area.

Loop detector installation was completed by pouring hot pitch into the saw cuts above the wires.

The prepared transducer pit with drain tube and sand bedding is shown in figure 12. As can be seen in photograph, cutouts were made in the drain tube for entry of the two copper lines which carry wires from the transducer assemblies. The cutouts also allow runoff of rain water which might make it past the rubber gasket used in sealing the later-to-be-installed load plates. The drain tube itself was fashioned from 1-inch (2.54 cm) schedule 40 PVC pipe. The end of this pipe, which ran to the shoulder area, was routed to a nearby ditch to facilitate the runoff of water entering the pit.

Installation of Frame and Bearing Pads

Frame and bearing pad installation began with setting the frame assembly in place along with the associated bearing pads on which the transducers themselves would rest. Various spacers and holding jigs were furnished to assure that the frame and pads would have the proper spacings, depths, etc. with respect to themselves and the surrounding pavement.

Figures 13 and 14 show the frame and bearing pads in place prior to the application of bonding and filler materials. A check was made to insure that each bearing pad had the correct clearance above the bottom of the excavation to allow the application of 1/4 to 1/2 inch (0.6-1.3 cm) of grout. More or less than this amount could cause problems, according to the manufacturer. The load measuring transducer devices (load cells) themselves rest on the bearing pads; hence a strong, direct footing is needed for the bearing pads.

The next step in installation was the partial filling of the excavated pit with quick-setting cement. With the frame still in place, all areas of the excavation except the areas under the bearing pads were filled with this material, shown being worked and in completed form in figures 15 and 16 respectively. This material was mixed at roadside in small batches due to its extremely fast setting time. The finished cement lacked a neat appearance, but nevertheless did its job of supporting the frame cross-members and providing a filler which would lessen the volume of very expensive two-part grout material required. It was only necessary that the grout be applied to the areas directly beneath the bearing pads where load forces would be greatest. The cement was therefore applied in all other areas up to the level of the frame cross members, as can be seen in figure 16. No particular difficulty was encountered in this cement placement, but careful planning in batching, proportioning and manpower usage was mandatory.

After the cement had set and been allowed to cure for an hour or so, the grout was prepared for placement under the bearing pads. The material used was a standard grout made for the Texas Highway Department for general-purpose bonding. It had been used quite successfully for bearing-pad support in earlier installations in Texas and New Mexico. A hand drill with a paint-mixing attachment was used to blend the two-part mix which was then poured directly from its one-gallon container into the aforementioned voids under the bearing pads. Grout was poured under each bearing pad to a level corresponding with the top of the previously worked quick-setting cement. Figure 17 shows grout being added to one of these bearing-pad cavities.

The entire transducer installation operation had generally run smoothly up to this point, the only difficulties having been with the slow progress of the pavement cutting operation and with necessary procurement of necessary tools and materials. A real problem appeared, however, when the aforementioned bearing-pad grout failed to set in a reasonable amount of time.

Since the installation area had a high volume of traffic with an occasional oversize house trailer and many trucks passing, it was imperative that both lanes of this roadway be open at night. It was therefore necessary this second day of work to remove the defective grout and completely fill the excavation with hot mix. The frame and quick setting cement were left in place and heavy brown wrapping paper was laid over the bottom of the cavity to prevent bonding of the hot mix and aid in later removal. The pit was cleaned out on Monday of the following week and work was once again started with a new batch of grout. The same procedures were followed in this second grout application. The material began to set up in appoximately 30 minutes with no problems.

After allowing adequate time for the grout to fully set, the supporting jigs were removed and the two load cell chassis were lowered into the now-completed transducer pits. After installation of the six steel cover plates and the associated gaskets, the most difficult portion of the transducer installation was finished. All that now remained was the necessary filling of the edges of the pit and of the trench through which the loop detector and load cell wires were run to the curbside junction boxes. The completed load cell assembly can be seen in figure 18.

