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Two makes of weigh-in-motion systems were evaluated, the PAT and the StreeterAmet systems.

The PAT scales were installed and evaluated at two sites. One site was a scale approach lane to a static enforcement weigh station; the second site was an open highway lane. The StreeterAmet system was also evaluated similarly but at different locations.

At the the weigh station sites, the PAT and StreeterAmet systems were evaluated for performance, reliability and durability. At the open highway sites, the PAT was mainly evaluated for its capability in acquiring data from a traffic stream; the StreetAmet system was not evaluated for that purpose.

Both systems were found to be suitable for in-motion weighing but were dependent on speed of traffic and user's need for degree of accuracy.

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

EVALUATION OF THE PAT AND STREETERAMET WEIGH-IN-MOTION SYSTEMS

Study Under General Direction of .. Donald L. Spellman, P.E.

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Report Prepared by .... William Chow, P.E.

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NOTICE

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Neither the State of California nor the United States Government endorse products or manufacturers. Trade or manufacturers' names appear herein only because they are considered essential to the object of this document.

CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quantity	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40 .02540	millimetres (mmm) metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2)	6.432×10^{-4}	square metres (m^2)
	square feet (ft^2) acres	.09290 .4047	square metres (m^2) hectares (ha)
Volume	gallons (gal)	3.785	litres (l)
	cubic feet (ft^3)	.02832	cubic metres (m^3)
	cubic yards (yd^3)	.7646	cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph) feet per second (fps)	.4470 .3048	metres per second (m/s) metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G)	9.807	metres per second squared (m/s^2)
Weight Density	pounds per cubic (lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lbs) kips (1000 lbs)	4.448 4448	newtons (N) newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb) foot-kips (ft-k)	1.356 1356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds (ft-lbs) foot-pounds (ft-lbs)	.1130 1.356	newton-metres (Nm) newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Stress Intensity	kips per square inch square root inch (ksi $\sqrt{in}$)	1.0988	mega pascals $\sqrt{metre}$ (MPa $\sqrt{m}$)
	pounds per square inch square root inch (psi $\sqrt{in}$)	1.0988	kilo pascals $\sqrt{metre}$ (KPa $\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{tF - 32}{1.8} = tC$	degrees celsius (°C)

ACKNOWLEDGEMENTS

We wish to extend our appreciation and thanks to the following organizations that have contributed to this project:

California Highway Patrol - Commercial and Technical Services Section
Caltrans - Office of Planning and Design
Caltrans - Office of Structures Maintenance

Though literally dozens of individuals contributed to this effort, our special gratitude goes to Richard Johnson, whose keen interest and dedicated work as the cognizant engineer, contributed immeasurably to this project.

TABLE OF CONTENTS

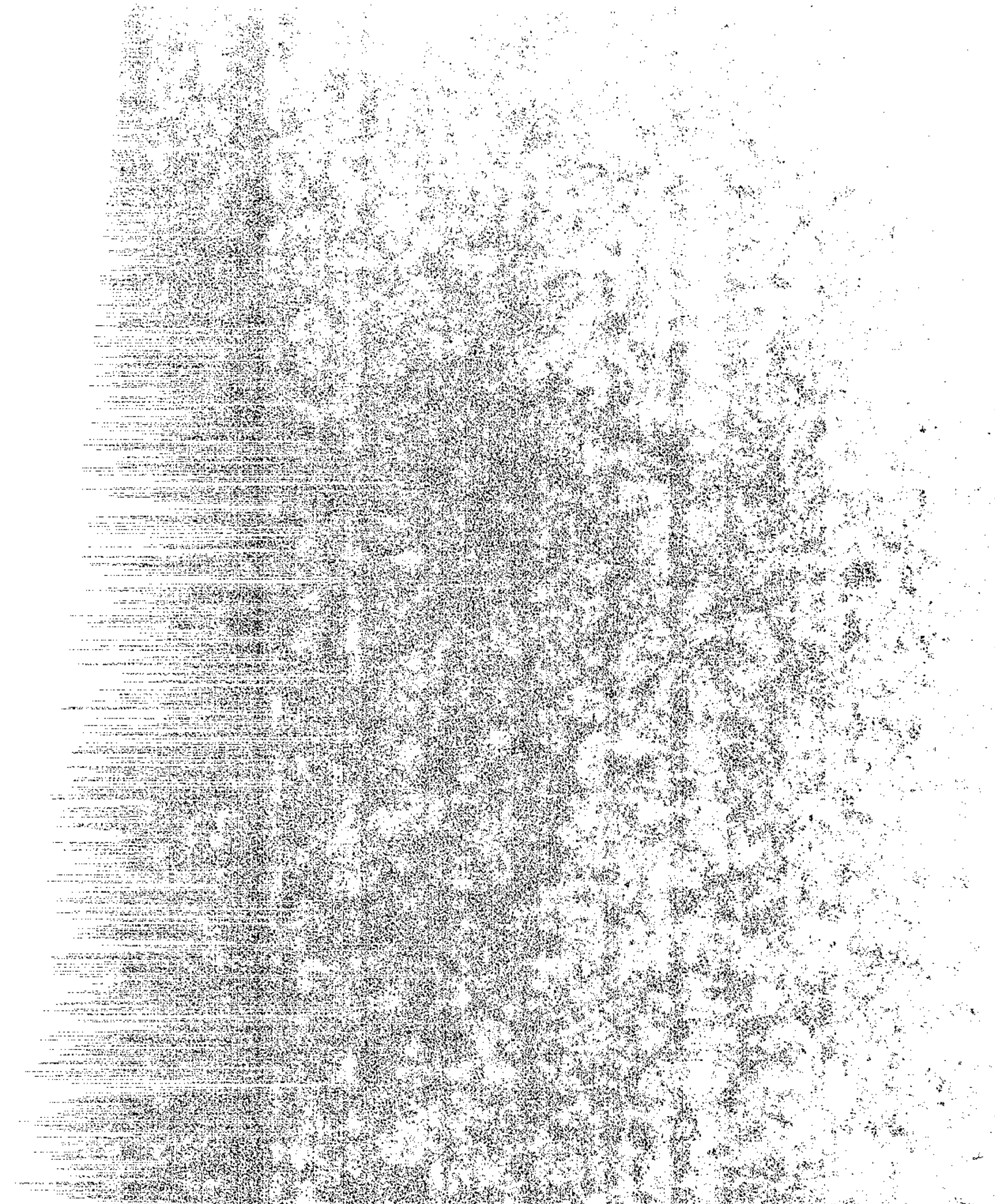


TABLE OF CONTENTS

ABSTRACT

A vehicle weigh-in-motion (WIM) system consists of electronic scales embedded flush across a roadway. With its supportive electronic equipment, the scales weighs vehicular axles crossing it without stopping. A WIM system may also provide supportive information such as gross weights, axle spacings, speed, vehicle classification, bridge formula violation, statistical summaries, time and date.

Currently (1982), there are four weigh-in-motion systems on the commercial market. They are:

(1) PAT Model DAW-209 WIM System
(2) StreeterAmet Rollweigh Model 5150 System
(3) Radian WIM System (formerly Unitek)
(4) International Road Dynamics WIM System

This report describes the evaluation of the PAT and StreeterAmet WIM systems. The Radian and International Road Dynamics WIM systems were not evaluated. However, some preliminary data on the Radian system supplied by the Idaho Department of Transportation is reported herein for information.

The WIM systems were evaluated in two environments:

(1) in a highway lane open to free flowing traffic,
(2) in a "truck-only" approach lane to a static weight enforcement station.

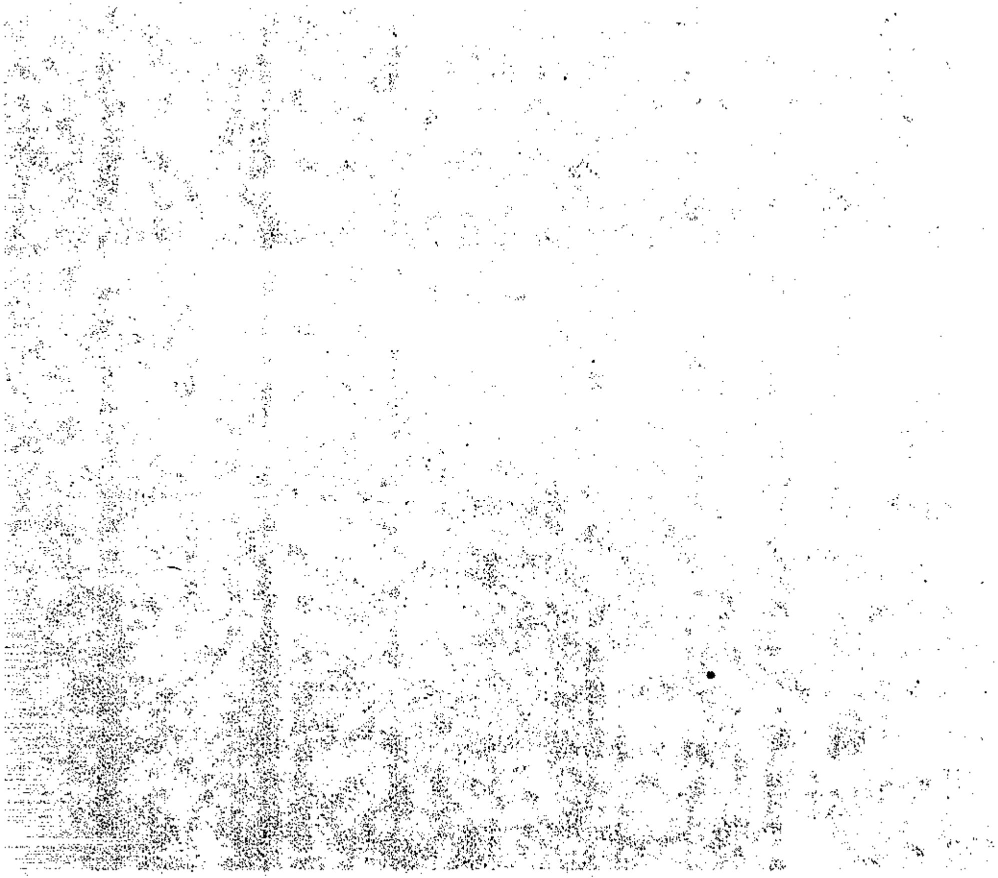
In the highway lane environment, capabilities of the PAT WIM system to collect statistical vehicle data from a

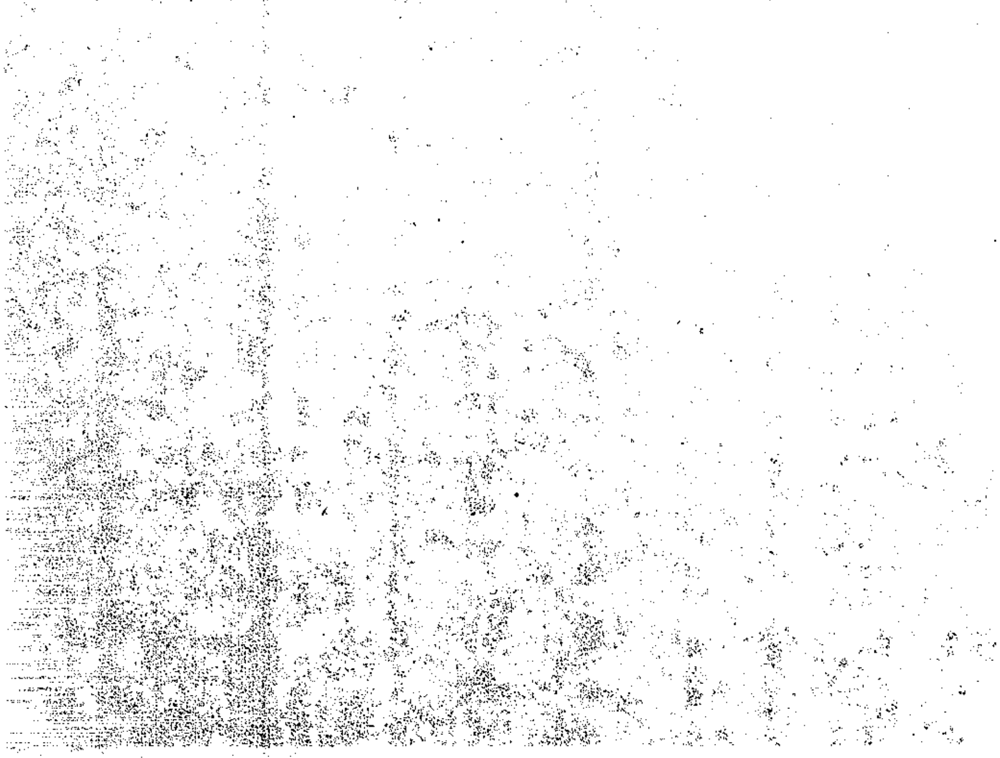
moving traffic stream was the main subject studied. Data accuracy was of secondary importance. In this environment, a set of PAT scales was installed on US Highway 99 near Lodi, California and a set of StreeterAmet scales was installed on the I-5 Freeway south of Sacramento, California. However, as described in the report, the StreeterAmet I-5 scale installation was limited to a structural durability study; it was not used to collect statistical vehicle data from a moving traffic stream.

In the weigh station approach lane environment, a set of PAT scales was installed in the scale approach lane to the California Highway Patrol (CHP) Antelope Weigh Station on the I-80 Freeway south of Roseville, California. Similarly, a set of StreeterAmet scales was installed on the scale approach lane to the CHP Castaic Weigh Station on the I-5 Freeway north of Los Angeles, California. In this environment, the measurement accuracies of the two WIM systems were the subject of major study.

Reliability and durability of the embedded scales were studied at both environments.

The PAT system from the onset has performed well with only minor start-up problems, and the embedded scales have proven to be durable, at least to about 1.8 million truck axle loadings. The StreeterAmet system has performed well after many major start-up problems were resolved; the original StreeterAmet embedded scales were structurally inadequate to bear traffic but the reworked and heavier scales have proven to be durable under traffic to at least 2.8 million truck axle loadings.





Both systems can weigh vehicles in-motion, but the acceptability of the data is dependent on the accuracy desired by the users. The PAT system met accuracy standards for gross weights, in California, for speeds tested up to 50 mph. The StreeterAmet system did not meet California standards for speeds tested up to 40 mph. Average truck gross weight error for the PAT system was 1.0% with a standard deviation of 3.2%, and for the StreeterAmet system it was -3.6% with a standard deviation of 6.6%. Average first-to-last axle spacing measurement error for the PAT system was 0.1 foot with a standard deviation of 0.3 foot and for the StreetrAmet system it was 1.4 feet with a standard deviation of 1.3 feet.

The PAT system can collect vehicle data from a moving traffic stream on an open highway. The StreeterAmet WIM system was not designed for data collection on an open highway and was not evaluated for that purpose.

INTRODUCTION

Content

This report describes the work performed, findings and conclusions, and recommendations from the evaluation of two commerically available weigh-in motion systems, the PAT Corporation Model DAW-209 and the StreeterAmet Company Model 5150 Rollweigh Weigh-In-Motion (WIM) systems. It reports the evaluation of the two systems for calculation of truck·weight, axle weight, axle spacings, and vehicle speeds from in-motion data, and it reports on the performance, reliability and durability of the two systems over the study period.

Project Scope

This study evaluated the PAT and StreeterAmet WIM systems for their performance, reliability and durability. A limited portion of the study evaluated the ability of the PAT WIm system to collect statistical vehicle data from a moving traffic stream on an open highway. The Streeter-Amet WIM system was not evaluated for that purpose because the system was not designed to collect statistical vehicle data nor for use at highway speeds.

One of the major potential applications of a WIM system would be an on-line operational "tool" to screen overweight trucks. Such an application (screening) was not in the work plan for investigation. Nevertheless, because of the inherent close relationship between in-motion weighing and screening, some preliminary study was given to the subject of screening and set forth in Appendix M.

Previous WIM Work by Caltrans

This study evolved from an earlier (1976) study* in which the Department evaluated the Rainhart Model 880 Wheel Load Transducers (wheel scale). They were installed in the scale approach lane to the California Highway Patrol weigh station at Cordelia (I-80 westbound). At that time, no supportive WIM instrumentation system was commercially available. Thus, except for the wheel scales, the Department designed and built its own first WIM system.

The earlier study concluded that despite some equipment problems the concept of WIM was feasible for the screening of weight violators from a moving platoon of trucks. However, it also concluded that further work was needed to develop more reliable operational wheel scales and additional work was needed to improve the reliability of WIM instrumentation systems.

Objective

To carry on the earlier study, this project was formulated with the main objective to determine if commercially available WIM systems are reliable, durable and of suitable performance for the in-motion measurements of gross weight, axle weight, axle spacing and speed for use in weigh stations.

*Report No. FHWA-CA-TL-78-17, "Dynamic Measurements of Commercial Highway Vehicles," June 1978.

A secondary objective of this study was to evaluate the suitability of WIM systems for the collection of statistical vehicle data from a moving traffic stream in an open highway.

Two WIM Systems Evaluated

The earlier work covered the period 1969 to 1976, in which the Rainhart Wheel Load Transducers were the only known commercially available wheel scales for in-motion weighing of trucks. Currently (1982), there are four turn-key WIM systems on the market. They are:

1. PAT Model DAW-209 WIM System
2. StreeterAmet Rollweigh Model 5150 System
3. Radian WIM System (incorporates the Rainhart Transducers)
4. International Road Dynamics WIM System

At the inception of this project in 1979, the first three listed systems were available. This study evaluated the first two systems listed above. Radian, the third WIM system was not evaluated because:

1. The Radian WIM system is believed to be the first and original WIM system available on the market and, thus, many users are familiar with its capabilities.

2. A limited budget dictated that funding priority be directed towards evaluation of the two relatively unknown WIM systems (PAT and StreeterAmet).

3. The Idaho Department of Transportation is currently (December 1982) evaluating the Radian WIM system. A parallel evaluation by this Department would be redundant.

As for the fourth system, the Department was unaware of the availability of the International Road Dynamics' WIM system until late in the study in 1980.

Therefore, only the PAT and StreeterAmet WIM systems were included in this study.

Participation

This project was funded under the Federal Highway Administration Highway Planning and Research Program designation F80TL01. It began on July 1, 1979 and was completed on June 30, 1982.

FINDINGS AND CONCLUSIONS

Accuracy

The results of this study indicate that the PAT WIM system met the Department's accuracy criteria (Page 26) for in-motion weighing of trucks at weigh stations, where speeds are relatively low (ave. 32 mph) and can be controlled. The StreeterAmet WIM system did not meet the Department's accuracy criteria for in-motion weighing of trucks at weigh stations.

It is recognized that the degree of in-motion weighing accuracy is dependent on the user's need or application and may be different from this Department's requirements.

The PAT weigh-in-motion system (two-threshold system) met the Department's accuracy criteria. It weighed truck gross weights to an average error of 1.0% with attendant standard deviation (s) of 3.2%, over an average speed of 32 mph (s = 7 mph). See Figure 7.

The StreeterAmet weigh-in-motion system (one-threshold system) did not meet the Department's accuracy criteria. It weighed truck gross weights to an average error of -3.6% with attendant standard deviation of 6.6% over an average speed of 26 mph (s = 6 mph). See Figure 11. The average error of -3.6% is attributed to the long term, no load span shift of the load cells and can be "span adjusted" to reduce it.

The weighing accuracy of the StreeterAmet system varied significantly over the tested speed range (0 - 40 mph). See Figures C-1, C-2 and C-3.

The PAT system exhibited more uniform accuracy over the tested speed range of 10-50 mph. See Figures C-1, C-2 and C-3.

Both WIM systems measured speeds to an accuracy of ± 1.0 miles per hour when individual truck speeds changed minimally over the scales.

Acceleration or deceleration of trucks passing over the scales adversely affect the ability to compute axle spacings accurately. The PAT system more consistently computed axle spacings (based on speed measurements) to the desired accuracy* than the StreeterAmet system.

In the measurement of first to last axle spacing, the PAT system average error was 0.1 foot with a standard deviation of 0.3 foot. Similarly, for the StreeterAmet system it was 1.4 feet with a standard deviation of 1.3 feet.

The weight and axle spacing measurements from the two-threshold PAT weigh-in-motion system (two axle scales in tandem) were more accurate than that from the one-threshold (one axle scale) StreeterAmet weigh-in-motion system. Inherently, weighing error decreases with multiple weighings of an axle by the factor of about $\frac{1}{\sqrt{N}}$ where N is the number of axle scales in a weigh-in-motion system. A two-threshold WIM system utilizing the two scales to measure axle speeds was more accurate than the two vehicle sensor loops for the same purpose.

*Accurate in-motion measurements of axle spacings to an error of ± 6 inches or less is necessary for the future incorporation of a computer programming for "Computation of Allowable Gross Weight" per California vehicle Code 35551.

Statistical Data Collection

The PAT system is judged adequate for the acquisition of statistical vehicle data from a highway traffic stream in the speed range of 20-50 mph. The StreeterAmet system was not evaluated for the collection of statistical vehicle data from a highway traffic stream. Basically, it is a low-speed system as stated in StreeterAmet's bulletin Form No. 2107-4/79, "Exceeds 90% accuracy up to 30 mph."

Scale Width

The narrow width (49 1/4") of the PAT wheel scales caused about 15% to 20% of the truck population to partially miss the scales. The same situation exists with the Streeter-Amet scales, but to a lesser degree, because its wheel scales are wider (53 1/8") than the PAT scales. See Figure 18.

Scale Maintenance

The PAT scales were virtually maintenance-free whereas the StreeterAmet scales required periodic maintenance inspections during the duration of this study.

Scale Longevity

Both systems (after some rework of the StreeterAmet scales) were sufficiently reliable and rugged for the length of this study. Beyond the length of the study, the long-term longevity and maintenance requirements for both systems are undetermined.

The PAT and StreeterAmet systems were operational and weighing consistently for about 23 and 21 months, respectively. However, in May 1982, both systems began to operate erratically and weighed inconsistently. The exact cause(s) of malfunctions need to be determined.

Scale Installation

Physical installation of the StreeterAmet scales in a pavement lane required major construction or reconstruction of the pavement structural section. The PAT scale installation required a less extensive effort and without construction or reconstruction of the pavement structural section.

Scale Lane Profile

Standard concrete pavement construction tolerance will provide sufficiently smooth WIM scale lanes. Scales should be embedded in a pavement having a Profile Index* of 7 inches/mile or less for a minimum 200-foot distance upstream from the scales to a 75-foot distance downstream from it.

Radian Data

The Idaho Department of Transportation is currently (June 1982) evaluating the Radian weigh-in-motion system. A limited portion of its preliminary data on the system is contained in this report. Because the Idaho study is not yet completed, no evaluation or conclusions were made. The Idaho Department of Transportation plans to report on the system upon completion of its study.

*California Test 526 "Operation of California Profilograph and Evaluation of Profiles."

RECOMMENDATIONS

Statistical Data Collection

The PAT WIM system is recommended for the collection of statistical vehicle data from a moving traffic stream in an open highway. However, further study is recommended to (1) assess the PAT's scale longevity and (2) assess WIM accuracy at highway traffic speeds greater than 50 mph.

WIM Advance Information at a Weigh Station (No Screening)

For providing advance information on truck weights and axle spacings, without screening, prior to the truck's arrival at the static scales of a weigh station:

1. The PAT WIM system is recommended where 1% gross weight error can be tolerated with attendant standard deviation(s) of 3.2% over an average speed of 32 mph (s=7 mph).

2. The StreeterAmet WIM system is recommended where -3.6% gross weight error can be tolerated with attendant standard deviation(s) of 6.6% over an average speed of 26 mph (s=6 mph).

3. The PAT system is recommended where 0.1-foot error can be tolerated (with attendant standard deviation(s) of 0.3-foot) for the first to last axle spacing measurement.

4. The StreeterAmet system is recommended where 1.4-foot error can be tolerated (with attendant standard deviation(s) of 1.3-foot) for the first to last axle spacing measurement.

Screening at a Weigh Station

To realize the maximum benefit of weigh-in-motion systems, further work is needed to develop and incorporate a truck traffic management and screening scheme with such systems for on-line production weighing and screening at high volume stations. It is recommneded that further work be done to bring weigh-in-motion traffic management and screening to full operational status. A weigh-in-motion system consistent with the performance of the PAT system is recommended for such developmental work in California.

The recommended major steps are:

(A) Scale Width

Develop scales that can span sufficient width of a pavement lane so that all trucks within the lane will be fully scale-borne.

(B) Allowable Truck Weight

Write and develop the computer software programming for California Vehicle Code Sections #35550, "Maximum Weight on Single Axle or Wheels" and #35551, "Computation of Allowable Gross Weight", for incorporation into the weigh-in-motion system program so that violations thereof can be detected and identified.

(C) Traffic Management Scheme

Develop a traffic management scheme for on-line operational screening, incorporating (B) above, wherein trucks that are within legal weight limits can be directed to bypass the weigh station static scales* and apparent overloaded trucks are identified, directed and tracked to the station for static weighing.

(D) Recommended Requirements

A recommended outline of requirements for an on-line operational weigh-in-motion system for screening of overweight trucks is set forth in Appendix M.

Determine Cause(s) of Erratic Data

Until the last few weeks of this study, the weight data collected from the PAT and StreeterAmet systems were within previously determined and expected error ranges. However, the most recent data appear to be erratic or contain obvious errors for which no cause is known. It is recommended that the cause(s) of these errors be determined as soon as possible.

*Safety inspection may be required.

IMPLEMENTATION

The results of this evaluation are known to the Department's Offices of Traffic Safety Program and Research, Structures Maintenance, Planning and Design, Highway Planning and Research, Transportation Planning and the California Highway Patrol (Commercial and Technical Services Section).

A Steering Committee which includes representatives from most of the above offices is guiding the development of a plan to implement the concept of weigh-in-motion, based on the findings and recommendations of this study, as well as their respective informational needs. Overall plans include the gathering of statistical truck data from the truck lane traffic stream for pavement planning, design, and performance evaluation and the in-motion weighing of trucks approaching a static weigh station for enforcement screening purposes.

BACKGROUND INFORMATION

Inadequacies of Static Weighing

The enforcement of laws to ensure safe and legal truck use of California highways are presently dependent upon scattered, costly, manually-operated static weighing and inspection stations. These stations obtain an incomplete sampling of truck traffic, cause economic loss through delay in transit for the trucking industry, and are becoming increasingly inadequate to handle the larger volume of truck traffic, thereby requiring many loaded trucks to bypass the station to avoid dangerous backup queues on the main traveled roadway.

The present method of stopping and then weighing each truck for overweight is slow, costly to all parties concerned, and also does not provide the volume of statistical truck and traffic data (truck dimensions, axle spacings, axle weights, gross weights, etc.) needed for planning and design purposes.

Weigh-In-Motion Systems

A weigh-in-motion (WIM) system is designed for the purpose of weighing trucks while they are in motion. The system usually consists of platform scales or "pads" embedded flush in a roadway, and loop detectors, also embedded in the pavement surface. Instrumentation signal cables from the scales and loop detectors connect to remotely sited instrumentation for processing of the signals into weight, axle spacing, and speed data. Trucks traveling across the scales are automatically weighed to a certain accuracy of "true" static weight. The weight data and other pertinent information such as axle spacings, speed, etc., are automatically conveyed to recorder/display components.

Need for WIM

There is a long-standing and growing need for in-motion truck weighing facilities for: (1) weigh-in-motion screening of trucks for weight law enforcement, and (2) the gathering of more comprehensive statistical data on truck weights and volumes for pavement planning, design and maintenance management. There are also Federal requirements for states to implement truck weighing operations to avoid sanction of Federal funds.

When used for enforcement screening and concurrent acquisition of statistical truck data, in-motion weighing would be a valuable tool to assist truck weight enforcement officials. In addition, the statistical data thus acquired should enable more rational designs of roadways and bridge structural sections compared to empirical equivalent axle loading formulas and static weight constants currently being used.

The need for in-motion truck weight screening at weigh stations is urgent because of the approximate 200 million commercial trucks travelling California's state highways annually. The northbound Castaic Weigh Station (about 35 miles north of Los Angeles on I-5) is a station experiencing a high volume of truck traffic, weighing about 750,000 trucks annually. It is one of the five highest volume weigh stations in California.

The current California Highway Patrol weigh stations provide only static weighing and, therefore, at peak traffic it has become necessary to bypass a large percentage of trucks around the stations to avoid the traffic safety hazards that would be created by the queues of trucks. Without adequate weight enforcement, California highways will require greater dollar outlays for maintenance and reconstruction and the State may lose allocated Federal funds.

Better truck weight data gathering is also needed, as mentioned above, to provide more compresensive data for structural design of pavements and bases, to design overlays, to upgrade existing pavements, to determine reconstruction needs, and for objectively planning pavement management strategies.

The objective of a proven, reliable and durable WIM system is to:

1. Reduce delays to commercial freight haulers by providing faster, smoother, and safer flow of truck traffic through weigh stations by screening of trucks and sorting out only suspected overloaded trucks for stop-check weighing.

2. Lower highway maintenance costs by better control of overloaded trucks and more efficient design of pavements.

3. Encourage trucking firms to apply for permits when hauling extra-legal, nondivisible loads on State highways.

4. Increase highway safety through total inspection/enforcement of the Vehicle Code at the weigh stations, for legal truck use of California's highways.

5. Conveniently acquire highway statistical vehicle data for planning and design purposes.

Commerical WIM Systems Available

In the Department's previous report, No. FHWA-CA-TL-78-17, "Dynamic Measurements of Commercial Highway Vehicle (Weighing-In-Motion)", it was concluded that:

> "The feasibility of weighing-in-motion on an operational basis was verified. Further study is needed to provide a more reliable weigh bridge and to improve the data acquisition and control system operation. New state of the art systems and components should be evaluated with the objective of incorporating the best features into a fully operational system."

The conclusion addressed the apparent unavailability of reliable WIM scales noted during the Department's prior project study era (1969-1976).

After 1977, turnkey WIM systems appeared on the market. Currently (June, 1982), there appears to be four manufacturers regularly engaged in the routine manufacture of WIM systems for highway vehicles. They are:

1. Radian Corporation
   8500 Shoal Creek
   Austin, Texas 78766
   Mr. G. L. Neely, Phone (512) 454-4797

2. StreeterAmet, A Division of Mangood Corporation
   3530 Golden Gateway
   Lafayette, California 94549
   Mr. T. Cartwright, Phone (415) 284-5733

3. Siemens/PAT Corporation
   860 Hinckley Road
   Burlingame, California 94010
   Mr. H. G. Doebert, Phone (415) 697-6851
   and
   Pat Equipment Corp.
   1661 Worchester Road
   Framingham, Mass. 01701
   Mr. J. J. Madek, Phone (617) 872-8211

4. International Road Dynamics, Inc.
   1822 Arlington Avenue
   Saskatoon, Saskatchewan
   CANADA S7H-2Y7
   Dr. A. T. Bergan, Phone (306) 374-5016

Under FHWA F80TL01 HPR sponsorship, the Department evaluated the PAT and the StreeterAmet systems. The evaluation is the subject of this report.

WORK PLAN AND REVISIONS

Work Plan

The Work Plan consisted of two phases. Phase A was planned to evaluate the first sets of scales at the I-5 Freeway site (about 25 miles south of Sacramento); Phase B was planned to evaluate the second sets of scales at the California Highway Patrol (CHP) Cordelia weigh station.

Site Changes

Figure 1 lists the original and revised scale installation sites.

Of the three sets of StreeterAmet scales, sets A and B were installed at the I-5 site as planned. However, they were not evaluated for data collection capability as explained later.

Of the two sets of PAT scales, set D was planned for installation at the I-5 site. However, it was not installed there because of late delivery of the PAT system. Instead, it was installed on U.S. Highway 99 near Lodi, California.

The remainder of the scale sets, sets C and E, originally planned for installation at the CHP Cordelia weigh station were not installed there because of a planned realignment of the scale lanes and a remodeling of the weigh station. Instead, StreeterAmet scale set C was installed at the CHP Castaic weigh station on I-5 near Castaic, California; the second set of PAT scales, set E, was installed at the CHP Antelope weigh station on I-80 near Roseville, California.

Phase A

Under Phase A, the PAT and StreeterAmet WIM systems were to be evaluated at a freeway site for their capability and suitability in fulfilling statistical vehicle and traffic data gathering needs.

The original freeway site was chosen near Point Pleasant, California, where the remaining connecting link of I-5 was under construction (May 1979). At this site, in the vicinity of 03-Sac-5, P.M. .26± (see Figure 2), and concurrent with the freeway construction, it was planned to install two sets of StreeterAmet WIM axle scales 150 feet upstream from the Mokelumne River Bridge (Br. No. 29-197-L). They were to be installed flush with the pavement in the southbound outside lane. A set of PAT WIM axle scales was to be similarly installed, concurrent with the freeway construction, on the southbound outside lane of the Mokelumne River Bridge near P.M. 0.19. Both WIM systems were to be evaluated for weighing accuracy, durability, and suitability to fulfill statistical data gathering needs.

Statistical data to be collected included at least the following parameters:

1. Axle weight
2. Gross weight
3. Axle spacing
4. Speed
5. Truck traffic volume

The WIM systems were to be partially evaluated before the freeway was opened to traffic. The plan consisted of loading the scales with several trucks with different loads and axle configurations, and at various truck speeds. Thus, the preliminary data was to provide an early insight into the validity of the data under simulated freeway operational conditions. After the freeway opening and with the anticipated truck traffic volumes, the reliability and durability of the axle scales were expected to become known within a few months.

The roadway plans for the scale installation at the I-5 Freeway site are shown in Figures 2 and 3.

<u>Incomplete Installation and Evaluation (I-5 Site)</u>

Under Phase A, the planned installation and evaluation of the two WIM systems at the I-5 Freeway site (Sacramento area) did not completely materialize for two reasons:

1. The PAT WIM system was finally delivered six months after the freeway opened, too late for installation. Closure of one of the bridge lanes for installation of the wheel scales was considered too hazardous. Thus, there were no PAT scales installed at the I-5 site.

2. The StreeterAmet WIM system was also delivered late and too close to the scheduled opening of the freeway to resolve all of the start-up problems for the subsequent evaluation. Thus, a large part of its evaluation could not be done at the I-5 site. A more complete performance evaluation was made later at the CHP Castaic site. However, the evaluation of the durability, under traffic of one set of reworked scales, was accomplished at the I-5 site.

Phase A Revision

For the above reasons, portions of the Phase A work were revised as follows:

1. Because of the late delivery of the PAT scales, a substitute site was selected for it on U.S. Highway 99 near Lodi (10-SJ-99) and the scales were installed during an asphaltic overlay project.

2. The StreeterAmet system was stated by the manufacture for use to 30 mph ("exceeds 90% accuracy"), which is considerably lower than average truck speeds on the highway. Thus, coupled with its mechanical and system problems, no extensive effort was made to evaluate it at the I-5 site for statistical data collection. Instead, the set as installed was evaluated for its durability and structural integrity under mainline traffic.

Phase B

Under Phase B, all three makes of scales were to be evaluated at a CHP weigh station for reliability, durability, and system performance, and for specific future potential for continuous operational truck overload screening. The three brands planned for evaluation were:

1. StreeterAmet Model #5151 Roll Weigh Instrumentation System.

2. PAT Model DAW209 Weigh-in-Motion System.

3. Rainhart #882 Wheel Load Transducers (scales only - incomplete system).

These WIM scales were to be installed in the truck deceleration approach lane to the CHP Cordelia weigh station static scales located on I-80 westbound. They were planned to be installed in tandem so the evaluation would be on a common basis. The main objectives were to evaluate them for:

1. Accuracy (weight, axle spacing and speed)
2. Reliability
3. Durability.

In order to quickly determine data accuracy and credibility and to attain knowledge of system performance, it was planned that there be no screening of overweight trucks. All loaded trucks that traversed the WIM motion scales would also be statically weighed in accordance with standard CHP routine. The WIM axle and gross weights obtained would be compared with the corresponding static weights. The accuracy of the WIM system would be expressed as a percentage error of the "true" static weight. Axle spacing accuracy would be determined in a similar way, i.e., comparison of the in-motion axle spacing measurement with the corresponding "stop-measure" axle spacing.

Phase B Revision

No WIM scales were installed at the CHP Cordelia weigh station as planned. After formulating the Work Plan, the local transportation district developed plans to upgrade the CHP Cordelia weigh station. A part of the plan included an additional truck scale lane, lane reconditioning and realignment to the scale house. The upgrading was scheduled for completion early in 1982. Thus, any WIM scale installation at the Cordelia weigh station would be a temporary installation. Therefore, plans were abandoned to install the scales at Cordelia. Instead, Phase B plans were revised to install a set of PAT scales at the CHP Antelope weigh station and a set of StreeterAmet scales at the CHP Castaic weigh station.

The final sitings of all WIM scales are listed in Figure 1.

Rainhart Transducers Not Evaluated

Although the Department owns three sets of the Rainhart Model 882 Wheel Load Transducers (they are an integral part of the Radian WIM system), the Department does not have the instrumentation and data processor portions of the Radian system.

The plan was to interface the three sets of Rainhart transducers with one of the two WIM systems under evaluation. If successfully done in the laboratory, the transducers would be installed in a scale lane for further evaluation. However, the plan was dropped because of late equipment deliveries, the multitude of startup problems with the WIM systems, and potential technical problems of interfacing the Rainhart transducers to a non-Radian WIM system.

Consequently, no Rainhart transducers were evaluated in this study.

However, the State of Idaho Department of Transportation preliminary data for the Radian system is included in this report to replace this Department's lack of data on the Radian system.

Our thanks to Mr. John Hammrick of the Idaho Department of Transportation for furnishing data on the Radian WIM system and for permission to include it in this report.

EVALUATION

The evaluation of the PAT and StreeterAmet WIM systems covered their 1) performance, 2) reliability, and 3) durability. Under performance, they were evaluated for their accuracies and functional capabilities; under reliability and durability, they were evaluated and monitored for failures, downtime and freedom from maintenance.

The following sections describes the evaluation:

Data Accuracy - Weight

The accuracy for the prediction of truck static weights from WIM weights was determined by direct comparison of the WIM weights with the corresponding static weights from the weigh station static scales. The accuracy is expressed in percent error of the static weight as follows:

$$\%\ \text{Error} = \frac{\text{WIM Weight} - \text{Static Weight}}{\text{Static Weight}} \times 100\%$$

The Department's previous WIM experience suggests that a reasonable criteria for gross weight WIM accuracy be within $\pm$ 10% at the 90% confidence level. That is, the static weight of a truck and its axles should be predictable from dynamic in-motion weighing to $\pm$ 10% of the static weight for 90% of the trucks weighed. It is believed that this level of accuracy would be adequate for WIM screening of overweight trucks at a weigh station, and also for statistical truck planning data. However, analysis of the in-motion weight error data indicates it is not normally distributed (Appendix B - Statistics). Therefore, it would be more appropriate to state the accuracy desired in terms of average error ($\bar{x}$) and attendant standard deviation(s) as follows:

Weight Accuracy Criteria

Axle Grouping	Error $\bar{x}$	Error s
Single axle weight	$\pm$ 4%	7
Tandem axle weight	$\pm$ 4%	5
Gross weight (all axles)	$\pm$ 4%	4

$\bar{x}$ = average error

s = standard deviation

PAT System Test Data

The data consisted of five test sets acquired at the CHP Antelope weigh station over the period April 1981 through October 1981. For that period:

1. A grand total of 975 trucks were weighed in-motion and correspondingly weighed statically.

2. Axle spacings were measured for 172 trucks while in-motion and correspondingly measured while stopped.

3. Speeds were measured.

4. Supportive data were collected.

For the 975 trucks weighed, their statistics are summarized and listed in Figures 4, 5, 6, and 7. The statistics in each of the figures, respectively, are in axle groupings of front axles, single axles, tandem axles and all axles (gross weight) and speed groups vs the accumlated statistics.

For a rapid overview, the accumulated statistic (n, $\bar{x}$, and s) from the figures for all speed groups are relisted below:

PAT WIM System	April-October 1981		
Axle Grouping	n	$\bar{x}$	s
Front Steering Axles	975	3.8	5.3
Single Axles (Steering Axle Included)	2043	2.7	5.7
Tandem Axles	1294	0.2	4.0
Gross Weights (all axles)	975	1.0	3.2

n = Number of measurements

$\bar{x}$ = Average weight error in percent

s = Standard deviation of $\bar{x}$

The above listed weight errors are all within the accuracy criteria set forth on page 26, i.e., $\pm$ 4% with s = 4 to 7.

Single axle weight measurements had larger errors than tandem and gross weight measurement. Note that the average error for single axle weight measurements for all speed groups was 2.7% with a standard deviation of 5.7%.

WIM tandem axle and gross weight accuracies were extremely good. Note that in the weighing of 1294 tandem axles, for all speed groups, the average error was 0.2% with a standard deviation of 4.0; in the weighing of 975 trucks (gross weight), the average error was 1.0% with a standard deviation of 3.2.

The statistics generated from the weighing of the 975 trucks indicate that the PAT system meets the criteria for WIM accuracy between the speeds of 10-50 mph.

In the sample of 975 trucks, liquid tankers and livestock trucks were purposely excluded from the sample weighings because of their shifting load. As well as could be done, every truck approaching the station in sequence was weighed in-motion, and then statically at the station. This assured that the accumulated statistics truly represents the probability of WIM accuracy attainable under actual truck traffic conditions.

Additional weight error statistics for the 975 trucks are presented in Appendix B. It contains frequency distribution data, sample statistics, and plots of error distribution against the normal curve. It also indicates the following kurtosis and skewness:

	*Kurtosis	**Coefficient of Skewness
All Single Axles	5.8	0.5
Tandem Axles	5.8	0.9
Gross Weight	4.2	0.4

*Kurtosis: The peakedness or flatness of the graphic representation of a frequency distribution.

**Skewness: Lack of symmetry in a frequency distribtuion.

A normal distribution has a kurtosis of 3 and a skewness of 0; thus, the error data is not normally distributed.

StreeterAmet System Test Data

The data for the StreeterAmet system consisted of seven test sets acquired at the CHP Castaic Weigh Station over the period October 1980 through September 1981. For that period:

1. A grand total of 1196 trucks were weighed in-motion and correspondingly weighed statically.

2. Axle spacings were measured for 167 trucks while in-motion and correspondingly measured while stopped.

3. Speeds were measured.

4. Supportive data were collected.

For the 1196 trucks weighed, their statistics are summarized and listed in Figures 8, 9, 10, and 11. The statistics in each of the figures, respectively, are in axle groupings of front axles, single axles, tandem axles, and all axles (gross weight) and speed groups vs the accumulated statistics.

For a rapid overview, the accumulated statistics (n, $\bar{x}$, s) from the figures for all speed groups are relisted below:

StreeterAmet System	Oct. 1980 - Sept. 1981		
Axle Grouping	n	$\bar{x}$	s
Front Steering Axles	1196	-1.2	6.7
Single Axles (Steering Axle Included)	2464	-0.5	8.6
Tandem Axles	1518	-6.2	7.4
Gross Weights (all axles)	1196	-3.6	6.6

n = Number of measurements

$\bar{x}$ = Average weight error in percent

s = Standard deviation of $\bar{x}$

In examining the above listed weight errors, some exceed the WIM error criteria set forth on page 26. (That criteria is $\bar{x} = \pm 4\%$ with s = 4 to 7.) The combination of average WIM error ($\bar{x}$) with attendant standard deviation(s) for either single axle, tandem axle or gross weight is larger than the stated error limits desirable for weigh-in-motion. Note that WIM error dispersion indicated by s ranged from 6.6 to 8.6, whereas a range of 4 to 7 is desired.

The data indicates that the StreeterAmet system did not meet the accuracy criteria set forth on page 26.

Like the PAT test, all trucks in sequence were weighed except liquid tankers and livestock trucks.

Additional WIM error statistics for the 1196 trucks are presented in Appendix B. It indicates the following kurtosis and skewness:

	Kurtosis	Coefficient of Skewness
All Single Axles	4.4	0.6
Tandem Axles	6.5	0.03
Gross Weight	4.4	0.4

Like the PAT error data, the StreeterAmet error data is also not normally distributed.

Radian System Test Data - Idaho

The following Radian data were furnished by the Idaho Department of Transportation. They acquired it on November 17-19, 1981, at the Bliss weigh station on I-84. A total of 341 trucks were weighed in-motion and correspondingly weighed statically at the station. Weight errors listed below are for the first three axles. The data are from Idaho's incomplete study and, therefore, no attempt is made to formulate conclusions. Upon completion of its study, Idaho plans to publish a report on its findings.

Radian System	Idaho Data		
Axle Grouping	n	$\bar{x}$	s
Front Steering Axles	341	2.0	6.5
Single Axles	417	1.8	6.8
Tandem Axles	298	4.1	6.1
Gross Weights (all axles)	341	2.2	5.7

n = Number of measurements

$\bar{x}$ = Average weight error in percent

s = Standard deviation of $\bar{x}$

Axle Spacing

The California Vehicle Code, Section 35551 (commonly known as the "Bridge Formula") "Computation of Allowable Gross Weight," provides, in table form, the "total gross weight in pounds that can be imposed on the highway by any group of two or more consecutive axles" in accordance with the axle spacing schedule listed therein. The axle spacings are "measured to the nearest whole foot. When a fraction is exactly six inches, the next larger whole foot shall be used." Thus, for a WIM system to successfully implement the "Bridge Formula" into its computational software program, axle spacings must be measured to an accuracy of $\pm$ 0.5 foot.

The accuracy of in-motion axle spacing measurement was determined by comparing the WIM measurements with the stop-measurements of the same axle spacings.

The WIM axle spacing accuracy is defined in units of "feet of error" to the nearest 0.1 foot as follows:

Axle spacing error (in feet) = WIM axle spacing (ft) - true axle spacing (ft).

WIM Axle Spacing Accuracy

All of the in-motion axle spacing measurements were converted to "axle spacing error" and summarized as descriptive statistics in Figures 12 and 13. The data are grouped into adjacent axle spacing, tandem axle spacing, steering axle to axle No. 2 spacing, and overall axle spacing. The spacing groups were further divided into speed groups.

For the PAT system, the spacing accuracy statistics were based on the measurement of 172 trucks over a three-day period (May 19-21, 1981). Similarly, for the StreeterAmet system, the accuracy statistics were based on the measurements of 167 trucks over another 3-day period (November 11-13, 1980). Examination of the data (Figures 12 and 13) shows that the PAT was more accurate than the StreeterAmet for the in-motion measurements of axle spacings. Statistics for the in-motion measurement of overall axle spacings, for all speed groups, for the two systems are relisted below (from Figures 12 and 13) for ready comparison:

	n	$\bar{x}$	s
PAT System	172	-0.1	0.3
StreeterAmet System	167	1.4	1.3

n = Number of trucks measured for overall axle spacings.

$\bar{x}$ = Average error in feet.

s = Standard deviation of $\bar{x}$.

As stated earlier, the in-motion axle spacings must be measured to an accuracy of $\pm$ 0.5 foot for use in the "Bridge Formula". The PAT system marginally met this requirement at $\bar{x}$ = 0.1 and s = 0.3. The StreeterAmet system did not.

The PAT system may be reprogrammed to calculate axle spacings based on the crossing speed corresponding to each spacing and its respective axles in question. This should improve the accuracy of axle spacing measurements over that of using the overall average truck speed in all spacing calculations.

The StreeterAmet average error in spacing measurement was $\bar{x}$ = 1.4 feet with attendant s = 1.3 feet. It is judged excessive and inappropriate for accurate axle spacing measurement.

Radian Axle Spacing Data (Idaho Data)

For the Radian system, the axle spacing data were furnished by the Idaho Department of Transportation. It is based on their measurements of 341 trucks over a three-day period (November 17-19, 1981). The data listed below are for the first 3 axles of a truck. Spacings for more than 3 axles are not listed other than steering axle to last axle.

Again, the data are from Idaho's incomplete study and evaluation and conclusions should await Idaho's completed study. The tentative axle spacing errors are:

	Spacings (ft.)			
Stat. Data	Adjacent Axle >6 ft.	Tandem Axle <6 ft.	Steering Axle to Axle #2	Overall Axle Spacing Steering Axle to Last Axle
n	379	298	341	341
$\bar{x}$	-1.4	-1.4	-.13	-5.8
s	1.2	0.3	1.2	3.4

n = Sample size

$\bar{x}$ = Average axle spacing error (ft.)

s = Standard deviation

Speed Measurements

Both the PAT and StreeterAmet WIM systems utilize a speed trap to measure truck speed. A speed trap measures the time it takes for a truck to travel a known distance and thereby its speed can be calculated.

The PAT WIM system utilizes the two sets of axle scales and the known distance between them (16.4 feet) to determine the speed of each vehicle axle. The 16.4 foot distance divided by the time it takes for a particular axle to cross it determines the speed. When an axle "strikes" the first axle scale, a d.c. voltage change occurs which is "noted" by the WIM system. Similarly, when the same axle "strikes" the second axle scale, the system again "notes" it. The system measures the "time" between the two "noted" events and divides it into the 16.4 foot spacing to provide the axle speed. Thus, the speed of every axle is determined in a similar fashion. Finally, the PAT system determines the average truck speed by averaging the calculated speeds of all the axles.

The StreeterAmet WIM system utilizes the two vehicle presence detection loops and the known distance between them (16.4 feet) to determine the speed of a truck. When a truck (not the axle) enters the loop boundary and triggers the first loop detector, a signal is generated which is "noted" by the WIM system. A second signal is generated and "noted" by the system when the same truck enters the boundary of the second loop detector. The system measures the "time" between the two "noted" events and divides it into the 16.4 foot spacing to provide the truck speed. Note that speed measurement for this system is based on only the front end of the truck "activating" the two detection loops.

Both the PAT and StreeterAmet systems measured truck speeds to an acceptable accuracy if the trucks have a reasonably constant speed (see Appendix N). Both systems were checked for accuracy of speed measurements against a "calibration standard" speed trap. The results were:

	Average Speed Error ($\bar{x}$), %	Standard Deviation (s)	Sample Size (n)	Range mph
PAT System	-0.84	0.95	70	8-48
StreeterAmet System	1.07	0.67	10	20-35

The PAT system was suitable for speed measurement where trucks were changing speed. This appears to be possible because the system measures the speed of each axle independently and calculates the overall average truck speed.