Power Hookup and Curbside Junction Boxes

During the aforementioned roadway transducer installation, electricians were installing the necessary power and transducer hookup terminals for the mobile trailer containing the computerized weigh-in-motion equipment. Two predrilled traffic signal boxes were furnished by Unitech for use as weatherproof enclosures for the wiring. The necessary hardware, sockets, etc. were furnished with the boxes so that installation was greatly simplified. The boxes were mounted on a wooden post assembly located approximately five feet from the shoulder of the roadway and in line with the trench which carried the signal lines to the loop detectors and load cells. Impact protection was afforded by an existing guardrail.

Three-wire 240-volt service was run underground from a nearby power pole. Figure 19 is an interior view of the junction boxes. The box on the left houses the power hookup while the right box contains the two system pressurizing inner tubes and loop detector and load cell wiring hookups. The box on the right remains closed during normal WIM operation since all connections are terminated on the outside of the front door of the enclosure in a military type receptacle.

With this arrangement, there are four connections to make at the site between trailer and transducers when weighing operations commence. Figure 20 is a roadside view of the equipment trailer in operation at the site. A large window in the end of the trailer (not shown in this picture) gives the operator a clear view of approaching traffic.

Summary

The 10 basic steps followed in preparing the weighing site can be summarized as follows:

1. Locations of the three detector loops and two load cell assemblies were marked off according to prescribed layout scheme.
2. Pavement saw cuts were made along lines drawn around load cell installation area to a depth of approximately 3-1/4 inches (8.3 cm). All material inside the load cell installation area was removed to this depth.
3. Saw cuts were likewise made along lines marking locations of the three detector loops. A minimum saw depth of 2 inches (5.1 cm) was used in making these cuts.
4. A narrow trench was cut from the near-side shoulder to the center of the farthest load cell assembly for installation of a plastic pipe which enclosed the load cell wires and carried runoff water from the load cell pits.
5. The three detector loops were installed in the saw kerfs. Hot pitch was poured over the imbedded wires to keep out debris and moisture.
6. Supporting jigs and bearing pads were attached to the two load cell frames which were then moved into final installation positions within the excavated pit. Chalked outlines were then made around bearing pad support areas.
7. Quick-setting cement filler was used to fill all areas of the excavated pit not outlined in the above step. The

maximum height of the material was restricted to allow load cell installation.

8. Special two-part grout material was poured into remaining voids under the bearing pads and allowed to set.

9. Curbside junction boxes were installed on wooden posts behind protective guardrail. Leads from the two load cell assemblies and the three detector loops were tied in along with a 240 volt single phase service line.

10. Site preparation was completed by filling gaps remaining around the transducer assemblies with hot mix and installing the load cell assemblies and plates.

Calibration

General

Calibration of the Weigh-in-Motion System was necessary prior to the commencement of weighing operations. Both static and dynamic weight calibrations were performed with the aid of a loaded dump truck, and a hand-held traffic radar unit was used as a reference to check the accuracy of the system's speed measurements.

Static Calibration

Two sets of portable enforcement scales were used to determine individual wheel weights on the loaded dump. These scales were tested for accuracy in approximate 1000-pound (454 kg) to 10,000 pound (4540 kg) increments on a laboratory-type, compressive-strength testing machine. Both scales were found to be accurate to within 1.5% at 10,000 pounds (4540 kg) and below.

Static calibration began with closing the lane containing the load cell assemblies. The dump truck was driven onto the closed portion of the roadway and weighed with the portable scales. The scales were placed so that left and right wheels on each axle were weighed at the same time.

The WIM controls were then set for normal dynamic weighing operations, and the system inputs from the detector loops were purposely shorted to inhibit the weighing sequence and allow static measurements. Pressing a button labeled "single" on the operator console then initiated a teletype printout of the estimated weight on each of the two load cell assemblies.