The StreeterAmet system was not as suitable for speed measurements where trucks were changing speed. This is because only the time it takes for the front of a truck to cross the speed trap is measured. Should a truck be decelerating and its back end takes more time to cross the speed trap, the presence detection system does not "recognize" it. Thus, the overall average truck speed across a speed trap may differ from that of its front and create errors in axle spacing measurements. Appendix N discusses speed changes and its effects on axle spacing measurement errors.

Factors Affecting WIM Accuracy

The accuracy of the prediction of static axle weight from in-motion weight is dependent on many factors other than the WIM system itself. These factors may adversely affect the accuracy of prediction:

1. Vehicle acceleration or deceleration
2. Wind
3. Wheel and vehicle suspension system
4. Pavement profile and cross slope
5. Scale width

The first three factors are generally beyond the control of WIM operators. The factors which can be controlled are cross slope and pavement profile. As a rule, however, cross slope can be controlled at weigh station ramps only. It is well-recognized that an undulating pavement profile, coupled with a vehicle's suspension system, will interact to cause vehicle oscillations which can appear as dynamic wheel forces on the pavement. The dynamic wheel force is what the pavement must truly bear, and it may be different from its static wheel weight.

Obviously, the smoother a pavement, smaller oscillatory wheel forces will be generated and the dynamic wheel force would be expected to more closely match that of its static weight. The question naturally arises as to "how smooth is smooth enough?" for a pavement profile approaching and leaving a WIM scale. Some literature generally states that pavement profile to within 0.1 inch is desirable. This would be most difficult to obtain in normal and practical pavement construction. How smooth should a WIM pavement be is answered in part by the Department's experience with WIM systems installed at the two CHP weigh stations and at the Lodi highway site. The pavement sections for these scales were not subjected to any special smoothing during the scale installations. The pavement profile indexes** (a measure of pavement roughness) for the two weigh stations and the highway site are listed below:

WIM Sites	Profile Date	Pavement Profile Index (in./mi.)		Age of Pavement, Years
		Left Track	Right Track	
Antelope CHP Weigh Station	April 14, 1981	23	28	8.5 (Concrete-scale lane)
Castaic CHP Weigh Station	May 2, 1981	40 31*	33 28*	0.8 (Concrete-scale lane)
Highway 99 at Lodi	June 29, 1981 (before scale placement)	1.5	3.0	New (Asphalt-mainline pavement)
	July 3, 1981 (Scale in Place)	3.5	3.5	New (Asphalt)
Caltrans Specification		7.0 Max.	7.0 Max.	Newly constructed PCC pavement

*Estimated after grinding of bump.

Due to the manner in which the Profile Index is determined, isolated "bumps" up to 0.3 inch may not count much in terms of inches per mile.

**As determined by California Test 526 "Operation of California Profilograph and Evaluation of Profiles."

Figures 14, 15, 16 and 17 are the pavement profilograms from which the above listed pavement profile indexes were derived. A visual examination of the profilograms confirm the above listed pavement indexes that show the Lodi highway (asphalt concrete) pavement profiles were smoother than that of the weigh stations (portland cement concrete).

At the Antelope Weigh Station, the left track and right. track profile index averaged 25.5 in./mi. After the bump grinding at the Castaic Weigh Station, the left track and right track profile index (estimated) averaged 29.5 in./mi. For the newly constructed asphalt overlay pavement near Lodi, the profile index was about 3.5 in./mi. The Department's profile index specification limit for newly constructed PCC pavement is 7 in./mi. Thus, the weigh station pavement profiles were about four times rougher than the maximum specified for a new PCC pavement. Because weighing accuracies were adequate at both weigh stations with a pavement profile index greater than that of a new PCC pavement, it is concluded that standard pavement construction practice (specifying 7 in./mi. of pavement profile index) will produce adequate pavement smoothness for WIM operations.

The profilogram of the StreeterAmet scale lane at the Castaic weigh station (Figure 15) shows a large bump in each wheel track. They are annotated as "Dummy Scale Pit-Patched." In May 1981, the bumps were removed by grinding and patching. It was done after the taking of Data Set No. 5 in March 1981 and before the taking of Data Set No. 6 in June 1981.

No profilogram was obtained after the grinding and patching. However, it is estimated that the improvement by the removal of the bumps resulted in a Profile Index of 28 and 31 inches/mile for the right and left wheel tracks, respectively.

Improvement of the pavement Profile Indexes in this case did not significantly change WIM weight accuracy. For example, note the weight error data dispersion (given by standard deviation, s) in Figure 11 for truck gross weight errors. Before the bump removal in March (Set 5), the standard deviation of the error was 4.4%. After its removal, it was 4.5% for the June Data Set 6. Not only was there no improvement in weighing accuracy, but there appeared to be a slight increase in data dispersion (from s of 4.4 to 4.5). Nevertheless, it is considered desirable to have smooth pavement on both sides of the wheel scales to ensure for the best possible WIM measurement accuracy.

The last factor listed that can affect WIM accuracy is scale width. Obviously, for valid in-motion weighing of vehicle axles, the left and right track scales must be wide enough so that all of the wheels are completely scale-borne under normal driving conditions. At the Lodi Highway 99 site no special efforts were made with either cones, stripes, or other means to direct a trucker to guide his truck over the centerline of scale. The result was that about 20% of the axles were only partially scale-borne. The number of "misses" is considered excessive for future gathering of statistical truck and traffic data, and for future on-line production WIM screening.

At a weigh station, any mechanical means to channel or guide a large truck is considered cumbersome and unreliable. The alternative solution is to develop scales wide enough to span a full lane and, thereby, alleviate all concern about nonscale-borne axles.

Figure 18 shows a typical axle with dual wheels optimally centered on a pair of PAT and StreeterAmet scales. It shows that should a truck driver allow his truck to stray from the lane centerline by more than 12 5/8 inches for the PAT scales or more than 17 inches for the StreeterAmet scales his wheels may not be completely scale-borne. The result would be an invalid axle weighing.

For a driver to keep his truck within 12 5/8 to 17 inches of lane centerline is too demanding of skill and attention. The optimum solution would be to have scales wide enough to completely span the width of a pavement lane.

Critique of WIM Systems

Operating the PAT and StreeterAmet WIM systems was generally straightforward and should be easily operated by weigh station personnel. The display format of WIM information for both systems, although different, adequately serves its purpose.

Other than the scales, the instrumentation, video display, and computational equipment of both WIM systems were adequate. Both WIM systems suffered the usual startup problems and minor problems during operation commensurate with complex computerized instrumentation systems. These problems were overcome and both WIM systems performed adequately after the "shakedown" period.

The most crucial components in a successful WIM system are the embedded wheel scales. Unlike the computational/ instrumentation components which are readily available for servicing, the scales are very difficult to service. Thus, the ideal scales should be durable and reliable. (By durable it is meant low maintenance, free of the need for periodic inspection and free of the need to readjust, realign, relevel or retighten bolted or screwed parts of the scale proper under repetitious loadings of heavy vehicular traffic.)

The PAT wheel scales best met the above requirements. At the CHP Antelope weigh station, four PAT wheel scales were installed in May 1980 and remain operational to date (May 1982). At Lodi, four PAT wheel scales were installed in a highway lane in July 1981. One scale failed within the first month of installation. It was replaced and all four scales remain operational to date (May 1982). Thus, over the two periods, the PAT scales have proven to be durable and reliable.

During the course of this project, the eight PAT scales did not require nor recieve any maintenance nor in-service adjustments. The scale proper, being of one-piece integral construction and completely vulcanized, had no openings, outlets nor fittings for in-service adjustments or maintenance. Shims were provided with the PAT scales to bring it to pavement elevation as required. No scale re-elevation was needed during this study. It should be noted, however, that if the foundation for the scales is inadequate or if not properly supported, some scale re-elevation with the pavement surface would be required.

One PAT scale failed within a month after its installation. Because of its integral construction, it could not be repaired in the field or in the laboratory. It was simply replaced with a spare scale. Replacement was simple and presented no problem.

The PAT scales and foundation frames were relatively easy to install. The heaviest part was the scale. It weighed 181 pounds but could be installed by two men without hoist or crane. Heated rubberized asphalt compound was required to "bed" the scale frame in the pit. A double kettle is needed to properly heat the rubber/asphalt compound.

The StreeterAmet reworked scales, at least over a two-year period, were durable. However, the original scales were not (see Appendix J for details).

The original first two sets of StreeterAmet axle scales installed at the I-5 test site proved to be structurally inadequate. Before the I-5 Freeway opening, a Caltrans tractor semi-trailer (see Figure I-2) was driven across the scales for the intitial test of the WIM system. The scales showed immediate signs of structural distress. Many of the plug and fillet welds fractured under the test axle loadings. Furthermore, the scales rocked when the test truck crossed it. The scale deficiencies and repairs are described fully in Appendix J, "StreeterAmet Scale Structural Deficiencies" and Appendix K, "StreeterAmet Scale Repairs".

Subsequently, StreeterAmet reworked all axle scales to improve their structural adequacy and durability, and to eliminate rocking.

The StreeterAmet solution to the above deficiencies was to strengthen the scales with thicker surface plates and with more and larger welds, thereby increasing scale weight from 540 to 700 pounds. The increased weight was supposed to reduce movement due to impact loads. In addition, the scales were retrofitted with vertical check rods to prevent them from rocking. However, the vertical check rods increased the scales' static errors so that subsequent scale installations were made without them.

The rework did increase the durability of the scales. A set of reworked scales were installed in July 1980 at the CHP Castaic weigh station. To date (May 1982), they have shown no structural distress.

The StreeterAmet reworked scales are durable but not worry-free nor maintenance free. They have many welded, bolted and screwed fittings which require adjustments or inspection. Cover plates were fastened with 1/4" - 20 screws. Some screws have broken under traffic. Appendix J describes in detail fastening problems with the cover plates.

To ensure traffic safety, it was necessary to inspect the screws, cover plates and the scales periodically. The scales also needed periodic adjustments. The scale platform is supported at each corner by a load cell and, on occasion, need releveling. Releveling the scales installed in the weigh station lane presented no problem, however, no attempt was made to relevel the scales at the I-5 Freeway lane because to do so required a lane closure.

The StreeterAmet scales were laborious to install. Appendix G describes in detail the installation procedure. A wheel scale weighed 700 pounds and required a chain hoist for its installation. Any need to service components within the scale proper or pit required a hoist or boom to lift the scale out.

Each StreeterAmet axle scale has eight load cells. In the field, all had to be electrically equalized for output with trimming resistors as a static load was placed at each scale corner. This procedure was both laborious and difficult. The trimming resistors and load cell connections were made in three connection boxes within the scale pits. Should the pits fill up with water, the connections could become wet and the system performance could degrade.

The StreeterAmet data processor and computational system has been reliable and durable (up to May, 1982). Other than the usual start-up problems that can be expected in debugging a complex system, the system has operated reliably and it is durable.

The experience from all three WIM sites (Antelope, Castaic and Lodi) indicates that the scales are too narrow. Because of the narrow scale widths, and without channeling, about 20% of the trucks will not be completely scaleborne. Figure 18 shows widths of 49 1/4 and 53 1/8 inches for PAT and StreeterAmet scales, respectively. To overcome this problem without resorting to channeling, the scales should be wide enough to completely span the width of a lane.

The PAT and StreeterAmet scales, when individually statically load tested in the laboratory, showed no significant accuracy advantage of one over the other. However, in an actual WIM installation the PAT system has the accuracy advantage because each axle is weighed twice (two threshold system). All other WIM systems utilize one axle scale for a single weighing of a given axle. Thus, with a two threshold system, a given axle is weighed twice reducing the weighing error by a factor of about $\frac{1}{\sqrt{N}}$ over that of a single weighing (N = number of axle scales). Also, the two-axle scale system is expected to provide more accurate axle spacing measurement necessary for implementation of the "Bridge Formula".

Weight Calibration

The major function of a WIM system is to predict truck static weight from in-motion weight to an acceptable accuracy. The WIM system may truly measure the combination of static weight and dynamic forces imposed on the scales (and pavement) but what is required under present law is the static weight only.

The WIM systems were calibrated both statically and dynamically. Both the PAT and StreeterAmet systems calibrated "well" under static conditions. However, the system static calibration settings are considered invalid for in-motion dynamic weighing. This is not a fault or deficiency of the WIM systems but inherent in the problem of predicting static weights from in-motion trucks with their attendant dynamic axle forces.

Dynamic calibration is the only valid method of calibrating a WIM system. However, a valid dynamic calibration is both laborious and difficult to achieve. It must encompass the range of truck speeds, suspension systems and axle configurations found in the truck population.

The dynamic calibration of the PAT system required two phases. The first phase was a preliminary calibration wherein a loaded 3-axle truck was driven across the scales at 3, 20, 40, and 60 mph, at least 15 times at each speed. The calibration settings (3, 20, 40, and 60 mph) were adjusted and readjusted to "match" the "dynamic weight" to that of the known "static weight" until the optimum setting was achieved.

After the preliminary calibration, a subsequent dynamic calibration or second phase encompassed the weighing of "real world" trucks crossing the PAT scales. These trucks crossed at various speeds with various axle combinations, suspensions, and loadings. The second calibration phase encompassed the weighing of these trucks in several groups -- about 100 trucks to a group. After each group weighing, the average group weighing error was determined without regard to speed. Knowing the average weighing errors from the last group, the lower speed calibration setting was readjusted to narrow the error between in-motion and static weight and another group of trucks weighed. This procedure was carried out for several group weighings until the optimum setting was achieved, i.e., best match between static and dynamic weights at all speeds. This provided a statistical and valid approach to the calibration of a WIM system. However, the entire calibration procedure was laborious, tedious and difficult and required about six days to accomplish.

The StreeterAmet system was calibrated in a similar manner. First, static calibration ensured that the system was functional prior to the dynamic calibration, and at this time the span output of the load cells were matched.

In principle, the dynamic calibration of the StreeterAmet system was similar to the PAT calibration in that the dynamic calibration should represent a statistical sampling of the truck population crossing the WIM scales at various speeds and with different axle combinations, suspensions, and loadings.

For the StreeterAmet system calibration, the matching of in-motion to static weights is done with one sensitivity adjuster. It is used for trucks crossing the scales at all speeds.

In the calibration procedure, about 100 trucks were sampled and weighed, and the WIM statistical error was determined for them as a group. Based on the statistical sample error of the group, the sensitivity adjustor was further adjusted to narrow the error between in-motion and static weight. Another sample of about 100 trucks were weighed and the procedure repeated until the setting was reached for optimum matching of in-motion weights to static weights. The above calibration procedure required four days and was laborious.

For successful WIM operation, to predict static weight from dynamic weight, an adequate and valid dynamic calibration is essential and cannot be avoided or "condensed" no matter how laborious. Static calibration is a simpler procedure, but it cannot replace a thorough dynamic calibration if valid prediction of static weight from dynamic weight is desired.

It is noted here that the "dynamic" weight may be more pertinent to the effects of moving loads on pavement than are "static" weights. Thus, the matching of dynamic weight to static weight may assume secondary importance for the assessment of effects of moving loads on pavement.

<u>Acquisition of Statistical Vehicle Data</u>

The evaluation of the PAT system to acquire statistical vehicle data from a traffic stream was done at the Lodi site on Highway 99. The evaluation indicates that the PAT system can acquire such data successfully.

Vehicle data from a traffic stream were automatically recorded serially on a Columbia magnetic tape recorder provided with the PAT system.

Data were recorded in data blocks. The block size (256 bytes) is finite so that the number of vehicles recorded on any block varies dependent upon the "volumetric" amount of data "attached" to a stream of vehicles. Usually a block contains data information on 4 to 6 vehicles. A single tape can run and record continuously for about one week.

The Columbia tape recorder was interconnected to a Hewlett-Packard Model 2100S microprogrammable computer. The Columbia block data was transmitted to the computer at a 1200 baud rate under Electronic Industries Association Standard RS-232 for the interfacing between data terminal equipment and data communication equipment employing serial binary data interchange.

The computer, in turn, transmitted the block data to a 9-track Daconics Model 2914 digital tape recorder for storage and processing. A Centronics Model 101 printer was also connected to the computer.

The Columbia block data was printed out in two formats on the Centronic printer under the control of the computer. Figure 19 shows the first printout available. It shows a portion of the "raw" block data recorded on the Columbia tape and its printout. Note that it includes data blocks #1 through #6.

Figure 20 shows the second printout available. It shows data block #5 decoded, printed and listing vehicle data such as vehicle number, weights, axle spacings and speeds for runs #84 through #89.

Once the data blocks are entered into a central computer, the data can be formatted in various ways to meet the user's needs.

The PAT system can record vehicles at normal highway speeds with a minimum headway of about 25 feet.

Longevity and Maintenance

An extended period (years) would be required to provide a valid evaluation and assessment of the longevity and maintenance characteristics of the PAT and StreeterAmet WIM systems. The short term of this study provided only a cursory and incomplete assessment.

Both the PAT and StreeterAmet WIM systems developed operational problems towards the end of this study. Results are reported herein with the proviso and limitations of a short-term evaluation. Thus, whether these problems are minor or serious, or whether they are the result of an inherent deficiency of the WIM systems was not determined.

It is estimated that the WIM scales at the three sites have accumulated the following number of truck axle loadings:

	Estimated Truck Axle Loadings to May 1, 1982	Days in Service to May 1, 1982
Highway 99 (Lodi) (PAT System)	1,600,000	300
Antelope Weigh Station (PAT System)	1,800,000	700
Castaic Weigh Station (StreeterAmet System)	2,800,000	640

In early May 1982, the PAT scales at the Lodi Highway 99 site (300 days after installation) started to show signs of drift and inconsistent in-motion weight measurements. Preliminary investigation indicated that three of the four wheel scales may be "suffering" from:

1. Transducer fatigue due to the accumulated 1.6 million axle loadings, or

2. Moisture intrusion into the strain gage transducer system, or

3. Other causes yet to be determined.

At the Antelope weigh station, one of the four PAT scales also started showing symptoms similar to those at the Lodi site. The Antelope scales have been in place 700 days to date and have accumulated about 1.8 million truck axle loadings.

There is no evidence of structural distress in any of the eight PAT scales at either of these two sites.

It may be surmised that the PAT scales may have a fatigue life of about 1.6 to 1.8 million axle loadings. However, it cannot be definitely stated what the cause of the problem is at this time. Nevertheless, a fatigue life considerably beyond 1.6 million axle loadings would be deemed necessary for a successful WIM scale because in some locations a total of 2 million axle loadings could be experienced in a few months.

The StreeterAmet scales at the Castaic weigh station have accumulated about 2.8 million truck axle loadings over an in-service period of 640 days. Within its error limits, the StreeterAmet system had continued to provide consistent weight measurements up to about May 1982. Thereafter, the system became inoperative. At this time, (July 1982) the definitive cause had not been determined. It appears to be in the data processor and may require only routine maintenance. Inspection of the scales (in-place) indicates no signs of structural distress.

COST OF AXLE SCALE INSTALLATIONS

Scale Installation

In the course of this study, the Department installed seven WIM axle scales, three of which were StreeterAmet scales and four were PAT scales. Of the two makes, the StreeterAmet scales required more work and were more expensive and difficult to install than the PAT scales.

Installation Cost

The installation costs (in 1980) were as follows:

StreeterAmet (for one axle scale)	$12,820.00
PAT (for two axle scales)	$ 3,860.00

The StreeterAmet WIM system is a one-axle scale system whereas the PAT is a two-axle scale system. Even though the PAT system required the installation of two axle scales (whereas the StreeterAmet system only one), the cost for installing them was only about one third as much as for installing the StreeterAmet one axle scale. The above costs were for weigh station sites where no main line lane closure was required.

The reasons the StreeterAmet scale were more costly to install were:

1. Axle scale concrete foundation pit required major construction.

2. The foundation pads and bolts required close tolerance and meticulous attention in installation.

3. The foundation frames and scale platform are heavy and required a hoist for their installation.

4. The scale system and its many parts were assembled and fastened by bolts and screws at the pavement site and required careful alignment and adjustment.

The PAT scale was relatively easy to install. A shallow pit was excavated in an existing highway lane to receive a foundation frame. The scale platform was anchored into the frame. The scale platform is an integral unit, completely encapsulated in rubber with no external screws and bolts and requires no tedious alignment or adjustment.

The specific details for installing the StreeterAmet and PAT scales are contained in Appendix G and H, respectively.

WIM EQUIPMENT COST

Cost of WIM Equipment purchased in 1979:

1. StreeterAmet Model 5150 Rollweigh Instrumentation System — $87,550.00

2. PAT Model 200 (DAW-209) — $74,308.85

Major Components Supplied

	Axle Scales	Computational & Display System	Printer	Recorder	Connecting Cable
StreeterAmet	3 (1 axle scale required per system)	2 (microcomputer, CRT display, keyboard, signal conditioning equipment, etc.)	None	None	500 ft.
PAT	4 (2 axle scales required per system)	1 (microcomputer, CRT display, keyboard, signal conditioning equipment, etc.)	1 (Anadex DP-8000)	1 (Columbia Model 300C cartridge recorder)	656 ft.

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FIGURES

FIGURE 1

ORIGINAL AND REVISED LOCATIONS FOR WIM SCALE SITES

	StreeterAmet WIM Scales			PAT WIM Scales		Rainhart WIM Scales
Original Site Plan	Set A	Set B	Set C	Set D	Set E	
I-5 Site Plan (Phase A)	(P)	(P)		P		
CHP Cordelia Weigh Station (Phase B)			P		P	P
Revised Site Plan						
Highway 99 - Lodi (Phase A)				(R)		NI
CHP Castaic Weigh Station (Phase B)			(R)			NI
CHP Antelope Weigh Station (Phase B)					(R)	NI

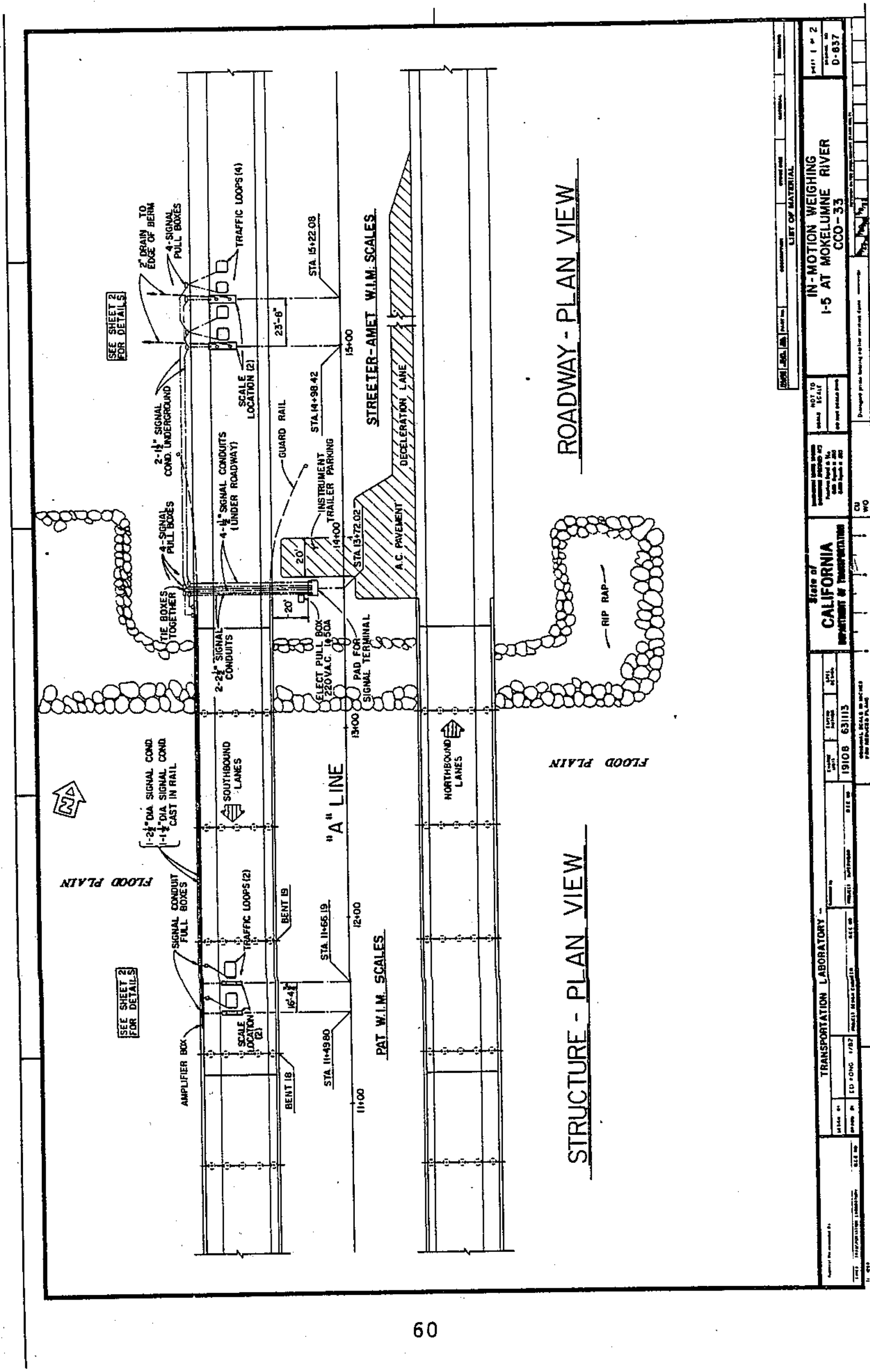
P = Planned Installation

(P) = Planned Installation Completed

(R) = Revised Installation Completed

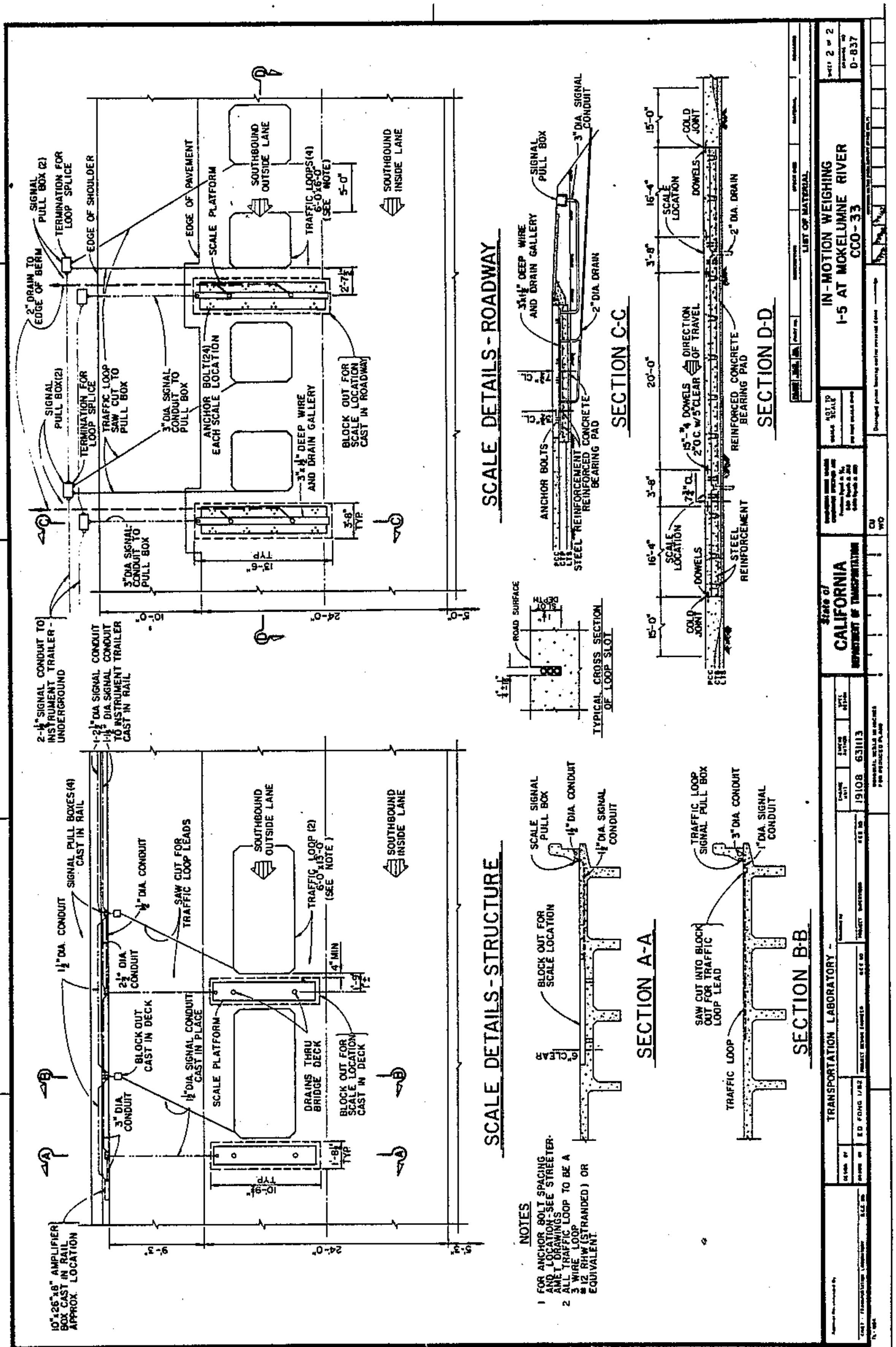
NI = No Installation

FIGURE 2



ROADWAY - PLAN VIEW
STRUCTURE - PLAN VIEW
STREETER-AMET W.I.M. SCALES
PAT W.I.M. SCALES
"A" LINE
SEE SHEET 2 FOR DETAILS
2" DRAIN TO EDGE OF BERM
4-SIGNAL PULL BOXES
TRAFFIC LOOPS (4)
STA 15+22.08
23'-6"
SCALE LOCATION (2)
15+00
2-1½" SIGNAL COND. UNDERGROUND
4-½" SIGNAL CONDUITS (UNDER ROADWAY)
GUARD RAIL
STA 14+98.42
INSTRUMENT TRAILER PARKING
DECELERATION LANE
A.C. PAVEMENT
14+00
STA 13+72.02
20'
TIE BOXES TOGETHER
2-2½" SIGNAL CONDUITS
ELECT PULL BOX 220 V.A.C. 150A
PAD FOR SIGNAL TERMINAL
RIP RAP
13+00
FLOOD PLAIN
SOUTHBOUND LANES
NORTHBOUND LANES
1-2½" DIA SIGNAL COND.
1-1½" DIA SIGNAL COND. CAST IN RAIL
SIGNAL CONDUIT PULL BOXES
TRAFFIC LOOPS (2)
BENT 19
STA 11+66.19
12+00
16'-4½"
SCALE LOCATION (2)
AMPLIFIER BOX
STA 11+49.80
BENT 18
11+00
IN-MOTION WEIGHING
I-5 AT MOKELUMNE RIVER
CCO-33
D-857
State of CALIFORNIA
DEPARTMENT OF TRANSPORTATION
TRANSPORTATION LABORATORY
NOT TO SCALE
LIST OF MATERIAL
19108
631115
ED FONG

FIGURE 3



SCALE DETAILS - ROADWAY
SCALE DETAILS - STRUCTURE
SECTION A-A
SECTION B-B
SECTION C-C
SECTION D-D
TYPICAL CROSS SECTION OF LOOP SLOT
SOUTHBOUND OUTSIDE LANE
SOUTHBOUND INSIDE LANE
SCALE PLATFORM
EDGE OF PAVEMENT
EDGE OF SHOULDER
SIGNAL PULL BOX (2)
TERMINATION FOR LOOP SPLICE
TRAFFIC LOOPS(4) 6'-0"x6'-0" (SEE NOTE)
ANCHOR BOLT(24) EACH SCALE LOCATION
BLOCK OUT FOR SCALE LOCATION CAST IN ROADWAY
BLOCK OUT FOR SCALE LOCATION CAST IN DECK
DRAINS THRU BRIDGE DECK
TRAFFIC LOOP (2) 6'-0"x15'-0" (SEE NOTE)
SAW CUT FOR TRAFFIC LOOP LEADS
SIGNAL PULL BOXES(4) CAST IN RAIL
REINFORCED CONCRETE BEARING PAD
STEEL REINFORCEMENT
COLD JOINT
DOWELS
SCALE LOCATION
DIRECTION OF TRAVEL
NOTES
1 FOR ANCHOR BOLT SPACING AND LOCATION-SEE STREETER-AMET DRAWINGS.
2 ALL TRAFFIC LOOP TO BE A 3 WIRE LOOP #12 RHW (STRANDED) OR EQUIVALENT.
State of CALIFORNIA DEPARTMENT OF TRANSPORTATION
IN-MOTION WEIGHING I-5 AT MOKELUMNE RIVER CCO-33
TRANSPORTATION LABORATORY
LIST OF MATERIAL
D-837

FIGURE 4

PAT WIM SYSTEM - ANTELOPE WEIGH STATION

STATISTICAL WIM FRONT AXLE WEIGHT ERRORS vs. SPEED GROUPS

Speed Group mph	Stat. Data	Set 1	Set 2	Set 3	Set 4	Set 5	All Sets
All	n	144	205	114	246	266	975
	$\bar{x}$	5.7	4.7	4.2	3.7	2.0	3.8
	s	5.4	5.6	5.9	4.7	4.5	5.3

n=number of front axles weighed
x=average weight error in %
s=standard deviation of weight error in %

Set 1 April 21, 28, 29, 1981
Set 2 May 19-21, 1981
Set 3 Aug. 13, 26, 27, 1981
Set 4 Sept. 2, 3, 15, 16, 1981
Set 5 Oct. 6, 7, 27, 28, 1981

FIGURE 5

PAT WIM SYSTEM - ANTELOPE WEIGH STATION

STATISTICAL WIM SINGLE AXLE WEIGHT ERRORS vs. SPEED GROUPS

Speed Group mph	Stat. Data	Set 1	Set 2	Set 3	Set 4	Set 5	All Sets	*
All Groups	n	309	430	243	480	581	2043	
	x	4.5	4.0	3.0	2.8	0.7	2.7	yes
	s	5.7	5.8	6.2	5.3	5.0	5.7	
0-9.9	n	-	-	-	-	-	-	
	x	-	-	-	-	-	-	-
	s	-	-	-	-	-	-	
10-14.9	n	5	3	1	-	5	14	
	x	-2.4	9.7	6.3	-	-5.4	-0.2	yes
	s	-	-	-	-	-	7.0	
15-19.9	n	6	6	10	19	18	59	
	x	1.0	1.9	0.6	-0.8	-1.3	-0.2	yes
	s	5.1	6.5	5.7	4.4	4.2	5.0	
20-24.9	n	45	46	21	27	37	176	
	x	3.3	5.4	0.7	2.7	0.2	2.8	yes
	s	3.9	9.3	4.8	4.7	5.5	6.5	
25-29.9	n	53	109	52	106	125	445	
	x	4.3	3.5	3.6	2.5	0.7	2.6	yes
	s	4.4	5.1	5.8	4.9	5.2	5.3	
30-34.9	n	76	106	79	150	194	605	
	x	4.9	3.9	3.4	3.5	1.0	2.9	yes
	s	5.0	5.1	6.6	4.5	4.2	5.1	
35-39.9	n	78	111	51	100	111	451	
	x	4.6	3.6	3.3	2.4	1.3	2.9	yes
	s	5.0	5.6	5.9	5.7	5.8	5.7	
40-44.9	n	38	30	20	55	79	222	
	x	5.9	5.6	3.8	4.1	-	3.1	yes
	s	8.9	4.3	7.5	5.2	5.0	6.5	
45-49.9	n	8	17	6	20	11	62	
	x	7.4	4.6	-0.4	1.2	3.4	3.1	no
	s	8.6	5.0	1.6	9.8	4.5	7.5	
50-54.9	n	-	2	2	3	1	8	
	x	-	4.4	-1.0	2.4	-	1.8	yes
	s	-	-	-	-	-	3.8	
55+	n	-	-	1	-	-	1	
	x	-	-	8.0	-	-	-	-
	s	-	-	-	-	-	-	

n=number of single axles weighed
x=average weight error in %
s=standard deviation of weight error in %

* = Met accuracy criteria of
$\bar{x}$ = + 4%, S=7?
See page 26

FIGURE 6

PAT WIM SYSTEM - ANTELOPE WEIGH STATION

STATISTICAL WIM TANDEM AXLE WEIGHT ERRORS vs. SPEED GROUPS

Speed Group mph	Stat. Data	Set 1	Set 2	Set 3	Set 4	Set 5	All Sets	*
All Groups	n	182	264	151	340	357	1294	
	$\bar{x}$	1.4	1.4	2.5	-0.2	-1.8	0.2	yes
	s	3.4	3.4	5.4	3.6	3.2	4.0	
0-9.9	n	-	-	-	-	-	-	
	$\bar{x}$	-	-	-	-	-	-	-
	s	-	-	-	-	-	-	
10-14.9	n	-	1	2	-	-	3	
	$\bar{x}$	-	-2.0	-2.4	-	-	-2.3	-
	s	-	-	-	-	-	-	
15-19.9	n	2	7	-	13	10	32	
	$\bar{x}$	0.7	1.2	-	-1.9	-3.0	-1.4	yes
	s	-	1.8	-	3.7	4.5	3.9	
20-24.9	n	24	29	16	24	42	135	
	$\bar{x}$	0.9	1.3	-1.4	-0.6	-1.7	-0.4	yes
	s	3.2	2.1	1.7	2.0	2.0	2.6	
25-29.9	n	43	66	31	91	85	316	
	$\bar{x}$	2.1	1.4	2.4	-0.3	-1.6	0.3	yes
	s	3.2	2.6	4.6	2.3	2.5	3.2	
30-34.9	n	50	70	44	97	108	369	
	$\bar{x}$	1.6	1.2	1.7	0.1	-1.3	0.3	yes
	s	2.6	3.3	4.2	3.2	3.0	3.4	
35-39.9	n	43	64	29	67	67	270	
	$\bar{x}$	0.2	1.2	3.0	-1.5	-2.3	-0.3	yes
	s	3.4	4.2	5.0	3.6	3.5	4.3	
40-44.9	n	19	24	17	38	35	133	
	$\bar{x}$	2.2	2.1	1.9	0.8	-2.6	0.5	no
	s	4.5	4.6	5.0	5.5	4.8	5.3	
45-49.9	n	1	3	6	8	8	26	
	$\bar{x}$	7.4	4.7	10.8	4.7	-1.7	4.1	no
	s	-	-	5.8	3.8	3.0	6.1	
50-54.9	n	-	-	4	2	2	8	
	$\bar{x}$	-	-	12.9	6.5	-5.2	6.8	no
	s	-	-	-	-	-	10.5	
55+	n	-	-	2	-	-	2	
	$\bar{x}$	-	-	7.1	-	-	7.1	-
	s	-	-	-	-	-	-	

n=number of tandem axles weighed
$\bar{x}$=average weight error in %
s=standard deviation of weight error in %

* = Met accuracy criteria of $\bar{x}$ = + 4%, S = 5?
See page 26

FIGURE 7

PAT WIM SYSTEM - ANTELOPE WEIGH STATION

STATISTICAL WIM TRUCK GROSS WEIGHT ERRORS vs. SPEED GROUPS

Speed Group mph	Stat. Data	Set 1	Set 2	Set 3	Set 4	Set 5	All Sets	*
All Groups	n	144	205	114	246	266	975	
	$\bar{x}$	2.4	2.2	2.3	0.8	-1.0	1.0	yes
	s	2.4	2.6	4.3	2.9	2.3	3.2	
0-9.9	n	-	-	-	-	-	-	
	$\bar{x}$	-	-	-	-	-	-	-
	s	-	-	-	-	-	-	
10-14.9	n	1	1	1	-	1	4	
	$\bar{x}$	2.8	4.4	-1.4	-	-5.7	0	-
	s	-	-	-	-	-	3.9	
15-19.9	n	2	5	2	9	8	26	
	$\bar{x}$	1.0	0.5	0.3	-1.8	-2.7	-1.2	yes
	s	-	-	-	2.5	1.9	2.8	
20-24.9	n	19	21	11	16	24	91	
	$\bar{x}$	1.8	2.7	-0.9	0.6	-1.6	0.6	yes
	s	1.3	2.6	1.2	2.4	1.6	2.6	
25-29.9	n	29	50	23	59	61	222	
	$\bar{x}$	2.7	2.0	2.5	0.4	-1.0	0.9	yes
	s	2.0	1.9	3.4	2.0	1.8	2.6	
30-34.9	n	38	53	36	72	84	283	
	$\bar{x}$	2.7	2.0	2.1	1.4	-0.5	1.2	yes
	s	1.8	2.2	4.6	2.6	2.0	2.9	
35-39.9	n	35	51	23	50	50	209	
	$\bar{x}$	1.9	1.9	3.0	-0.1	-1.1	0.8	yes
	s	2.9	3.0	4.0	2.9	3.0	3.4	
40-44.9	n	17	17	11	29	31	105	
	$\bar{x}$	2.9	3.3	2.2	2.0	-1.5	1.3	yes
	s	3.4	3.7	4.2	3.8	2.8	4.0	
45-49.9	n	3	6	4	9	6	28	
	$\bar{x}$	4.9	4.0	5.8	1.8	-0.6	2.6	yes
	s	-	1.6	-	4.3	2.0	3.8	
50-54.9	n	-	1	2	2	1	6	
	$\bar{x}$	-	4.7	9.4	3.7	-4.6	4.4	-
	s	-	-	-	-	-	5.9	
55+	n	-	-	1	-	-	1	
	$\bar{x}$	-	-	7.3	-	-	7.3	-
	s	-	-	-	-	-	-	

n=number of trucks weighed
x=average weight error in %
s=standard deviation of weight error in %

* = Met accuracy criteria of
$\bar{x}$ = + 4%, S=4?
See page 26

FIGURE 8

STREETERAMET WIM SYSTEM - CASTAIC WEIGH STATION

STATISTICAL WIM FRONT AXLE WEIGHT ERRORS vs. SPEED GROUPS

Speed Group mph	Stat. Data	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7	All Sets
All Groups	n	53	208	227	196	79	243	190	1196
	$\bar{x}$	1.5	2.6	2.9	-1.7	-2.7	-5.1	-5.2	-1.2
	s	5.9	6.3	6.0	5.8	5.3	5.4	5.2	6.7

n=number of front axles weighed
$\bar{x}$=average weight error in %
s=standard deviation of weight error in %

Set 1 Oct. 9-10, 1980
Set 2 Oct. 28-31, 1980
Set 3 Nov. 11-14, 1980
Set 4 Feb. 3-6, 1981
Set 5 March 17-18, 1981
Set 6 June 1-4, 1981
Set 7 Sept. 15-18, 1981

FIGURE 9

STREETERAMET WIM SYSTEM - CASTAIC WEIGH STATION

STATISTICAL WIM SINGLE AXLE WEIGHT ERRORS vs. SPEED GROUPS

Speed Group mph	Stat. Data	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7	All Sets	*
All Groups	n	114	502	499	343	155	503	348	2464	
	$\bar{x}$	4.4	3.0	3.4	-1.4	-2.2	-5.0	-4.6	-0.5	no
	s	9.0	8.9	8.4	7.4	7.1	6.2	7.6	8.6	
0-9.9	n	-	5	1	1	-	4	3	14	
	$\bar{x}$	-	-20.5	-6.8	-10.8	-	-17.5	-14.0	-16.6	no
	s	-	-	-	-	-	-	-	18.3	
10-14.9	n	5	5	20	9	5	24	32	100	
	$\bar{x}$	-0.5	-1.9	-2.8	-5.9	-3.1	-8.5	-7.2	-5.8	no
	s	-	-	5.8	2.4	-	3.3	5.6	5.5	
15-19.9	n	6	53	61	48	22	100	65	355	
	$\bar{x}$	-0.1	-2.2	-0.1	-4.4	-2.5	-6.6	-6.6	-4.2	no
	s	6.2	5.7	6.5	6.6	7.5	5.8	5.7	6.6	
20-24.9	n	40	181	138	112	54	180	127	832	
	$\bar{x}$	1.2	0.5	1.9	-3.1	-3.6	-5.2	-4.9	-2.0	no
	s	6.1	8.2	8.2	6.9	6.1	6.1	8.0	7.9	
25-29.9	n	34	158	171	113	55	143	91	765	
	$\bar{x}$	1.3	3.9	3.6	-0.6	-2.7	-4.7	-3.8	0.1	no
	s	6.1	7.4	7.8	6.3	7.7	5.7	7.5	7.8	
30-34.9	n	18	87	82	50	18	44	23	322	
	$\bar{x}$	14.8	9.5	7.0	3.9	3.5	0.4	0.1	6.0	no
	s	9.0	7.5	7.2	9.0	5.2	5.8	7.9	8.5	
35-39.9	n	11	13	20	9	-	7	7	67	
	$\bar{x}$	13.3	14.1	13.2	2.0	-	1.6	8.0	10.1	no
	s	8.5	7.1	9.5	4.4	-	3.2	4.9	8.9	
40-44.9	n	-	-	6	1	1	1	-	9	
	$\bar{x}$	-	-	12.4	-5.4	8.4	-6.1	-	7.9	no
	s	-	-	10.3	-	-	-	-	11.2	

n=number of single axles weighed
$\bar{x}$=average weight error in %
s=standard deviation of weight error in %
* = Met accuracy criteria of $\bar{x}$ = ± 4%, S=7? See page 26

FIGURE 10

STREETERAMET WIM SYSTEM - CASTAIC WEIGH STATION

STATISTICAL WIM TANDEM AXLE WEIGHT ERRORS vs. SPEED GROUPS

Speed Group mph	Stat. Data	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7	All Sets	*
All Groups	n	68	233	256	275	106	310	270	1518	
	$\bar{x}$	-3.9	-1.7	-1.6	-7.3	-7.7	-9.6	-9.3	-6.2	no
	s	5.0	6.8	6.8	7.8	5.7	5.7	6.2	7.4	
0-9.9	n	-	-	2	2	-	5	6	15	
	$\bar{x}$	-	-	-12.6	-11.0	-	-15.0	-17.2	-15.0	no
	s	-	-	-	-	-	-	4.1	3.6	
10-14.9	n	-	4	9	15	7	18	27	80	
	$\bar{x}$	-	-6.1	-1.4	-8.6	-5.5	-8.8	-9.5	-7.7	no
	s	-	-	3.8	6.9	3.9	4.5	5.4	6.2	
15-19.9	n	7	34	15	31	13	59	46	205	
	$\bar{x}$	-4.0	-2.9	-4.7	-8.9	-9.3	-9.9	-9.2	-7.8	no
	s	2.9	5.5	8.6	4.7	5.0	5.0	5.7	6.1	
20-24.9	n	30	72	73	78	38	100	102	493	
	$\bar{x}$	-6.0	-5.7	-3.7	-9.5	-8.6	-11.0	-11.2	-8.5	no
	s	4.9	5.3	5.3	5.1	5.2	5.0	5.8	6.0	
25-29.9	n	23	81	104	94	35	84	69	490	
	$\bar{x}$	-2.6	-0.4	-1.8	-7.5	-8.1	-10.4	-8.1	-5.5	no
	s	4.8	6.2	5.8	7.8	4.8	5.8	5.8	7.2	
30-34.9	n	6	34	45	42	11	33	16	187	
	$\bar{x}$	-0.3	2.1	1.5	-5.1	-5.0	-5.3	-1.9	-2.4	no
	s	4.1	4.0	5.2	8.3	8.3	3.7	4.3	6.9	
35-39.9	n	2	8	7	11	-	10	4	42	
	$\bar{x}$	-0.2	12.1	6.9	4.6	-	-2.1	-1.6	4.0	no
	s	-	5.7	9.0	11.0	-	3.9	-	9.2	
40-44.9	n	-	-	1	2	2	1	-	6	
	$\bar{x}$	-	-	40.0	13.2	4.3	15.8	-	15.1	no
	s	-	-	-	-	-	-	-	12.4	

n=number of tandem axle weighed
$\bar{x}$=average weight error in %
s=standard deviation of weight error in %
* = Met accuracy criteria of $\bar{x} = \pm 4\%$, S=5? See page 26

FIGURE 11

STREETERAMET WIM SYSTEM - CASTAIC WEIGH STATION

STATISTICAL WIM TRUCK GROSS WEIGHT ERRORS vs. SPEED GROUPS

Speed Group mph	Stat. Data	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7	All Sets	*
All Groups	n	53	208	227	196	79	243	190	1196	
	$\bar{x}$	-0.2	0.7	1.1	-4.9	-5.4	-7.5	-7.4	-3.6	no
	s	6.5	5.9	5.9	5.9	4.4	4.5	4.8	6.6	
0-9.9	n	-	1	1	1	-	3	3	9	
	$\bar{x}$	-	-22.3	13.2	-11.0	-	-16.1	-16.4	-13.1	no
	s	-	-	-	-	-	-	-	9.8	
10-14.9	n	1	3	8	8	4	12	19	55	
	$\bar{x}$	-0.1	-2.6	-2.1	-8.0	-4.7	-8.6	-8.1	-6.6	no
	s	-	-	3.4	4.0	-	3.0	3.6	4.2	
15-19.9	n	5	27	21	25	10	46	33	167	
	$\bar{x}$	-3.0	-2.7	-1.6	-6.9	-6.3	-8.5	-8.5	-6.2	no
	s	-	3.4	4.4	4.1	4.1	3.5	3.5	4.6	
20-24.9	n	21	67	63	57	28	82	70	388	
	$\bar{x}$	-3.2	-2.5	-1.1	-6.9	-6.6	-8.3	-9.1	-5.7	no
	s	4.2	4.0	4.8	4.0	3.4	3.7	3.9	5.1	
25-29.9	n	17	69	81	66	27	67	49	376	
	$\bar{x}$	-0.6	1.7	0.5	-4.8	-6.0	-7.8	-6.2	-3.1	no
	s	4.1	4.1	4.7	5.8	3.2	4.5	4.6	5.9	
30-34.9	n	6	34	41	31	9	26	13	160	
	$\bar{x}$	9.1	6.1	4.3	-1.4	-0.9	-2.8	-0.3	1.9	no
	s	8.1	5.3	4.3	6.8	6.0	3.8	3.2	6.4	
35-39.9	n	3	7	9	7	-	6	3	35	
	$\bar{x}$	9.9	12.4	11.8	3.8	-	-0.8	2.7	7.2	no
	s	-	5.1	6.1	4.7	-	2.6	-	7.2	
40-44.9	n	-	-	3	1	1	1	-	6	
	$\bar{x}$	-	-	17.3	9.8	5.3	7.2	-	12.4	
	s	-	-	-	-	-	-	-	6.9	

n=number of trucks weighed
$\bar{x}$=average weight error in %
s=standard deviation of weight error in %
* = Met accuracy criteria of $\bar{x}$ = ± 4%, S=4? See page 26

FIGURE 12

Statistical Summary of WIM Axle Spacing Error vs Speed Groups

PAT WIM System - Test Date: May 19-21, 1981

n=sample size; $\bar{x}$=ave. axle spacing error (ft.); s=standard deviation of error

		Spacings (ft.)			
Speed Group	Stat. Data	Adjacent Axle >6 ft.	Tandem Axle <6 ft.	Steering Axle to Axle #2	Overall Axle Spacing Steering Axle to Last Axle
Ø-9.9	n				
	$\bar{x}$	-	-	-	-
	s				
10-14.9	n	3	1		1
	$\bar{x}$	-0.1	0	-	-0.4
	s	0.3	-		-
15-19.9	n	4	3		3
	$\bar{x}$	-0.4	-0.2	-	-0.4
	s	0.3	0.1		0.4
20-24.9	n	43	28		18
	$\bar{x}$	-0.1	0.1	-	-0.1
	s	0.3	0.2		0.3
25-29.9	n	97	59		41
	$\bar{x}$	-0.1	0.1	-	-0.1
	s	0.2	0.2		0.3
30-34.9	n	102	60		44
	$\bar{x}$	-0.1	0.1	-	-0.2
	s	0.2	0.2		0.3
35-39.9	n	107	55		43
	$\bar{x}$	-0.1	0.1	-	-0.1
	s	0.2	0.2		0.4
40-44.9	n	32	21		15
	$\bar{x}$	-0.1	0.1	-	-0.3
	s	0.2	0.3		0.4
45-49.9	n	14	3		6
	$\bar{x}$	-0.1	0.2	-	0.1
	s	0.3	0.1		0.4
50-54.9	n	1			1
	$\bar{x}$	0	-	-	0
	s	-			-
All Groups	n	403	230	172	172
	$\bar{x}$	-0.1	0.1	-0.2	-0.1
	s	0.2	0.2	0.2	0.3

Note: Overall average truck speed at the Antelope weigh Station - 32 mph (s=7 mph, n=171 trucks).

FIGURE 13

Statistical Summary of WIM Axle Spacing Error vs Speed Groups

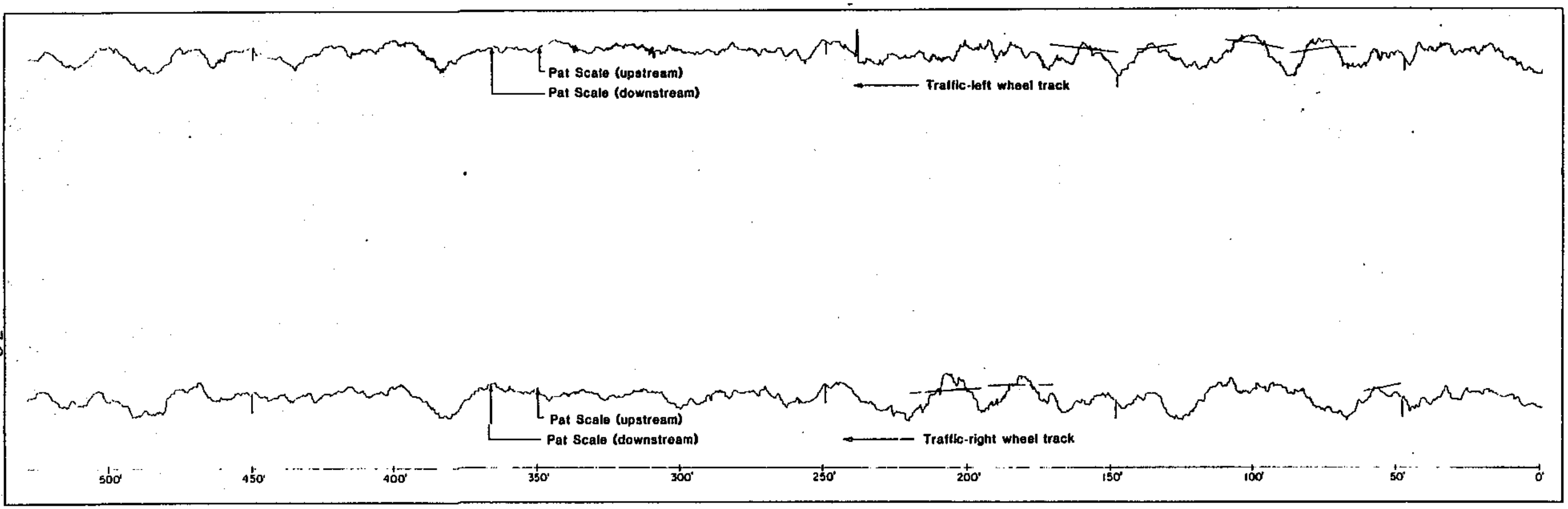
StreeterAmet System - Test Date: Nov. 11-13, 1980

n=sample size; $\bar{x}$=ave. axle spacing error (ft.); s=standard deviation of error

Speed Group	Stat. Data	Spacings (ft.) Adjacent Axle >6 ft.	Tandem Axle <6 ft.	Steering Axle to Axle #2	Overall Axle Spacing First to Last Axle
Ø-9.9	n	2	2	-	1
	$\bar{x}$	2.2	0.6		5.5
	s	0.9	0.2		-
10-14.9	n	17	5	-	6
	$\bar{x}$	0.8	0.4		2.6
	s	1.1	0.3		2.7
15-19.9	n	37	11	-	14
	$\bar{x}$	0.7	0.1		2.0
	s	0.7	0.2		1.6
20-24.9	n	97	60	-	44
	$\bar{x}$	0.6	0.2		1.6
	s	0.9	0.2		1.6
25-29.9	n	133	82	-	59
	$\bar{x}$	0.5	0.1		1.3
	s	0.6	0.1		1.0
30-34.9	n	64	38	-	32
	$\bar{x}$	0.5	0.1		1.2
	s	0.5	0.1		0.9
35-39.9	n	17	6	-	8
	$\bar{x}$	0.3	0.1		0.8
	s	0.3	0.1		0.6
40-44.9	n	4	1	-	3
	$\bar{x}$	0.2	-0.1		0.2
	s	0.8	-		0.1
All Groups	n	371	205	167	167
	$\bar{x}$	0.6	0.1	0.2	1.4
	s	0.7	0.2	0.3	1.3

Note: Overall average truck speed at the Castaic weigh station - 26 mph (s=6 mph, n=167 trucks).

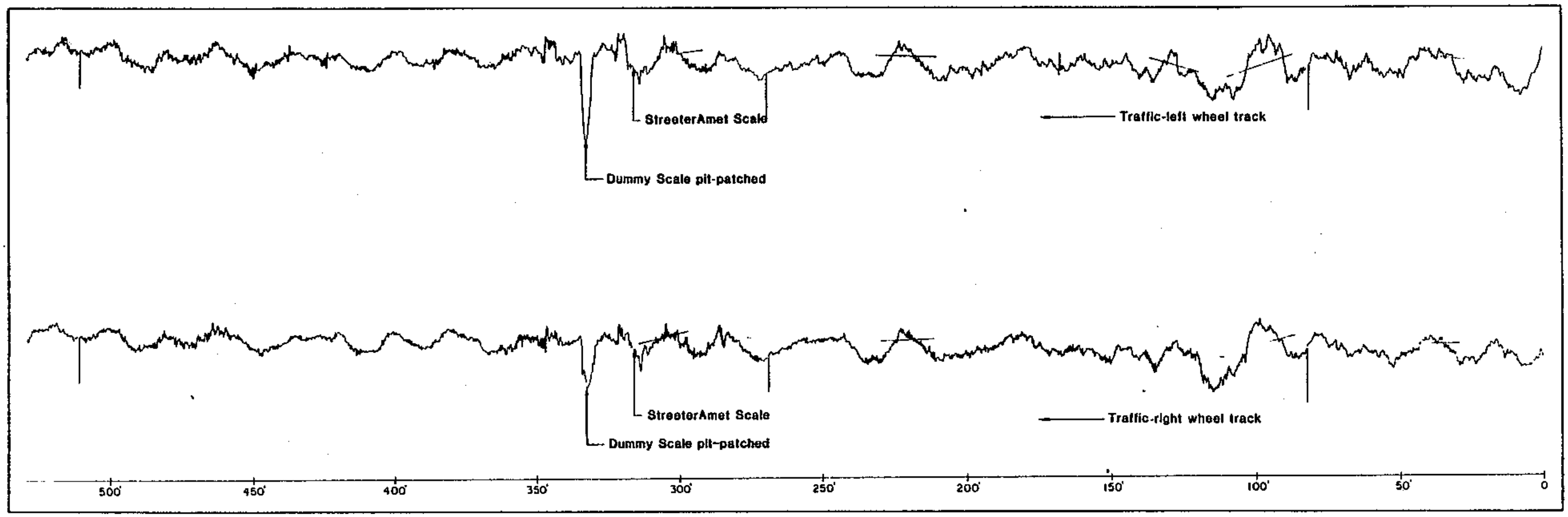
FIGURE 14



03-SAC-80 (WESTBOUND)

CHP ANTELOPE WEIGH STATION
PROFILOGRAM OF PAT WEIGH-IN-MOTION SCALE LANE

Profile Date: April 14, 1981 (morning, clear, sunny)
Profile Index (rt. wheel track): 28
Profile Index (lt. wheel track): 23

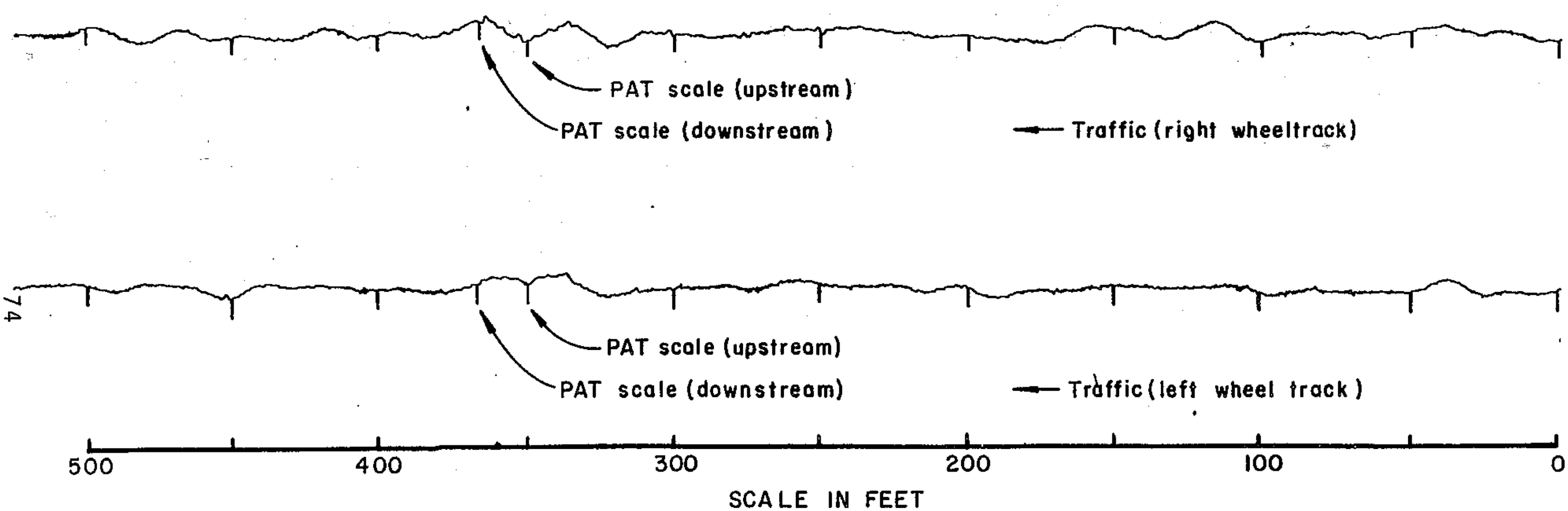


07-LA-5 (NORTHBOUND)

CHP CASTAIC WEIGH STATION
PROFILOGRAM OF STREETERAMET
WEIGH-IN-MOTION SCALE LANE

Profile Date: May 2, 1981 (morning, clear, sunny)
Profile Index (rt. wheel track): 33,28 (est.-no patch)
Profile Index (lt. wheel track): 40,31 (est.-no patch)

FIGURE 16

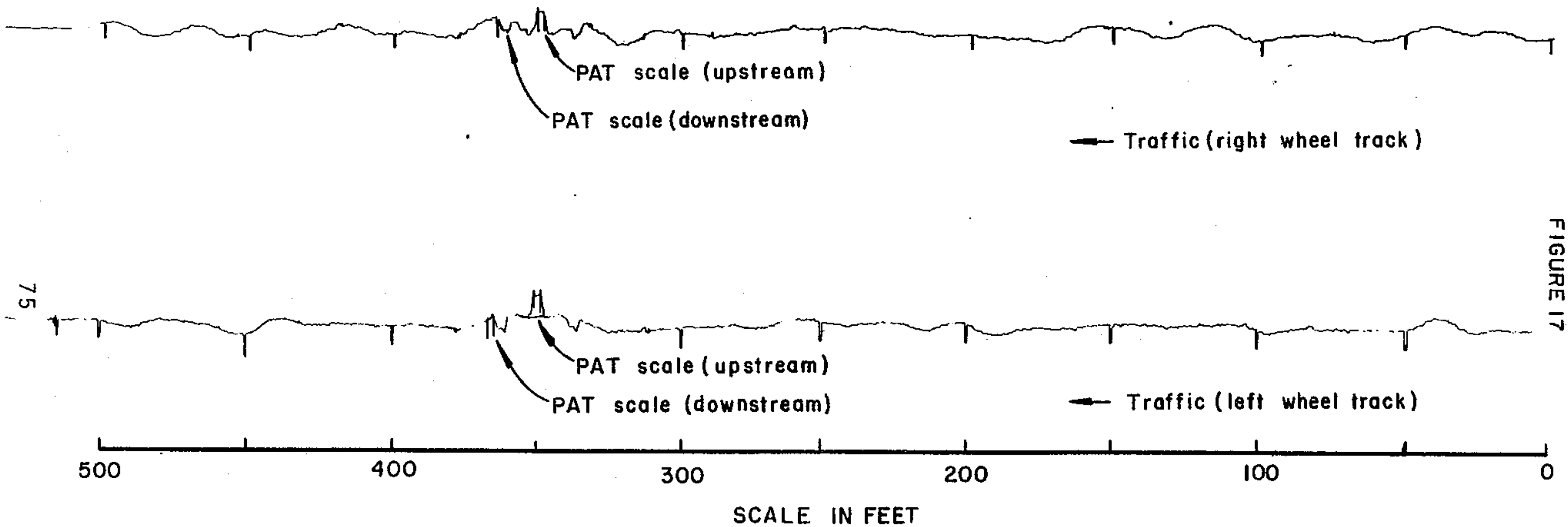


10-SJ-99(21.9/28.6) Southbound Outside Lane

LODI WIM SITE
PROFILOGRAM OF SCALE LANE BEFORE SCALE INSTALLATION

Profile Date: June 29, 1981
Profile Index (rt. wheel track): 3.0
Profile Index (lt. wheel track): 1.5

FIGURE 17

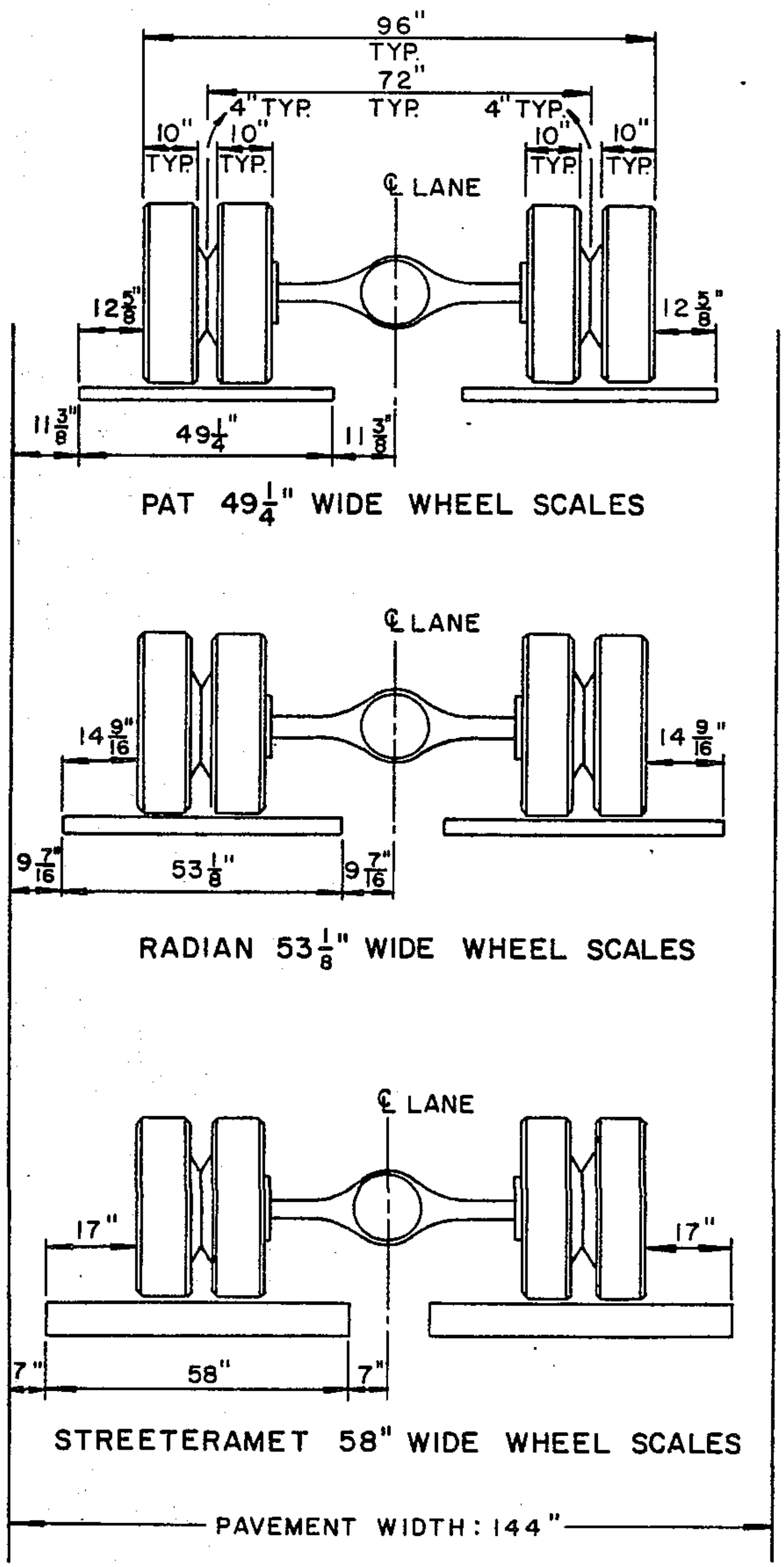


10-SJ-99(21.9/28.6) Southbound Outside Lane

LODI WIM SITE
PROFILOGRAM OF PAT WEIGH-IN-MOTION SCALE LANE

Profile Date: July 3, 1981
Profile Index (rt. wheel track): 3.5
Profile Index (lt. wheel track): 3.5

FIGURE 18



WIDTH OF WHEEL SCALES

Figure 19
PAT/Columbia Raw Block Data

```
0000 0000
0016 0000 0000 0000 0015 0005 2B0A 020F 5109 0000 0000 0000 0000 0000 0000 3030
006E 0064 0000 0020 0075 0077 0020 0068 002C 0020 0034 0133 0020 003B 0027 0020
10D7 0191 0225 0035 0043 FFFF 006F 004A 0000 0020 0056 00AB 0020 0066 002A 0020
0080 00DE 0020 00B9 0029 0020 1673 0116 0214 0035 0042 FFFF 0070 003B 0000 0020
00AD 0081 0020 0915 0182 00DA 0015 0020 FFFF 0071 0026 0000 0020 004E 0067 0020
0487 0195 008D 0015 0043 FFFF 0072 005A 0000 0020 007E 0064 0020 006E 00B8 0020
0067 0063 0020 0055 00C5 0020 1410 0120 0266 0032 0042 FFFF 0073 003F 0000 0020
0056 00A6 0029 05D4 018B 00EE 0015 0041 FFFF 0000 0000 0000 0000 0000 0000 0016
```

Block 2

```
0000 0000
0017 0000 0000 0000 0016 0005 2E0A 0225 5109 0000 0000 0000 0000 0000 0000 3030
0074 001E 0000 0020 0018 0063 0020 021F 0217 008A 000A 0020 FFFF 0075 0072 0000
0020 00A8 0090 0020 0095 002A 0020 00A8 0124 0020 00A4 0027 0020 1DC1 011E 0223
0035 0041 FFFF 0076 005A 0000 0020 0031 0090 0020 0034 002B 0020 0027 00C2 0020
0024 00B5 0020 0A63 0110 0253 0034 0042 FFFF 0077 004B 0000 0020 0051 00DA 0020
0614 00F8 0135 0015 0041 FFFF 0078 0044 0000 0020 004E 00B3 0020 05AE 017E 00E5
0015 0041 FFFF 0079 0055 0000 0020 0033 00AE 0020 0036 002A 0020 002F 00BA 0020
002A 00BA 0020 0AE1 014D 026E 0034 0041 FFFF 0000 0000 0000 0000 0000 7A00 6C00
```

Block 3

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0000 0000
0018 0000 0000 0000 0017 0005 330A 020C 5109 0000 0000 0000 0000 0000 0000 3030
007A 006C 0000 0020 0089 0067 0020 0085 002B 0020 008A 011D 0020 00B0 0029 0020
1B0C 00BF 0211 0035 0042 FFFF 007B 0054 0000 0020 003B 00AE 0020 0037 0029 0020
0030 00BA 0020 0029 00B9 0020 0B2C 01CD 0265 0034 0043 FFFF 007C 005E 0000 0020
0082 008E 0020 007B 002D 0020 003E 0130 0020 0041 0029 0020 1284 0179 022D 0035
0043 FFFF 007D 0060 0000 0020 0055 0068 0020 0055 002B 0020 0037 0133 0020 0045
0027 0020 0F3D 01B9 021E 0035 0043 FFFF 007E 0039 0000 0020 006F 00B9 0020 068B
0123 00EA 0015 0042 FFFF 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0018
```

Block 4

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0000 0000
0019 0000 0000 0000 0018 0005 370A 0208 5109 0000 0000 0000 0000 0000 0000 3030
007F 0023 0000 0020 0029 0082 0020 001F 00CA 0034 0429 01D4 0182 000B 0043 FFFF
0080 0060 0000 0020 009F 00B5 0020 009A 002D 0020 00AA 00E7 0020 00AF 0054 0020
1D77 00C8 0239 0034 0042 FFFF 0081 0047 0000 0020 0045 008D 0020 0572 0169 00F4
0015 0041 FFFF 0082 0077 0000 0020 00A6 0090 0020 009C 00B0 0020 0088 005F 0020
0085 00B2 0020 1B93 0195 0263 0032 0043 FFFF 0083 0051 0000 0020 0081 0094 0020
0099 0025 0020 0056 00DF 0020 0040 0029 0020 1360 01A5 0220 0035 0043 FFFF 0000
0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 8400 6800
```

Block 5

```
0000 0000
001A 0000 0000 0000 0019 0005 380A 022F 5109 0000 0000 0000 0000 0000 0000 3030
0084 0068 0000 0020 0098 00B4 0020 009F 0027 0020 0083 0099 0020 009C 002B 0020
1B71 0191 01B8 0035 0043 FFFF 0085 001F 0000 0020 0027 0076 0020 02B7 01AF 00BD
000A 0020 FFFF 0086 0057 0000 0020 004D 0067 0020 004A 002A 0020 004A 011F 0020
004F 0026 0020 0F43 01AE 01FB 0035 0042 FFFF 0087 005A 0000 0020 005C 00AB 0020
005D 002D 0020 0AB9 00E6 010A 001F 0043 FFFF 0088 006B 0000 0020 0039 00AC 0020
003B 002A 0020 0030 00B8 0020 0024 00C1 0020 0BFD 0149 0268 0034 0043 FFFF 0000
0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 001A
```

Block 6

```
0000 0000
001B 0000 0000 0000 001A 0005 390A 0225 5109 0000 0000 0000 0000 0000 0000 3030
0089 0085 0000 0020 0060 0061 0020 00C4 002B 0020 0061 0109 0020 006D 0028 0020
18AD 0173 01E2 0035 0043 FFFF 008A 0057 0000 0020 0055 0090 0020 002B 009C 0020
0024 0084 0020 0024 009D 0020 0B2A 0140 0269 0032 0041 FFFF 008B 0056 0000 0020
005F 0061 0020 0017 0083 003C 07F0 008D 00A7 001E 0047 FFFF 008C 0057 0000 0020
0079 008C 0020 0073 0029 0020 0059 013B 0020 0050 0028 0020 133E 0153 01C8 0035
0043 FFFF 008D 0040 0000 0020 004F 00A8 0020 059B 0119 012A 0015 0020 FFFF 0000
0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 8E00 6B00
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PAT/Columbia Decoded Block Data

```
A1      2.3   KIPS     .0 FT.
A2      4.4   KIPS   10.3 FT.
A3      3.6   KIPS   22.4 FT.
A4      2.8   KIPS    3.4 FT.
34      6.4T  KIPS     **

       13.13 KIPS  44.1 FT.   49.9 MPH   12     C

RUN NUMBER    83 -   2 AXLES
A1       .5   KIPS     .0 FT.    A
A2       .2   KIPS    3.3 FT.    E
12       .7T  KIPS     **

         .75 KIPS 651.7 FT.   21.3 MPH  999     D

***** BLOCK     5     CA99 TYPE 5 10/08/81 10:25:25 LODI

RUN NUMBER    84 -   5 AXLES
A1      7.0   KIPS     .0 FT.
A2      7.6   KIPS    8.5 FT.
A3      4.4   KIPS   15.9 FT.
A4      4.8   KIPS   10.4 FT.
A5      4.7   KIPS   16.9 FT.

       28.45 KIPS  55.3 FT.   50.9 MPH   50     C

RUN NUMBER    85 -   2 AXLES
A1      3.0   KIPS     .0 FT.    A
A2      5.6   KIPS   14.2 FT.    A

        8.60 KIPS  19.5 FT.   51.9 MPH   10

RUN NUMBER    86 -   4 AXLES
A1      7.3   KIPS     .0 FT.
A2     12.0   KIPS    9.3 FT.
A3      7.3   KIPS    4.1 FT.
23     19.3T  KIPS     **
A4      5.5   KIPS   30.7 FT.

       32.11 KIPS  52.8 FT.   59.3 MPH   42     B

RUN NUMBER    87 -   2 AXLES
A1      2.9   KIPS     .0 FT.
A2      6.8   KIPS   13.1 FT.

        9.71 KIPS  19.2 FT.   58.3 MPH   21     C

RUN NUMBER    88 -   2 AXLES
A1       .6   KIPS     .0 FT.    A
A2       .7   KIPS    8.0 FT.    A

        1.36 KIPS  12.3 FT.   58.3 MPH  999

RUN NUMBER    89 -   2 AXLES
A1      1.0   KIPS     .0 FT.    A
A2       .9   KIPS    9.7 FT.    A

        1.92 KIPS  14.6 FT.   58.3 MPH   10

***** BLOCK     6     CA99 TYPE 5 10/08/81 10:26:21 LODI
```

APPENDIX

A. WIM Project Chronology

B. Statistics

C. Graphs

D. General Description of the PAT WIM In-Motion Truck Weighing System

E. General Description of the StreeterAmet Rollweigh In-Motion Truck Weighing System

F. Static Scale Tests in the Laboratory

G. StreeterAmet WIM Scale Installation Procedure

H. PAT WIM Scale Installation Procedure

I. Preparation and First Test of the StreeterAmet WIM System at the I-5 Site

J. StreeterAmet Scale Structural Deficiencies

K. StreeterAmet Scale Rework

L. In-Laboratory Evaluation of StreeterAmet Reworked Wheel Scale

M. Outline Requirements for a WIM System

N. Errors in In-Motion Axle Spacing Measurements

APPENDIX A

WIM Project Chronology

April 1976	Caltrans unpublished interim report CA-DOT-TL-1594-1-76-11, "Weighing-In-Motion in California", concluded that further work was needed to develop a more reliable operational weighing transducer (axle scale) and further work was needed to improve the reliability of WIM instrumentation systems. The above interim report covered the work done in testing the Rainhart Model 880 wheel transducers with supportive WIM instrumentation built by Caltrans. Turnkey WIM systems were unavailable from industry at that period.
July 1977	Subsequent state-funded feasibility study, "Improve Performance/Reliability of Dynamic Truck Weighing Scales", was started to follow up on recommendations set forth in the unpublished interim report.
June 1978	Interim report published as final report, "Dynamic Measurements of Commercial Highway Vehicles", No. FHWA-CA-TL-78-17, in June 1978. Contents, findings and recommendations of the final report were the same as that for the interim report.

May 1979 — Completed state-funded study project, "Improve Performance/Reliability of Dynamic Truck Weighing Scales", and work documented in Summary Report. The design study and investigation concluded that currently available commercial WIM systems should meet WIM objectives/requirements. Decision made to purchase such systems with state funds for evaluation. Purchase order issued with state funds for one PAT Model DAW-209 WIM system with two sets of scales and two StreeterAmet Rollweigh WIM systems with three sets of scales. State service contract issued to the Rainhart Company to remodel six Rainhart Model 880 wheel load transducers to new Model 882.

The present project was submitted to the FHWA for its possible participation and approval in July 1979. It evolved from the above state-funded feasibility study project.

Sept. 26, 1979 — Installed two sets of StreeterAmet axle scales in the outside lane at the I-5 Freeway site near the Mokelumne River Bridge.

Oct. 9, 1979 — Final components delivered for one complete StreeterAmet WIM data processor.

Oct. 10-11, 1979	StreeterAmet WIM system was not functional and was unable to weigh in-motion test truck. Furthermore, scales were found to be structurally inadequate to support wheel loads and rocked by passing loads. Removed all load cells from the two axle scales to prevent possible rocking damage from forthcoming opening of freeway to traffic. Replaced them with Caltrans-built dummy cells.
Oct. 12, 1979	I-5 Freeway opened to traffic. Late delivery of the StreeterAmet WIM system, compounded by it being nonfunctional and with structurally inadequate scales, resulted in no meaningful preliminary tests and evaluations prior to freeway opening. Lengthy scale repairs, coupled with WIM system problems, has resulted in no useful WIM data from this installation.
	Nondelivery of the PAT WIM system prior to the freeway opening resulted in losing the opportunity to evaluate it at this site.
December 1979	The third set of StreeterAmet scales, yet to be installed, were returned to the company for corrective rework. Later testing in the Caltrans Laboratory indicated increased static scale errors with the StreeterAmet retrofitted vertical check rods designed to prevent scale rocking. Check rods were not installed in later installations.

February 1980	The two sets of StreeterAmet axle scales, originally installed at the I-5 site on October 12, 1979, were removed and one set was replaced with the reworked third scale set. The second set was replaced with a laboratory built dummy scale platform. Both of the removed scale sets were structurally inadequate and were returned to Streeter-Amet's plant in Grayslake, Illinois for its rework.
March 1980	PAT WIM system delivered (about five months late). Plans to install it at the I-5 site were abandoned.
	Plans were abandoned to install Rainhart scales and PAT and StreeterAmet WIM systems at CHP Cordelia weigh station because of subsequent plans to remodel the station. New plans were formulated to install the PAT WIM system at the CHP Antelope weigh station and the StreeterAmet WIM system at the CHP Castaic weigh station.
May 1980	Installed the first set of PAT scales at the CHP Antelope weigh station.
July 1980	Installed scale set No. 2 of a reworked StreeterAmet axle scale at the CHP Castaic weigh station.

October 1980	Began full-scale program to accumulate WIM test data (axle and gross weights, axle spacings, speeds, etc.) from the PAT and StreeterAmet systems.
July 1981	Installed the second set of PAT WIM scales in the outside lane on southbound Highway 99 near Lodi, California. This installation evaluated the capability of the PAT system for collecting statistical vehicle data from a moving traffic stream.
October 1981	Accumulation of WIM test data completed.
June 1982	Final report on project is completed.

APPENDIX B - STATISTICS*

SA = Single Axle; TA = Tandem Axle; GW = Gross Weight

Figures	Sample Statistics	Chi-Squared	Frequency Distribution
StreeterAmet			
B-1	SA		
B-2		SA	
B-3			SA
B-4	TA		
B-5		TA	
B-6			TA
B-7	GW		
B-8		GW	
B-9			GW
PAT			
B-10	SA		
B-11		SA	
B-12			SA
B-13	TA		
B-14		TA	
B-15			TA
B-16	GW		
B-17		GW	
B-18			GW

*In-motion weight accuracies expressed as % error of static weights.

Figure B-1

SAMPLE STATISTICS

CASTAIC SINGLE AXLES - ALL

OBSERVATIONS= 2.4640E+03	MEAN= -.4994E+00	STD.DEV.= 8.5896E+00
MINIMUM= -.3462E+02	RANGE= 8.1937E+01	MAXIMUM= 4.7321E+01
VARIANCE= 7.3782E+01	SKEWNESS= 6.1184E-01	KURTOSIS= 4.4432E+00
COEFF. VAR.= -.1720E+04	AVG.DEV.= 6.6654E+00	RMS DEV.= 8.5879E+00

11 CELLS - CELL INTERVAL = 8

MIDPOINT	NO. OBS.	% TOTAL	Z-SCORE(RMS)
-.3200E+02	1.0	0.041	-3.668
-.2400E+02	11.0	0.446	-2.736
-.1600E+02	146.0	5.925	-1.805
-.8000E+01	739.0	29.992	-.873
7.7716E-15	900.0	36.526	0.058
8.0000E+00	488.0	19.805	0.990
1.6000E+01	133.0	5.398	1.921
2.4000E+01	34.0	1.380	2.853
3.2000E+01	5.0	0.203	3.784
4.0000E+01	6.0	0.244	4.716
4.8000E+01	1.0	0.041	5.647

ENTER:
1 - FOR PLOT
2 - FOR NEW CELL PARAMETERS
3 - FOR NEXT FILE
4 - FOR STOP

WHICH ? >2

NEW CELL MIDPOINT,INTERVAL ? >.5,1

Figure B-2

CHI-SQUARED TEST FOR GOODNESS OF FIT TO NORMAL CURVE

DATA FROM FILE: CASTS CHISQ A1

GROUP: CASTAIC SINGLE AXLES

NUMBER OF DATA POINTS = 2464

MEAN OF DATA POINTS = -.499409

SMALLEST DATA POINT = -34.61538

LARGEST DATA POINT = 47.32143

RMS DEVIATION = 8.587894

CHI SQUARED = 27817.878188 WITH 80 D.F.

F R E Q U E N C Y D I S T R I B U T I O N

FROM	TO	OBSERVED FREQUENCY	THEORETICAL FREQUENCY	CHI-SQUARE
-35	-34	1	1.181E-01	6.585E+00
-34	-33	0	7.173E-02	7.173E-02
-33	-32	0	1.114E-01	1.114E-01
-32	-31	0	1.706E-01	1.706E-01
-31	-30	0	2.579E-01	2.579E-01
-30	-29	0	3.846E-01	3.846E-01
-29	-28	0	5.657E-01	5.657E-01
-28	-27	0	8.210E-01	8.210E-01
-27	-26	2	1.176E+00	5.783E-01
-26	-25	0	1.660E+00	1.660E+00
-25	-24	0	2.314E+00	2.314E+00
-24	-23	1	3.181E+00	1.495E+00
-23	-22	4	4.314E+00	2.289E-02
-22	-21	2	5.773E+00	2.466E+00
-21	-20	1	7.620E+00	5.751E+00

Figure B-3

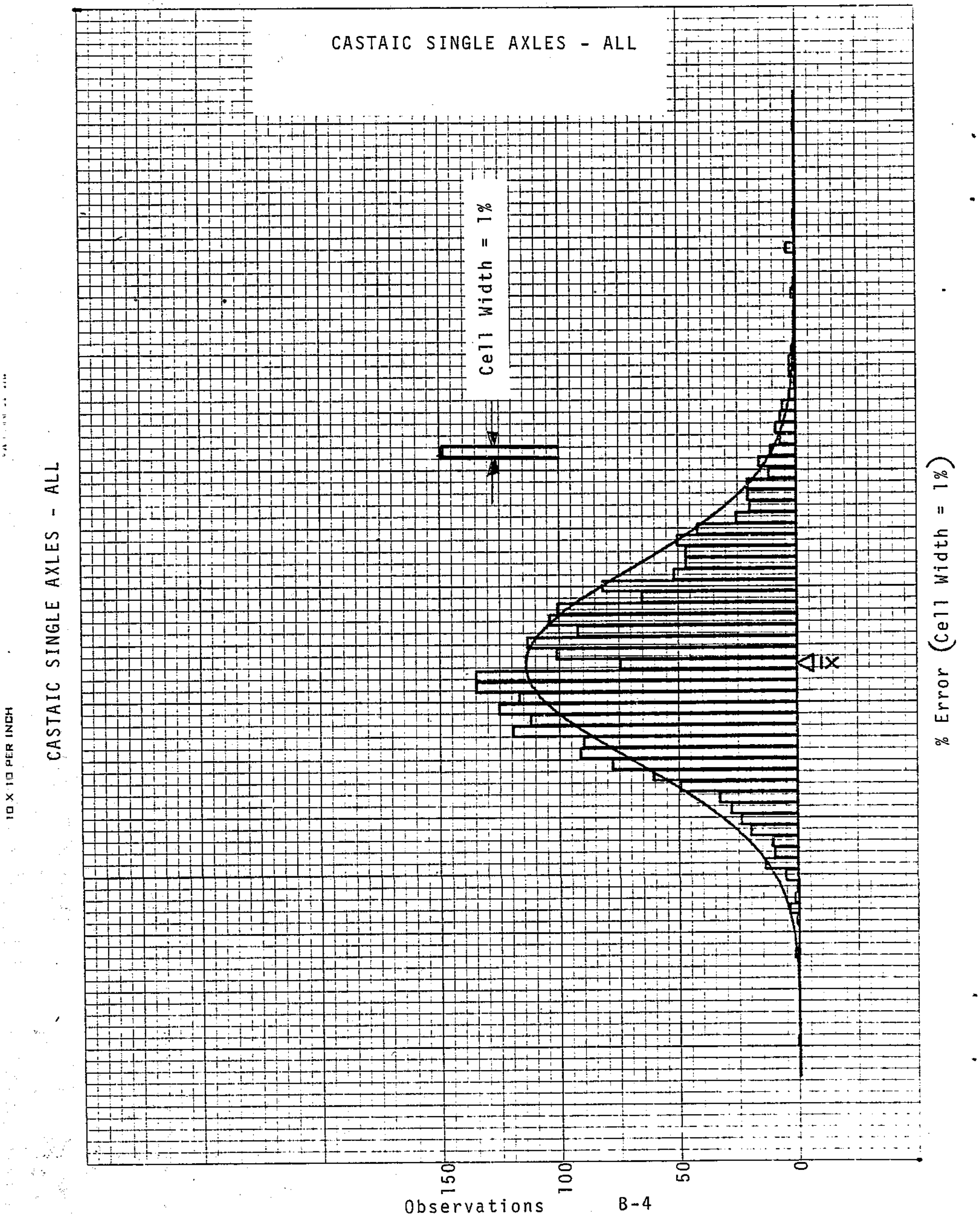

CASTAIC SINGLE AXLES - ALL
CASTAIC SINGLE AXLES - ALL
Cell Width = 1%
◁IX
% Error (Cell Width = 1%)
150
100
50
0
Observations
10 X 10 PER INCH

Figure B-4

SAMPLE STATISTICS

CASTAIC TANDEM AXLES - ALL

OBSERVATIONS=	1.5200E+03	MEAN=	-.6235E+01	STD.DEV.=	7.4568E+00
MINIMUM=	-.4900E+02	RANGE=	8.9052E+01	MAXIMUM=	4.0054E+01
VARIANCE=	5.5603E+01	SKEWNESS=	3.4713E-02	KURTOSIS=	6.5316E+00
COEFF. VAR.=	-.1196E+03	AVG.DEV.=	5.4782E+00	RMS DEV.=	7.4543E+00

12 CELLS - CELL INTERVAL = 8

MIDPOINT	NO. OBS.	% TOTAL	Z-SCORE(RMS)
-.5000E+02	1.0	0.066	-5.871
-.4200E+02	3.0	0.197	-4.798
-.3400E+02	3.0	0.197	-3.725
-.2600E+02	25.0	1.645	-2.652
-.1800E+02	136.0	8.947	-1.578
-.1000E+02	612.0	40.263	-.505
-.2000E+01	582.0	38.289	0.568
6.0000E+00	130.0	8.553	1.641
1.4000E+01	21.0	1.382	2.714
2.2000E+01	5.0	0.329	3.788
3.0000E+01	0.0	0.000	4.861
3.8000E+01	2.0	0.132	5.934

```
ENTER:
        1 - FOR PLOT
        2 - FOR NEW CELL PARAMETERS
        3 - FOR NEXT FILE
        4 - FOR STOP

      WHICH ? >2

NEW CELL MIDPOINT,INTERVAL ? >.5,1
```

Figure B-5

CHI-SQUARED TEST FOR GOODNESS OF FIT TO NORMAL CURVE

DATA FROM FILE: CASTT CHICK A1

GROUP: CASTAIC TANDEM AXLES

NUMBER OF DATA POINTS = 1520

MEAN OF DATA POINTS = -6.234691

SMALLEST DATA POINT = -48.99713

LARGEST DATA POINT = 40.0545

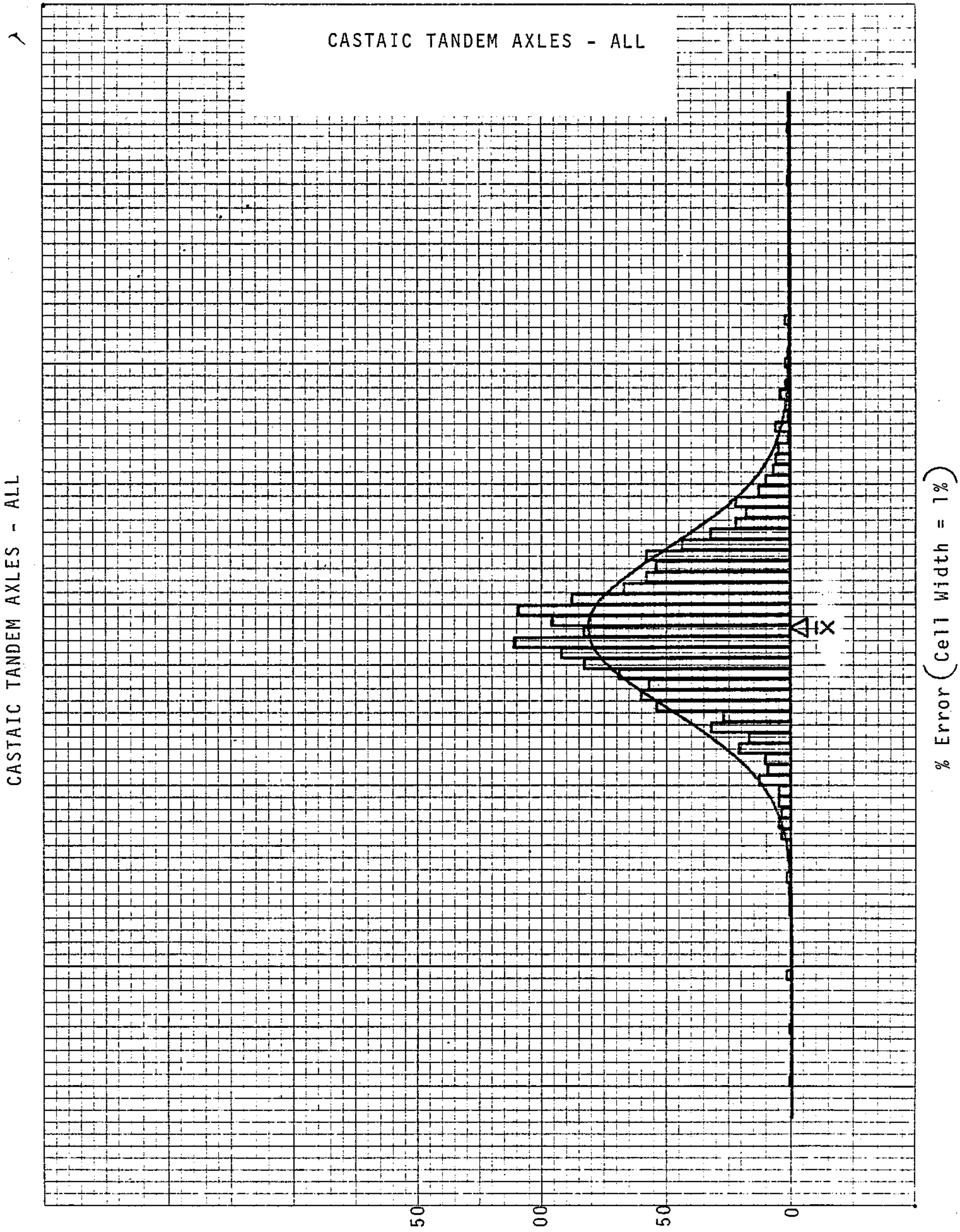
RMS DEVIATION = 7.454308

CHI SQUARED = 2.499715E+06 WITH 87 D.F.

F R E Q U E N C Y   D I S T R I B U T I O N

FROM	TO	OBSERVED FREQUENCY	THEORETICAL FREQUENCY	CHI-SQUARE
-49	-48	1	1.607E-05	6.223E+04
-48	-47	0	1.847E-05	1.847E-05
-47	-46	0	3.842E-05	3.842E-05
-46	-45	0	7.848E-05	7.848E-05
-45	-44	0	1.575E-04	1.575E-04
-44	-43	1	3.103E-04	3.220E+03
-43	-42	0	6.007E-04	6.007E-04
-42	-41	0	1.142E-03	1.142E-03
-41	-40	0	2.133E-03	2.133E-03
-40	-39	0	3.912E-03	3.912E-03
-39	-38	2	7.048E-03	5.636E+02
-38	-37	0	1.247E-02	1.247E-02
-37	-36	0	2.167E-02	2.167E-02
-36	-35	0	3.700E-02	3.700E-02
-35	-34	0	6.204E-02	6.204E-02

Figure B-6



Observations

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DIETZGEN CORPORATION
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Figure B-7

SAMPLE STATISTICS

CASTAIC GROSS AXLES WTS.

OBSERVATIONS= 1.1970E+03	MEAN= -.3575E+01	STD.DEV.= 6.6291E+00
MINIMUM= -.3312E+02	RANGE= 5.6765E+01	MAXIMUM= 2.3649E+01
VARIANCE= 4.3945E+01	SKEWNESS= 3.9632E-01	KURTOSIS= 4.4461E+00
COEFF. VAR.= -.1854E+03	AVG.DEV.= 5.0743E+00	RMS DEV.= 6.6264E+00

11 CELLS - CELL INTERVAL = 6

MIDPOINT	NO. OBS.	% TOTAL	Z-SCORE(RMS)
-.3400E+02	1.0	0.084	-4.591
-.2800E+02	3.0	0.251	-3.686
-.2200E+02	6.0	0.501	-2.781
-.1600E+02	44.0	3.676	-1.875
-.1000E+02	330.0	27.569	-.970
-.4000E+01	437.0	36.508	-.064
2.0000E+00	257.0	21.470	0.841
8.0000E+00	88.0	7.352	1.747
1.4000E+01	24.0	2.005	2.652
2.0000E+01	6.0	0.501	3.558
2.6000E+01	1.0	0.084	4.463

ENTER:

1 - FOR PLOT
2 - FOR NEW CELL PARAMETERS
3 - FOR NEXT FILE
4 - FOR STOP

WHICH ? >2

NEW CELL MIDPOINT,INTERVAL ? >.5,1

Figure B-8

CHI-SQUARED TEST FOR GOODNESS OF FIT TO NORMAL CURVE

DATA FROM FILE: CASTG CHICK A1

GROUP: CASTAIC GROSS AXLE WTS.

NUMBER OF DATA POINTS = 1197

MEAN OF DATA POINTS = -3.575137

SMALLEST DATA POINT = -33.11604

LARGEST DATA POINT = 23.64865

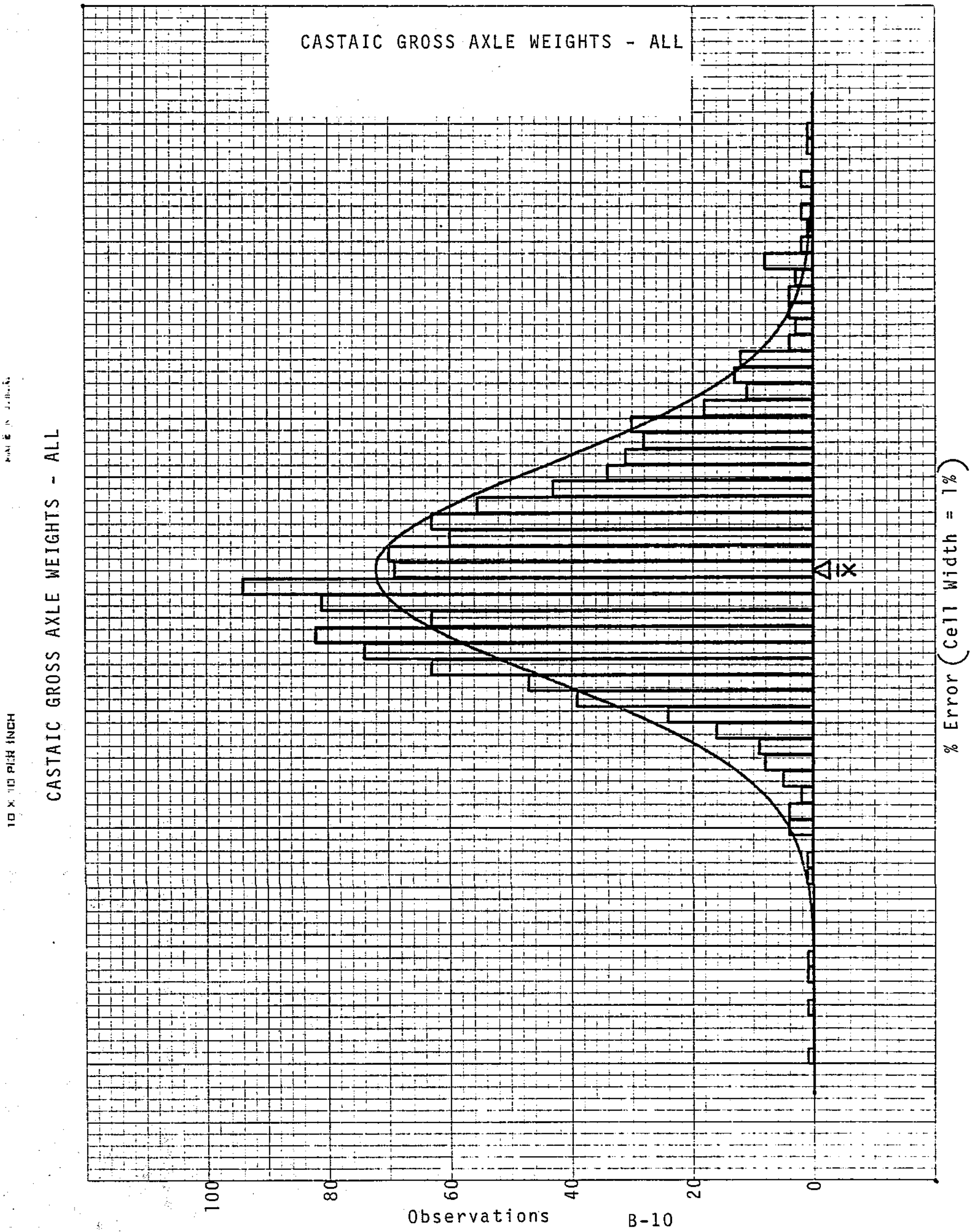
RMS DEVIATION = 6.626354

CHI SQUARED = 475.403574 WITH 55 D.F.

F R E Q U E N C Y   D I S T R I B U T I O N

FROM	TO	OBSERVED FREQUENCY	THEORETICAL FREQUENCY	CHI-SQUARE
-34	-33	1	5.374E-03	1.841E+02
-33	-32	0	5.343E-03	5.343E-03
-32	-31	0	1.019E-02	1.019E-02
-31	-30	1	1.901E-02	5.061E+01
-30	-29	0	3.466E-02	3.466E-02
-29	-28	1	6.178E-02	1.425E+01
-28	-27	1	1.076E-01	7.398E+00
-27	-26	0	1.833E-01	1.833E-01
-26	-25	0	3.052E-01	3.052E-01
-25	-24	0	4.967E-01	4.967E-01
-24	-23	0	7.901E-01	7.901E-01
-23	-22	1	1.229E+00	4.258E-02
-22	-21	1	1.868E+00	4.032E-01
-21	-20	0	2.776E+00	2.776E+00
-20	-19	4	4.032E+00	2.538E-04

Figure B-9



CASTAIC GROSS AXLE WEIGHTS - ALL
CASTAIC GROSS AXLE WEIGHTS - ALL
100
80
60
40
20
0
Observations
% Error (Cell Width = 1%)

Figure B-10

SAMPLE STATISTICS

ANTELOPE SINGLE AXLES - ALL

OBSERVATIONS= 2.0420E+03	MEAN= 2.7162E+00	STD.DEV.= 5.5936E+00
MINIMUM= -.3186E+02	RANGE= 6.8012E+01	MAXIMUM= 3.6154E+01
VARIANCE= 3.1289E+01	SKEWNESS= 5.1015E-01	KURTOSIS= 5.7730E+00
COEFF. VAR.= 2.0593E+02	AVG.DEV.= 4.2028E+00	RMS DEV.= 5.5923E+00

13 CELLS - CELL INTERVAL = 6

MIDPOINT	NO. OBS.	% TOTAL	Z-SCORE(RMS)
-.3400E+02	1.0	0.049	-6.566
-.2800E+02	0.0	0.000	-5.493
-.2200E+02	0.0	0.000	-4.420
-.1600E+02	7.0	0.343	-3.347
-.1000E+02	41.0	2.008	-2.274
-.4000E+01	451.0	22.086	-1.201
2.0000E+00	934.0	45.739	-.128
8.0000E+00	473.0	23.164	0.945
1.4000E+01	108.0	5.289	2.018
2.0000E+01	19.0	0.930	3.091
2.6000E+01	5.0	0.245	4.164
3.2000E+01	2.0	0.098	5.236
3.8000E+01	1.0	0.049	6.309