The left and right assemblies were first checked in unloaded condition. Indexed calibration potentiometers located on the front of the unit's operator console were adjusted so that both printouts approached zero, effectively cancelling out the weight of the plates on the load cells. This was a rather lengthy process involving several incremental movements of the adjustment pots and a complete recalibration of the WIM circuitry after each change.

The assemblies were next checked for loaded static response with the aforementioned portable scale readings used as a reference. The truck was driven onto a platform and checked one axle at a time. Calibration potentiometer settings were changed very slightly to compensate for slight variations in weight indications due to nonlinearity. This entire calibration procedure was repeated following the final phase of the study to once again verify the accuracy of the equipment. It was found that potentiometer resistance settings of 700 and 600 ohms for the left and right channels (wheel paths) respectively provided the most accurate readings. These settings were used throughout the data-gathering phase.

Data Gathering

After the installation was completed, data acquisition was begun to verify the functionability and accuracy of the system. Weight data from several hundred vehicles including light passenger automobiles and trucks were put onto magnetic tape and underwent processing by an IBM 370 computer at the Department's Headquarters complex. After minor programming problems were worked out, data processing and recovery were not difficult, and the major correlation portion of the study was begun.

A two-way radio was installed in the equipment trailer to provide communication with the weight enforcement station for this phase of the study.

The speed measurement function in the system was checked for accuracy against a hand-held traffic radar unit. Minor changes were made in the inductive detector loop settings for optimum results.

A similar check was run at the conclusion of the correlation testing to verify the system's continued accuracy.

Weight correlations began on October 4, 1974, and continued through January 23, 1975. Comparative data was gathered for a total of 173 vehicle observations. Data for each vehicle thus obtained from the enforcement scale and the 370 computer was transferred to tally sheets for comparison and summarization.

The data-gathering phase of the study was carried out with two men stationed in the WIM trailer and one at the LDH weight enforcement scales about three miles (4.8 km) west of the WIM site. A two-way radio link was set up between the two locations for exchanges of information during weighing operations.

Correlative data from these two weighing systems was obtained for a total of 173 trucks. The general procedure for obtaining this data simply involved the WIM operators waiting for a truck to correctly pass over the transducers with the system operating and the subsequent manual switching on of the teletype for an approximate weight printout. If a preliminary check of the printed weights indicated a probable "good" set of readings, a description of the truck along with the computer file number appearing on the operator console and printout was radioed to the person on duty at the weight enforcement station.

It was then this person's duty to request two printouts of the enforcement scale weight ticket from the scale operator for the soon-to-arrive truck. After arrival of the truck it was necessary to ask the driver to allow a check of his steering axle weight in addition to the weight of his load-carrying axles which are routinely checked on all trucks in weight enforcement operations. The computer file number was written on the extra weight ticket copy at this time to minimize later chances of error.

DATA ANALYSIS

An axle-to-axle correlation between the WIM and weight enforcement scale was not attempted since most of the trucks checked were equipped with one or more pairs of closely spaced tandem axles which were all but impossible to weigh individually at the enforcement scale. Consequently the measured weights shown in table 1 of the appendix include only the total weight of each truck. The percent error of each dynamically weighed sample is also shown on the chart. The percent error was based on the use of the enforcement scale weight as the standard. The median weight error on this basis for the entire group of 173 trucks was 4.45 percent with a standard deviation of 3.84 percent. No trend toward either positive or negative error was discernable from the data. Tables 2 and 3 stratify the 173 readings by weight and speed categories. Since no attempt was made to gather equal amounts of data from each of these groups, some rather arbitrary grouping of trucks was necessary in the lower speed and weight categories.. The speeds shown in the chart were WIM indicated speeds of the trucks as they passed over the system's transducers.

There were only two correlations involving actual weights of 10,000 pounds (4540 kg) or less and only three within the range of 10,050 to 20,000 pounds (4563-9080 kg). These two groups were combined to provide a more reasonable sampling population. It should be mentioned that the enforcement scale indicated weight only to the nearest 50-pound (22.7 kg) increment.

The lowest error group with respect to weight (using the enforcement scale as a standard) was the 60,050 to 70,000-pound (27,263-31,780 kg) category with a mean error of 3.07 percent and a standard deviation of 3.03 percent. There was a total of 30 samples (trucks) in this group.

The largest number of trucks by weight were in the 70,050 to 80,000-pound (31,803-36,320 kg) category. There was a total of 61 in this group. The mean error was 3.69 percent with a standard deviation of

3.24 percent.

Samples grouped according to rate of speed at time of measurement shown in table 3 reveal that the lowest weight error was in the 41 to 45-miles-per-hour (66-72 km/hr) group. The mean error was 3.75 percent with a standard deviation of 3.11 percent. There were, however, only twelve samples in this speed range. The largest number of trucks was dynamically weighed in the speed range of 51 to 55 miles per hour (82-89 km/hr). There were 53 trucks in this range of the 173 total.

Graph 1 in the appendix is a scatter of static/dynamic data. The fitted line has a slope of 1/1.003 and was derived by the use of standard regression procedures. Good correlation is indicated.

Several more general trends can be surmised from the data. They are:

1. Variance does not appear to be significantly different between the "speed of measurement" groupings; hence, measurement accuracy appears to be equally good for vehicles traveling at different highway speeds. The larger difference in the lowest speed group was the result of two high-error readings out of the mere thirteen samples.

2. Accuracy appears to generally increase with increased truck weights. The three highest weight groups shown in the table were the three most accurate categories, although accuracy within all categories appears to be satisfactory.

3. The confidence level of this equipment's accuracy increases with increased sample size.

4. Some instances of larger-than-normal deviation between WIM weight readings and static weight may have been due to in-motion sloshing and resultant weight shifting in trucks hauling liquid cargoes. Even static measurement is sometimes made difficult by this sloshing action.

Although data pertaining to axle spacing, overall length, and weight with respect to left and right wheels was available from the WIM, correlative checks were not maintained continuously on these functions and no such data is presented here. Necessary manual data gathering for these comparisons would have necessitated either stopping the selected trucks after passing the WIM site or causing delays at the enforcement scale as measurements were taken manually either before or after the trucks were weighed.

Accuracy tests were run on the WIM speed measurement function at the beginning and end of the data-gathering phase of the study. The standard of comparison was a hand-held traffic radar unit with digital readout which was aimed out the side door of the WIM to measure speeds of vehicles in the outside lane just prior to their crossing the WIM transducers. Both trucks and cars were used indiscriminately in this correlation.

Data from the second of these two test sequences is included in Table 4. These readings were obtained with the presence control on the loop detector units set at the "minimum" position and the sensitivity control set at the "medium" position. These settings yielded an average error of only 2.24 mph (3.60 km/hr) using the traffic radar unit as a standard. Control settings other than these resulted in larger errors.

CONCLUSIONS

Based on the results of this study, it has been concluded that:

1. The Unitech Weigh-in-Motion equipment used in this study is capable of acceptable accuracy when properly installed, operated and maintained.

2. The performance is quite adequate for use in gathering truck weight data in the "Louisiana Experimental Base Study."

RECOMMENDATIONS

In accordance with the findings and experiences of this study, the following recommendations are offered:

1. Future installations of this Weigh-in-Motion System should be made with extreme care, using experienced personnel. Careful attention to details of load cell support and pavement smoothness should be high priority.

2. The type of load cell assembly used in this study should be checked every few days for alignment and looseness.

3. A minimum of two persons should be present in the WIM trailer during weighing operations. One person should be used as an observer to insure that vehicles being weighed pass over the sensors in the proper manner. All "bad" data cannot be recognized by a quick analysis of individual wheel and axle readings alone.