```
ENTER:
        1 - FOR PLOT
        2 - FOR NEW CELL PARAMETERS
        3 - FOR NEXT FILE
        4 - FOR STOP

      WHICH ? >2

NEW CELL MIDPOINT,INTERVAL ? >.5,1
```

CHI-SQUARED TEST FOR GOODNESS OF FIT TO NORMAL CURVE

DATA FROM FILE: ANTES CHICK A1

GROUP: ANTELOPE SINGLES

NUMBER OF DATA POINTS = 2042

MEAN OF DATA POINTS = 2.716243

SMALLEST DATA POINT = -31.85841

LARGEST DATA POINT = 36.15385

RMS DEVIATION = 5.592279

CHI SQUARED = 971297.829136 WITH 66 D.F.

F R E Q U E N C Y   D I S T R I B U T I O N

FROM	TO	OBSERVED FREQUENCY	THEORETICAL FREQUENCY	CHI-SQUARE
-32	-31	1	1.690E-06	5.918E+05
-31	-30	0	3.338E-06	3.338E-06
-30	-29	0	9.471E-06	9.471E-06
-29	-28	0	2.603E-05	2.603E-05
-28	-27	0	6.932E-05	6.932E-05
-27	-26	0	1.788E-04	1.788E-04
-26	-25	0	4.466E-04	4.466E-04
-25	-24	0	1.081E-03	1.081E-03
-24	-23	0	2.533E-03	2.533E-03
-23	-22	0	5.751E-03	5.751E-03
-22	-21	0	1.265E-02	1.265E-02
-21	-20	0	2.694E-02	2.694E-02
-20	-19	0	5.559E-02	5.559E-02
-19	-18	0	1.111E-01	1.111E-01
-18	-17	1	2.151E-01	2.864E+00

Figure B-12

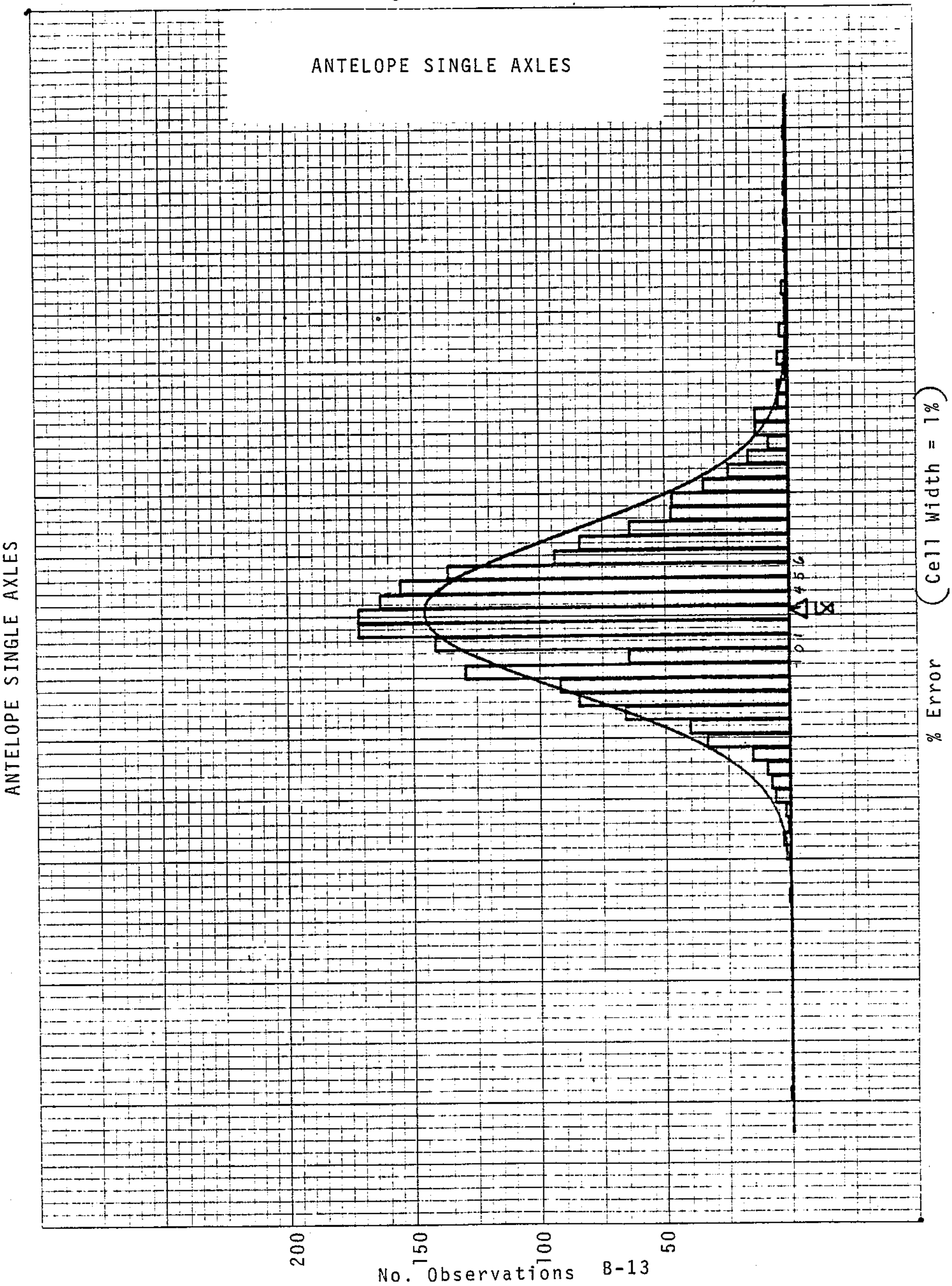


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Figure B-13

SAMPLE STATISTICS

ANTELOPE TANDEM AXLES - ALL

```
OBSERVATIONS= 1,2920E+03        MEAN= 1.9496E-01     STD.DEV.= 4.0050E+00
     MINIMUM= -.1420E+02       RANGE= 3.9959E+01      MAXIMUM= 2.5758E+01
    VARIANCE= 1.6040E+01    SKEWNESS= 9.2296E-01     KURTOSIS= 5.8382E+00
 COEFF. VAR.= 2.0543E+03    AVG.DEV.= 2.9657E+00     RMS DEV.= 4.0034E+00
```

11 CELLS - CELL INTERVAL = 4

MIDPOINT	NO. OBS.	% TOTAL	Z-SCORE(RMS)
-.1600E+02	1.0	0.077	-4.045
-.1200E+02	4.0	0.310	-3.046
-.8000E+01	41.0	3.173	-2.047
-.4000E+01	332.0	25.697	-1.048
-.4441E-15	569.5	44.079	-.049
4.0000E+00	244.5	18.924	0.950
8.0000E+00	67.0	5.186	1.950
1.2000E+01	24.5	1.896	2.949
1.6000E+01	5.0	0.387	3.948
2.0000E+01	1.0	0.077	4.947
2.4000E+01	1.0	0.077	5.946

```
ENTER:
        1 - FOR PLOT
        2 - FOR NEW CELL PARAMETERS
        3 - FOR NEXT FILE
        4 - FOR STOP

       WHICH ? >2

NEW CELL MIDPOINT,INTERVAL ? >.5,1
```

Figure B-14

CHI-SQUARED TEST FOR GOODNESS OF FIT TO NORMAL CURVE

DATA FROM FILE: ANTET CHICK A1

GROUP: ANTE1-TANDEM AXLE

NUMBER OF DATA POINTS = 1292

MEAN OF DATA POINTS = .194957

SMALLEST DATA POINT = -14.20118

LARGEST DATA POINT = 25.75758

RMS DEVIATION = 4.003426

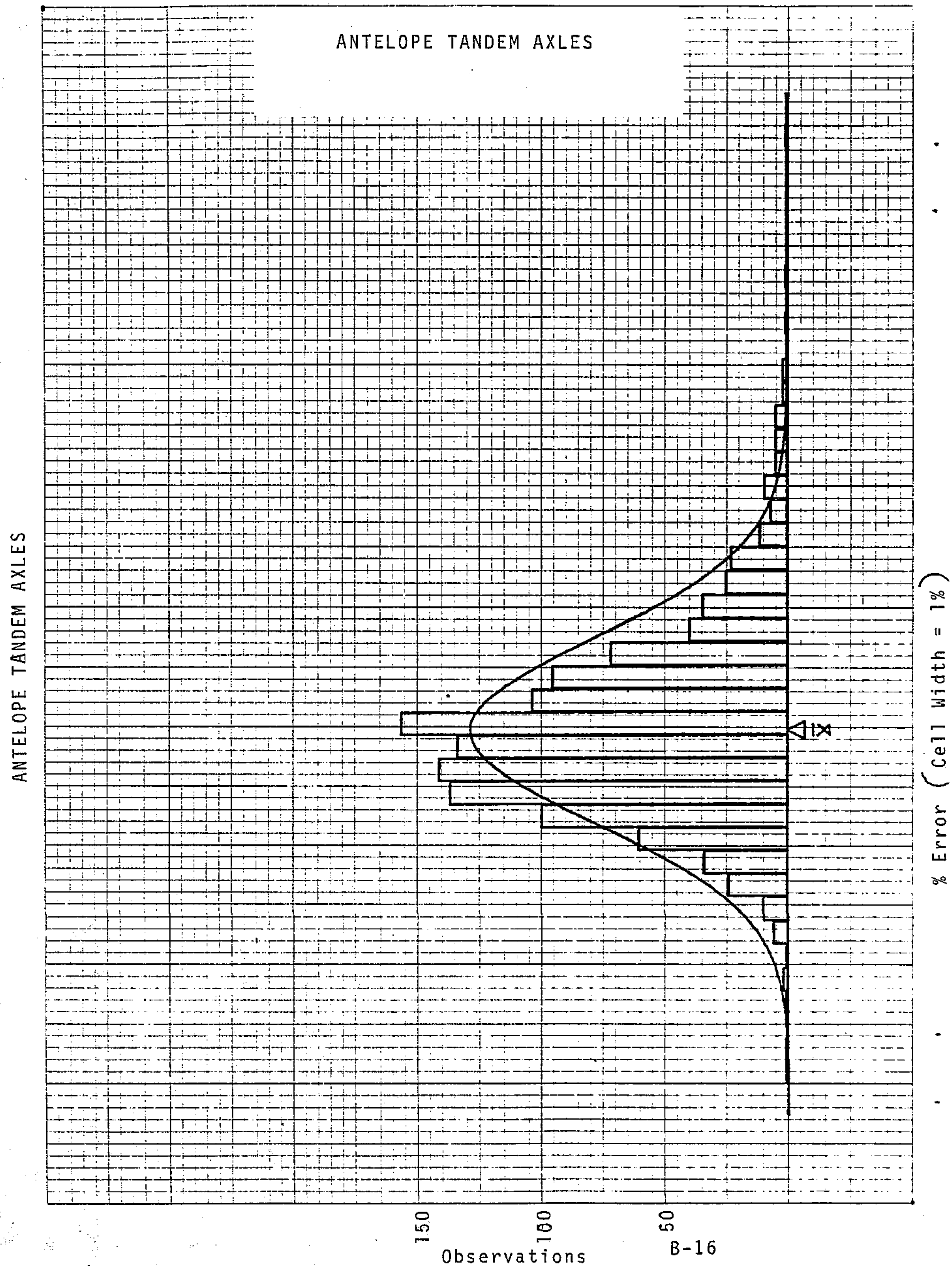
CHI SQUARED = 2.662291E+06 WITH 38 D.F.

F R E Q U E N C Y D I S T R I B U T I O N

FROM	TO	OBSERVED FREQUENCY	THEORETICAL FREQUENCY	CHI-SQUARE
-15	-14	1	2.530E-01	2.205E+00
-14	-13	1	3.808E-01	1.007E+00
-13	-12	0	8.638E-01	8.638E-01
-12	-11	1	1.841E+00	3.844E-01
-11	-10	2	3.689E+00	7.733E-01
-10	-9	1	6.946E+00	5.090E+00
-9	-8	6	1.229E+01	3.221E+00
-8	-7	10	2.044E+01	5.334E+00
-7	-6	24	3.195E+01	1.979E+00
-6	-5	34	4.693E+01	3.564E+00
-5	-4	61	6.479E+01	2.219E-01
-4	-3	100	8.406E+01	3.022E+00
-3	-2	137	1.025E+02	1.161E+01
-2	-1	142	1.175E+02	5.127E+00
-1	0	134	1.265E+02	4.442E-01

Figure B-15

ANTELOPE TANDEM AXLES



NO. 340-10 DIETZGEN GRAPH PAPER
10 X 10 PER INCH
DIETZGEN CORPORATION
MADE IN U.S.A.

Figure B-16

SAMPLE STATISTICS

ANTELOPE GROSS WTS.- ALL

OBSERVATIONS= 9.7400E+02	MEAN= 9.9007E-01	STD.DEV.= 3.1525E+00
MINIMUM= -.1456E+02	RANGE= 2.9788E+01	MAXIMUM= 1.5232E+01
VARIANCE= 9.9381E+00	SKEWNESS= 3.9266E-01	KURTOSIS= 4.2105E+00
COEFF. VAR.= 3.1841E+02	AVG.DEV.= 2.4476E+00	RMS DEV.= 3.1509E+00

11 CELLS - CELL INTERVAL = 3

MIDPOINT	NO. OBS.	% TOTAL	Z-SCORE(RMS)
-.1400E+02	1.0	0.103	-4.757
-.1100E+02	0.0	0.000	-3.805
-.8000E+01	2.0	0.205	-2.853
-.5000E+01	51.0	5.236	-1.901
-.2000E+01	264.0	27.105	-.949
1.0000E+00	373.0	38.296	0.003
4.0000E+00	210.0	21.561	0.955
7.0000E+00	52.0	5.339	1.907
1.0000E+01	17.0	1.745	2.860
1.3000E+01	3.0	0.308	3.812
1.6000E+01	1.0	0.103	4.764

ENTER:
1 - FOR PLOT
2 - FOR NEW CELL PARAMETERS
3 - FOR NEXT FILE
4 - FOR STOP

WHICH ? >2

NEW CELL MIDPOINT,INTERVAL ? >.5,1

Figure B-17

CHI-SQUARED TEST FOR GOODNESS OF FIT TO NORMAL CURVE

DATA FROM FILE: ANTEG CHICK A1

GROUP: ANTELOPE GROSS WTS.

NUMBER OF DATA POINTS = 974

MEAN OF DATA POINTS = .990073

SMALLEST DATA POINT = -14.55577

LARGEST DATA POINT = 15.23179

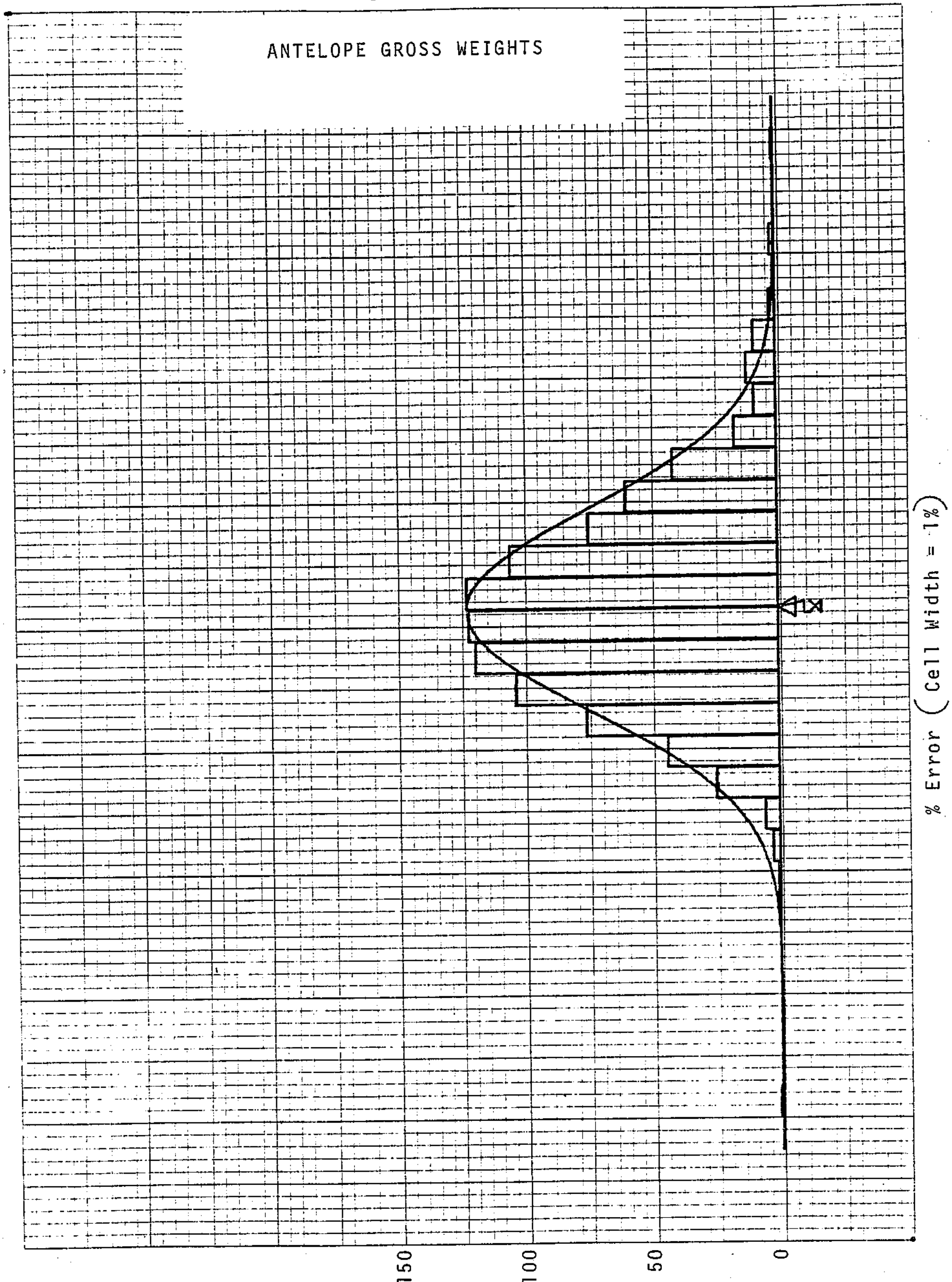
RMS DEVIATION = 3.15086

CHI SQUARED = 1339.162348 WITH 28 D.F.

F R E Q U E N C Y   D I S T R I B U T I O N

FROM	TO	OBSERVED FREQUENCY	THEORETICAL FREQUENCY	CHI-SQUARE
-15	-14	1	9.559E-04	1.044E+03
-14	-13	0	3.427E-03	3.427E-03
-13	-12	0	1.386E-02	1.386E-02
-12	-11	0	5.074E-02	5.074E-02
-11	-10	0	1.681E-01	1.681E-01
-10	-9	0	5.039E-01	5.039E-01
-9	-8	1	1.367E+00	9.845E-02
-8	-7	1	3.355E+00	1.653E+00
-7	-6	3	7.454E+00	2.661E+00
-6	-5	6	1.498E+01	5.386E+00
-5	-4	25	2.726E+01	1.868E-01
-4	-3	44	4.487E+01	1.680E-02
-3	-2	76	6.684E+01	1.256E+00
-2	-1	104	9.010E+01	2.144E+00
-1	0	120	1.099E+02	9.250E-01

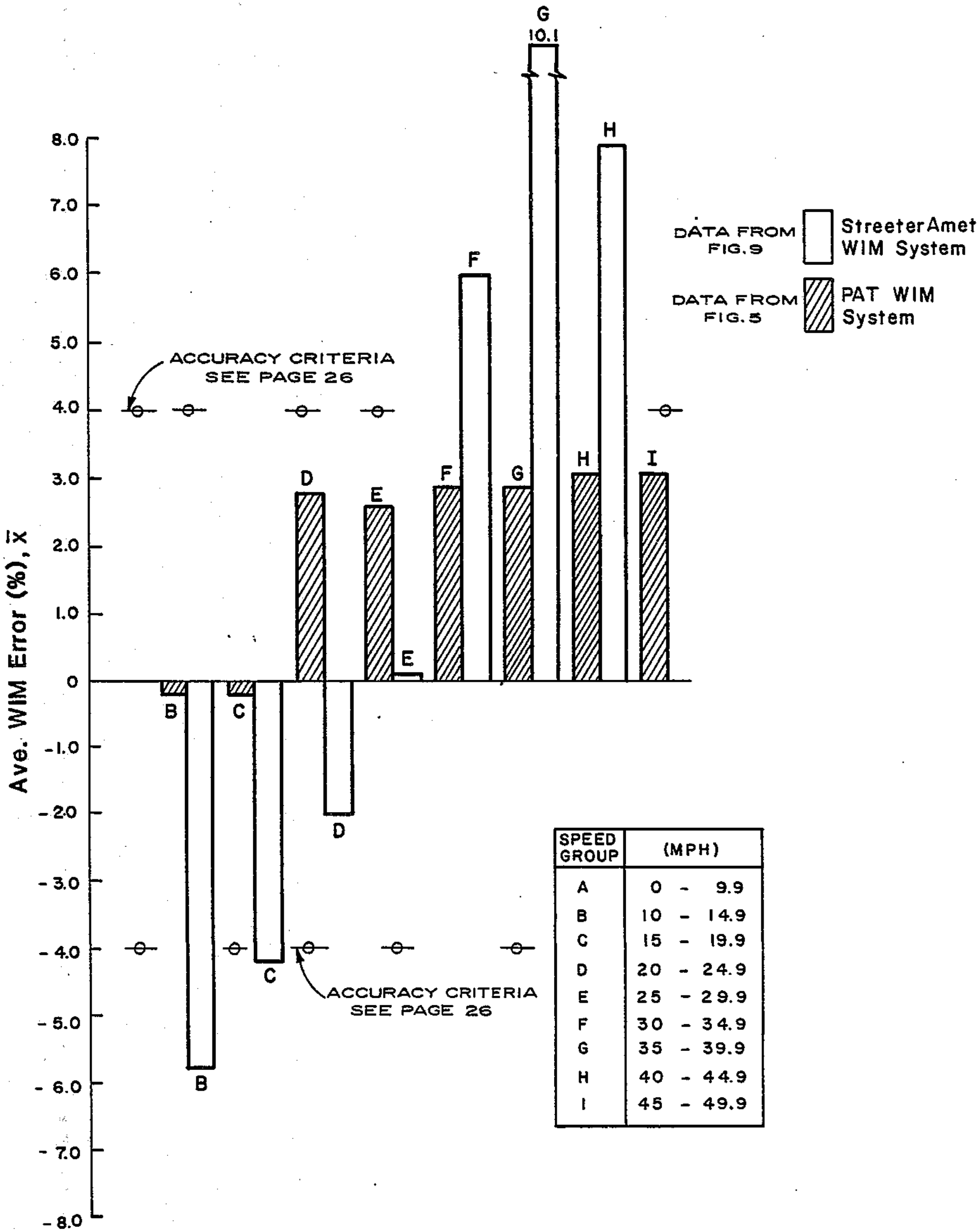
Figure B-18



NO. 340-10 DIETZGEN GRAPH PAPER
10 X 10 PER INCH
DIETZGEN CORPORATION
MADE IN U.S.A.

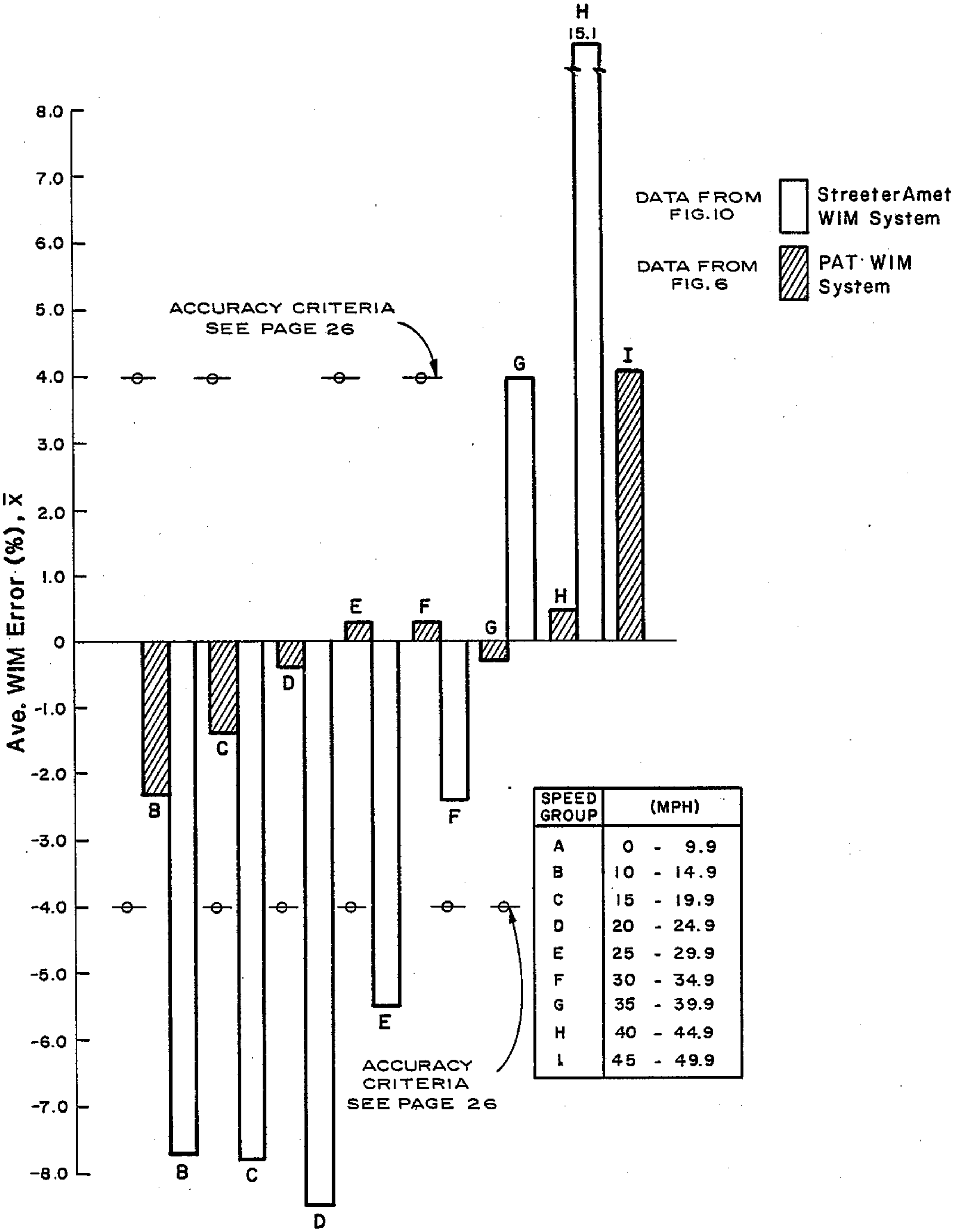
APPENDIX C - GRAPHS

FIGURE C-1



AVERAGE SINGLE AXLE WEIGHT ERROR (%) VS SPEED GROUPS

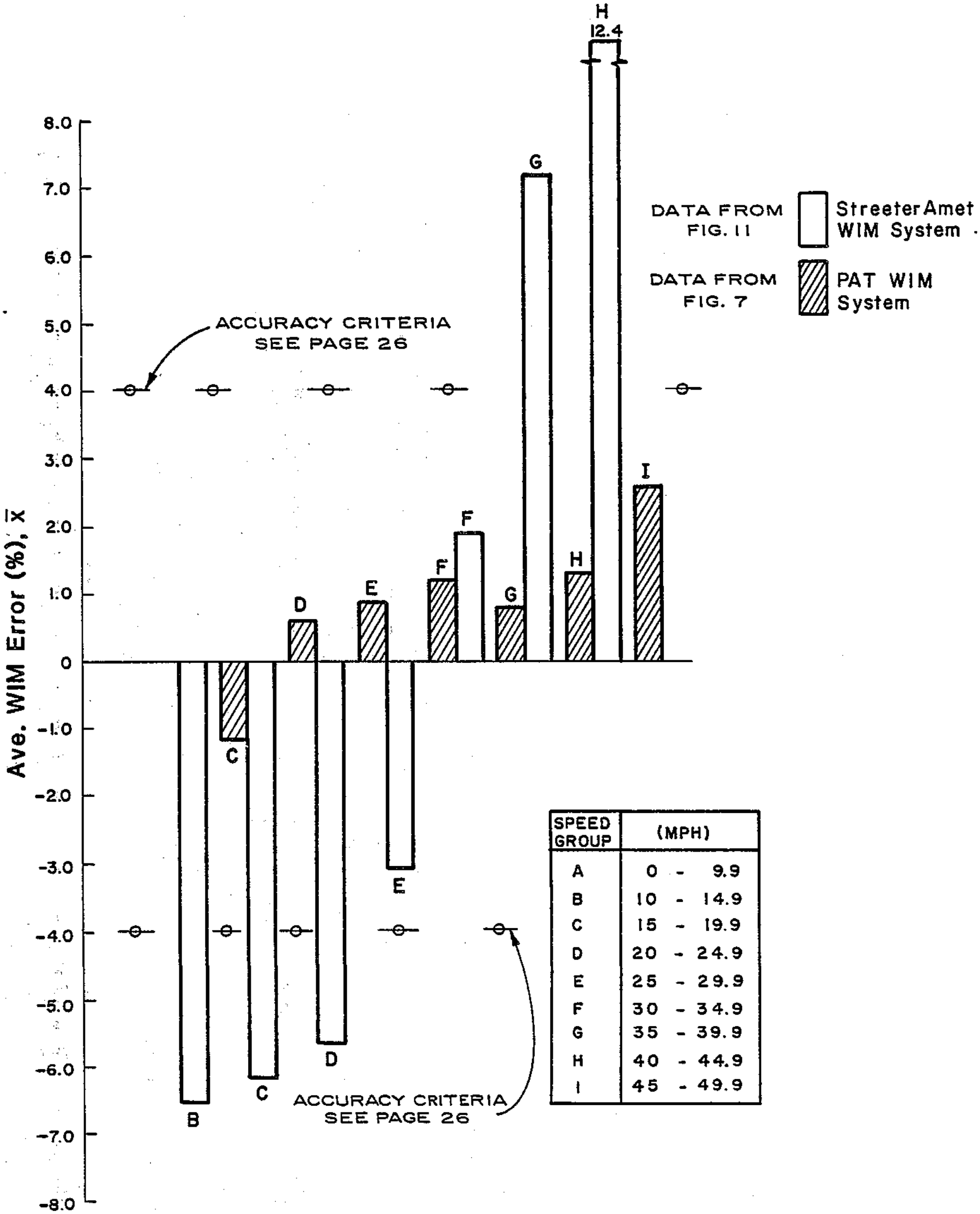
FIGURE C-2



SPEED GROUP	(MPH)
A	0 - 9.9
B	10 - 14.9
C	15 - 19.9
D	20 - 24.9
E	25 - 29.9
F	30 - 34.9
G	35 - 39.9
H	40 - 44.9
I	45 - 49.9

AVERAGE TANDEM WEIGHT ERROR (%) VS SPEED GROUPS

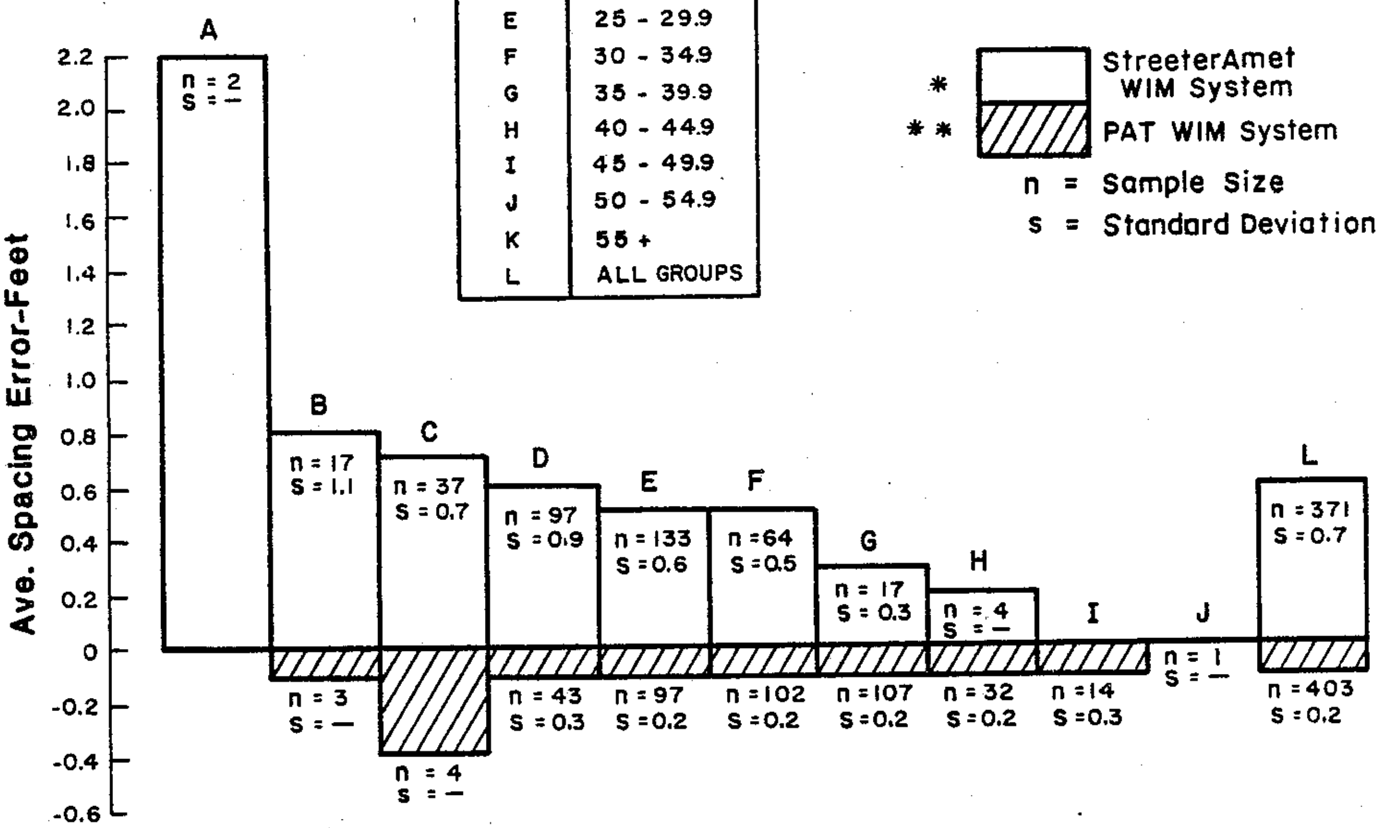
FIGURE C-3



AVERAGE TRUCK GROSS WEIGHT ERROR (%) VS SPEED GROUPS

FIGURE C-4

SPEED GROUP	(MPH)
A	0 - 9.9
B	10 - 14.9
C	15 - 19.9
D	20 - 24.9
E	25 - 29.9
F	30 - 34.9
G	35 - 39.9
H	40 - 44.9
I	45 - 49.9
J	50 - 54.9
K	55 +
L	ALL GROUPS



* * PAT DATA FROM FIG. 12

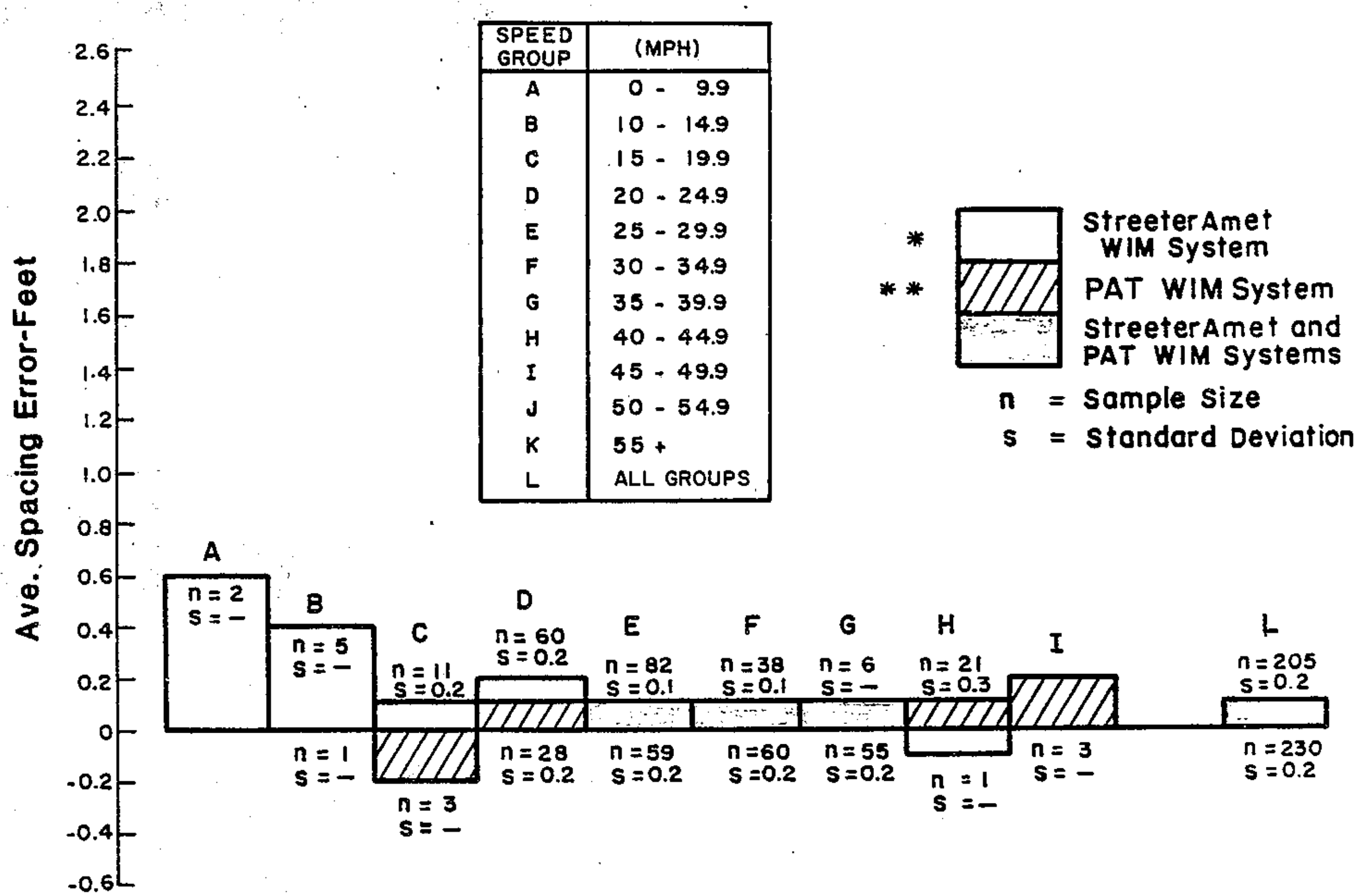
* STREETERAMET DATA FROM FIG. 13

GROUP TRUCK SPEED

ADJACENT AXLE SPACING ERROR VS SPEED GROUPS

SPACING : SIX FEET OR GREATER

FIGURE C-5



SPEED GROUP	(MPH)
A	0 - 9.9
B	10 - 14.9
C	15 - 19.9
D	20 - 24.9
E	25 - 29.9
F	30 - 34.9
G	35 - 39.9
H	40 - 44.9
I	45 - 49.9
J	50 - 54.9
K	55 +
L	ALL GROUPS

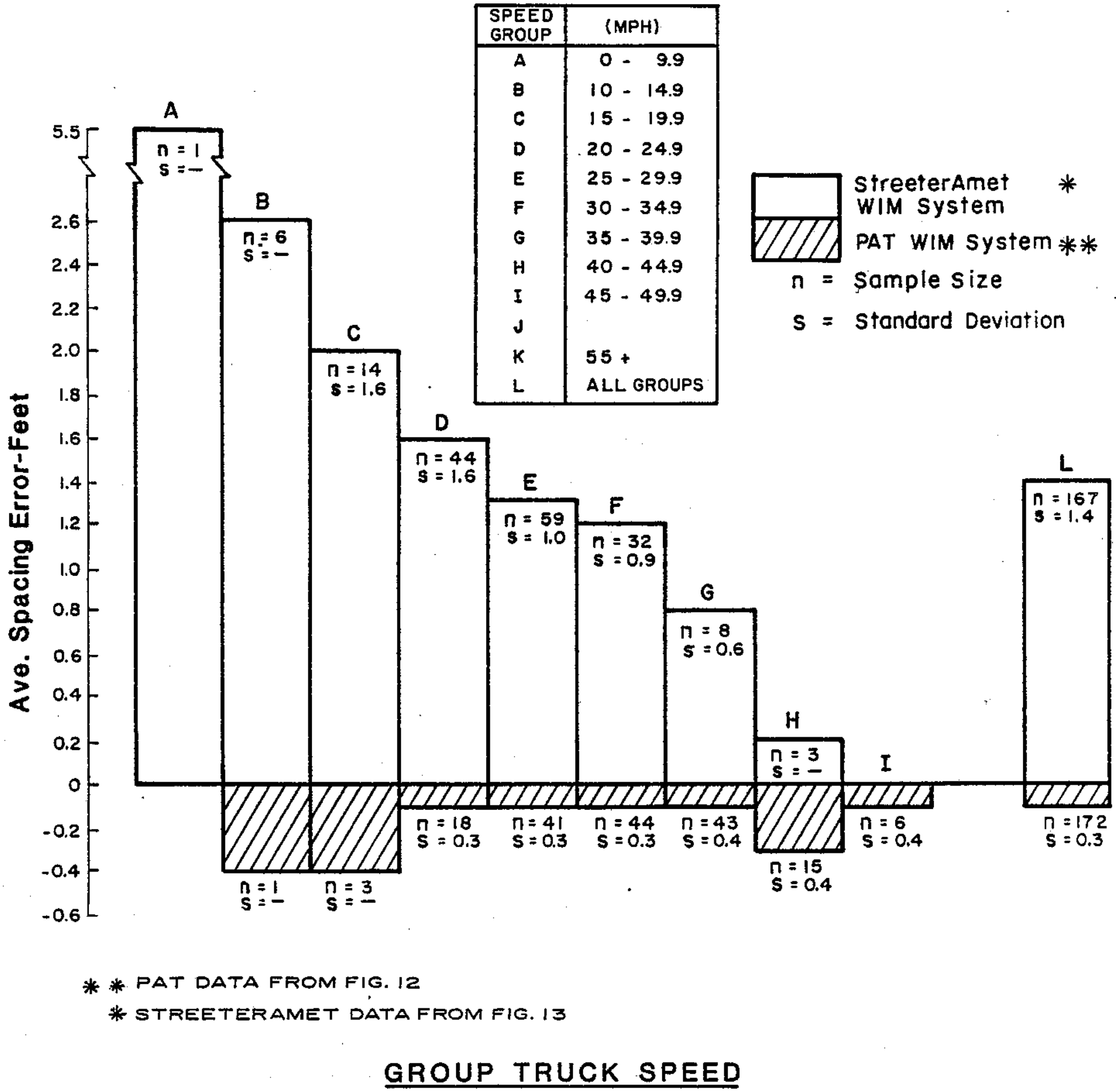
** PAT DATA FROM FIG. 12
* STREETERAMET DATA FROM FIG. 13

GROUP TRUCK SPEED

TANDEM AXLE SPACING ERROR VS SPEED GROUPS

SPACING : SIX FEET OR LESS

FIGURE C-6



OVERALL* AXLE SPACING ERROR VS SPEED GROUPS

*STEERING AXLE TO LAST AXLE

APPENDIX D

GENERAL DESCRIPTION OF THE PAT WIM IN-MOTION TRUCK WEIGHING SYSTEM

General

The PAT Equipment Corporation Model DAW-209 Data Analyzer, commonly known as a weigh-in-motion (WIM) system, includes two sets of axial scales, two traffic loops, a digital processor, a CRT terminal and a recorder. With the two sets of axle scales and the associated equipment, trucks are weighed while in-motion. Truck speed and axle spacings are calculated in addition to the recording of other supportive data.

The PAT data processing unit is shown in Figure D-1.

Axle Scale

At the pavement site, the two axle scales are placed 16.4 feet (5 meters) apart and embedded flush in a traffic lane. An axle scale consists of an independent left wheel track and a right wheel track scale. Thus, four independent wheel scales comprise a PAT two-axle WIM system. A typical PAT WIM layout is shown in Figure D-2 for the CHP Antelope weigh station.

A two-axle scale system is superior in weighing accuracy over a one-axle scale system. In the two-axle weighing system, a wheel or axle is weighed twice so that the resultant weighing error is about 70% ($\frac{1}{\sqrt{2}}$) of the error of a single weighing with a one-axle scale system.

The physical size of a PAT wheel scale is 49-1/4" x 20" x 7/8" (125 x 51 x 2.2 cm) and weighs 181 pounds (82 kg). Its wheel load capacity is 10,000 pounds (4536 kg) for an axle load capacity of 20,000 pounds (9072 kg).

Each weigh scale consists of a rectangular steel plate supported lengthwise at the edges. Parallel to the length, grooves are milled into the bottom of the plate near each support. Into the two stress riser grooves are attached strain gages. The instant the plate is deflected by a wheel load, the strains occurring in the grooves are sensed by the strain gages.

The strain gages are arranged in the grooves to produce an analog wheel load signal almost independent of the location of loading on the scale. The gages are connected with associated resistors, forming a Wheatstone Bridge, and then connected to an amplifier. The amplifier output signal is analogous to the load and used to determine the weight of the wheel passing above. The strain gages and wiring are protected against the adverse influence of moisture and physical damage by filling the grooves with a protective compound while the entire plate is encapsulated with vulcanized synthetic rubber, with the result that the scale is self-contained and almost unaffected by atmospheric conditions.

Two wheel scales next to one another form an axle weighing scale. The signals from the two wheel scales are electronically added to provide the axle weight.

Preamplifier

The output signals from the wheel scales are cable-transmitted up to 65 feet (20 meters), without amplification, to a preamplifier in a cabinet located at the pavement shoulder. It provides about 40 db gain and the amplified signal is transmitted via cable to the WIM data processing unit.

Axle Spacings

The PAT system utilizes the two-axle scales to derive axle spacings. It is a more accurate method than the use of a pair of vehicle detector loops for the same purpose.

Vehicle Detector Loops

A vehicle detector loop is embedded in the pavement ahead of each axle scale. Scale and loop placement is shown in Figure D-2. The loops "signal" the presence or absence of a truck in the measuring area. It consists of several windings of insulated wire. It has a rectangular shape of 6' x 13'. The loop decoding circuitry is housed in the preamplifier cabinet. Two independent loops are connected to the preamplifier cabinet. When a vehicle passes over the two loops, the output of the decoding circuitry supplies digital signals which are processed in the WIM data processing unit.

WIM Data Processing Unit

The data processing unit is a microcomputer-based instrument that accepts, via the preamplifier, analog signals from the wheel scales and pulse signals from the traffic loops and produces digital outputs indicating truck axle and gross weights, overweight conditions, axle spacings, speed and other pertinent information. It provides data output to the peripheral gear and intermediate storage of the data. The microcomputer is a Siemens Model 210.

The microcomputer, with appropriate software, executes the following functions:

- Zero tuning (tare) of wheel scales when a truck has reached the detector loop at the beginning of the measuring section and no other vehicle is located within the measuring section.
- Measurement of the peak scale signal at each wheel scale.
- Average value computation of all the wheel scale signals.
- Calculation of speed, axle spacings, and truck length from the time interval between the scale signals.
- Classification of truck type from axle spacings and axle weights.
- Calculates gross weight and multiple axle weights.
- Calculates overload for individual axles, multiple axles and of vehicle.
- Outputs the results.

Data Cartridge Recorder

The recorder is a Columbia Data Products Model 300C tape recorder. It utilizes a 3M Type DC-300A data cartridge which contains 450 feet of 1/4 inch computer grade magnetic tape.

There are four tracks on the tape. Each track is independent of the other. On each track, blocks of data are written in serial fashion. A block of data consists of a preamble, 256 characters of data, 16-bit check character, and a postamble. The preamble and postamble are each 16 bits long.

Video Display

The CRT terminal consists of a television type display plus keyboard and acts as the interface between the operator and the WIM system. It is used to initiate operations, recall data on a truck and display the truck axle and total weights, as well as axle spacings, speed, time, station number, operator number and truck number. It provides a "scrolling" record of weights for the last 10 trucks and indicates overweight axles and trucks. The CRT screen is 24 lines (64 characters per line) and displays the truck data in real time. The data are displayed in several modes and selectable by the operator. The various modes are shown in Figures D-3 through D-7. Figure D-8 is a pictorial representation of the primary and mode 3 displays. The PAT classification codes for weights, spacings and speeds are shown in Figure D-9. Figure D-10 shows the PAT classification for trucks.

Printer

An Anadex Model DP8000 is supplied with the system. It is a dot matrix impact printer with EIA Standard RS-232-C interface. The printer accepts the complete 128 character ACSII code set, printing bi-directionally at a speed of 84 lines per minute. The data rate for the asynchronous serial interfaces is internally switch selectable from 110 through 9600 baud.

Truck Classification

The truck class is determined on the basis of the number of axles and wheelbases. Each truck class is designated with a two-digit number taken from a table shown in Figure D-10. The table shows the total weights of the respective truck class. The assignment of the truck classes to the two-digit numbers and the total permissible weights are programmable. Trucks not contained in the table are designated as "999".

Note that the truck classes are that of the PAT system and the equivalent U.S. classes are not listed. Also, the axle and gross weights are not in accord with California Vehicle Code Sections 35550 and 35551.

Technical Data PAT Model DAW 209

Transducer:	4 wheel scales Type 2010 2 vehicle detection loops

Cable Lengths:

Maximum cable length from axle scale (transducer) to preamplifier: 66 feet (20 m)

Maximum cable length from preamplifier to WIM data processing unit: 1640 feet (500 m)

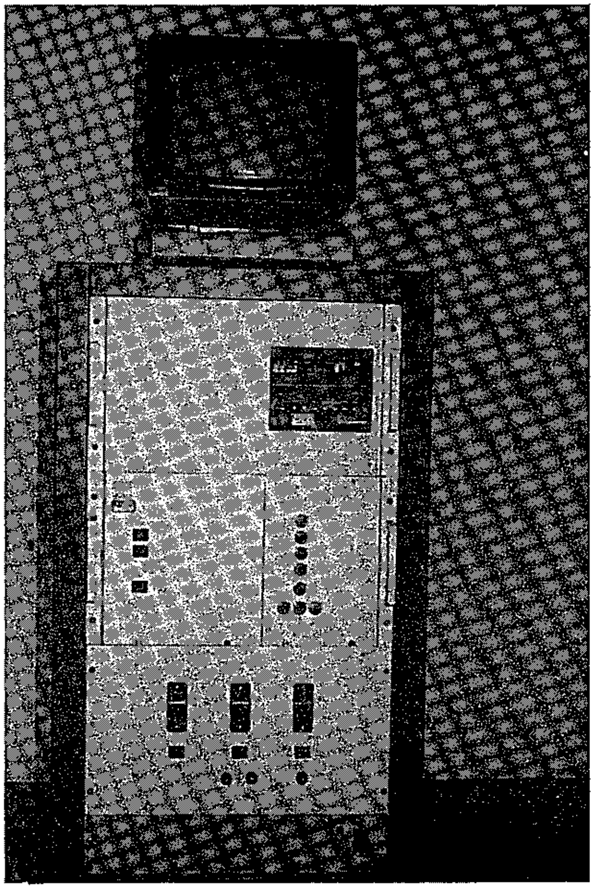
Speed Range

Dynamic weighing: 3 to 60 mph (4.8 to 96.0 km/h)

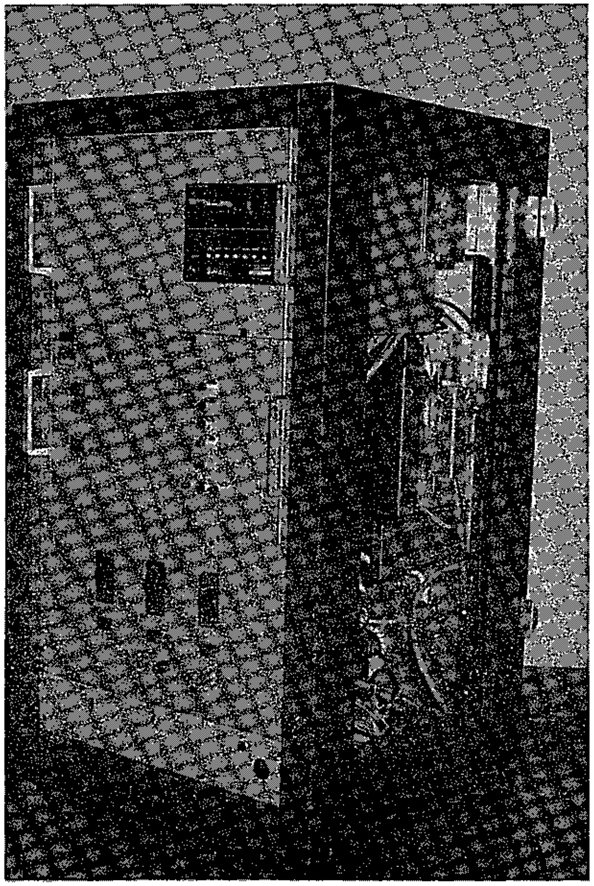
Figure D-1

MAJOR COMPONENTS OF THE PAT WIM SYSTEM

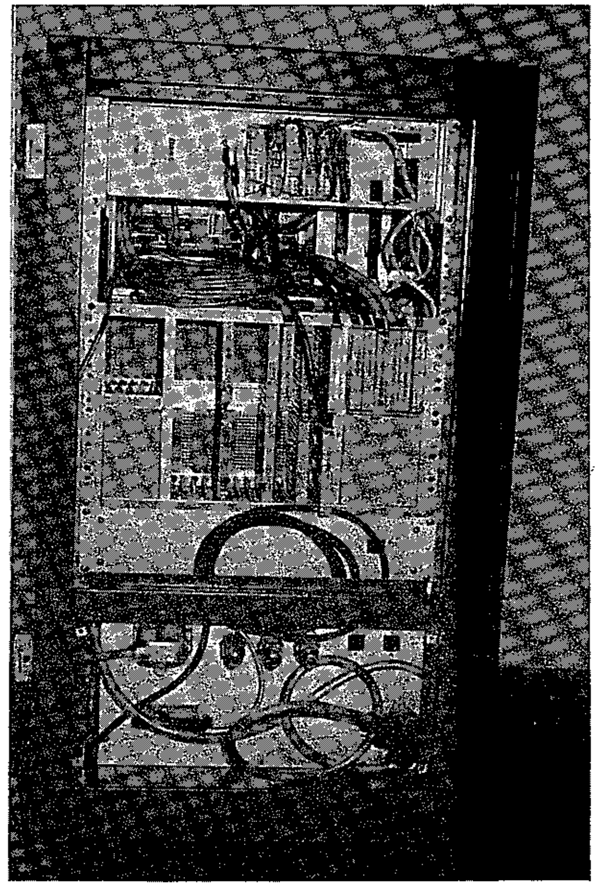
SCALES AND PRINTER NOT SHOWN



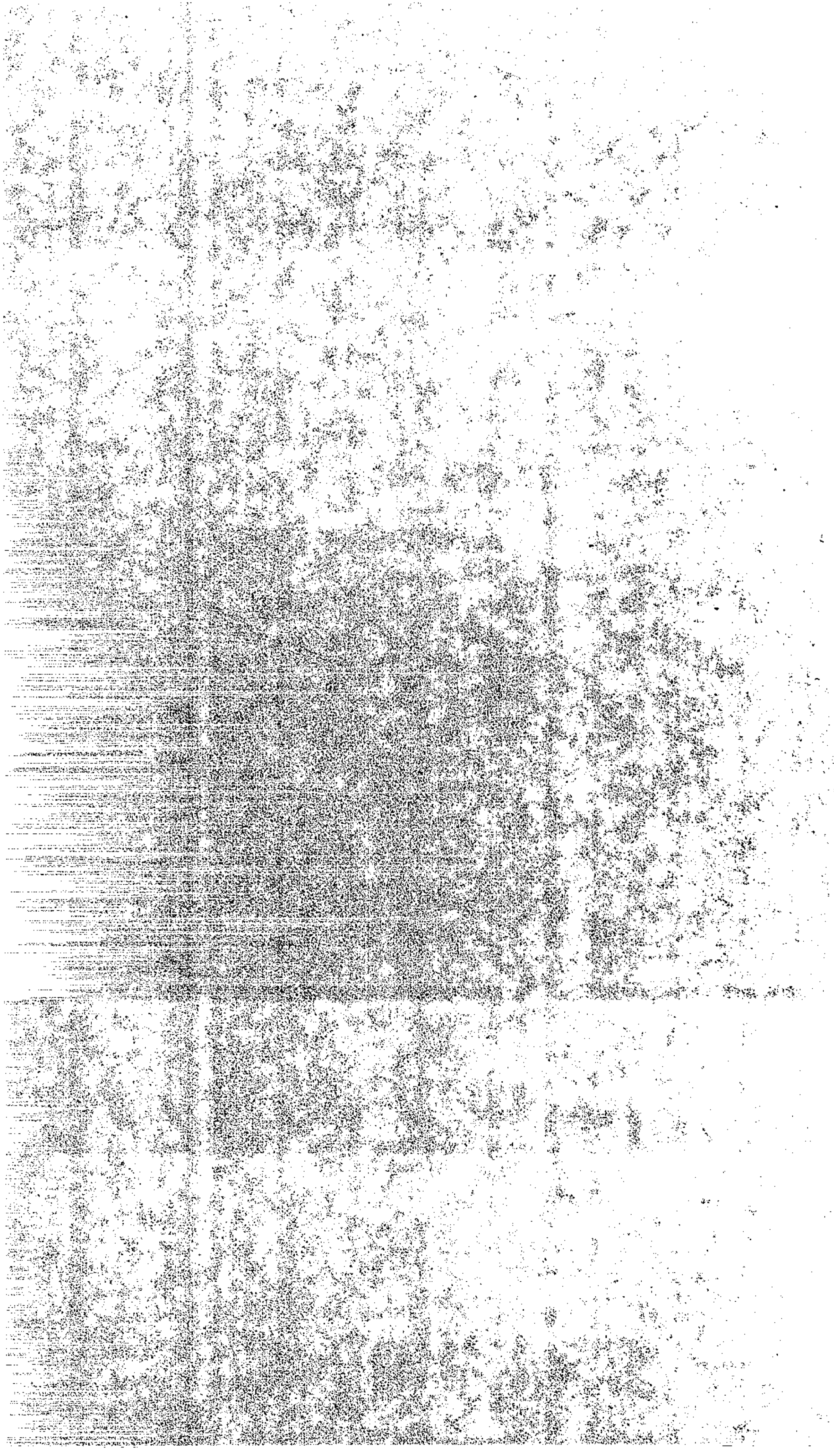
Front View

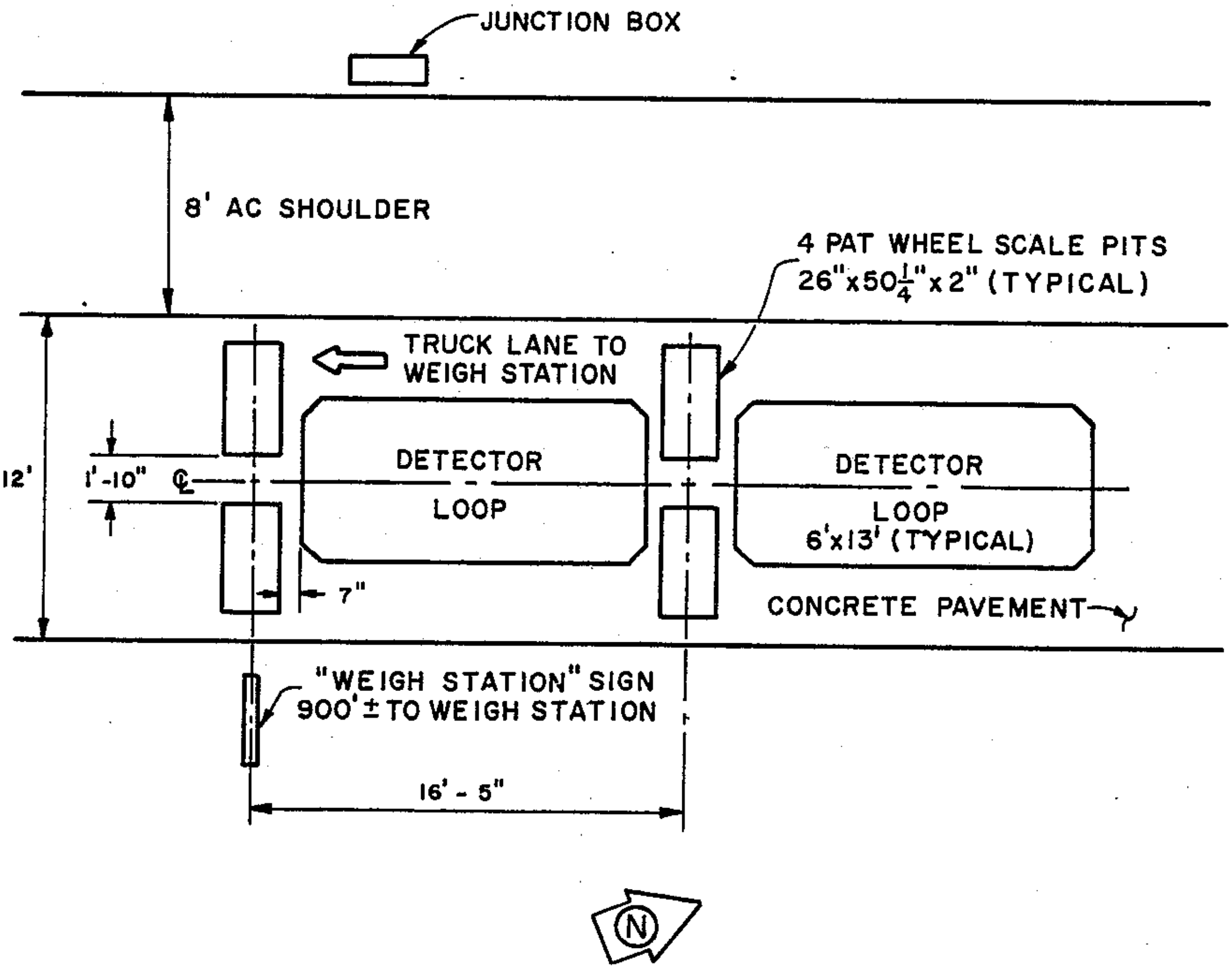


3/4 View



Back View





LAYOUT OF PAT WIM INSTALLATION
ANTELOPE CHP WEIGH STATION
03-SAC-80 (WESTBOUND)

FIGURE D-3

PAT MODE DISPLAYS

DATE: 21.12.81 TIME: 14:41:04 STAT.: 1 BLOCK-NO: 28

MEAS-NO: 130 REGISTR. P DATA-RECORDER: NO CARTRIDGE

NO.	TIME	AWT1	ASP1	AWT2	ASP2	AWT3	*	TOT.	LIM.	SPEED	CAT	M
130	14:40	11.1	14.5	16.0	4.2	14.7	31.2	12.8	4.2	14.4		
							*	69.0		42.8	53	A
129	14:40	8.9	15.7	4.5	4.3	4.4	*	17.8		36.3	31	C
128	14:38	7.8	10.1	7.7	18.1	6.8	10.1	6.3	19.5	6.7		
							*	35.2		35.6	50	A
127	14:37	2.4	12.3	3.0			*	5.4		46.8	10	A
126	14:37	8.9	14.5	16.0	4.3	15.6	29.0	10.4	3.8	10.5		
							*	61.4		43.7	53	B
125	14:37	9.8	15.8	15.1			*	24.8		46.1	21	C

Primary Mode: no mode number assignment

*Gross Weight

FIGURE D-4

PAT MODE DISPLAYS

DATE: 21.12.81 TIME: 14:32:00 STAT.: 1 BLOCK-NO: 24

MEAS-NO: 109 REGISTR. P V S DATA-RECORDER: STARTED !

DATE	TRUCK	AXS	GROUP	SPA.	ALLOW.	W.I.M.	DIFF.	STOP
12-21-81	14	3	13	20	51.0	42.0	.0	
12-21-81	14	2	23	4	34.0	31.4	.0	
12-21-81	14	4	14	50	76.0	56.9	.0	
12-21-81	14	3	24	34	60.0	46.3	.0	
12-21-81	14	2	34	30	40.0	30.6	.0	
12-21-81	14	5	15	54	80.0	71.8	.0	
12-21-81	14	4	25	38	68.0	61.2	.0	
12-21-81	14	3	35	34	60.0	45.5	.0	
12-21-81	14	2	45	4	34.0	29.8	.0	
12-21-81	15	3	13	30	58.5	46.8	.0	
12-21-81	15	2	23	20	40.0	36.8	.0	
12-21-81	15	4	14	39	68.5	63.2	.0	
12-21-81	15	3	24	29	57.5	53.2	.0	
12-21-81	15	2	34	9	39.0	35.5	.0	
12-21-81	15	5	15	60	80.0	81.0	1.0	
12-21-81	15	4	25	50	76.0	71.0	.0	
12-21-81	15	3	35	30	58.5	53.2	.0	
12-21-81	15	2	45	21	40.0	34.2	.0	
12-21-81	19	3	13	15	47.0	39.4	.0	
12-21-81	19	2	23	4	34.0	30.1	.0	
12-21-81	19	4	14	42	70.5	53.0	.0	
12-21-81	19	3	24	31	59.0	43.6	.0	
12-21-81	19	2	34	27	40.0	29.0	.0	
12-21-81	19	5	15	46	76.5	67.8	.0	
12-21-81	19	4	25	35	66.0	58.5	.0	
12-21-81	19	3	35	31	59.0	43.8	.0	
12-21-81	19	2	45	4	34.0	28.4	.0	

Mode 2 Display: Computed listing of weight differences per California Vehicle Code #35551 ("Bridge Law" Violations).

FIGURE D-5

PAT MODE DISPLAYS

DATE: 21.12.81   TIME: 14:33:34   STAT.:   1 BLOCK-NO: 25

MEAS-NO: 116   REGISTR.   P V S   DATA-RECORDER: STARTED !

- -

AXLE	LEFT	RIGHT	WEIGHT	SPACE	OV.LOAD	ERR
A1	4.27	4.27	8.5			5
A2	8.93	8.93	17.9	16.5		5
A3	7.54	7.54	15.1	4.1		5
23	16.47	16.47	32.9	**		
A4	8.51	8.51	17.0	28.4		5
A5	6.13	6.13	12.3	4.2		5
45	14.64	14.64	29.3	**		

GROSS WEIGHT	:	70760 LBS	VEHICLE-LENGTH	: 50.7 FEET
OVER LOAD	:	00 LBS	VEHICLE-CLASS	: 53
MEASUREMENT-NO.	:	115	VEHICLE-SPEED	: 22.4 MPH

Mode 3 Display: Single Vehicle Data

FIGURE D-6

PAT MODE DISPLAYS

DATE: 21.12.81 TIME: 14:41:17 STAT.: 1 BLOCK-NO: 28

MEAS-NO: 131 REGISTR. P DATA-RECORDER: NO CARTRIDGE

CLASS	SINGLE	TANDEM	LENGTH	SPEED	VEHICLE CATEGORIES			
1	0	1	4	6				
2	14	4	6	12	10:	3	62:	0
3	11	2	1	4	11:	0	63:	0
4	24	7	1	5	12:	0	64:	0
5	23	2	0	0	21:	6	69:	0
6	7	1	0	0	30:	2	70:	0
7	4	2	5	0	31:	1	72:	0
8	11	3	3	0	40:	0	74:	0
9	2	0	3	0	41:	3	76:	0
10	0	0	4	0	42:	0	82:	0
11	0	0	0	0	45:	0	85:	0
12	0	0	0	0	50:	2	:	0
13	0	0	0	0	51:	0	:	0
14	0	0	0		52:	1	:	0
15	0	0	0		53:	8	999:	1
16	0	0	0		57:	0	TOT:	27

Mode 4 Display: Statistical Report (histogram).
Figure lists classification codes.

FIGURE D-7

PAT MODE DISPLAYS