REFERENCES

1. McCann, Howard, and Elmore Dean, "The Texas Procedure for Weighing Trucks in Motion," _Highway Planning Technical Report No. 36_. Federal Highway Administration, May, 1974.

2. "Analytical Study of Weighing Methods for Highway Vehicles in Motion," _National Cooperative Highway Research Program Report No. 71_. Highway Research Board, 1969.

APPENDIX

TABLE 1

CORRELATIVE WEIGHT DATA FROM ALL VEHICLES WEIGHED

uctober 4, 1974 - January 23, 1975

Vehicle No.	Static Wt. (lb.) (enforcement scale)	Dynamic Wt. (lb.) (WIM system)	Percent Error (using static wt. as std.)
1	86,900	84.000	-3.3
2	76,950	64,700	-15.9
3	69,200	65,200	-5.8
4	37,450	35,100	-6.3
5	42,100	41,200	-2.1
6	77,150	77,900	+1.0
7	76,350	75,100	-1.6
8	31,950	30,300	-5.2
9	23,650	27,900	+18.0
10	60,850	61,100	+0.4
11	76,750	77,900	+1.5
12	78,600	78,300	-0.4
13	57,000	54,900	-3.7
14	71,300	68,200	-4.3
15	36,800	40,100	+9.0
16	80,700	75,300	-6.7
17	82,250	79,100	-3.8
18	20,600	20,500	-0.5
19	31,000	31,500	+1.6
20	35,950	35,200	-2.1
21	79,550	72,200	-9.2
22	35,250	35,100	-0.4
23	68,600	69,600	+1.5
24	71,800	70,800	-1.4
25	71,900	68,700	-4.5
26	25,350	26,800	+5.7

Note: 1000 lb. = 4540 kg.

TABLE 1 (cont'd)

Vehicle No.	Static Wt. (lb.) (enforcement scale)	Dynamic Wt. (lb.) (WIM system)	Percent Error (using static wt. as std.)
27	68,100	77,400	+13.7
28	71,350	69,700	-2.3
29	76,100	77,800	+2.2
30	69,250	69,300	+0.1
31	72,750	74,300	+2.1
32	76,000	78,200	+2.9
33	15,950	16,500	+3.4
34	22,200	21,500	-3.2
35	30,550	33,100	+8.3
36	30,900	29,600	-4.2
37	32,400	34,500	+6.5
38	40,350	47,400	+17.5
39	56,400	55,200	-2.1
40	68,850	64,900	-5.7
41	76,050	80,400	+5.7
42	78,850	75,600	-4.1
43	79,100	74,200	-6.2
44	79,700	74,400	-6.6
45	81,050	74,200	-8.5
46	9,100	10,200	+12.1
47	27,750	29,400	+5.9
48	37,700	40,800	+8.2
49	44,250	44,500	+0.6
50	47,700	46,500	-2.5
51	66,950	65,600	-2.0
52	67,450	70,400	+4.4
53	68,050	67,400	-1.0
54	68,350	69,600	+1.8
55	70,550	71,100	+0.8
56	78,000	79,400	+1.8
57	79,550	77,200	-3.0
58	79,950	74,600	-6.7

Mote: 1000 lb. = 4540 kg.

TABLE 1 (cont'd)

Vehicle No.	Static Wt. (lb.) (enforcement scale)	Dynamic Wt. (lb.) (WIM system)	Percent Error (using static wt. as std.)
123	41,150	42,000	+2.0
124	49,650	53,300	+7.4
125	75,250	76,600	+1.8
126	75,800	78,600	+3.7
127	75,950	74,200	-2.3
128	78,600	72,900	-7.3
129	26,600	27,300	+2.6
130	33,800	36,100	+6.8
131	38,850	41,200	+6.0
132	64,250	64,800	+0.9
133	67,350	63,300	-6.0
134	70,550	72,100	+2.2
135	72,250	71,500	-1.0
136	72,750	79,000	+8.6
137	73,650	73,100	-0.7
138	79,050	78,900	-0.2
139	82,950	85,200	+2.7
140	28,500	26,600	-6.7
141	32,050	32,300	+0.8
142	46,350	50,500	+9.0
143	52,700	57,100	+8.6
144	67,750	66,000	-2.6
145	71,550	74,400	+4.0
146	77,750	74,000	-4.8
147	79,750	84,200	+5.6
148	80,400	77,800	-3.2
149	42,850	43,500	+1.5
150	53,250	60,900	+14.4
151	69,950	72,500	+3.6
152	76,400	75,800	-0.8
153	77,100	77,300	+0.3