```
-------------------------------------------------------------
         TIME: 09:29:17   STAT.:    1 BLOCK-NO:

MEAS-NO:       REGISTR.  P      DATA-RECORDER: NO CARTRIDGE
-------------------------------------------------------------

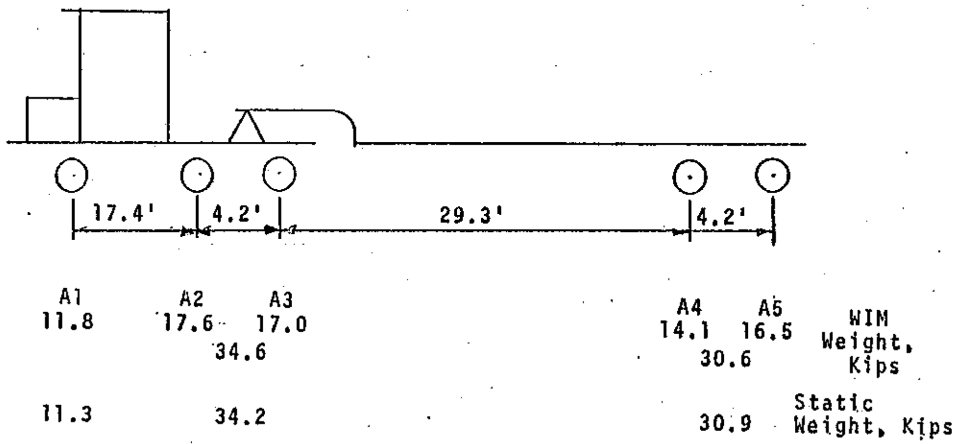
               *---------------------------------------------*
               I                                             I
               I  MODE  TEST?           ACTION               I
               I --------------------------------------------I
               I    1     -    PARAMETER-INPUT               I
               I    2     -    BRIDGE GROSS WEIGHT           I
               I    3     -    DISPLAY SINGLE VEHICLE DATA   I
               I    4     -    DISPLAY STATISTICAL REPORT    I
               I    5     -    KIND OF REGISTRATION P/V/S    I
               I    6     -    REC.-INTERV. OF STAT. REPORT  I
               I    7     -    DISPLAY OF THIS MODE SUMMARY  I
               I CTRL/P   -    COPY CRT SCREEN TO PRINTER    I
               I    A   TEST   ZERO-POINT SCALING            I
               I    B   TEST   STATIC SCALING                I
               I    C   TEST   DATA-RECORDER CONTROL         I
               I    D   TEST   SINGLE PAD SCALING CONTROL    I
               *---------------------------------------------*
```

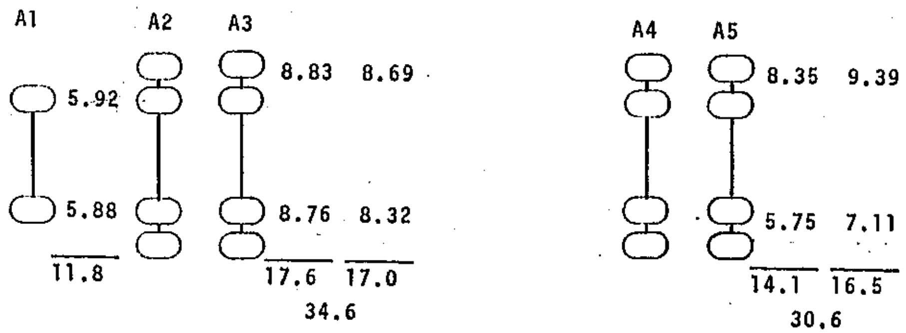
Mode 7 Display: Display of this Mode Summary

NOTE: Primary mode (default mode) has no mode assignment number.

PAT WEIGH-IN-MOTION (WIM) SYSTEM

Measurement No. 265 - Tractor & Semitrailer (3S2)





Gross Weight (WIM) = 77.0 Kips
Gross Weight (Static) = 76.4 Kips

PRIMARY MODE DISPLAY (Axle Weights)

```
DATE: 01.04.81   TIME: 11:50:40   STAT.    1  BLOCK-NO:    84

MEAS-NO:    265  REGISTR.    V S DATA-RECORDER: STARTED !
--------------------------------------------------------------

 NO.  TIME AWT1 ASP1 AWT2 ASP2 AWT3 * TOT. LIM. SPEED CAT M

 265 11:50 11.8 17.4 17.6  4.2 17.0 29.3 14.1  4.2 16.5
                                    * 77.0       16.6  53 G

 266   -     -    -    -    -    -    -    -    -    -

 267   -     -    -    -    -    -    -    -    -    -
```

MODE THREE DISPLAY (Wheel Weights)

AXLE	LEFT	RIGHT	WEIGHT	SPACE	OV.LOAD	ERR
A1	5.88	5.92	11.8			
A2	8.76	8.83	17.6	17.4		
A3	8.32	8.69	17.0	4.2		
23	17.08	17.52	34.6	**	.6	
A4	5.75	8.35	14.1	29.3		
A5	7.11	9.39	16.5	4.2		
45	12.86	17.74	30.6	**		

```
GROSS WEIGHT    :  77000 LBS      VEHICLE-LENGTH :  55.3 FEET
OVER LOAD       :     00 LBS      VEHICLE-CLASS  :  53
MEASUREMENT-NO.:     265          VEHICLE-SPEED  :  16.6 MPH

                   * * IMBALANCE ! * * * SPEED VARIATION *
```

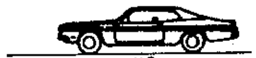
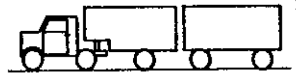
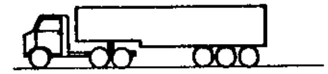
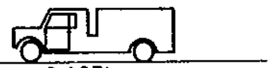
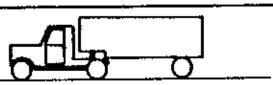
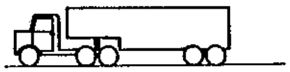
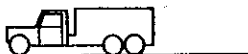
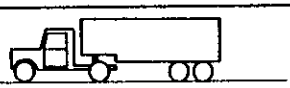
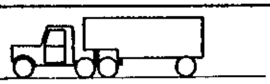
FIGURE D-8

FIGURE D-9

PAT WEIGH-IN-MOTION CLASSIFICATION CODE

CLASS	AXLE WEIGHT (1000 LBS.) SINGLE	TANDEM	LENGTH (FEET)	SPEED (MPH)
1	< = 2.0	< = 6.0	< = 20.0	< = 35.0
2	2.1 - 4.0	6.1 - 10.0	20.1 - 25.0	35.1 - 40.0
3	4.1 - 6.0	10.1 - 14.0	25.1 - 30.0	40.1 - 45.0
4	6.1 - 8.0	14.1 - 18.0	30.1 - 35.0	45.1 - 50.0
5	8.1 - 10.0	18.1 - 22.0	35.1 - 40.0	50.1 - 55.0
6	10.1 - 12.0	22.1 - 26.0	40.1 - 45.0	55.1 - 60.0
7	12.1 - 14.0	26.1 - 30.0	45.1 - 50.0	60.1 - 65.0
8	14.1 - 16.0	30.1 - 34.0	50.1 - 55.0	65.1 - 70.0
9	16.1 - 18.0	34.1 - 38.0	55.1 - 60.0	70.1 - 75.0
10	18.1 - 20.0	38.1 - 42.0	60.1 - 65.0	75.1 - 80.0
11	20.1 - 22.0	42.1 - 46.0	65.1 - 70.0	80.1 - 85.0
12	22.1 - 24.0	46.1 - 50.0	70.1 - 75.0	85.1 - 90.0
13	24.1 - 26.0	50.1 - 54.0	75.1 - 80.0	> 90.0
14	26.1 - 28.0	54.1 - 58.0	80.1 - 85.0	-
15	28.1 - 30.0	58.1 - 62.0	85.1 - 90.0	-
16	> 30.0	> 62.0	> 90.0	

FIGURE D-10

NO.	TYPE	TOTAL WEIGHT (KIPS)	PAT. CLASS	U. S. CLASS	NO.	TYPE	TOTAL WEIGHT (KIPS)	PAT. CLASS	U. S. CLASS	NO.	TYPE	TOTAL WEIGHT (KIPS)	PAT. CLASS	U. S. CLASS
1	 4 <12 6	10	10	-	10	 34 34	68	45	-	18	 14 34 34 20	102	64	-
2	 4 6 6	16	11	-	11	 14 20 20 20 20	94	50	-	19	 14 34 42	90	69	-
3	 4 6 6 6	22	12	-	12	 14 20 20 34	88	51	-	20	 14 20 20 20 20 20 20	134	70	-
4	 14 >12Ft. 20	34	21	-	13	 14 34 20 20	88	52	-	21	 14 34 20 20 20 20	128	72	-
5	 14 20 20	54	30	-	14	 14 34 34	82	53	-	22	 14 34 34 20 20	122	74	-
6	 14 <8Ft. 34	48	31	-	15	 14 20 42	76	54	-	23	 34 20 34 20 20	128	76	-
7	 14 20 20 20	74	40	-	16	 14 34 20 20 20	108	62	-	24	 14 34 20 20 20 20 20	148	82	-
8	 14 20 34	68	41	-	17	 14 34 20 34	102	63	-	25	 14 34 34 20 34	136	85	-
9	 14 34 20	68	42	-										

PAT TRUCK VEHICLE CLASSIFICATION

WEIGHT IN KIPS (1,000 lbs.)

APPENDIX E

GENERAL DESCRIPTION OF THE STREETERAMET ROLLWEIGH IN-MOTION TRUCK WEIGHING SYSTEM

General

The StreeterAmet Company Model 5150 Rollweigh In-Motion truck weighing system, commonly known as weigh-in-motion (WIM) system, includes an axial scale, vehicle detector loops, digital processor and a CRT terminal.

The StreeterAmet data processor is shown in Figure E-1.

The axle scale consists of an independent right and left track wheel scales. The determination of when the truck wheels are fully scale-borne is made by the processor based on the weight information received from the scale.

A pair of vehicle detector loops is embedded in the pavement with the axle scale between them. The front detector loop signals when a truck is approaching the scale. The "after" scale detector loop signals passage of the truck. Together, the set of loops determines the truck speed.

The Model 5150 processor is a microcomputer-based instrument that accepts analog signals from the axle scale and pulse signals from the traffic loops and produces digital outputs indicating truck axle and gross weights, overweight conditions, axle spacings, speed and other supportive information.

The CRT terminal consists of a television type display plus keyboard and acts as the interface between the operator and the Model 5150 processor. It is used to initiate operations and to display the truck axle and total weights, as well as axle spacings, speed, time, station number, operator number and truck number. It provides an updated record of weights and data for the last four trucks and indicates overweight axles and trucks.

Caltrans furnished an Anadex Model DP-8000 printer for use with this WIM system.

The system is designed for in-motion weighing of trucks to about 30 mph.

Basic Components

1. Digital processor, includes digital and analog electronics and power supply (one per system).

2. CRT Terminal (one per system).

3. Two StreeterAmet 27" x 58" (69 cm x 147 cm) wheel scales with 40,000 pounds (18144 kg) total axle scale capacity.

System Description - Processor

The basic processor consists of a Central Processing Unit (CPU) which contains various control and timing circuits. The CPU performs all the control and logic functions based on programs stored in the Permanent Memory and the Changeable Memory; each is located on separate P.C. boards.

The analog system, which includes the analog-to-digital (A/D) converter module and power supply, is accessible by swinging up the upper part of the housing and locking it into position with the knee bracket. The A/D converter and preamplifier are contained in the small shielded enclosure. All the boards are of the plug-in type. The A/D converter is a high rate conversion type, allowing many scans to be made of the scale's output to provide good averaging. The preamplifier is a special StreeterAmet design with thermal compensation.

The power supply provides all the supply voltage for the digital and analog electronics, displays, lights and load cells. It uses a single printed circuit board that is connector-coupled to the rest of the system.

CRT Terminal

Figure E-2 shows a typical output display on the CRT screen. The terminal has a relatively large screen and self-contained memory. The keyboard is a standard type with special functions added. The display arrangement shows header information on the top line with weight and identifying data on the following lines. The display simultaneously shows data for four trucks weighed. With subsequent trucks arriving for "display," the most recent truck display appears on the bottom line and the oldest is "scrolled" off. Thus, the display always shows the weight and data for the last four trucks. Overweights are detected and indicated with an asterisk.

Printer

No printer was ordered with the system. Caltrans furnished an Anadex Model DP-8000 printer for use with the system because of its availability in the Department and for economy.

Wheel Scale

The StreeterAmet axle scale consists of two wheel scales, each 27" long (in the direction of traffic) and 58" wide.

The 27" scale length assures that two adjacent axles cannot be on the scale at the same time, yet wheels will be on the scale for a long enough period to assure maximum accuracy of weight readings. The scale requires a pit about 8" deep. The scale is constructed using a "honey-comb" concept to maximize stiffness.

The StreeterAmet scale utilizes four, low-profile 10,000 lb. capacity load cells. The load cell bearing arrangement is adjustable in elevation to provide a smooth transition from the roadway to the scale deck. Spherical washers provide a uniform bearing on the load cells.

Specifications

The following specifications are provided by StreeterAmet:

5150 Microprocessor

Dimensions:	20"x19"x15" (50.8x48.2x38.1 cm)
Weight:	Approximately 50 lbs (22.5 kg)
Power Input:	Two 6V rechargeable gel cell batteries for power back-up.
Temperature Range:	+32°F - +100°F (0°C - +38°C)

CRT Terminal

Dimensions:	12"x16"x21" (30.4x40.6x53.3 cm)
Weight:	45 lbs (20.2 kg)
Power Input:	115 VAC ± 10%, 50-60 Hz

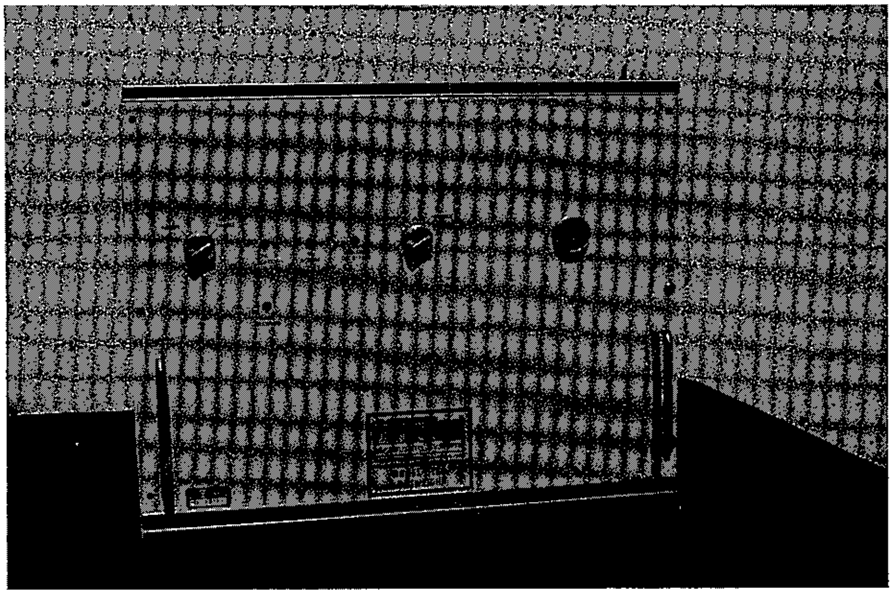
Wheel Scale (2 Required)

Dimensions:	27" long in the direction of traffic, and 58" wide (68.6 cm x 147.3 cm)
Pit Depth:	8" deep (20.3 cm)
Load Cells:	4 low profile, high side load capacity, 10,000 lbs (4500 kg) cells

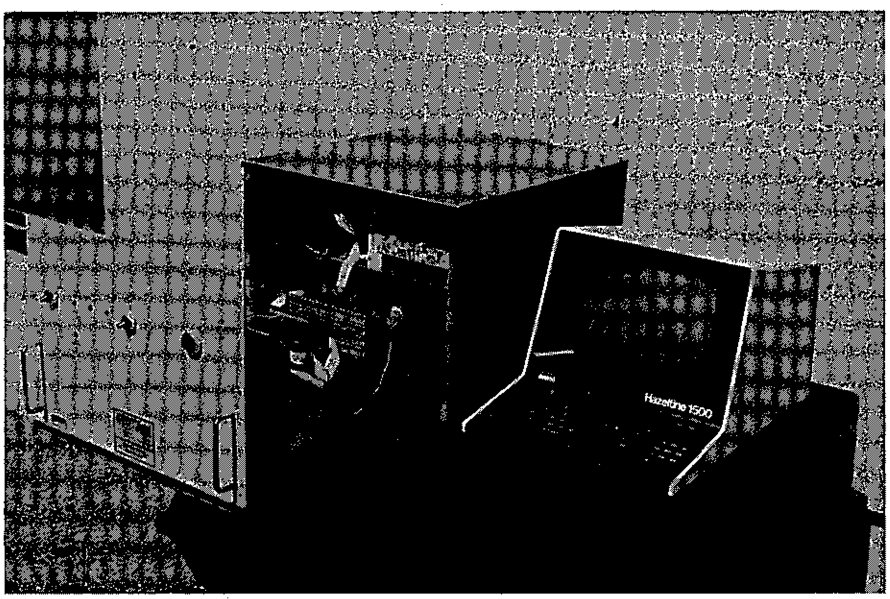
Figure E-1

Major Components of the StreeterAmet WIM System

Scales Not Shown



Model 5150 Rollweigh Data Processor



Data Processor and CRT Terminal

Figure E-2

STREETERAMET WIM OUTPUT DISPLAY

```
STATION:               OPERATOR:                  TIME:                 DATE:

0001 SPEED:  25  TOTAL WT.: 198.0  TOTAL LENGTH:  94.5  NO. AXLES:  11
     WEIGHTS: 18.0    18.0    18.0    18.0    18.0    18.0    18.0    18.0    18.0    18.0    18.0
     TAN WTS:             36.0            36.0            36.0            36.0            36.0
     SPACING:     10.0    3.9     14.0    3.9     17.5    3.9     14.3    3.9     13.2    3.9

0002 SPEED:  31  TOTAL WT.:  60.0  TOTAL LENGTH:  56.0  NO. AXLES:  5
 "s" WEIGHTS:  7.7    13.7    13.1    12.6    12.9
     TAN WTS:             26.8            25.5
     SPACING:     10.0    4.0     32.0    4.0

0003 SPEED:  10  TOTAL WT.:  200.1*  TOTAL LENGTH:  67.8  NO. AXLES:  8
     WEIGHTS: 20.0    50.1*   40.7*   18.0    18.0    18.0    17.1    18.2
   * TAN WTS:             90.8*           36.0                    35.3
     SPACING:     10.0    3.8     14.3    3.7     10.4    15.7    3.9

0004 SPEED:  6  TOTAL WT.:  17.2  TOTAL LENGTH:  23.6  NO. AXLES:  3
     WEIGHTS:  1.8     8.2     8.2
     TAN WTS:             16.4
     SPACING:     14.0    3.6