Note: 1000 lb. = 4540 kg.

TABLE 1 (cont'd)

Vehicle No.	Static Wt. (lb.) (enforcement scale)	Dynamic Wt. (lb.) (WIM system)	Percent Error (using static wt. as std.)
154	78,200	74,200	-5.1
155	51,000	55,900	+9.6
156	51,200	54,200	+5.9
157	60,500	62,200	+2.8
158	66,750	66,400	-0.5
159	76,100	74,500	-2.1
160	27,050	30,200	+11.6
161	69,550	70,200	+0.9
162	70,200	71,700	+2.1
163	77,150	82,000	+6.3
164	83,050	86,500	+4.2
165	73,050	78,300	+7.2
166	80,400	81,100	+0.9
167	9,200	9,000	-2.2
168	48,200	49,400	+2.5
169	70,550	71,100	+0.8
170	73,500	76,000	+3.4
171	30,150	31,900	+5.8
172	26,800	29,700	+10.8
173	73,500	71,500	-2.7

Note: 1000 lb. = 4540 kg.

TABLE 2

SUMMARIZATION OF ACCURACY ACCORDING TO WEIGHT CLASSES

Weight Class (lb.)	No. of Samples	Mean Error ($\bar{X}$)	Std. Dev. (S)
0-20,000	5	4.1 %	4.5 %
20,050-30,000	15	6.8 %	4.4 %
30,050-40,000	21	6.0 %	4.0 %
40,050-50,000	13	5.7 %	4.9 %
50,050-60,000	10	6.4 %	5.0 %
60,050-70,000	30	3.1 %	3.0 %
70,050-80,000	61	3.7 %	3.2 %
80,050-90,000	18	3.7 %	3.2 %

Note: 1000 lb. = 4540 kg.

TABLE 3

SUMMARIZATION OF WEIGHT ACCURACY ACCORDING TO SPEED AT TIME OF WIM MEASUREMENT

Speed Class (MPH)	No. of Samples	Mean Error ($\bar{X}$)	Std. Dev. (S)
0-40	13	5.0 %	5.7 %
41-45	12	3.8 %	3.1 %
46-50	50	4.9 %	3.8 %
51-55	53	4.3 %	4.0 %
56-60	31	4.2 %	3.4 %
61-69	14	4.4 %	3.5 %