GROSS WEIGHT:  80.0    AXLE MAX.  20.0    SEQ. NO.      TAN WT MAX  34.0
```

*Indicates overweight
sIndicates overspeed or underspeed

APPENDIX F

STATIC SCALE TESTS IN THE LABORATORY

The WIM axle scales were separately tested, disconnected from their systems, prior to any system calibration tests. They were tested in the laboratory under static loading in a universal testing machine.

The static test evaluated the scales for accuracy, linearity, resolution and repeatability. Poor performance under static test conditions would suggest questionable operation under dynamic conditions. However, both makes of scales (PAT and StreeterAmet) performed adequately under static loadings. The static testing also ensured that all scales were functional prior to field installation and for later dynamic system calibration.

PAT Wheel Scale Tests

All eight of the PAT wheel scales were static load tested in the laboratory, prior to field installation, in a MTS Universal Testing Machine. For the test, the output of the scales was connected to a Strainsert Model HWI-D strain gage indicator. The main purpose of the static test was to evaluate the scales separately from its instrumentation system; thus, the Strainsert Indicator connected as the readout instrument rather than the WIM system.

Figure F-1 (bottom) shows a scale in place in the MTS machine and being test loaded through an 8"x8" rubber bearing pad. The scale platform size is 49-1/2"x20"x7/8" and weighs 181 pounds. The channel frame visible in the photograph bearing the scale is not a part of the PAT system. It was fabricated for testing the scales in the MTS machine.

The results of the test on five scales are summarized in Figure F-2. Each scale was individually statically loaded with five test loads in 2000-pound increments up to 10,000 pounds. These five loads were applied on the platform at five locations as shown in Figure F-2. They were applied through an 8"x8" rubber bearing pad. All of the output in pounds listed in the figure are the averages of several repeated load applications.

Each of the scale's outputs for repeated load applications were excellent, varying by not more than 20 pounds between repeated loads; furthermore, in many of the repeated groups of load applications, several measured outputs were identical. Thus, the five scales tested had excellent repeatability. The scales have good resolution and can indicate 20 pounds in 10,000 pounds for a resolution of 0.2%. Subsequent tests of the remaining three scales had similar results.

Examination of the output test data in Figure F-2, for the five scales tested, indicates that repeated test loads applied off-center from the scale's central Position No. 1 resulted in outputs different from that at Position No. 1. Thus, there are scale output errors associated with off-center load positions. These errors, for the 10,000 pound test loads applied off-center at Locations No. 2 and No. 4, ranged from +2.3% to -1.6% of the central position's true weight output. The above error ranges resulted from the five scales tested. Similarly, for greater off-center test loadings at Positions No. 3 and No. 5, their errors ranged from -0.2% to -4.8% of the central position's "true" output. Off-center test loadings of less than 10,000 pounds (4000 to 6000 pounds) indicates similar range of errors as for the 10,000 pound loading. Thus, loads not in the immediate center of the scale platform caused static weighing errors ranging from about +2.3% to -4.8%.

The same load applied through different size load areas (like different tire sizes) did not change the scale outputs.

For example, the following tires have about the following contact size areas at 75 psi:

7.50 x 20	45.4 sq. in.
10.00 x 20	67.8 sq. in.
11.00 x 20	77.7 sq. in.

To simulate the above range of tire prints, the following pads were used.:

49 sq. in., (7" x 7")
64 sq. in., (8" x 8")
81 sq. in., (9" x 9")
90 sq. in., (7.75" x 14" oval)

The PAT Corporation supplied the rubber oval pad as it indicated that it was the most representative or typical tire print to be borne by a scale.

Loads were applied through these four pads onto a PAT scale (S/N 80-1-364). Responses are tabulated in Figure F-3. For comparison purposes, the load applied through the 8" x 8" pad was chosen as the "correct" scale output. For ready comparison, the scale's output and its errors for the four pads (at Position No. 1) at the 10,000 pound loading are relisted below:

Pad Size	Output	Error, %
49 sq. in. (7" x 7")	9,950	-0.5
64 sq. in. (8" x 8")	10,000	0.0
81 sq. in. (9" x 9")	10,030	+0.3
90 sq. in. (Oval)	9,760	-2.4

It shows that for the three simulated tire sizes (7.50x20, 10.00x20, and 11.00x20), large changes in area sizes produced almost identical scale outputs. The scale output errors were -.5% and +0.3%, respectively, for pad sizes 49 sq. in. and 81 sq. in. This indicates that tires of different contact areas should create very small scale output weighing errors.

As for the oval pad's relatively large (-2.4%) "error" as compared to that of the other two pads, we surmised that its tire print length of 14" was too long for the scale and thus, overlapped the cantilevered weight-sensing portion of the scale platform. In other words, this weight error of -2.4% may be because the 14" length tire print overlapped beyond the scaleborne portion of the platform so that a portion of the simulated tire weight was borne by the nonweighing portion of the scale frame. Thus, we believe that the data listed in Figure F-3 for the 14" oval pad are invalid.

How structurally adequate were the PAT scales? To answer this, a scale was cyclically loaded in the MTS machine from 0 to 10,000 pounds for 100,000 cycles. After completion of the cyclic loadings, our examination revealed no structural distress nor structural failure of the scale. Furthermore, the scale remained in calibration with no zero shift in its output. The above findings are all supportive indications that the scales are structurally adequate and should be able to withstand cyclic loadings.

In summary, the static weighing capabilities of the PAT scales were judged to be adequate with an error range of about +2.3% to -4.8%.

StreeterAmet Scale Tests

The StreeterAmet scales were also statically tested in the laboratory prior to field installation. For similar reasons, the StreeterAmet scales were also connected to a Strainsert HWI-D gage indicator for the in-laboratory static tests.

The StreeterAmet system consists of an independent left and right track wheel scale. The two scales together comprise an axle scale. Each wheel scale is supported at its four corners by a Toroid load cell. Thus, there are eight load cells for an axle scale.

The cells were manufactured by Toroid Corporation, Post Office Box 1435, Huntsville, Alabama 35807, and identified as Models 47-132-BDF, 10,000 pound capacity (compression), 350-ohm bridge with 2 mv/v output. The individual characteristics of each cell are listed in Figure F-4. Figure F-5 shows two of the 24 cells and the setup for testing them. From our experience with other flat load cells, adequate bearing support for the cells is of extreme importance for repeatable and accurate test. Thus, as shown in the figure, the cells were mounted on rigid 2"x5"x9" steel blocks for the test. They were mounted with four bolts, each torqued to a uniform 120 inch-pounds, thus assuring uniform bearing to the block's surface.

The average test results of the cells were:

1. Nonlinearity - 0.41%
2. Repeatability - 0.10%
3. Test output - 7466 units
4. Errors (combined) - 0.51%

Figure F-6 is the test data for two cells (serial numbers 51309 and 51303). The results are typical and representative of all 24 cells and, for the sake of brevity, the test results of the remaining 22 cells are not included herein.

Examination of the static loading data in Figure F-6 indicate the cells performed well.

Nonlinearity of the two cells are evaluated and summarized in Figure F-7. The data indicate that cells #51309 and #51303 have nonlinearities of 0.30% and 0.41%, respectively.

The repeatability of the two cells were good and well within 0.1% from the data listed in Figure F-6.

The test output of the 24 cells ranged from 7133 to 7620 units (see Figure F-4) for an average output of 7466 units. Percentagewise, it ranged from -4.5% to +2.1% of average. However, the variations of test output among the 24 cells were later equalized with appropriate series resistors.

From the above work and for a "worst" case condition, we assumed that the static errors of the other 23 cells are equal to the "worst" cell #51303, i.e., assume all cells have a static error of 0.51%. As described previously, four cells are installed in a wheel track scale and their outputs are summed to provide the scale output. However, the errors of the four cells are not summed to give 2.04% error but most probably the RMS error of the four cells combined, i.e., 0.51%. Thus, we believed that the scale platform, borne by four cells, would have a static error of 0.51%.

However, this did not turn out to be true. When we installed four cells into a wheel track scale and test loaded it in a universal testing machine, its error approached 3%. Upon our further investigation, we found that the threaded load button (load button shown in Figure F-5) directly affected the error of the cell. The load button serves two purposes:

1. Transmits the platform load into the cell proper, and

2. Is threaded to raise or lower the scale platform to the correct elevation and levelness.

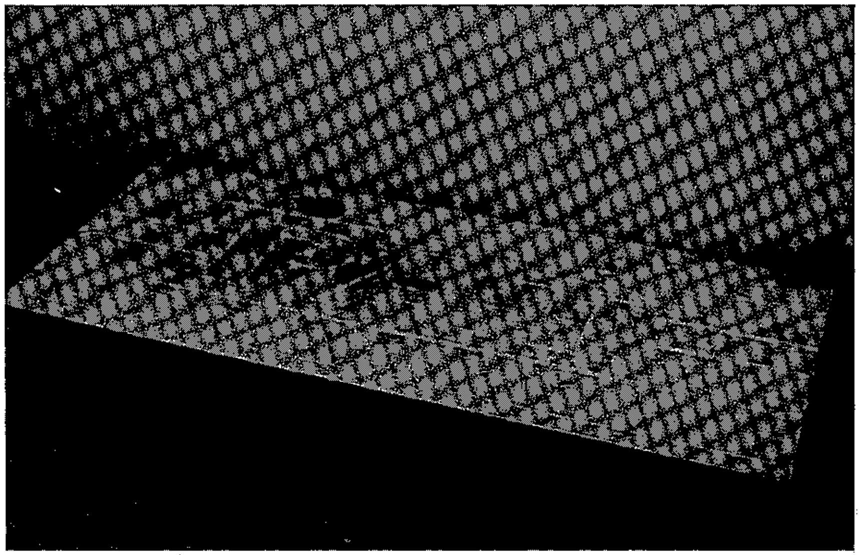
We found the error of the cell varied in relation to the elevation of the load button. This is shown in Figure F-8, where eight cells were tested, individually, at rated load (10,000 pounds) versus elevation of its load button in increments of 1/8 turn up to one complete turn. The largest button-related elevation error was found in cell #CHC 51217 (see Figure F-8). Over one complete rotation of the button, the error varied from +3.7% to -2.6%. Eight cells are utilized in an axle scale. For the eight cells and their elevation related errors listed in Figure F-8, the most probable error for them in combination would be their RMS error which calculates out to be 1.87% or say 2.0%. Thus, the static error of the StreeterAmet scales is expected to be about 2.0%.

As our evaluation has shown, the button elevation varies the cell's error and there is no way, using the present design, to "fix" the buttons' elevation, as it is used in the roadway to elevate the scale platform to grade. In our judgment, the scale performance could be improved by developing other means to elevate it to grade other than with the threaded load button.

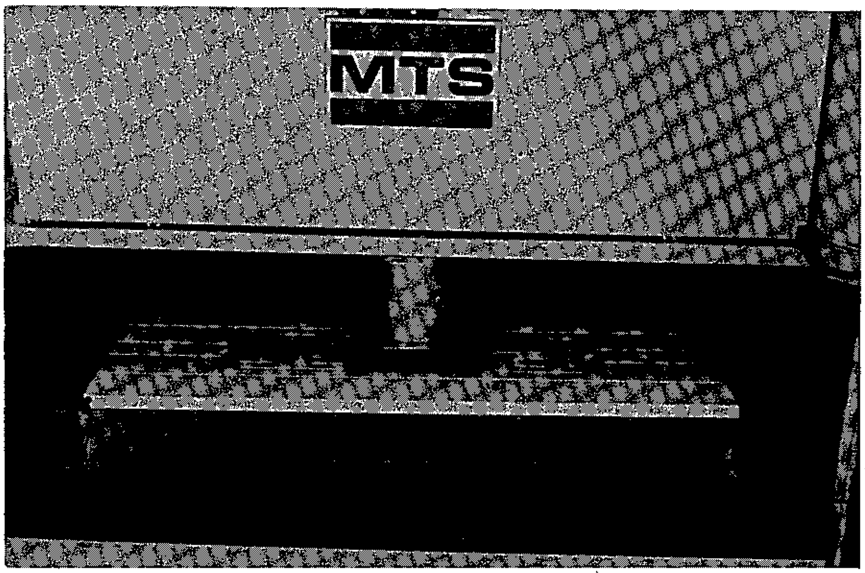
After completion of the above tests, the scales were installed in the field and found to be structurally inadequate. StreeterAmet reworked the scales to improve structural adequacy. Appendices J and K describe the inadequacies and rework, respectively. We retested the reworked scales and the work is described in Appendix L, "In-Laboratory Evaluation of StreeterAmet Reworked Wheel Scale".

Figure F-1

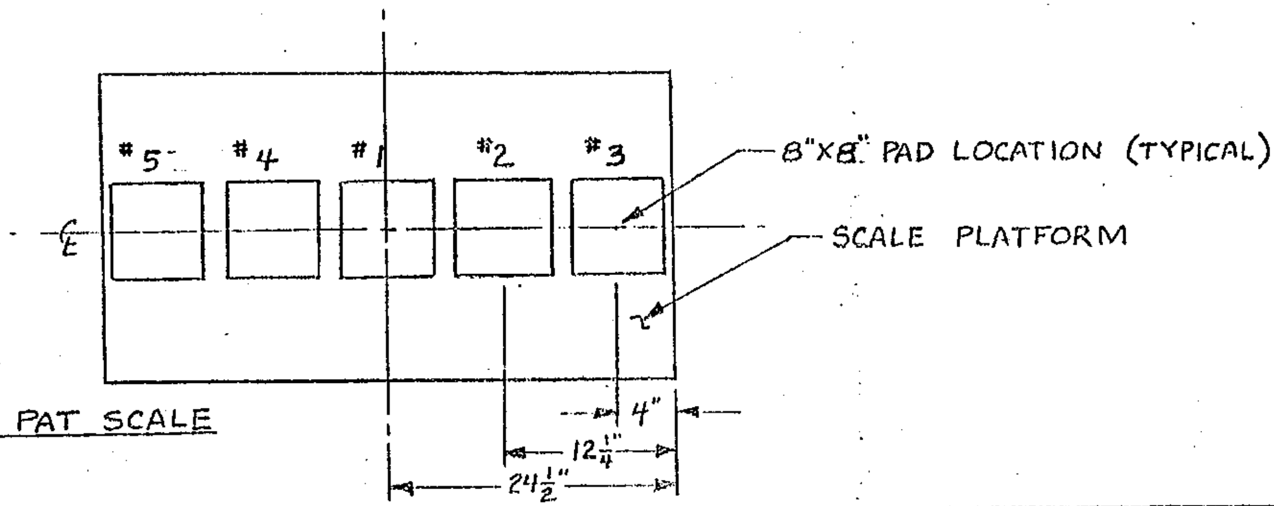
IN-LABORATORY EVALUATION OF A PAT
WHEEL SCALE PLATFORM



A PAT wheel scale platform. Dimensions: 49-1/4" x 20" x 7/8". Weight: 181 pounds (with cable).



Test loading a PAT wheel scale platform in the MTS Testing Machine



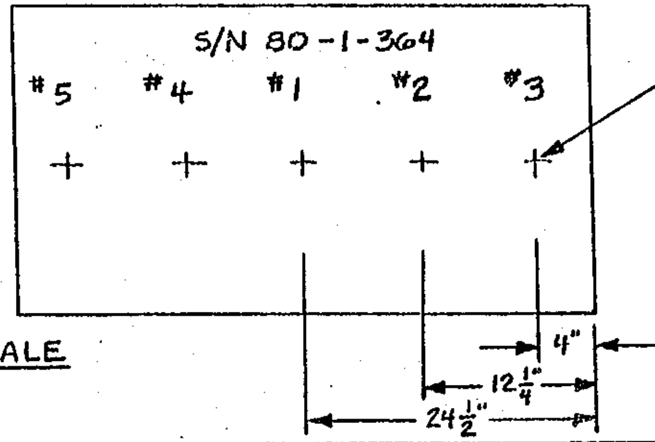
CALIBRATION OF FIVE PAT SCALE PLATFORMS

CALIB. TEST LOAD, POUNDS	PAT SCALE CALIBRATION OUTPUT - POUNDS														
	S/N 79-11-270					S/N 79-12-362					S/N 80-1-363				
	5	4	1	2	3	5	4	1	2	3	5	4	1	2	3
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	2160	2150	2220	2250	2220	2140	2170	2170	2290	2320	2150	2130	2180	2220	2180
4000	4070	4120	4230	4280	4070	4070	4140	4210	4350	4280	4130	4110	4210	4230	4130
6000	5930	6050	6190	6220	5900	5980	6080	6190	6350	6200	6030	6050	6150	6200	6010
8000	7760	7930	8120	8070	7720	7870	7990	8120	8300	8100	7890	7950	8090	8110	7860
10000	9630	9800	10000	9950	9520	9740	9870	10000	10230	9980	9750	9840	10010	9970	9750
0	30	0	0	0	10	30	0	0	10	0	10	0	0	0	30

CALIB. TEST LOAD, POUNDS	S/N 80-1-364					S/N 80-1-380				
	5	4	1	2	3	5	4	1	2	3
0	0	0	0	0	0	0	0	0	0	0
2000	2270	2250	2190	2170	2130	2160	2150	2160	2210	2190
4000	4230	4320	4190	4150	4120	4150	4180	4210	4250	4130
6000	6100	6280	6160	6090	5990	6070	6140	6190	6210	6020
8000	7940	8180	8100	7960	7830	7920	8050	8100	8090	7880
10000	9780	10040	10000	9840	9660	9730	9930	10000	9940	9720
0	0	0	0	0	0	0	0	0	0	0

CALIFORNIA
DEPARTMENT OF TRANSPORTATION
OFFICE OF TRANSPORTATION LABORATORY
WEIGH-IN-MOTION SCALE PROJECT
631113

Figure F-2



PLACEMENT CENTERS FOR 7", 8" AND 9" SQUARE PADS AND ALSO AN OVAL PAD.

PAD LOADS APPLIED SINGULARLY AT FIVE LOCATIONS.

CALIBRATION OF A PAT SCALE PLATFORM

CALIB. TEST LOAD, POUNDS	PAT SCALE CALIBRATION OUTPUT - POUNDS (S/N 80-1-364)														
	7" X 7" PAD					8"X8" PAD					9"X 9" PAD				
	5	4	1	2	3	5	4	1	2	3	5	4	1	2	3
0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	2150	2180	2150	2230	2240	2270	2250	2190	2170	2130	2150	2150	2170	2270	2290
4000	4090	4170	4160	4250	4180	4230	4320	4190	4150	4120	4130	4140	4190	4330	4270
6000	6000	6100	6150	6240	6050	6100	6280	6160	6090	5990	6040	6090	6200	6290	6200
8000	7820	8030	8050	8130	7900	7940	8180	8100	7960	7830	7920	8000	8120	8200	8060
10000	9660	9860	9950	9980	9710	9780	10040	10000	9840	9660	9760	9880	10030	10090	9870
0	0	10	0	0	20	0	10	0	0	0	0	0	0	0	0

CALIB. TEST LOAD, POUNDS	OVAL PAD (64 IN² APPROX)				
	5	4	1	2	3
0	0	0	0	0	0
2000	2100	2100	2050	2100	2120
4000	4000	4000	4020	4030	4000
6000	5830	5860	5950	6000	5800
8000	7660	7660	7870	7750	7590
10000	9460	9510	9760	9560	9350

CALIFORNIA DEPARTMENT OF TRANSPORTATION
OFFICE OF TRANSPORTATION LABORATORY
WEIGH-IN-MOTION SCALE PROJECT
631113

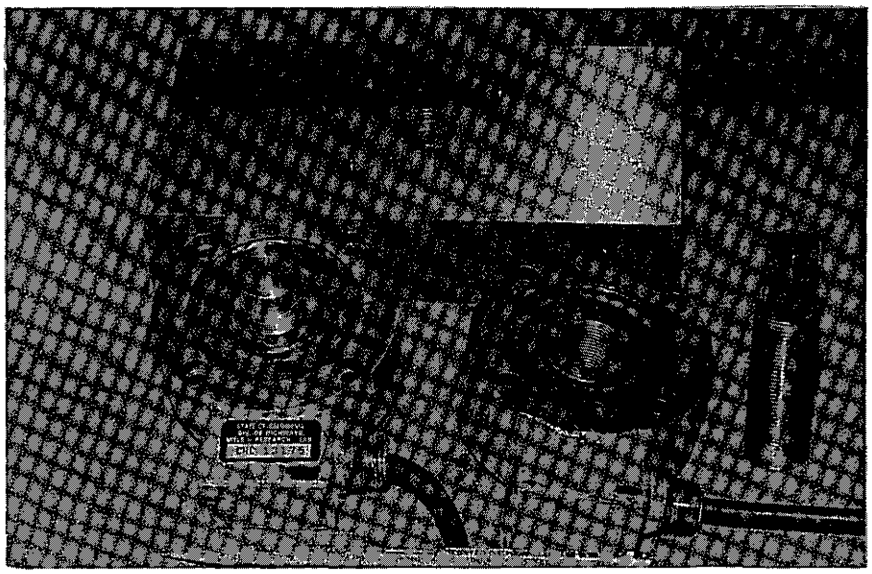
Figure F-4

STREETERAMET/TOROID LOAD CELL DATA

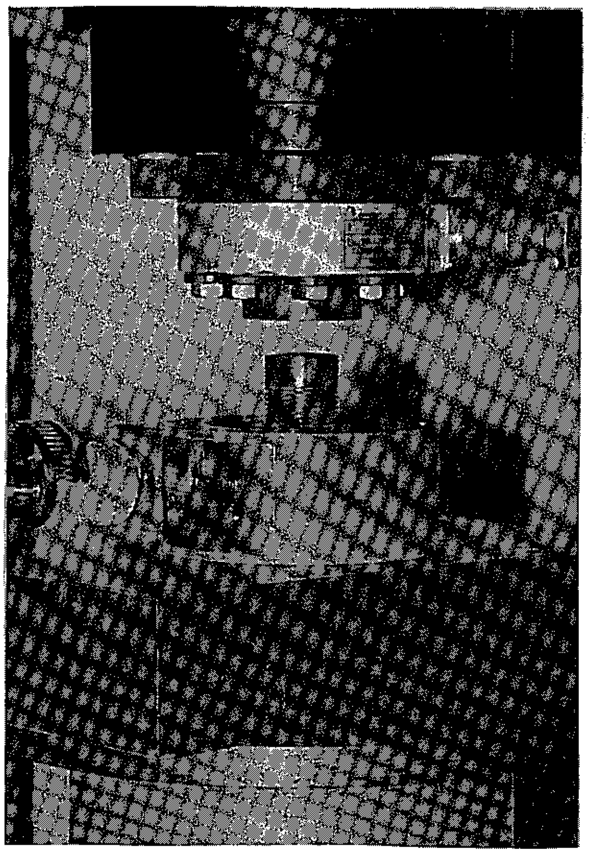
Toroid Cells Serial No.	CHC No.	Ohms Input	Ohms Output	Test Output, Units 10,000 lbs	Non-linearity, %	Resistance Added (Ohms) To Normalize Output
51217	13162			7620		0.0
51218	13161	347	348	7433		
51219	13174	347	349	7298		
51220	13169			7496		
51221	13163			7463		
51222	13166	347	348	7133		
51223	13158			7481		
51224	13178	347	349	7423		
51225	13159			7487		
51226	13167			7558		0.0
51297	13177	347	349	7150		
51298	13173			7515		
51299	13168			7495		
51300	13176	346	346	7425		
51301	13170			7577		6.0
51302	13165	347	349	7342		
51303	13155			7579	0.41	3.0
51304	13171			7537		1.0
51305	13164			7531		
51306	13175	347	349	7429		
51307	13172			7572		1.5
51308	13160			7556		1.0
51309	13156			7499	0.30	
51310	13157			7595		5.0
Average				7466		

Figure F-5

STREETERAMET/TOROID LOAD CELLS



2" x 5" x 9" calibration bearing block in background. Two cells and a load button unthreaded in foreground.



Load cell calibration test setup with cell mounted on its 2" x 5" x 9" bearing block and calibration with a "series" cell (Strainsert Model FL10u-c - 3S PKT, Serial No. Q 4933-1, 10,000 pounds capacity).

Figure F-6

COMPRESSION CALIBRATION OF TWO STREETERAMET/TOROID LOAD CELLS

True Static Load (Pounds)	Units Output *									
	Load Cell S/N 51309				Load Cell S/N 51303					
	Run No. 1		Run No. 2		Run No. 1		Run No. 2		Run No. 3	
0	1000		1000		1023		1024		1022	
		726		722		787		786		788
1000	1726		1722		1810		1810		1810	
		750		752		765		763		763
2000	2476		2474		2575		2573		2573	
		752		752		757		758		757
3000	3228		3226		3332		3331		3330	
		756		754		760		759		759
4000	3984		3980		4092		4090		4089	
		753		755		756		755		757
5000	4737		4736		4848		4845		4846	
		753		754		754		755		755
6000	5490		5490		5602		5600		5601	
		753		753		752		753		752
7000	6243		6243		6354		6353		6353	
		753		754		751		750		751
8000	6996		6997		7105		7103		7104	
		754		752		751		751		752
9000	7750		7749		7856		7854		7856	
		749		750		746		749		746
10,000	8499		8499		8602		8603		8602	
Non-linearity, %	0.30				0.41					

*Units output read with a Strainsert Indicator Model HWI-D set at G.F. = 1.09.

NON-LINEARITY OF STREETERAMET/TOROID LOAD CELLS

Note: Cell output units read with a Strainsert Indicator Model HW1-D set at G.F. = 1.09.

Static Test Load In Pounds (X)	Load Cell #51309				Load Cell #51303			
	Cell Output Units (Y)	(Y')	Deviation Units	Non-linearity %	Cell Output Units (Y)	(Y')	Deviation Units	Non-linearity %
0	1000				1023			
1000	1724	1750	26	0.30	1810	1781	29	0.34
2000	2475	2450	25	0.29	2574	2539	35	0.41
3000	3227	3250	23	0.27	3331	3297	34	0.39
4000	3982	4000	18	0.21	4090	4123	33	0.38
5000	4736	4749	13	0.15	4846	4812	34	0.39
6000	5490	5499	9	0.10	5601	5570	31	0.36
7000	6243	6249	6	0.07	6353	6328	25	0.29
8000	6996	6999	3	0.03	7104	7086	18	0.21
9000	7750	7749	1	0.01	7855	7844	11	0.13
10,000	8499	8499	0	0.00	8602	8602	0	0.00

Load Cell #51309:

$$Y' = mx + b = \frac{8499 - 1000}{10000} X + 1000$$

Load Cell #51303:

$$Y' = mx + b = \frac{8602 - 1023}{10000} X + 1023$$

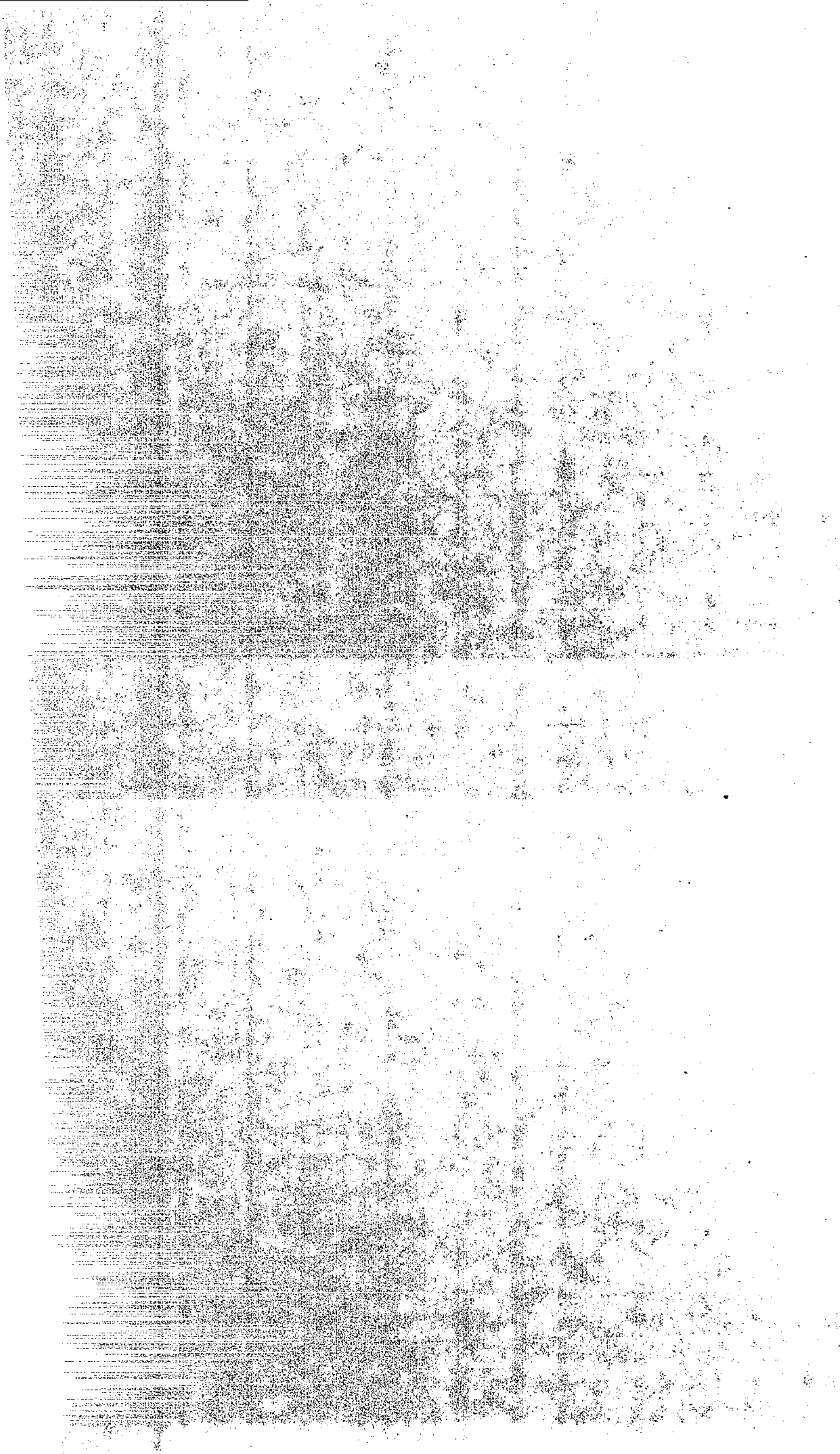
Figure F-7

Figure F-8

ACCURACY EVALUATION OF LOAD CELLS

Turns Rotation of Threaded Load Button	10,000 Pounds True Static Load Applied Readout (Units) Versus Turns Rotation — Load Cell Serial Number							
	51301	51303	51310	51217	51304	51308	51226	51307
0	998	1021	994	975	996	983	990	994
1/8	1012	981	1006	1037	1010	993	1006	984
2/8	1003	1010	989	999	991	1013	989	998
3/8	995	989	1010	1013	982	1013	994	1018
4/8	1013	1018	996	980	997	984	1009	989
5/8	1003	991	1006	1029	1011	989	1019	986
6/8	994	1016	994	989	990	1017	987	1004
7/8	988	990	1012	1005	982	1016	985	1014
8/8	1010	1019	994	974	1002	987	992	991
Average	1002	1004	1000	1000	996	999	997	998
Max. Plus Error, %	1.3	2.1	1.2	3.7	1.1	1.7	1.9	1.8
Max. Minus Error, %	1.2	1.9	1.1	2.6	1.8	1.7	1.5	1.6
RMS Error				1.87				

Note: All eight load cells connected in summation (parallel) and connected to the StreeterAmet System readout with one cell tested at a time.



APPENDIX G

STREETERAMET WIM SCALE INSTALLATION PROCEDURE

Three sets of StreeterAmet WIM axle scales were installed, two sets at the I-5 Freeway site and one set at the CHP (California Highway Patrol) Castaic weigh station. All three sets were installed concurrent with portland cement concrete pavement construction.

Installation procedures were very similar for both sites. Thus, the following photographs (Figures G-1 through G-11) of the installation procedure at the I-5 site typically represents similar procedure at the Castaic weigh station.

From examining the photographs, it is apparent that the StreeterAmet scales require a large amount of work to install. The foundation frame and axle scale required the assembly of a multitude of parts having many bolted and screwed connections. The number of parts and mechanical fasteners (screws, washers, bolts, nuts, etc.) totaled 290 for one axle scale and its foundation frame. Furthermore, the pit anchor bolts and many scale parts required critical alignment and adjustments in the field. The tensioning of the horizontal check rods were tedious as they had to be maintained horizontally under tension. Bearing pads were tedious to form and cast. Many scale parts were heavy and cumbersome to handle. A wheel scale and a foundation frame weigh 700 and 276 pounds, respectively, and required a hoist and boom for placement.

Installation of the StreeterAmet pit frames into the preformed concrete pits was started on September 6, 1979 and completed on September 14, 1979. No particular difficulty was encountered during the installation of the frames; however, it took longer than estimated because of the critical leveling adjustments needed to elevate and slope the frames. Experience would no doubt speed installation. Photographs of the major steps in the installation procedure are shown in Figures G-1 through G-7.

Installation of the wheel scales into the pit frames was started on September 24 and completed on September 26. Photographs of the major steps in mounting the load cells onto the scale proper and its installation into the foundation pits are shown in Figures G-8 through G-11.

Installation of the pit frames and scales was done under the advisement and general direction of the StreeterAmet technical representative.

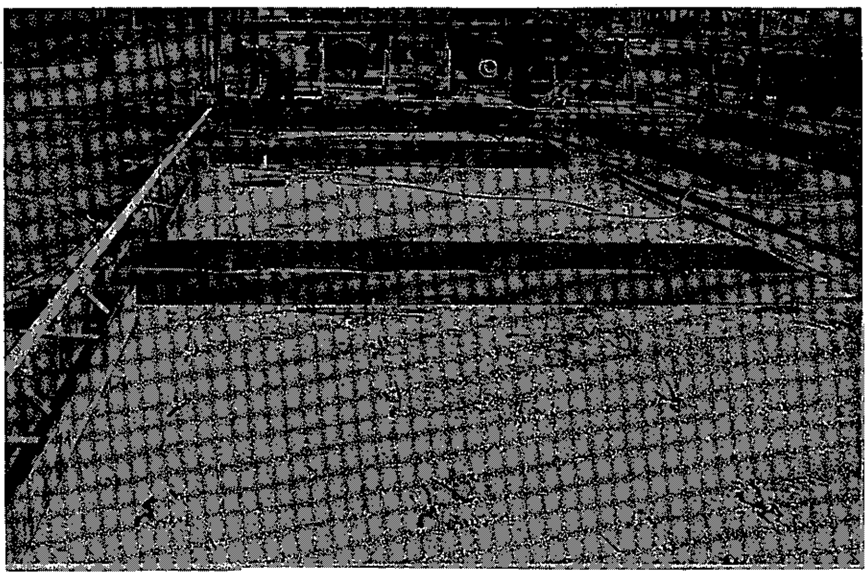
At the Castaic weigh station, the major effort to install an axle scale was started on Tuesday, July 29, 1980, and completed on Tuesday, August 5, 1980. It required a four-man crew.

The approximate cost to install the scale at the Castaic location was $12,820 and details are as follows:

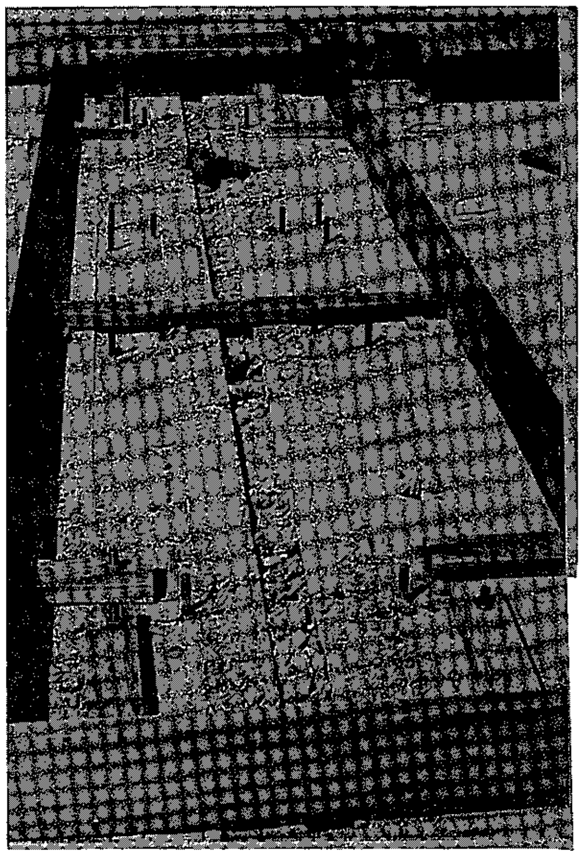
1.	Foundation construction	$ 2,500
2.	Sawing of loop grooves in pavement	500
3.	On-site labor	8,040
4.	Materials	
	Set 45	345
	Epoxy grout	225
	Electrical materials	1,210
5.	Equipment cost (boom truck, pickup, mechanics wagon, trailer, etc.)	0
	Total	$12,820

Figure G-1

Installation of StreeterAmet WIM Scales
at the I-5 Site (03-Sac-5)



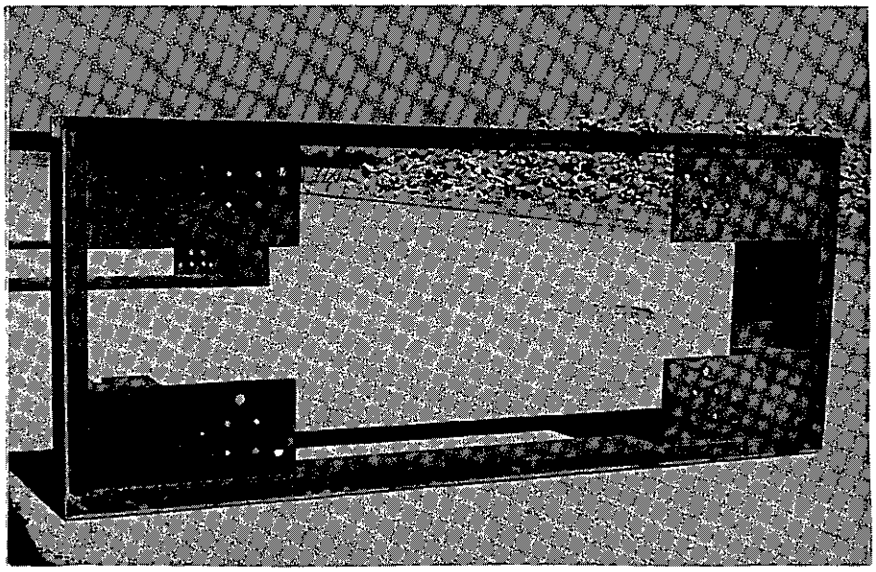
Frame blockouts for the two foundation pits in the outside lane.



Embedded 5/8" - 11 UNC bearing pad anchor bolts in the pit.

Figure G-3

Installation of StreeterAmet WIM Scales
at the I-5 Site (03-Sac-5)

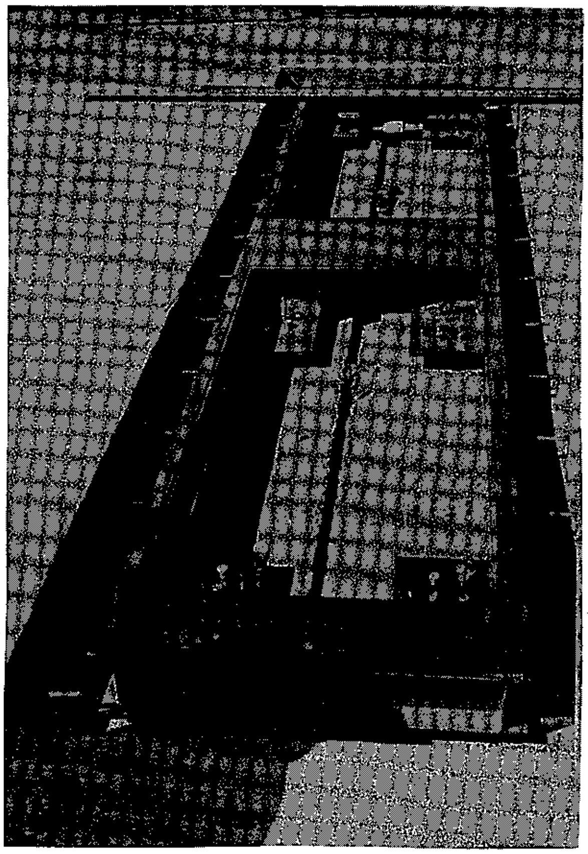


Pit frame on edge. Bottomside view. Frame in position for sandblasting of bonding surfaces to grout and concrete.

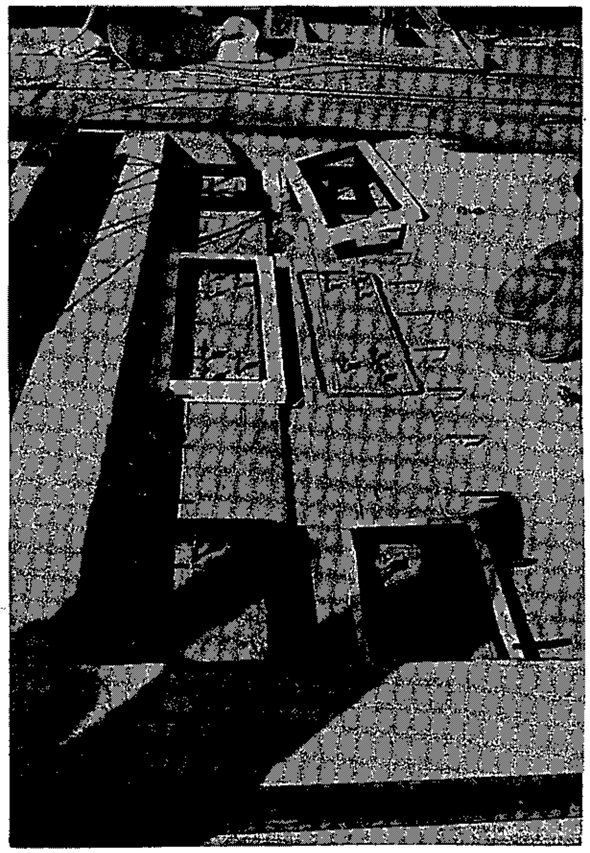
Lowering of inside wheel track pit frame into pit.

Figure G-4

Installation of StreeterAmet WIM Scales
at the I-5 Site (03-Sac-5)



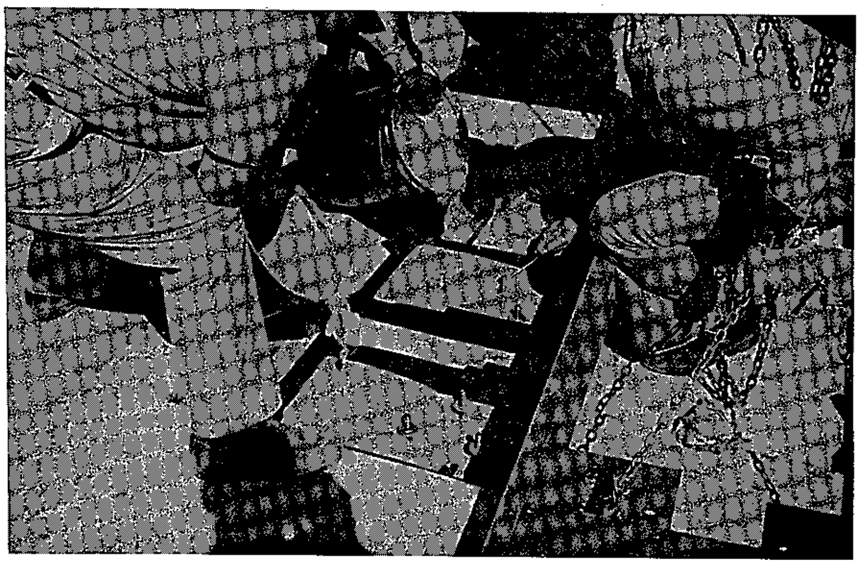
Inside and outside wheel track frames installed and adjusted for elevation, levelness and 2% cross slope. Center cover in place.



Pit frames removed for placement of bearing pad grouting forms.

Figure G-5

Installation of StreeterAmet WIM Scales
at the I-5 Site (03-Sac-5)



Placement of bearing pad epoxy grout (Sika Chemical Corporation Sikadur Industrial Grout-Pak).

Completed grouting of bearing pads. Grouting forms removed.

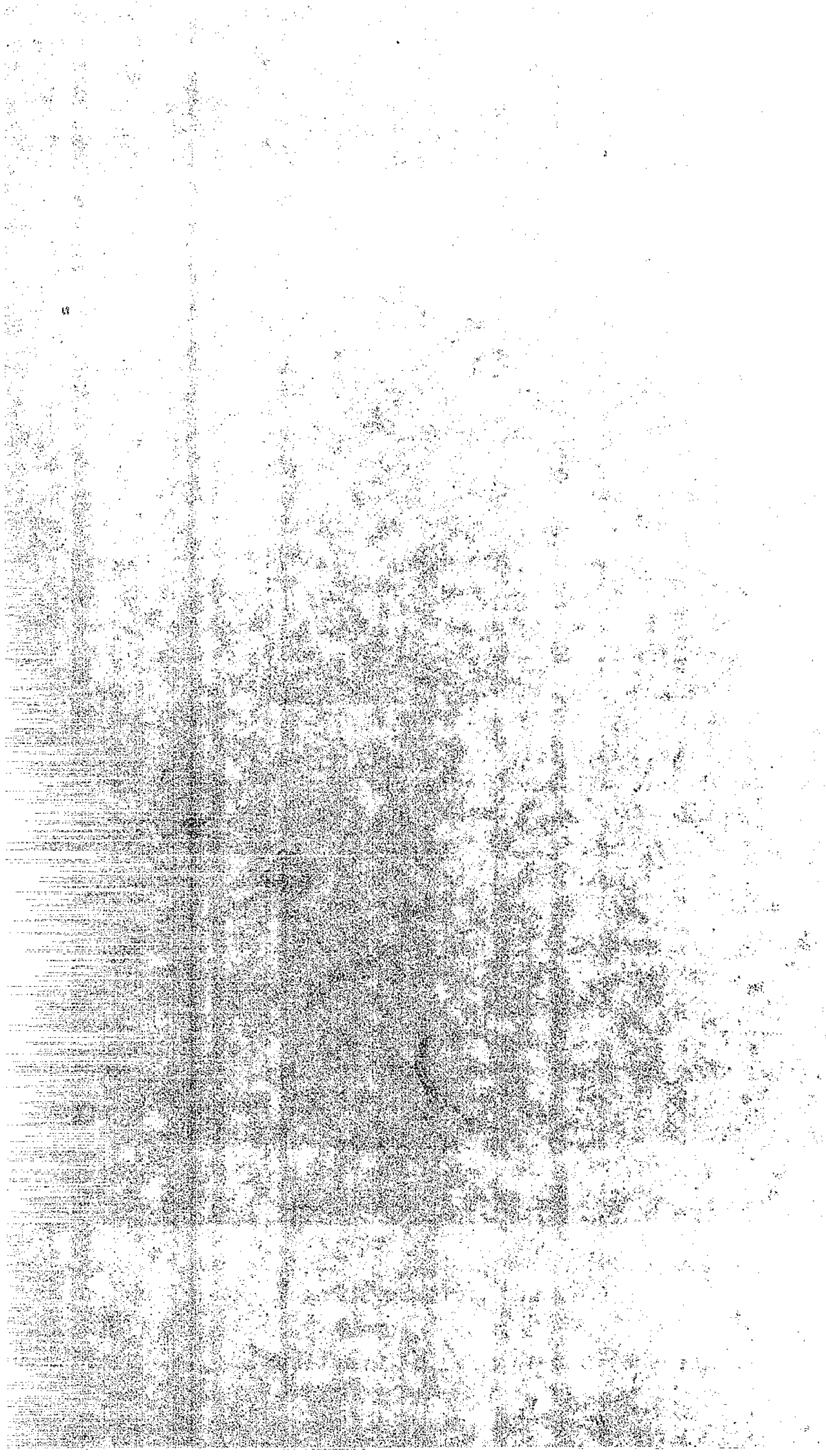
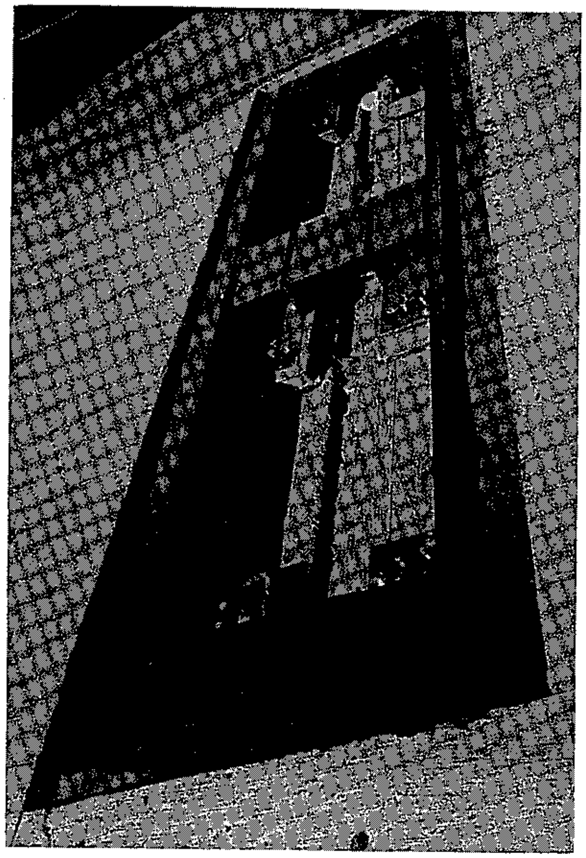


Figure G-6

Installation of StreeterAmet WIM Scales
at the I-5 Site (03-Sac-5)

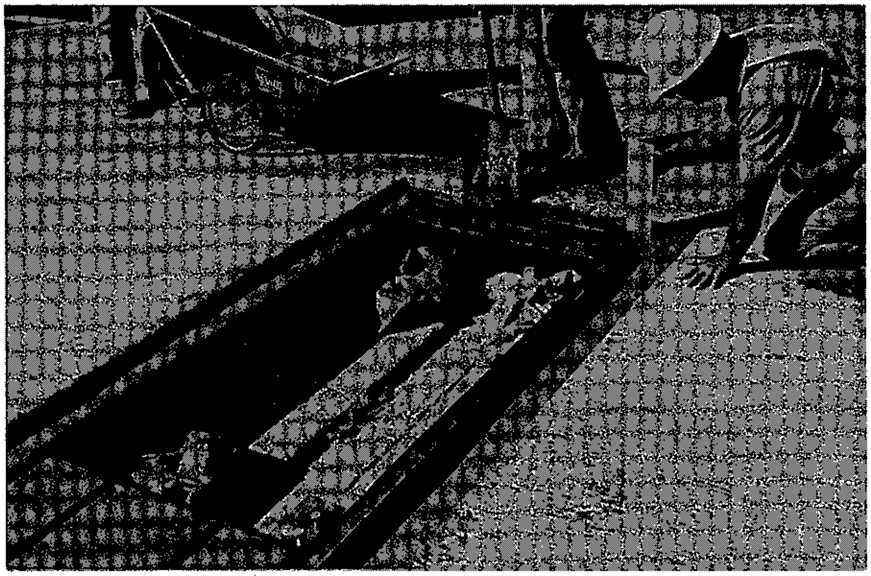


First lift of magnesium phosphate concrete (Set Products SET-45) placed around outside of pit frame.

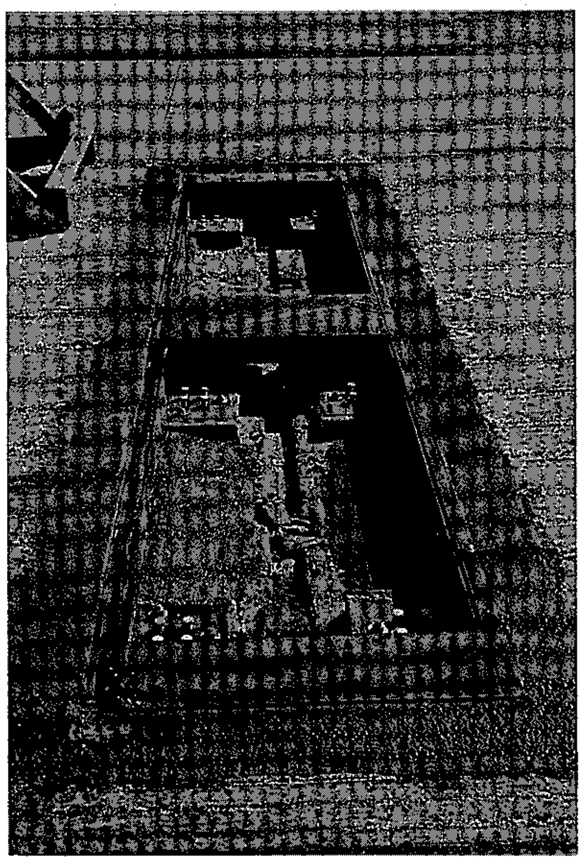
Rechecking of frame cross slope with an Engis Equipment Corp. Talyvel Model 1191-1040 electronic level. Completed in-place frame cross slope: 2.2°

Figure G-7

Installation of StreeterAmet WIM Scales
at the I-5 Site (03-Sac-5)



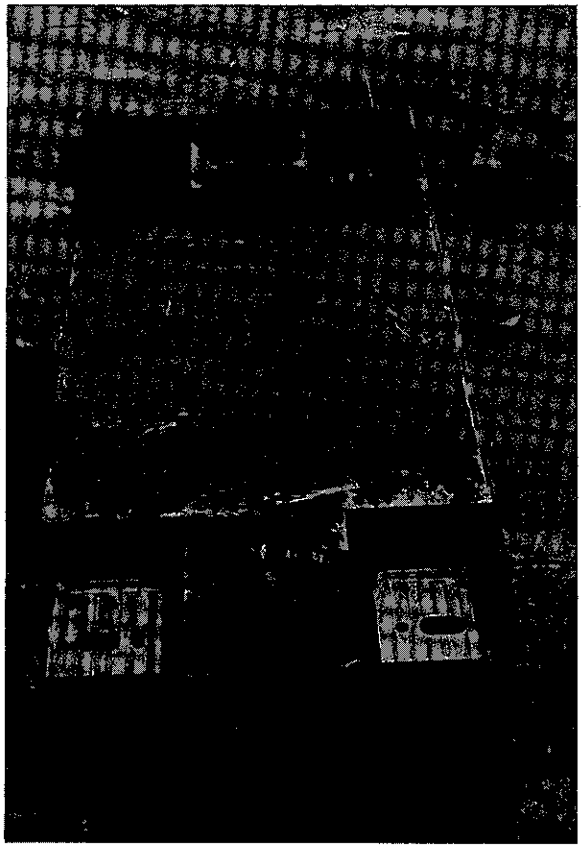
Placing of the second and the last lift of magnesium phosphate concrete around the outside of pit frame.



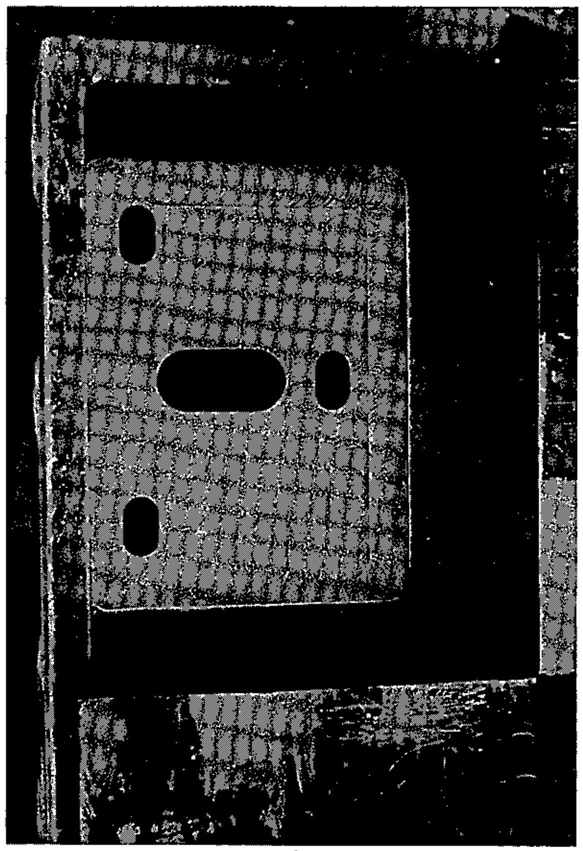
Completed installation of the pit frame in its pit.

Figure G-8

Installation of StreeterAmet WIM Scales
at the I-5 Site (03-Sac-5)



Bottom view of a scale platform for one wheel track. Note four corner cavities for attachment of bearing plates and load cells.



Platform bearing surface machined to level tolerance of 0.015"/ft in two directions and all four bearing surfaces machined to the same plane within 0.09375".

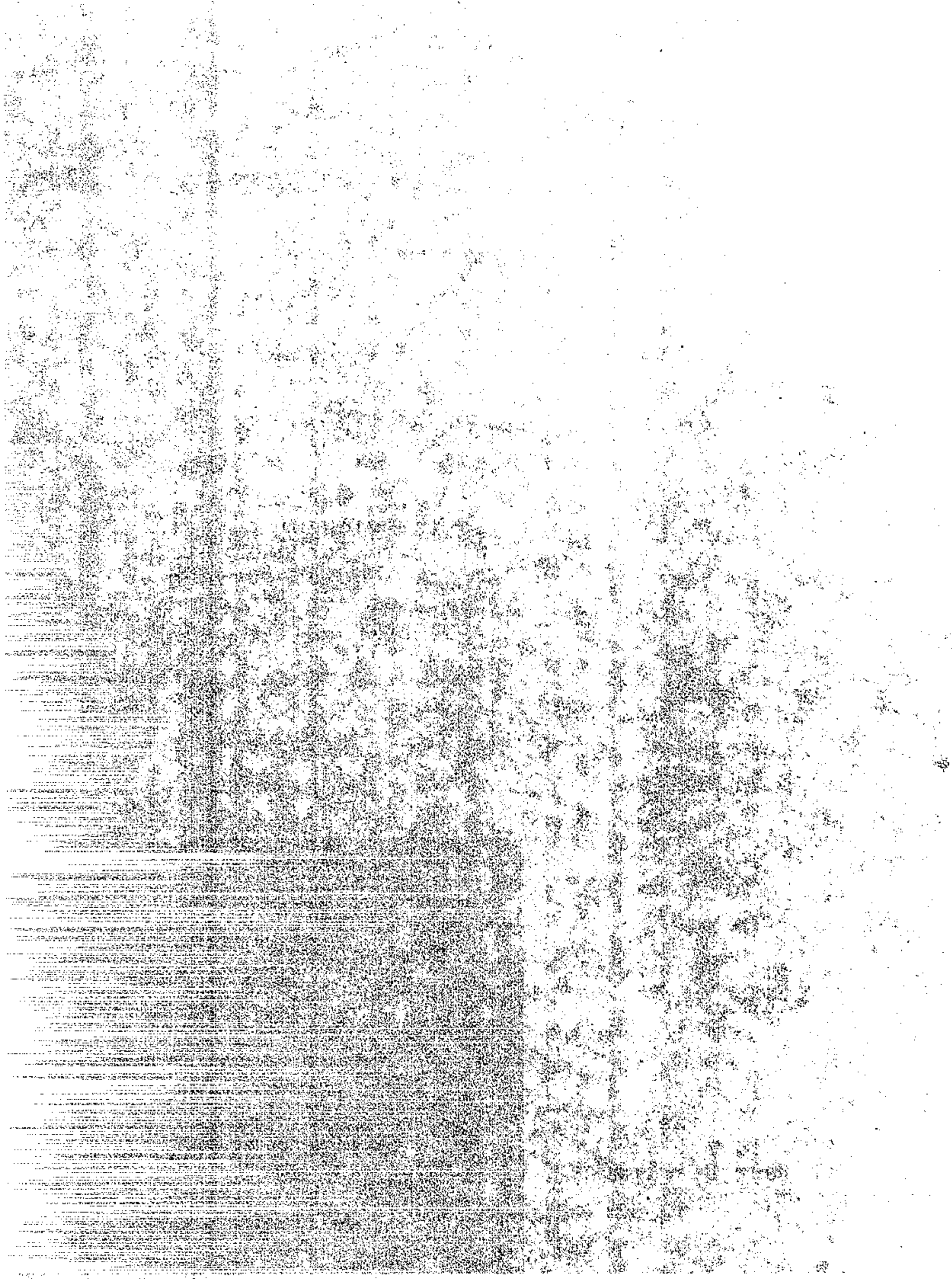
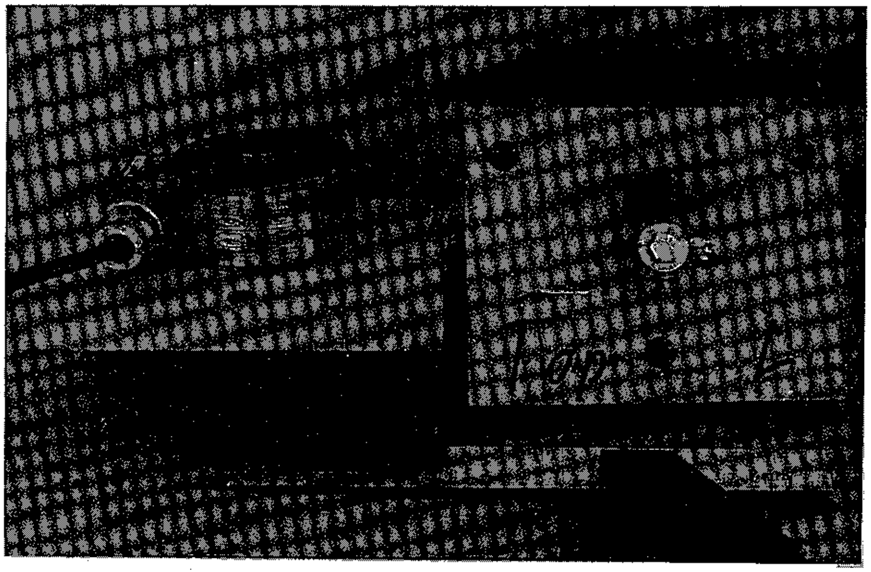
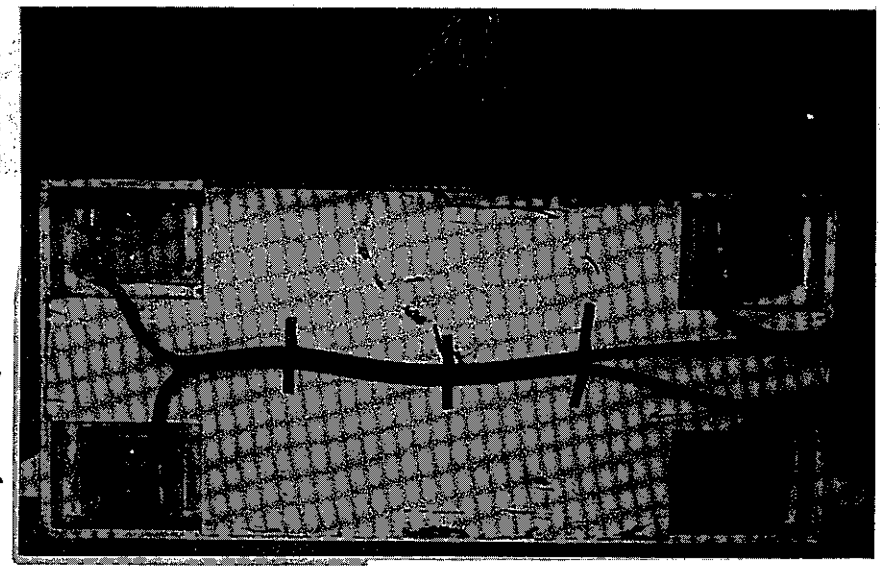


Figure G-9

Installation of StreeterAmet WIM Scales
at the I-5 Site (03-Sac-5)



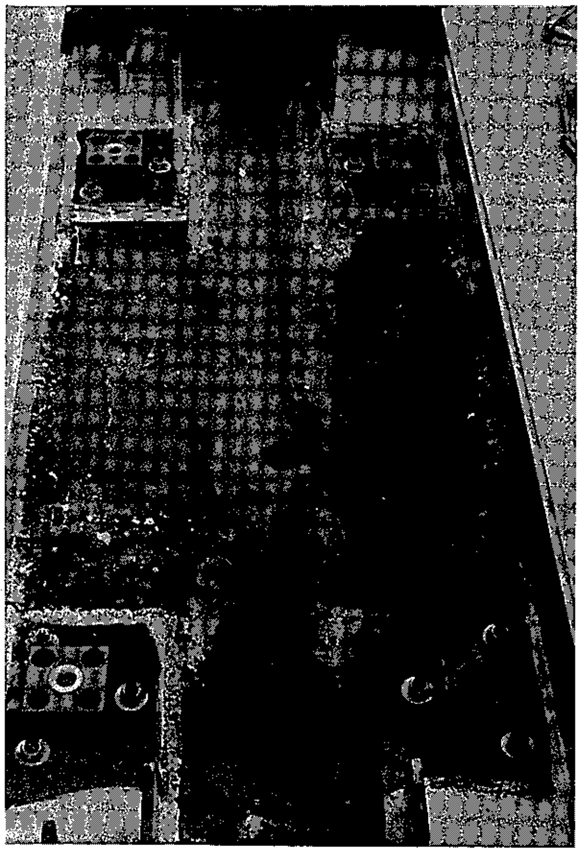
Left view: Toroid load cell attached to its top bearing plate. Toroid Corporation load cell Model 47-132-BDF, 10,000 pounds capacity, 350 ohm bridge with 2mv/v output.
Right view: Top view of top bearing plate and locking "V" clip.



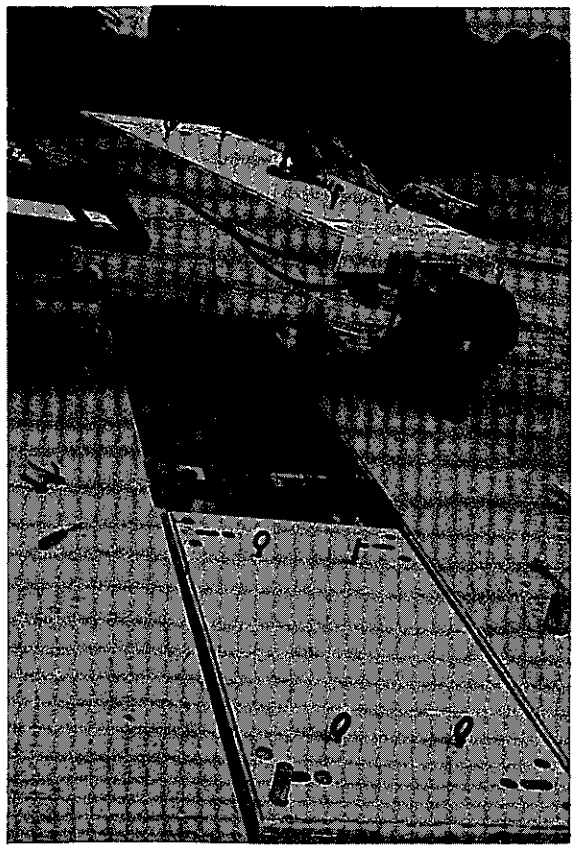
Bottom view of a scale platform with all four Toroid load cells attached and load cell cables routed to junction box.

Figure G-10

Installation of StreeterAmet WIM Scales
at the I-5 Site (03-Sac-5)



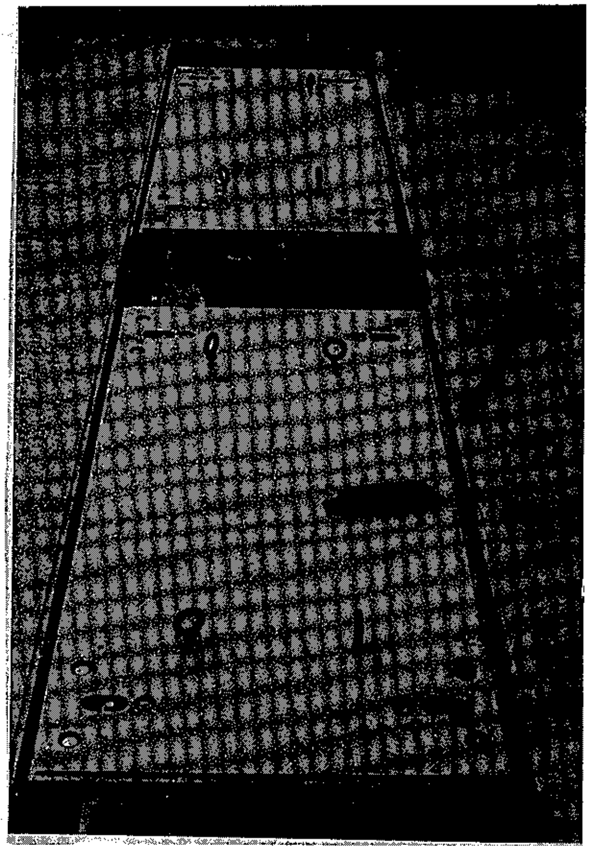
Load cell bearing blocks (four each per scale platform) installed in a pit frame.



Placement of scale platforms into a pit frame.

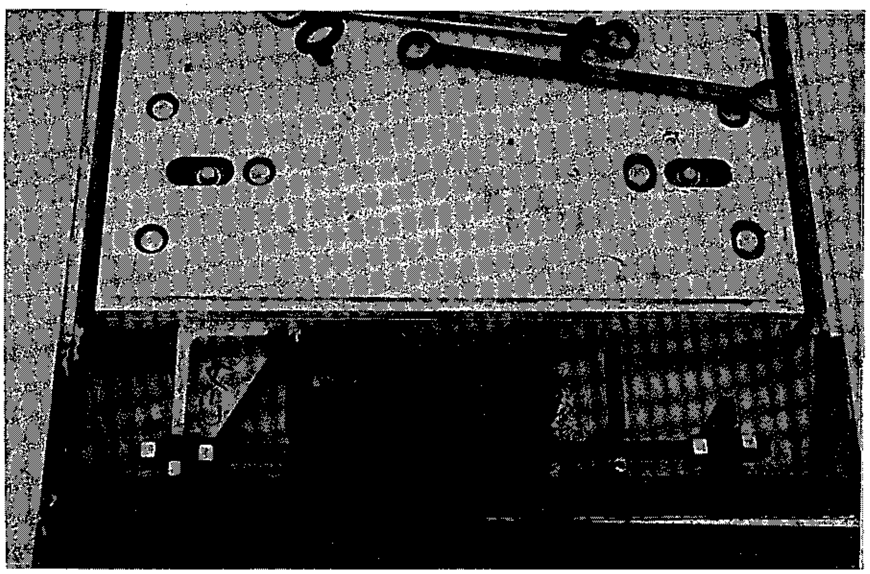
Figure G-11

Installation of StreeterAmet WIM Scales
at the I-5 Site (03-Sac-5)



Scale Platforms in place.
End and center cover plates
not in place.

View of end check rod.



APPENDIX H

PAT WIM SCALE INSTALLATION PROCEDURE

Two sets of PAT WIM scales were installed. One set at the CHP Antelope weigh station and the second set on U.S. Highway 99 near Lodi, California. The set at the weigh station was installed in a portland cement concrete pavement, whereas the set on U.S. Highway 99 was installed in new asphalt concrete overlaying an old portland cement concrete pavement.

Installation procedures were very similar for both sites so that the following description of the weigh station installation typically represents the same procedure used for the U.S. Highway 99 site.

The Antelope weigh station, located on westbound I-80, about four miles southwest of Roseville, California, was chosen for our first installation of the PAT scales. Site for the installation was located about 900 feet upstream from the weigh station and in the truck approach scale lane. The installation consisted of two axle scales and two vehicle loop detectors as shown in the layout plan in Figure H-1. The upper photograph in Figure H-2 is a view of the site.

The number of parts and mechanical fasteners totaled 48 for assemblage of one axle scale and its foundation frame, or a total of 96 for the two scales.

The scale installation was begun on Friday, May 9, and completed on the following Thursday, May 15, 1980.

The first order of work was to excavate four scale pits in the concrete pavement for embedment of the scale frames, and sawing the slots for the signals and detector loop conductors. The concrete sawing was awarded to a private contractor at a cost of $522.75. They started and completed the sawing in one day -- Friday.

In addition to the sawn outline of the scale pits, the areas within the pit outlines were sawn with crosshatch cuts for ease of chipping out the concrete. The work of chipping out the concrete was done by Caltrans personnel. A complete excavated axle scale pit (50-1/4" x 26" x 2") is shown in Figure H-2 (lower photograph).

Figure H-3 shows the signal and vehicle loop detector conduit runs to the junction box and the drain line from the pits.

In Figure H-4, the top photograph shows the two foundation frames (upside down) on the pavement next to their pits and ready for placement. Note that the pits have received a course of Set-45 Magnesium Phosphate ($MgPO_4$) grout, creating a level surface, except in the central area. The central area was depressed to facilitate drainage of water which might find its way under the scales. Next, a 1/8-inch thick layer of asphalt (Crafco Over-Flex MS asphalt modified rubber compound) was applied on top of the SET-45 grout layer. It provided a leveling course for the foundation frames.

While the asphalt was in its soft and hot state, the frames were "bedded" into it as shown in the bottom photograph of Figure H-4

A purported secondary purpose of the asphalt was to "stick" the frame to the foundation pit. Additionally, the frame is held in place by six steel hold-down stakes anchored to the concrete pavement. These stakes (7" shank with a 45° hook) were inserted into six predrilled 1-inch diameter holes drilled at a 45° angle into the concrete pavement slab. With the six stakes inserted, the holes were filled with the hot asphalt/rubber compound. In the lower photograph in Figure H-4, the six black spots are the asphalt/rubber compound overflow from the filling of the anchor stake holes. They were scraped away before the next installation step, placement of the shims.

The lower photograph in Figure H-5 shows the placement of shims in the foundation frame so that when the scale platform was installed, it would match the pavement grade. Figure H-6 shows the checking for correct depth using a straightedge.

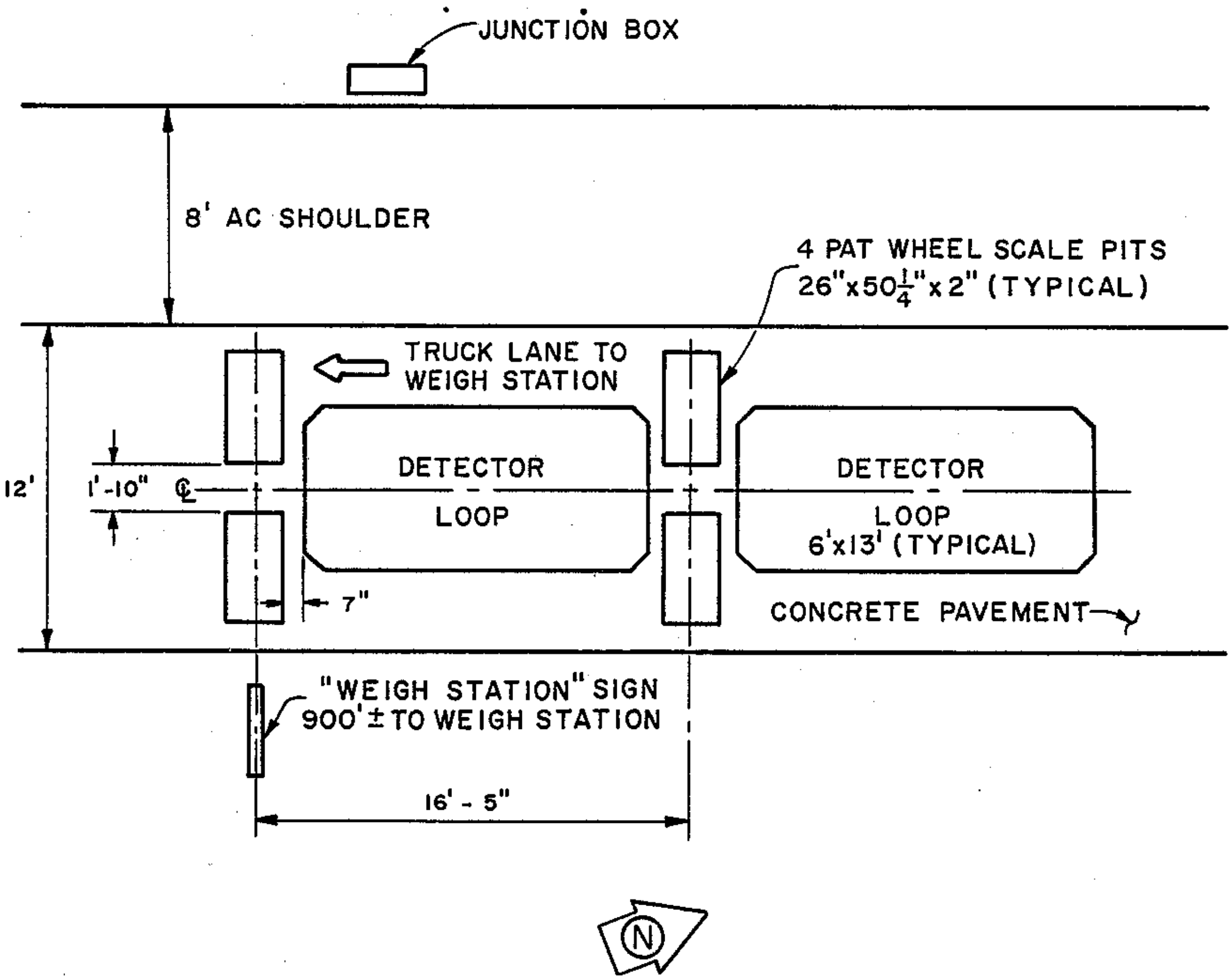
The remainder of the photographs in Figures H-6 and H-7 shows the completed PAT scale platform and loop installations.

No particular problems were encountered in the installation except for the difficulty of obtaining locally a specialized double-boiler type kettle required to heat the asphalt/rubber compound. One was finally located in Caltrans District 02 Maintenance Department in Redding, California, and brought to Sacramento with two experienced operators to complete this part of the installation.

Two PAT representatives were also present and observed the complete installation.

The approximate cost to install the two axle scales amounted to $3861.30 and is detailed as follows:

1.	Sawing concrete (private contractor) 1 day's work, May 12, 1980	$ 522.75
2.	Chipping concrete for the four foundation pits.	552.00
3.	Boring 24 1-inch diameter by 8" holes in concrete pavement for the frame anchor stakes.	552.00
4.	District 02 supplied labor, asphalt/rubber compound and bitumen heater	794.55
5.	Installed four scale platforms, shimmed and adjusted to grade and levelness and bolting in place.	480.00
6.	Installed loop conductors, junction box, conduits, and routed conductors through conduits.	480.00
7.	Miscellaneous work.	480.00
	Total	$3,861.30

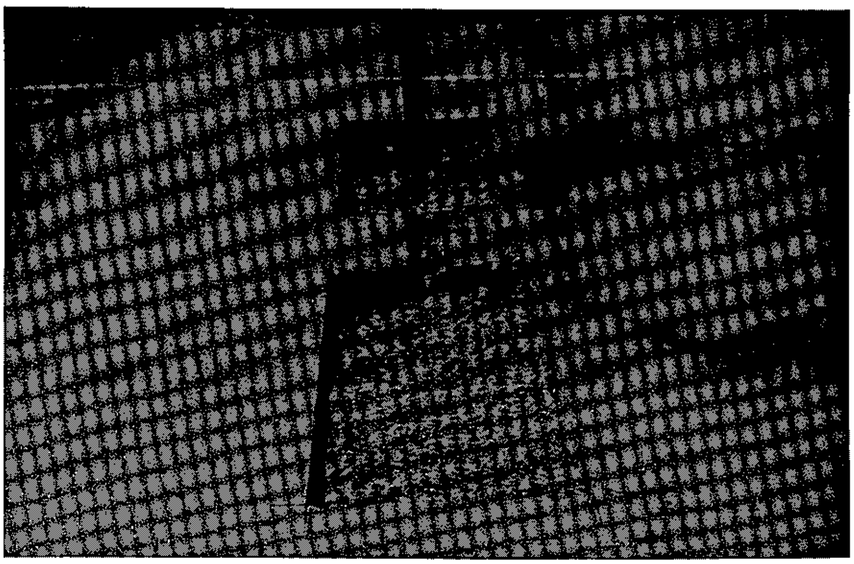


LAYOUT OF PAT WIM INSTALLATION
ANTELOPE CHP WEIGH STATION
03-SAC-80 (WESTBOUND)

Figure H-2

INSTALLATION OF PAT WIM SCALES AT THE
CALIFORNIA HIGHWAY PATROL ANTELOPE WEIGH STATION

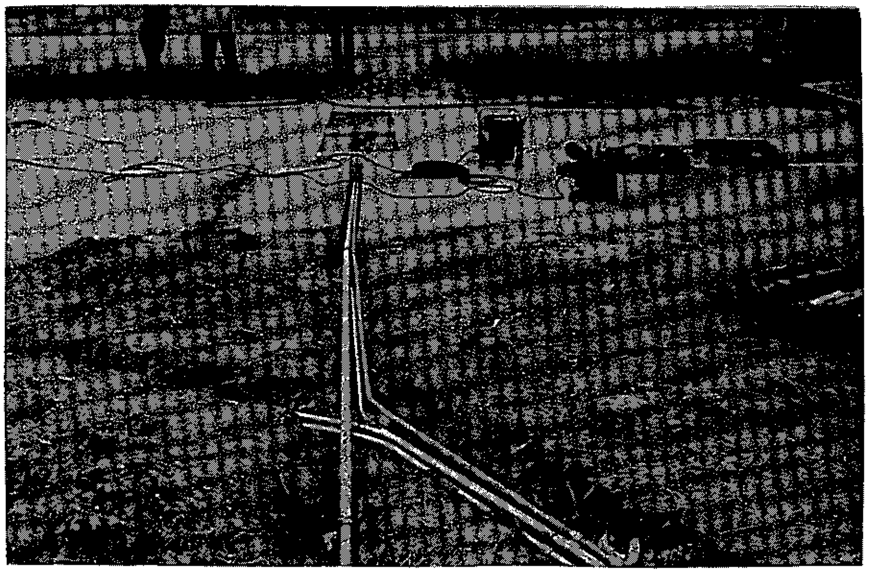
PAT scale installation site. Truck approach lane to Antelope Weigh Station. Station is in the background.



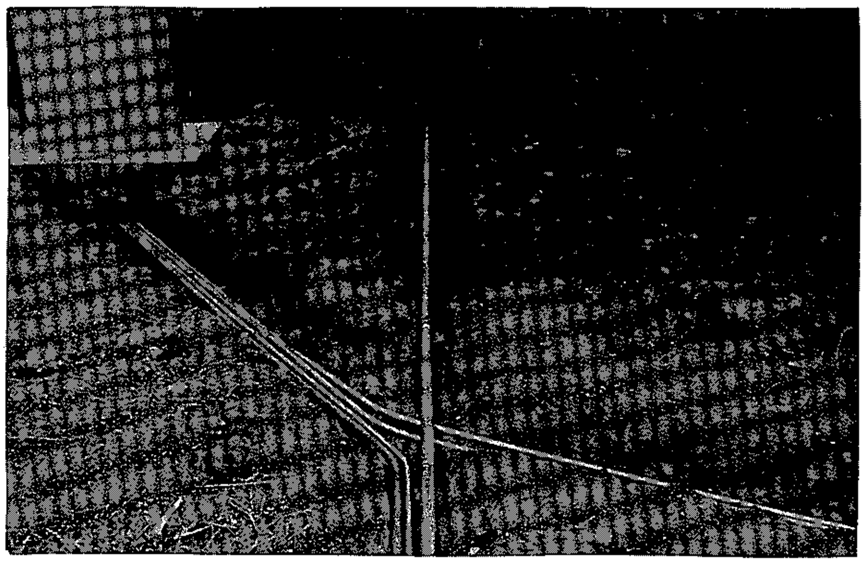
Completed excavated scale pits (50-1/4" x 26" x 2") for scale frame embedment.

Figure H-3

INSTALLATION OF PAT WIM SCALES AT THE
CALIFORNIA HIGHWAY PATROL ANTELOPE WEIGH STATION



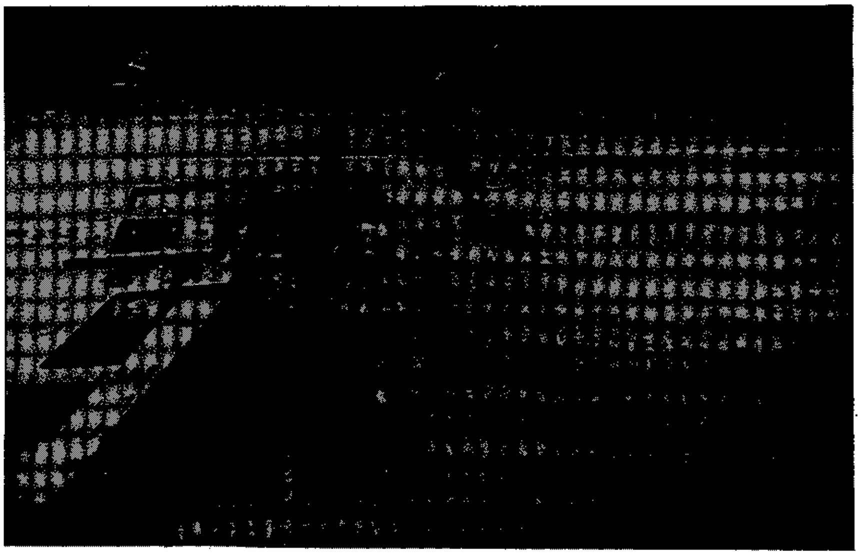
Drain line and conduit runs for signal and detector conductors.



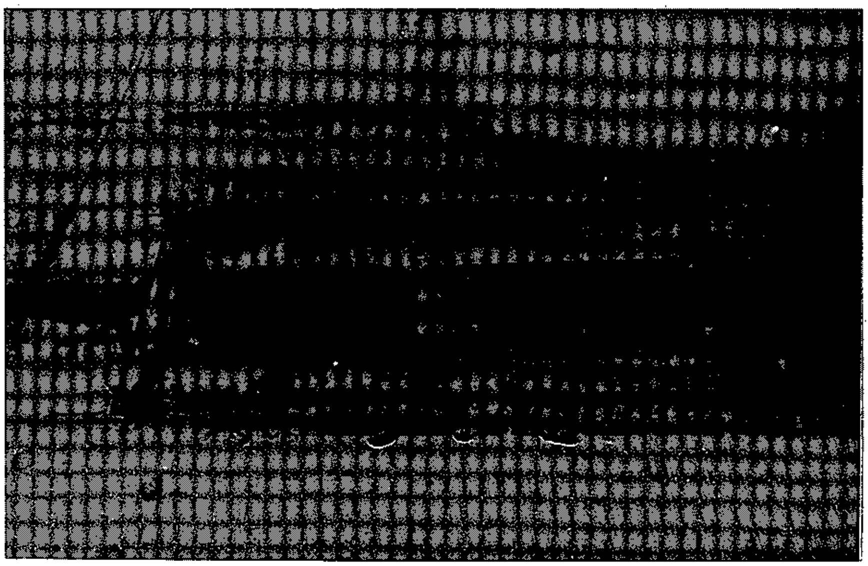
Conduit runs to junction box and drain line discharge.

Figure H-4

INSTALLATION OF PAT WIM SCALES AT THE
CALIFORNIA HIGHWAY PATROL ANTELOPE WEIGH STATION



PAT scale foundation frames



Embedded foundation frame

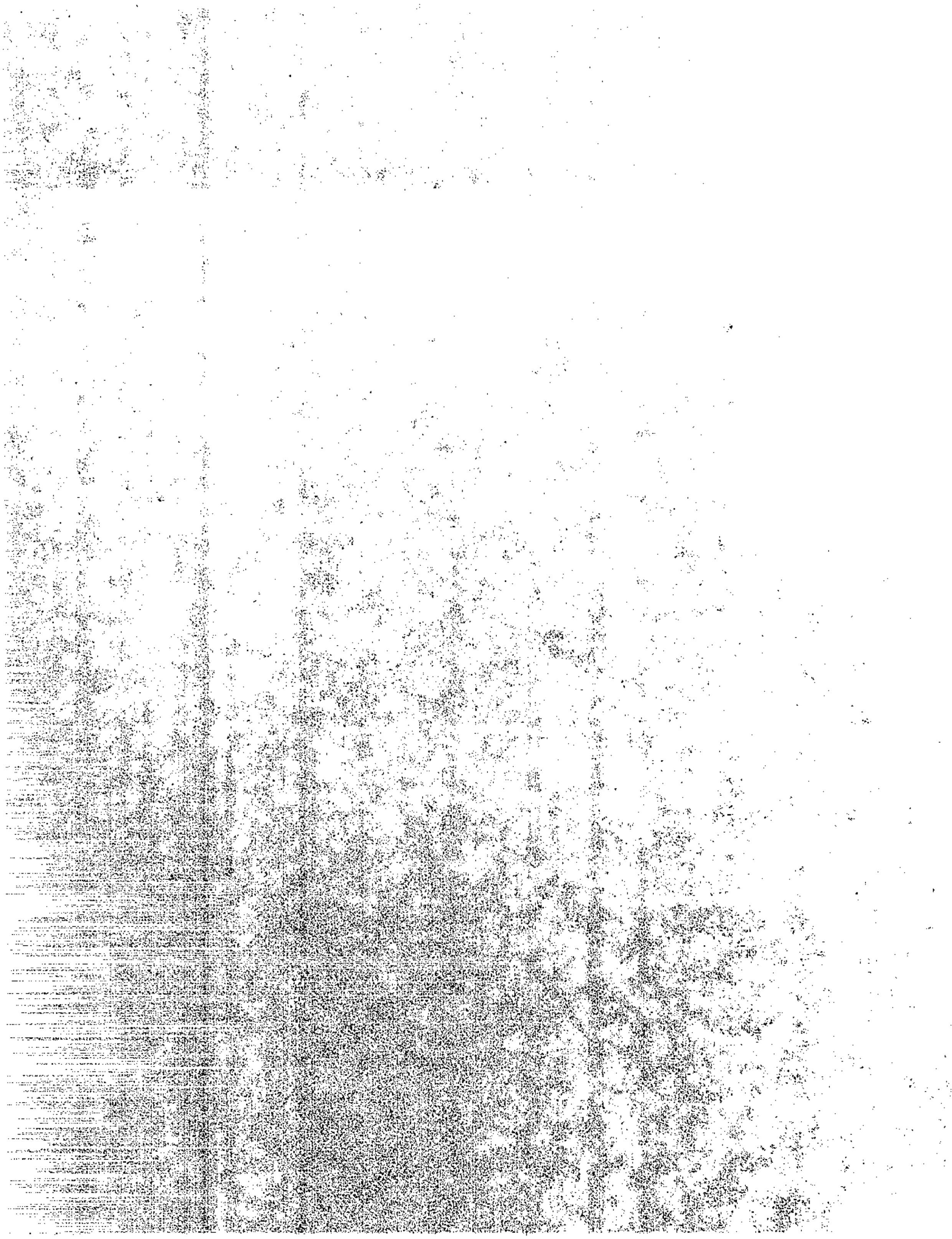


Figure H-5

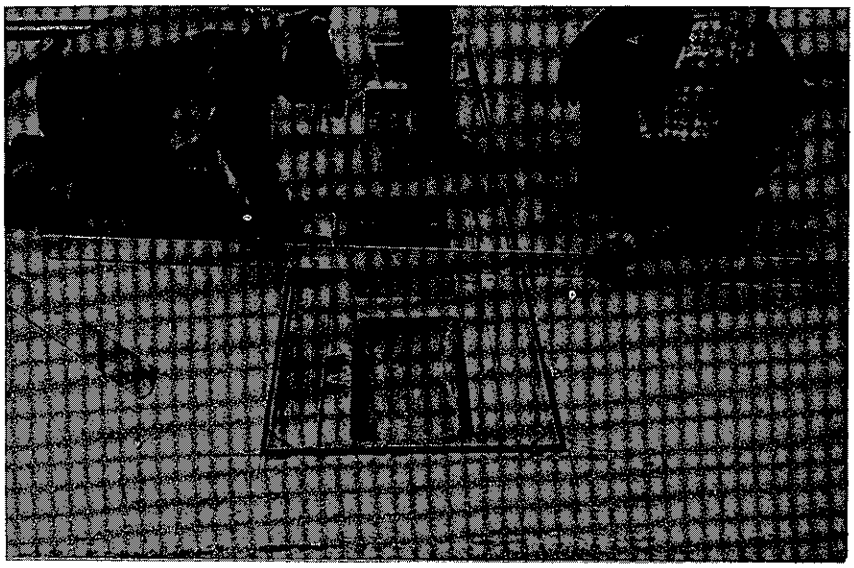
INSTALLATION OF PAT WIM SCALES AT THE CALIFORNIA HIGHWAY PATROL ANTELOPE WEIGH STATION

Embedded foundation frames

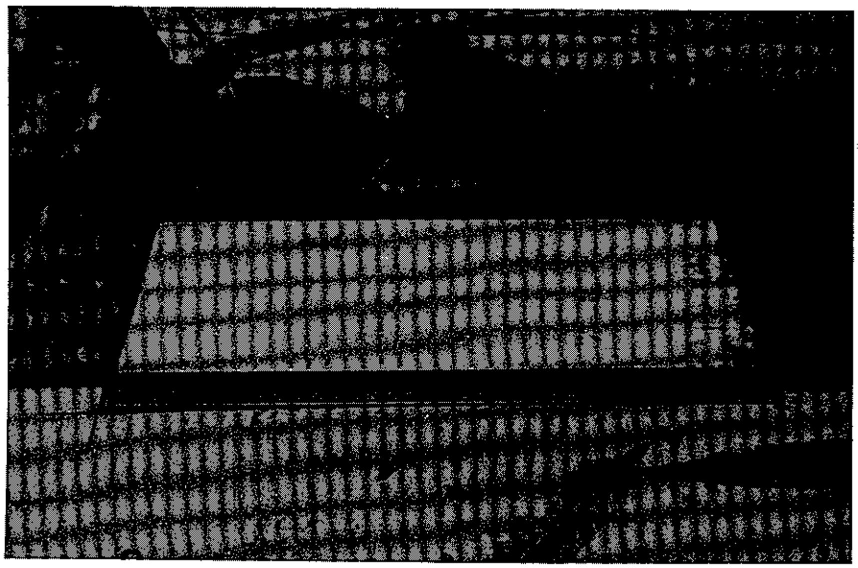
Placement of shims onto foundation frame for elevation of scale platform to match pavement grade.

Figure H-6

INSTALLATION OF PAT WIM SCALES AT THE
CALIFORNIA HIGHWAY PATROL ANTELOPE WEIGH STATION



With shims in place, checking for correct depth to receive scale platform.



Scale platform bolted to foundation frame

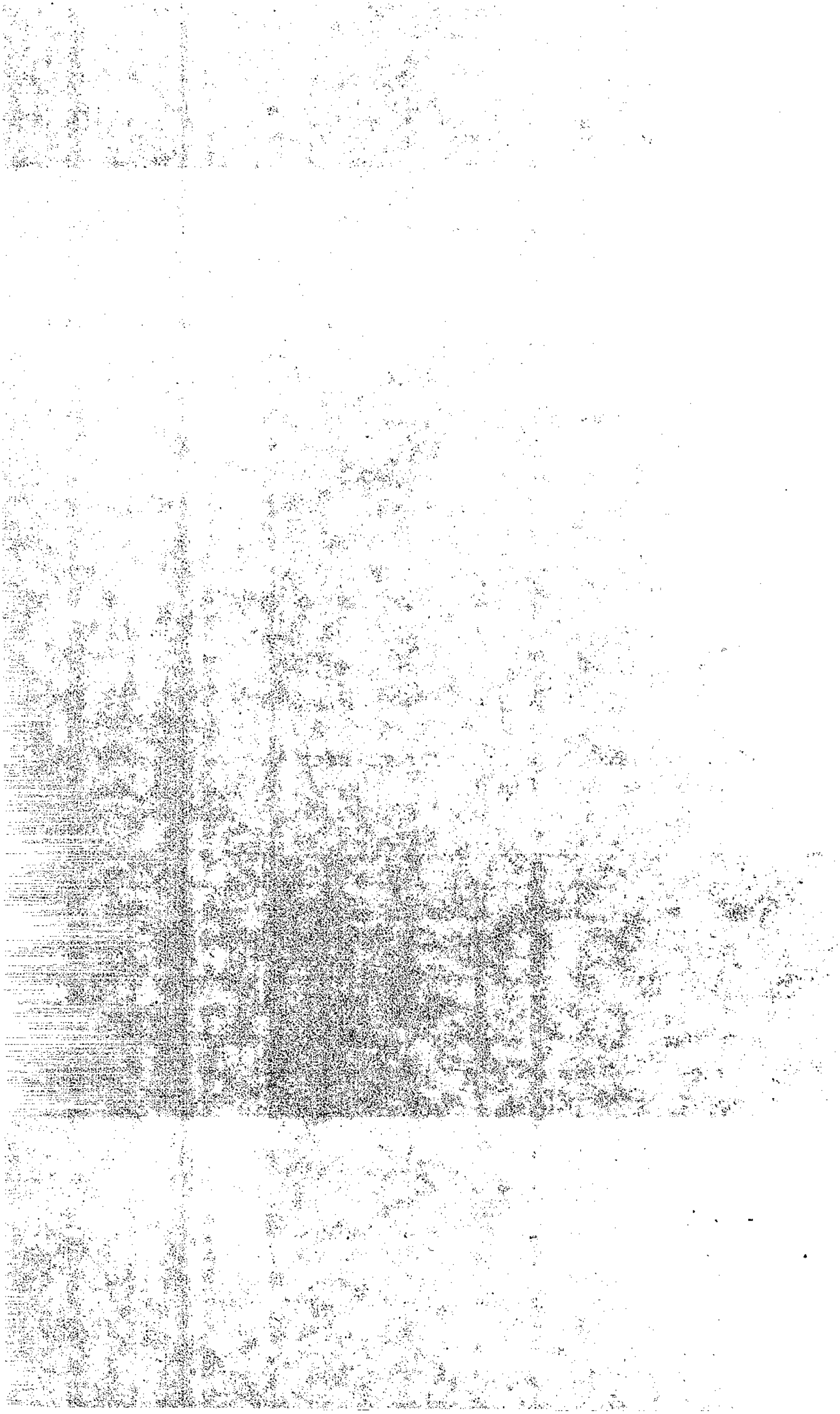
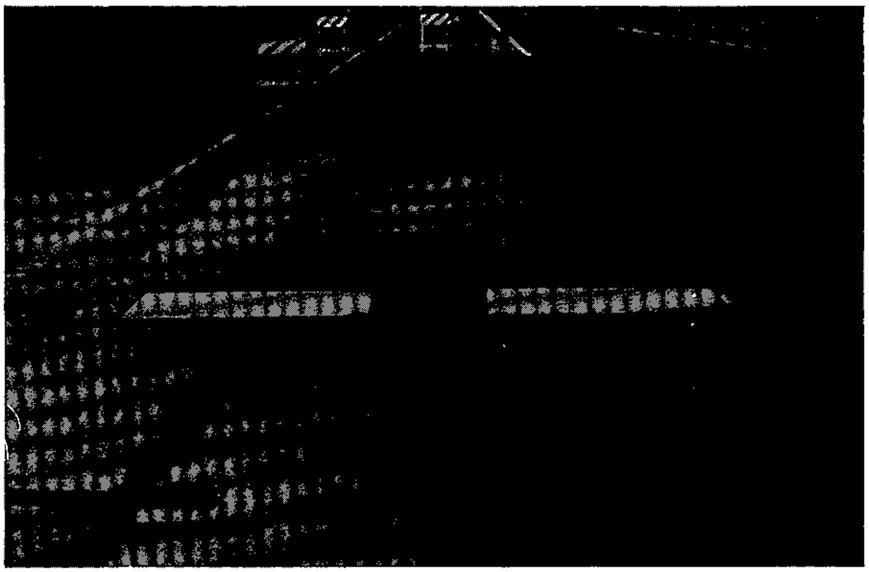


Figure H-7

INSTALLATION OF PAT WIM SCALES AT THE
CALIFORNIA HIGHWAY PATROL ANTELOPE WEIGH STATION



View of completed upstream axle scale platform. Downstream axle scale platform is in the foreground and not visible.

APPENDIX I

PREPARATION AND FIRST TEST OF THE STREETERAMET WIM SYSTEM AT THE I-5 SITE

At the Freeway site on October 3-5, 1979, and under the direction of a StreeterAmet field engineer, we proceeded to equalize the electrical outputs from each wheel scale with a 2027-pound load as shown in Figure I-1.

An axle scale consists of two separate wheel scales, i.e., a left-track and a right-track scale. Each scale is supported by four load cells. When the scale is loaded, each load cell outputs an analog voltage proportional to the total load on it. The output sensitivity or response to a given load on each load cell is slightly different. Thus, it was necessary to electrically adjust each cell so that they all had the same sensitivity to equal loads. This was done with the aforementioned 2027-pound load placed at different spots on the scale platform while trim-balance resistors were connected to each load cell for the output equalization adjustment.

The above work was done with a StreeterAmet Model 4500 static indicator because the Model 5150 system readout for the scales had not arrived. With each load cell properly adjusted for sensitivity with its trim-balance resistor, the scale readings did not differ by more than 1% when the load was variously placed within the area of the scale platform.

The complete StreeterAmet Rollweigh Model 5150 in-motion truck weighing system was received on Tuesday, October 9, 1979. This was three days before the opening of the freeway to public traffic scheduled for Friday morning, October 12, 1979.

The Model 5150 WIM system and its readout instruments were installed in the test van. A loaded and preweighed Caltrans tractor and semitrailer truck was driven onto the scale to statically load it and to calibrate the system. Figure I-2 shows the truck and lists its axle weights.

The system would not calibrate as each axle of the truck was stopped on the scale for static loading. The StreeterAmet computational program computed the axle weights but there appeared to be no correlation between them and the "true" static axle weights. Two StreeterAmet engineers were at the jobsite to aid in the initial startup of the system. They could not resolve the weight computational difficulty on site and indicated on Thursday evening (October 11) that the computational program would have to be returned to their factory for debugging.

Another problem surfaced at this time. As each successive axle of the test truck crossed the scales, an audible "clunk-clunk" sound was emitted. Close observation of the action of a tire crossing a scale (at creep speed) showed that a tire crossing a scale's upstream edge would tip up the opposite edge, and the same tire leaving the downstream edge would tip up the upstream edge. Thus, a tire crossing the scales was causing it to rock on its supports. This condition was more pronounced with axles 2 and 3 (driving axles) than with axles 4 and 5. No visible rocking action was observed with axle 1 (steering axle). Perhaps this problem may be attributed partially to, or in combination with, the tire sizes, tire loads and tire prints. Figure I-3 shows the driver and trailer tires on a scale platform with tire sizes 12R22 and 8.25R15, respectively.