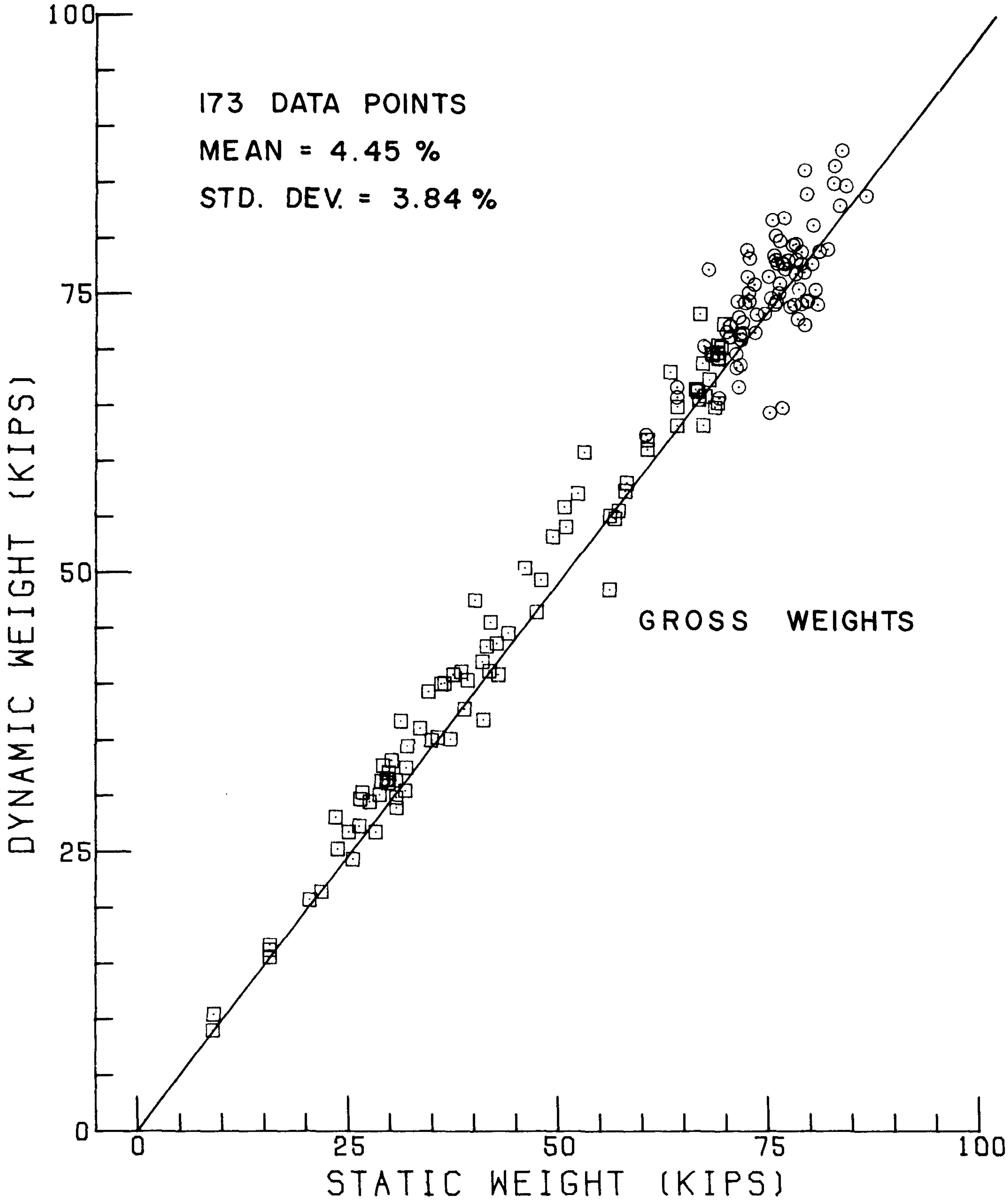
Note: 1 mile/hr. = 1.609 km/hr.

TABLE 4

CORRELATIVE DATA FROM SPEED INDICATION ACCURACY TESTS
(Controls set for optimum accuracy)

WIM Indication (MPH)	Radar Indication (MPH)	Error (MPH)
58	57	+1
53	51	+2
43	41	+2
58	55	+3
49	51	-2
29	26	+3
53	50	+3
58	55	+3
54	53	+1
49	47	+2
55	52	+3
52	48	+4
57	56	+1
56	54	+2
46	48	-2
49	47	+2
59	55	+4
54	54	0
56	54	+2
47	49	-2
50	48	+2
57	54	+3
56	53	+3
56	53	+3
53	52	+1

Note: 1 mile/hr. = 1.609 km/hr.



GRAPH I - STATIC VS. DYNAMIC WEIGHTS OF 173 SAMPLE VEHICLES