In Figure I-4, the bottom photograph shows a tire just fully scaleborne on the upstream edge of the right wheel track scale. It is the tire (12R22) on axle 2 of the Caltrans tractor. This is the tire position, on the scale, which would cause the scale's downstream edge to tip up about 1/4 to 3/8 inch. Conversely, with the tire repositioned similarly but at its downstream edge, the other edge (upstream) would tip up a similar amount. This explained the audible "clunk-clunk" mentioned above.

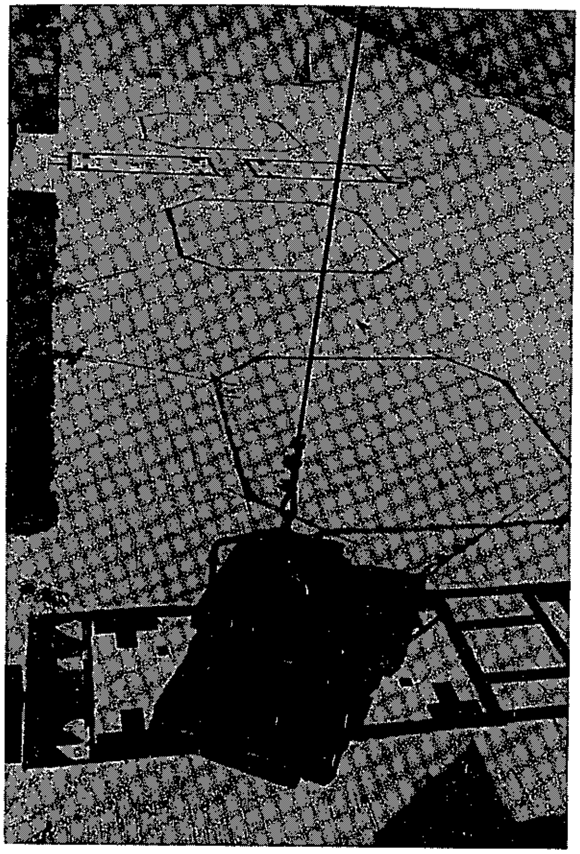
Each wheel track scale is supported by four load cells, one near each corner. The support point of each cell is three inches in from the edge of the scale. We surmise that with the three inch "lever arm" thus created, coupled with the 12R22 tire print and load, sufficient leverage was developed to tip and rock the scale.

When one edge of the scale tipped up, it could be pushed down with some foot pressure. Thus, the idea was to add weight to each corner sufficient to prevent tipping and rocking. Different combinations of weights were placed at the corners ranging from about 50 to 100 pounds. Some of these weight combinations are shown in the photographs in Figure I-4. The top photograph shows the Caltrans lowboy lined up to cross the scales with corner weights in place.

Different weights at the corners, several crawl speeds and static wheel loading were tried, none of which eliminated the rocking action. We concluded that the problem was a basic design flaw associated with the lever arm action and too large to be counterbalanced by the scale's own weight, or with the added corner weights.

Pending StreeterAmet's solution to the problem on Thursday evening, October 11, we removed all load cells from all four wheel scales so that any potential tipping and rocking action from the forthcoming freeway traffic would not damage them. The load cells were replaced with dummy pedestals (Caltrans supplied) as shown in Figure I-5. StreeterAmet's solution to the problem is described in Appendix K.

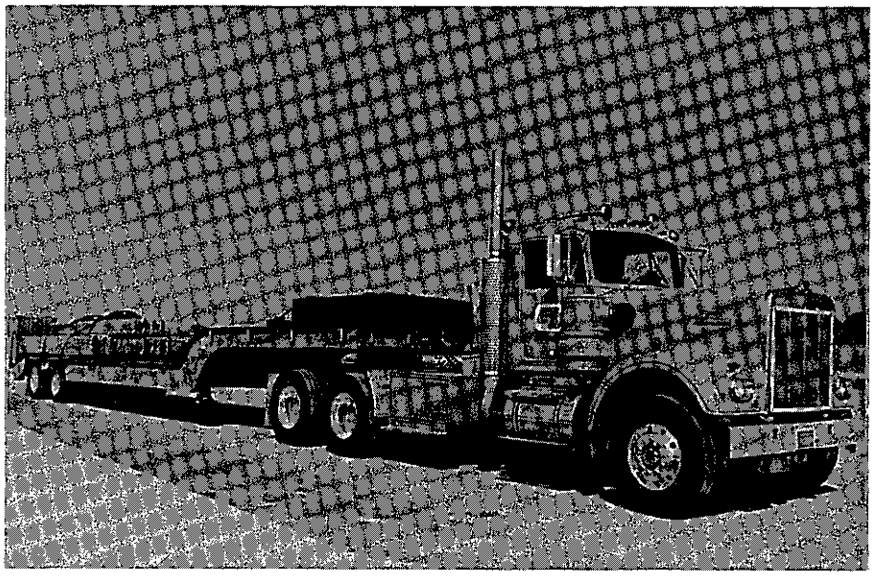
Figure I-1



Suspended 2027-pound load above right wheel track scale. Placement of the load on different spots on the scale platform is for checking electrical balance output.

Note upstream scales and loop detectors in background.

Figure I-2



CALTRANS TRACTOR AND LOWBOY TRAILER

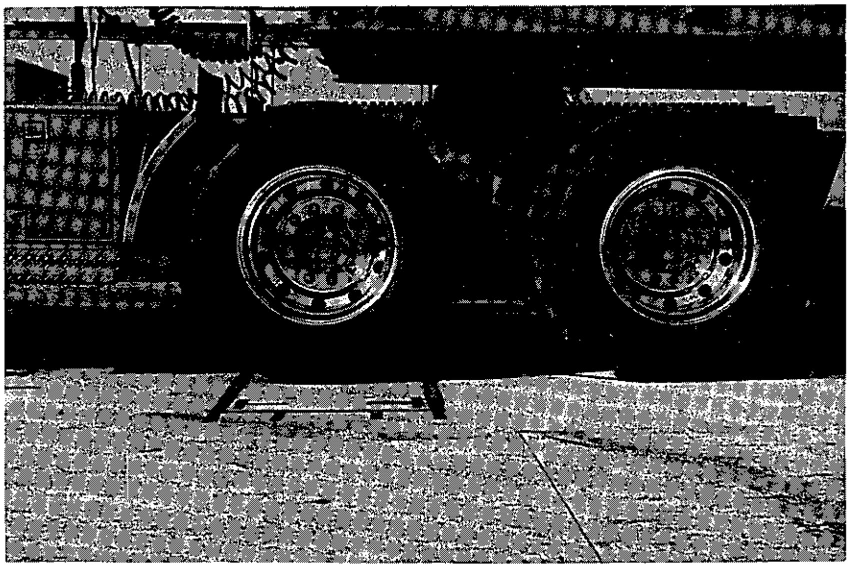
Axles	5	4	3	2	1	Gross Weight, Lbs.
Axle Weights (Lbs.)	16,560	16,480	15,600	15,990	10,200	74,830
Tandem Weights (Lbs.)	33,420		32,230		10,200	75,850

Tire Size

Tractor: 12 R 22.5XZA 105 psi

Trailer: 8.25 R 15 105 psi

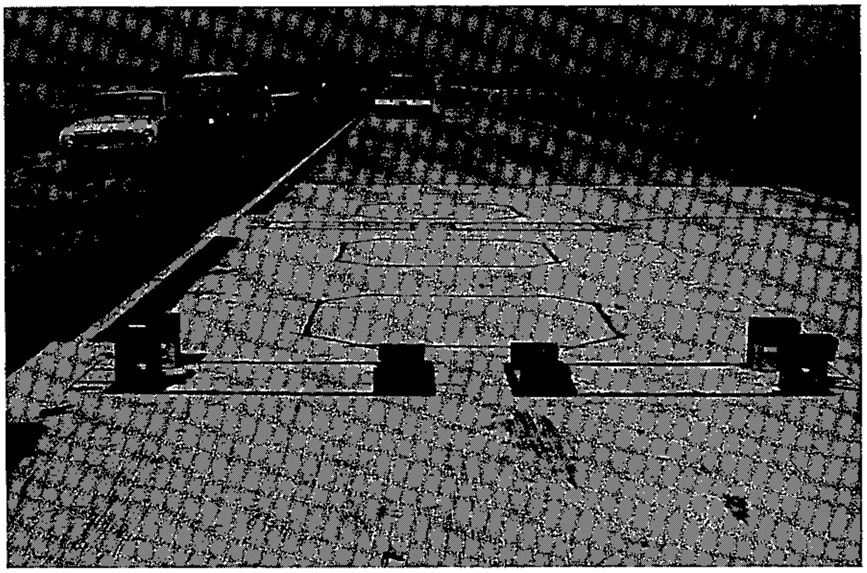
Figure I-3



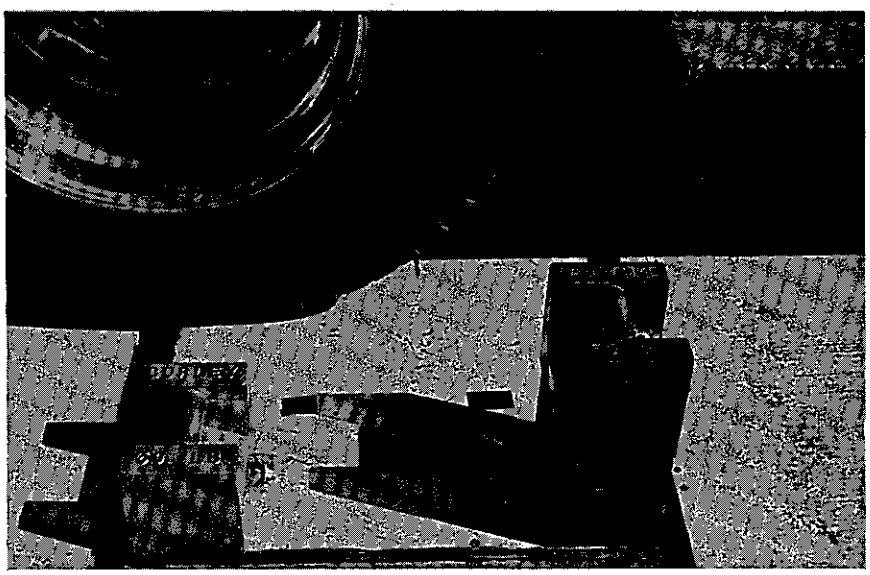
Caltrans tractor axles 2 and 3
Tire Size: 12R22
Axle spacing: 4.35 feet

Caltrans trailer axles 4 and 5
Tire size: 8.25R15
Axle spacing: 4.17 feet

Figure I-4



Weights added to corners of scales in experiment to eliminate scale rocking.



Closeup view of weights at two corners of scale.

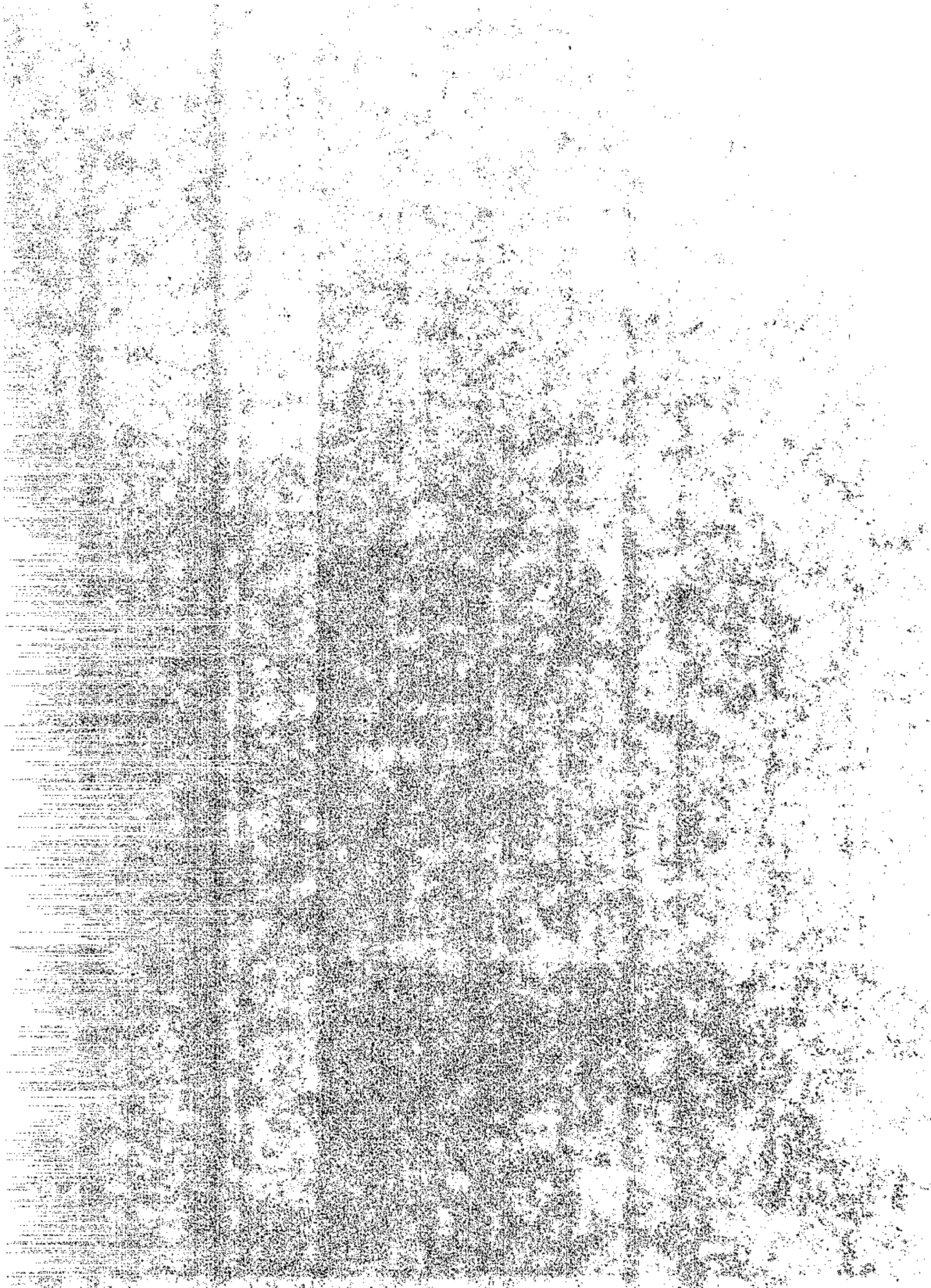
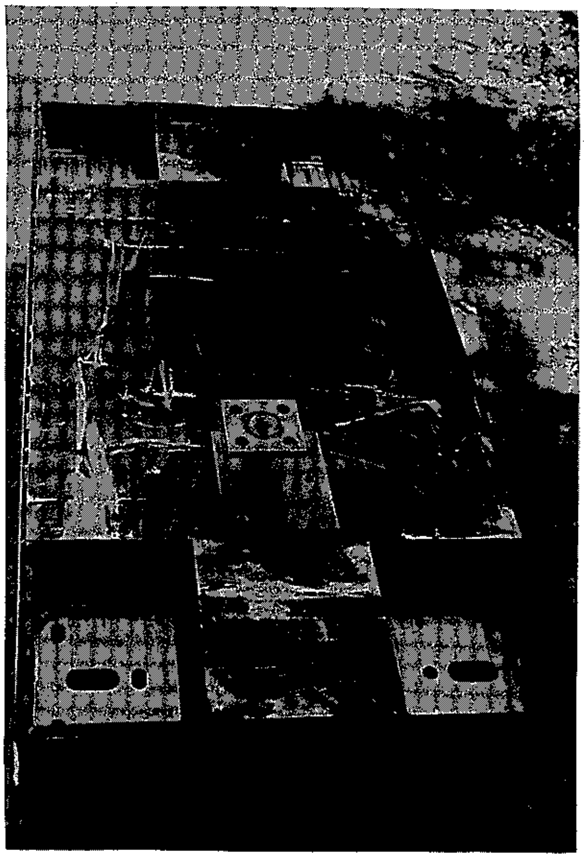
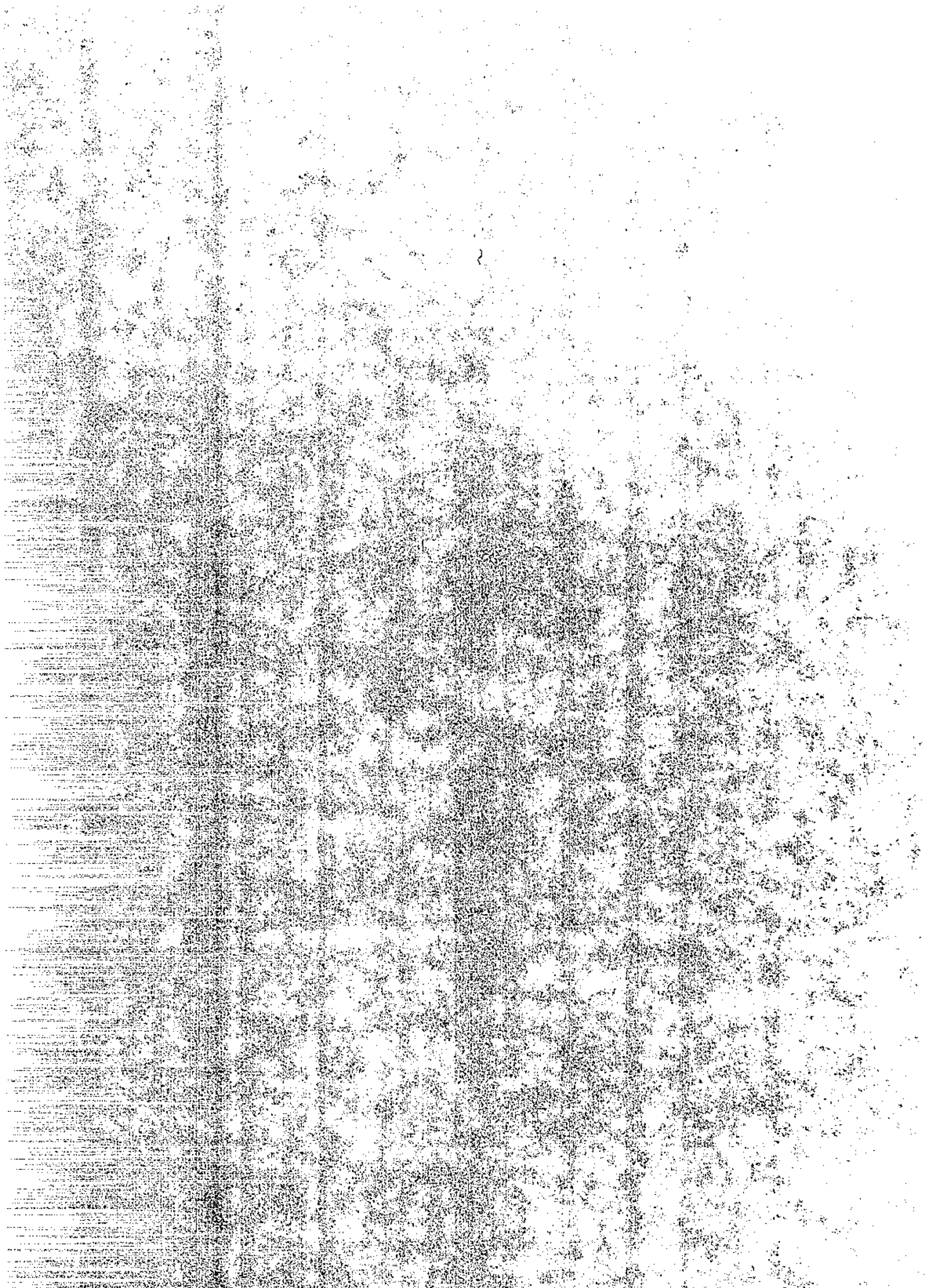


Figure I-5



View of dummy pedestal for replacement of a load cell. Load cells are to be bolted into each of the corner cavities.



APPENDIX J

STREETERAMET SCALE STRUCTURAL DEFICIENCIES

For the first tests of the StreeterAmet system at the I-5 Freeway site on October 3-5, 1979, we found the Streeter-Amet scales structurally inadequate to bear wheel loads. For the first scale test we drove a Caltrans tractor and semitrailer truck (see Figure I-2) at creep speed across the scales about 15 times. After the above repeated loadings, our close visual examination revealed that some of the surface plug welds had fractured and separated from the scale platform. This was clearly evident by the cracked outlines around some of the welds on the scale platform's surface. These eight plug welds and fillet welds (Figure J-1) attached the scale platform to its wheel scale frame. Fractures were observed on two of the four wheel scales.

This was discovered late Thursday evening (October 11) and the freeway was scheduled to open the next morning. The next morning, before the freeway opening, we judged that the scale platform could be held in place with four (1/4-13NC) cap bolts screwed into the lifting eye bolt holes (see Figure J-1), even if all plug and fillet welds failed. However, we viewed this as only a temporary expediency to permit the freeway opening, subject to later more permanent repairs by StreeterAmet. Thus, on Friday morning we cap bolted the two downstream wheel scales which had fractured welds, and to ensure complete site safety, we also cap bolted the other upstream wheel scales.

By November 27, all eight of the plug welds had broken loose on both downstream right and left wheel track scales. For the upsteam axle scale, several of the plug welds had also broken loose.

In addition to the broken plug welds, another structural defect developed (after the freeway opening) under the repetitious loading of freeway traffic. The repetitious loadings had fractured the fillet welds around the periphery of the scale platform. Figure J-2 shows some of the one-inch fillet welds used to "tack" the edges of the scale platform to the scale frame. The cross-sectional areas of these welds had been machined and thereby reduced in area about 50%. The machining was done so that the "T" shaped neoprene sealer would fit into the groove between the edges of the scale platform and its foundation frame.

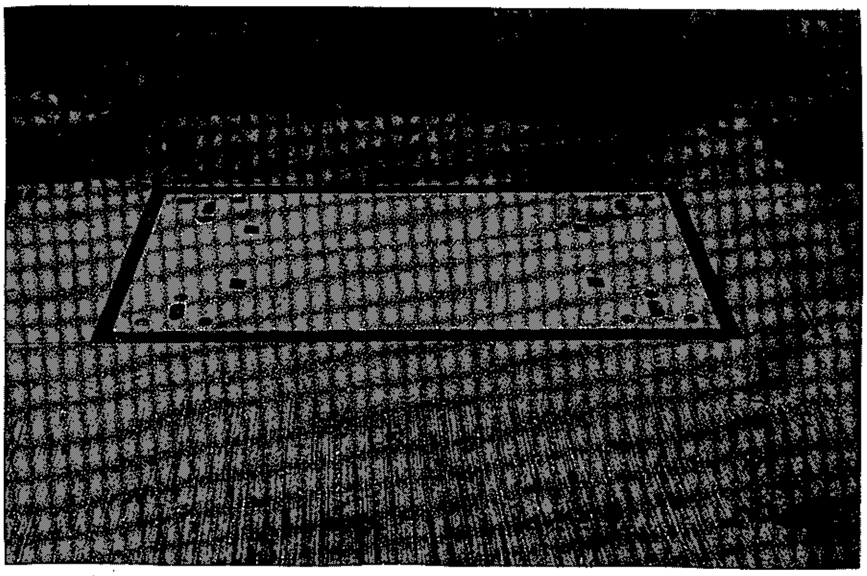
The reduction in cross-sectional area and the repetitious traffic loadings had fractured these fillet welds. All of them on the left track, downstream scale had fractured in addition to the eight surface plug welds that failed earlier. Thus, only the four cap bolts on this scale were holding the scale platform in place. An audible "clunk-clunk" emanated from this scale as vehicles crossed it. The other three wheel scales had cracked fillet welds but of unknown number.

For each axle scale there are two side covers and one center cover. Figure J-1 shows a center cover and a left side cover. The covers consist of two 1/4" steel plates sandwiched and held together with tack welds along the edge. Figure J-2 shows a center cover and some of the tack welds which were structurally inadequate to hold the two plates together. By November 27, under the repetitious pounding of traffic, all of the tack welds had fractured on several of these "sandwiched" covers. Allen head fillet screws (1/4" - 20) were used to fasten these "sandwiched" covers to their frames. We were greatly concerned about the structural inadequacy of these "sandwiched" covers and attachment method.

Because of the potential safety hazard to vehicular traffic, we conducted weekly visual scale inspections for pending or worsening signs of structural inadequacies. Inspections were made between traffic, without lane closures. However, on November 19, 1979, we closed the scale lane to traffic for our minute inspection of the scales. We removed and inspected all 16 cap bolts (four per wheel scale) and retorqued them to 90-100 foot-pounds. All Allen cap screws for the center and side covers were unscrewed and discarded. Three of the Allen cap screws were broken and two were loose. The six covers were examined and many of the covers had cracked tack welds. One cover had all of its tack welds broken. After the inspection, we reinstalled the cover plates and fastened them with our specially designed extended-fatigue life screw/washer system.

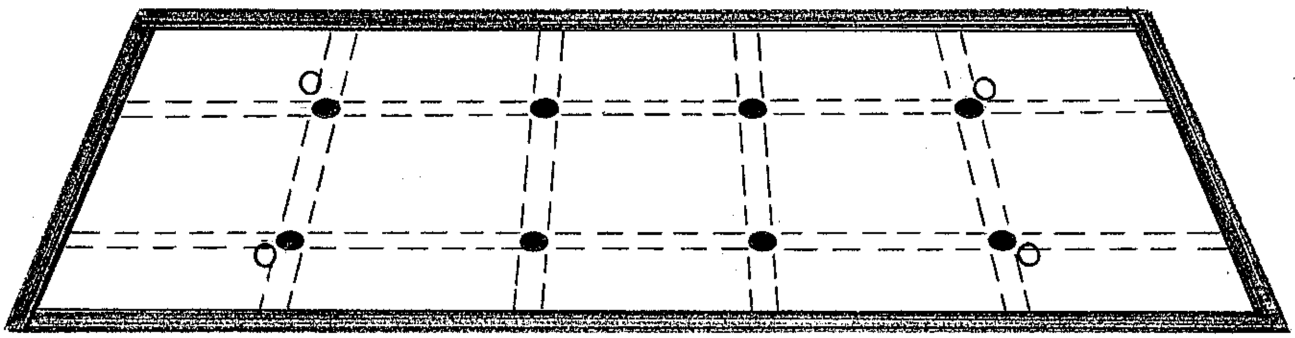
Figure J-1

Center Cover



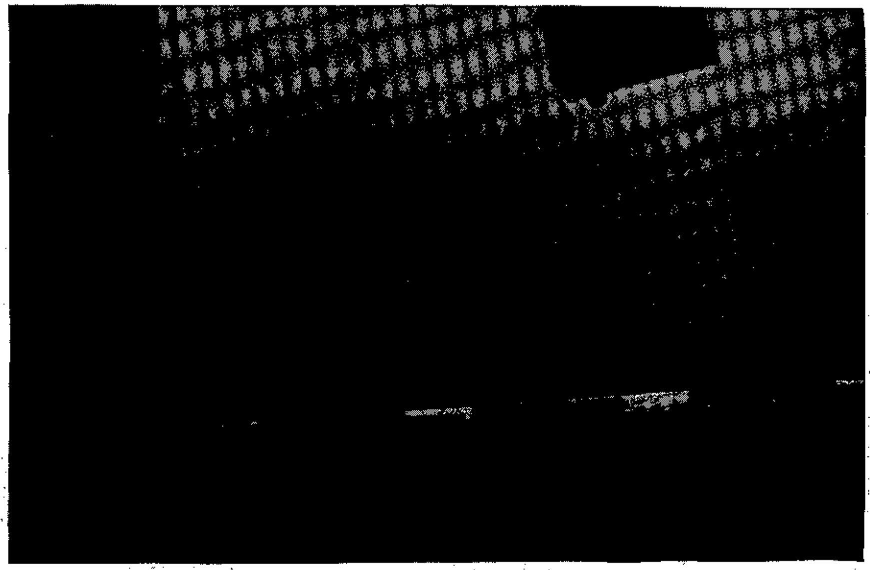
Leftside Cover

Scale Platform with center and side covers in place.

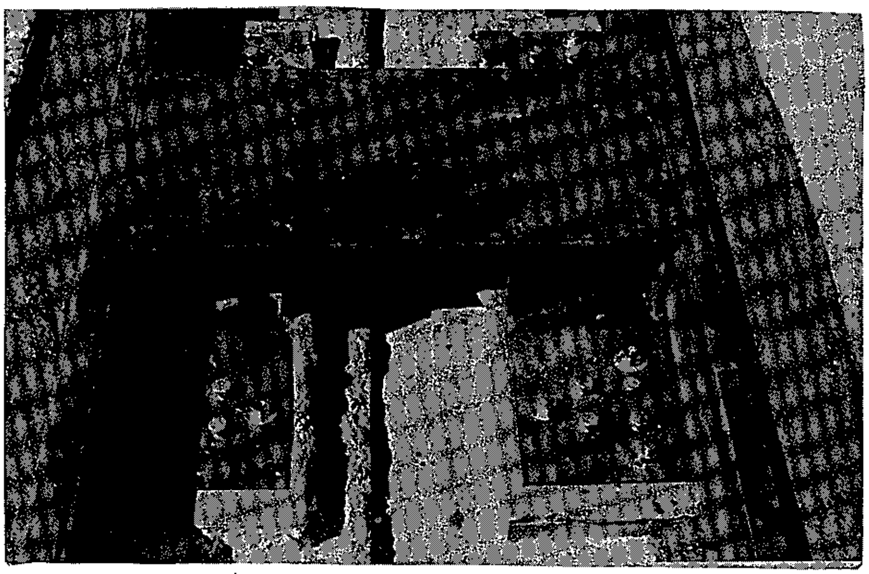


Plan view of scale platform showing locations of the eight plug welds (●). Bolt holes for the lifting eyes are shown as (○).

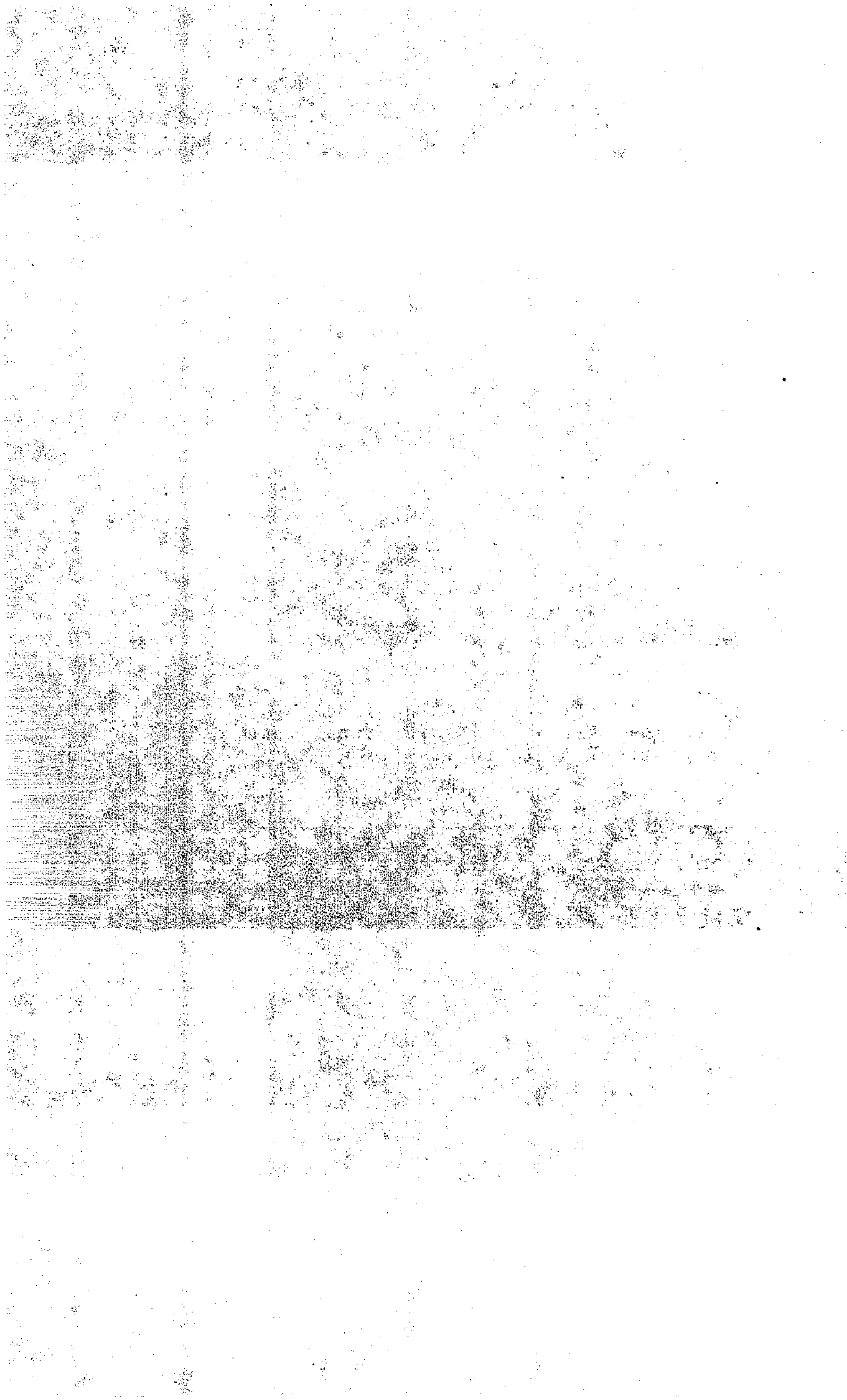
Figure J-2



A corner of a scale platform showing some typical 1-inch long fillet welds for attachment of the scale platform plate to its frame.



Build-up of center cover with two sandwiched 1/4" steel plates tack welded along its edges.



APPENDIX K

STREETERAMET SCALE REWORK

Two StreeterAmet engineers arrived Monday, October 15, 1979, after the freeway opening on the previous Friday, to resolve the problems with the scales. After we inspected the freeway scale site and conferred on the ramifications of the problem, they proposed the following remedial work:

1. Increase the weight of each wheel scale from 540 pounds to 700 pounds to match a similar WIM scale system installed for another state department of transportation. (They indicated it did not rock, and attributed it to the fact that it weighs 700 pounds.)

2. Install vertical check rods at each of the four scale corners to aid in preventing scale platform from rocking or tipping.

3. Remove the "thin" platform steel plate. Replace it with a 3/8 inch plate. Fasten it to the scale frame with larger plug welds and continuous fillet welds around the plate edges to increase its structural adequacy.

All three sets of scales were subsequently reworked as outlined above.

APPENDIX L

IN-LABORATORY EVALUATION OF STREETERAMET REWORKED WHEEL SCALE

StreeterAmet reworked the three sets of scales as described in Appendix K. The rework consisted mainly of structural reinforcement, installation of the vertical check rod system (see Figure L-1), and increasing each scale's weight from 540 pounds to 700 pounds. The combination of the vertical check rods and increased weight was to eliminate the rocking of the scale platform. After the rework completion, we evaluated a scale under static loading in our laboratory. The individual load cells for the scales were previously tested, evaluated, and reported in Appendix F. For the evaluation, a set of four cells was installed into a left-track and a right-track wheel scale for static load tests. The cells, comprising a particular set, were chosen on the basis of matched output to enhance each scale's accuracy and electrical balance. The cells making up the two sets were:

Left-track scale: S/N: 51301; 51303; 51310; 51217
Right-track scale: S/N: 51304; 51308; 51226; 51307

The evaluation consisted of three phases:

1. Scale performance with the vertical check rods installed.

2. Scale performance with the check rods removed.

3. Check for scale platform tilt.

For the above evaluation, we placed the right-track scale in the MTS Universal Testing Machine (see bottom photograph in Figure L-1). The scale was test loaded in increments of 1000 pounds to 10,000 pounds and in nine different scale-borne areas as shown in Figure L-2. It was test loaded with the following pretensile force on each of its four vertical check rods:

1. 25 pounds tensile force
2. 100 pounds tensile force
3. 300 pounds tensile force
4. 500 pounds tensile force
5. Check rods removed

The data resulting from the above tests are listed in Figures L-3 through L-7. The scale platform did not tilt in the above test, probably because all-nine test-load locations were within the area bounded by the four load cells. For the above five test runs, the scale error for each load increment and at each of the areas was calculated. In addition, for each of the five test runs, their respective average error ($\bar{x}$) and standard deviation (s) were calculated and listed below for ready comparison:

Figure	Pretensile Load on Check Rod, Pounds	$\bar{x}$	s
L-3	0	0.5%	0.8%
L-4	25	2.7%	1.4%
L-5	100	2.5%	2.8%
L-6	300	3.0%	4.3%
L-7	500	4.1%	6.6%

The figures clearly indicate that the tensile load on the check rods, from 25 to 500 pounds, increased the scale's average errors up to eight times, from 0.5% (no load) to 4.1% (500 pound load). Note the trend showing both increasing average error ($\overline{x}$) and standard deviation (s) with increasing tensile loads on the check rods.

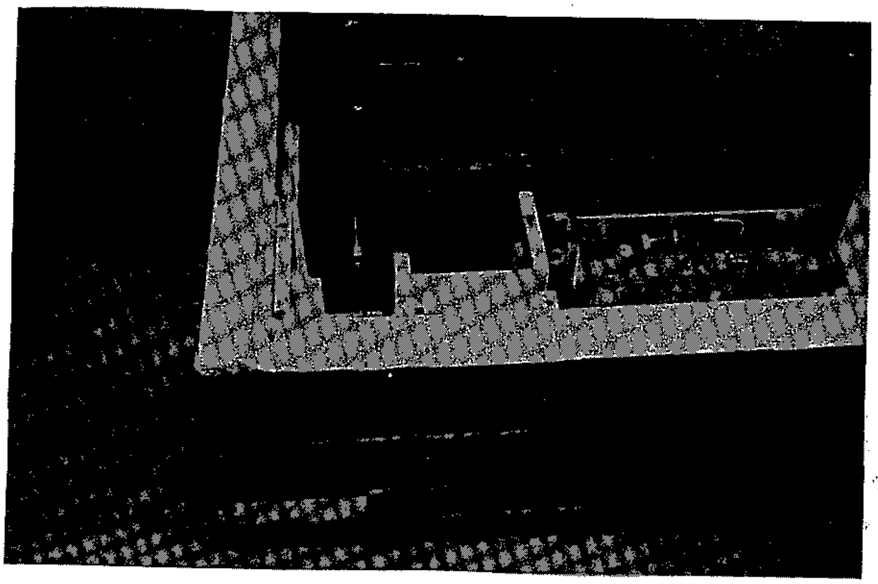
Because of the above results, the vertical check rods for preventing scale platform tilt is considered a deficiency in design concept because it increased scale error. In the later field installation of a set of scales at the I-5 Freeway site and at the CHP Castaic weigh station, the vertical check rods were not installed.

The scale platform did not tilt for any of the combinations of loads and scale-borne load positions discussed above and shown in Figure L-2. It is obvious that it should not tilt because the loads were all within the boundary line of the load cells supporting the platform.

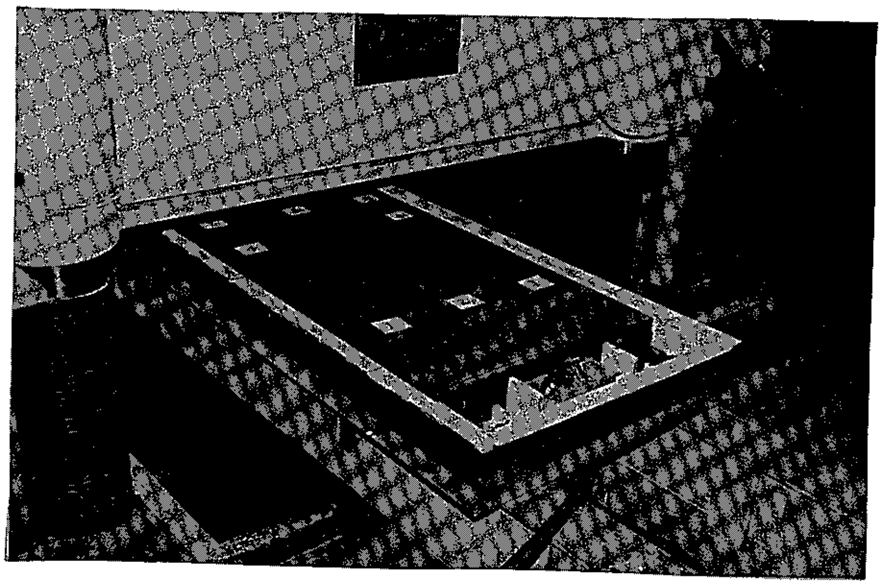
However, the scale did tilt with loads applied at the edge of the scale which would represent a tire just moving onto the platform. For this tilt condition, the specific location of the four loading areas through three pad sizes (1"x6", 6"x8", and 4-1/2"x12") on the platform are shown in Figure L-8. All resulted in scale tilt and the results are annotated in the figure. Note that three of the four loading conditions were completely scale-borne whereas one was not; that loading condition was half-borne by the scale and half-borne by the area outside of the scale platform. Nevertheless, it also tilted.

It is our judgment that relocation of the load cells, as close to the edge of the platform as physically possible, should improve the scale's performance and reduce the tendency to cause tilting.

Figure L-1



StreeterAmet WIM Scale - Vertical Check Rod at one of four corners



Static load test setup in the MTS machine. Loading areas numbered and load applied through steel plate/ neoprene bearing pad (8" x 8" x 1-1/4").

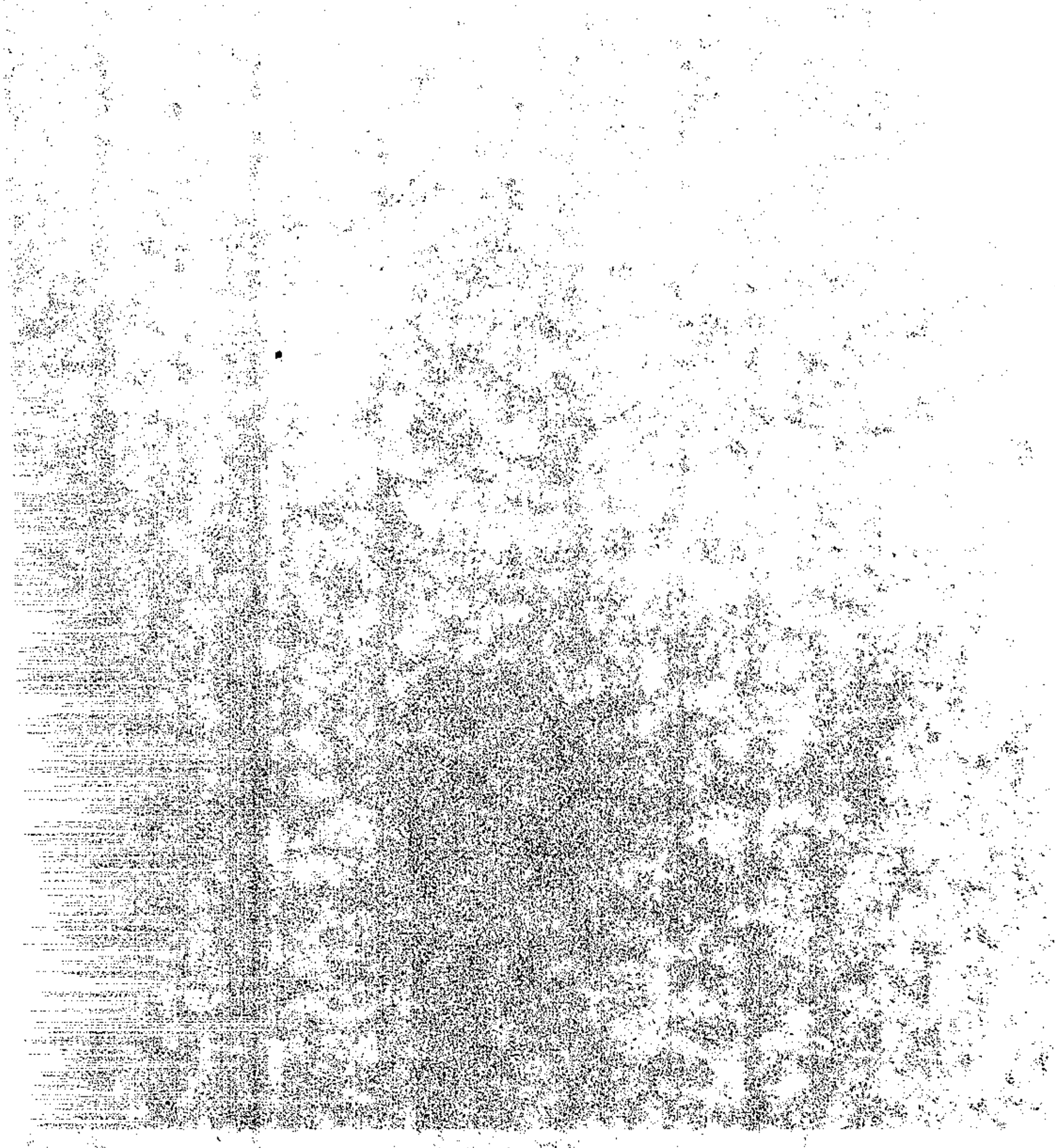


Figure L-2

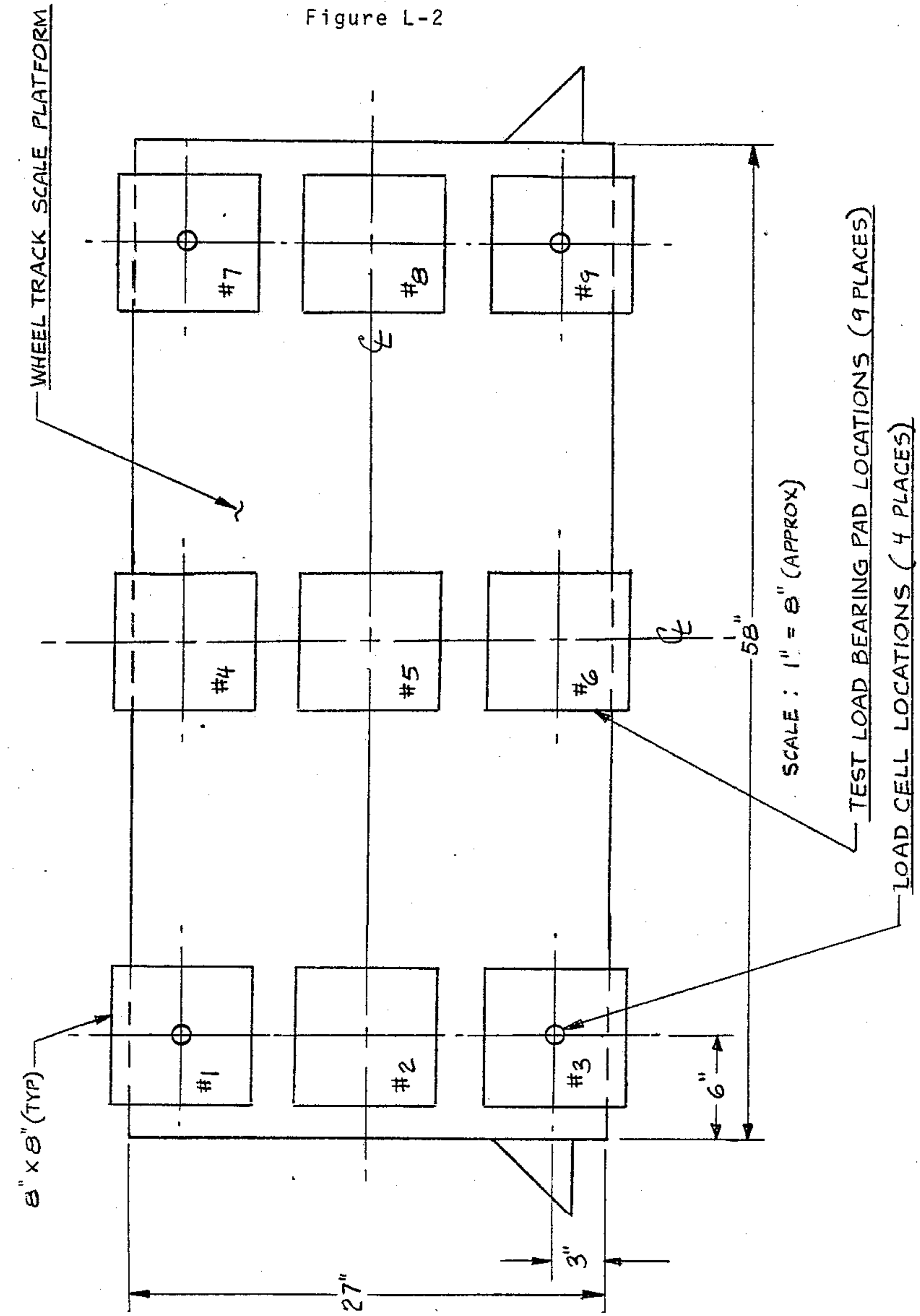

WHEEL TRACK SCALE PLATFORM
TEST LOAD BEARING PAD LOCATIONS (9 PLACES)
LOAD CELL LOCATIONS (4 PLACES)
SCALE: 1" = 8" (APPROX)
8" x 8" (TYP)
58"
6"
3"
27"
#1
#2
#3
#4
#5
#6
#7
#8
#9

Figure L-3

STREETERAMET SCALE CALIBRATION - STATIC LOADING
LOAD ON EACH OF FOUR VERTICAL CHECK ROD: ZERO POUNDS

Test Load Pounds	Location of Test Load on Scale Platform (See Figure L-2)								
	1	2	3	4	5	6	7	8	9
1000	990	1020	990	1000	990	1010	1040	1000	1000
% Error	-1.0	2.0	-1.0	0	-1.0	1.0	4.0	0	0
2000	1990	2030	2040	2010	2000	2020	2040	2010	2020
% Error	-0.5	1.5	2.0	0.5	0	1.0	2.0	0.5	1.0
3000	2990	3030	3060	3020	2990	3020	3050	3010	3020
% Error	-0.3	1.0	2.0	0.7	-0.3	0.7	1.7	0.3	0.7
4000	4000	4040	4060	4030	4000	4020	4040	4010	4020
% Error	0	1.0	1.5	0.7	0	0.5	1.0	0.2	0.5
5000	5000	5050	5080	5050	5020	5010	5030	5000	5010
% Error	0	1.0	1.6	1.0	0.4	0.2	0.6	0	0.2
6000	6000	6060	6070	6030	6000	6000	6040	5980	6020
% Error	0	1.0	1.2	0.5	0	0	0.7	-0.3	0.3
7000	7000	7070	7090	7050	7000	7000	7040	6970	7020
% Error	0	1.0	1.3	0.7	0	0	0.6	-0.4	0.3
8000	8000	8080	8080	8050	8010	7990	8040	7960	8010
% Error	0	1.0	1.0	0.6	0.1	-0.1	0.5	-0.5	0.1
9000	9020	9090	9100	9060	9000	8980	9030	8960	9000
% Error	0.2	1.0	1.1	0.7	0	-0.2	0.3	-0.4	0
10000	10020	10090	10090	10060	10000	9980	10000	9960	10000
% Error	0.2	0.9	0.9	0.6	0	-0.2	0	-0.4	0

Average Error, $\overline{X}$: 0.5%

Standard Deviation, σ : 0.8%

Figure L-4

STREETERAMET SCALE CALIBRATION - STATIC LOADING
LOAD ON EACH OF FOUR VERTICAL CHECK ROD: 25 POUNDS

Test Load Pounds	Location of Test Load on Scale Platform (See Figure L-2)								
	1	2	3	4	5	6	7	8	9
1000	990		1030		1070		1010		1030
% Error	-1.0		3.0		7.0		1.0		3.0
2000	2040		2080		2100		2030		2060
% Error	2.0		4.0		5.0		1.5		3.0
3000	3070		3110		3150		3070		3090
% Error	2.3		3.7		5.0		2.3		3.0
4000	4110		4100		4180		4080		4120
% Error	2.7		2.5		4.5		2.0		3.0
5000	5150		5080		5240		5110		5150
% Error	3.0		1.6		4.8		2.2		3.0
6000	6180		6060		6290		6110		6170
% Error	3.0		1.0		4.8		1.8		2.8
7000	7190		7070		7330		7120		7200
% Error	2.7		1.0		4.7		1.7		2.8
8000	8220		8080		8370		8140		8230
% Error	2.7		1.0		4.6		1.7		2.3
9000	9250		9090		9370		9130		9250
% Error	2.7		1.0		4.1		1.4		2.7
10000	10250		10100		10430		10130		10260
% Error	2.5		1.0		4.3		1.3		2.6

Average Error, $\overline{X}$: 2.7%

Standard Deviation, σ : 1.4%

Figure L-5

STREETERAMET SCALE CALIBRATION - STATIC LOADING
LOAD ON EACH OF FOUR VERTICAL CHECK ROD: 100 POUNDS

Test Load, Pounds	Location of Test Load on Scale Platform (See Figure L-2)		
	1	3	5
1000	930	1070	1070
% Error	-7.0	7.0	7.0
2000	1970	2100	2110
% Error	-1.5	5.0	5.5
3000	3020	3110	3130
% Error	4.3	3.7	0.7
4000	4060	4100	4170
% Error	1.5	2.5	4.3
5000	5110	5070	5170
% Error	2.2	1.4	3.4
6000	6130	6020	6250
% Error	2.2	0.3	4.2
7000	7170	7020	7290
% Error	2.4	0.3	4.1
8000	8190	8020	8340
% Error	2.4	0.3	4.3
9000	9240	9020	9420
% Error	2.7	0.2	4.7
10000	10240	10000	10460
% Error	2.4	0	4.6

Average Error, $\overline{X}$: 2.5%

Standard Deviation, σ : 2.8%

Figure L-6

STREETERAMET SCALE CALIBRATION - STATIC LOADING
LOAD ON EACH OF FOUR VERTICAL CHECK ROD: 300 POUNDS

Test Load, Pounds	Location of Test Load on Scale Platform (See Figure L-2)			
	1	3	5	5
1000	870	1090	1070	1080
% Error	-13.0	9.0	7.0	8.0
2000	1850	2190	2130	2120
% Error	-7.5	7.5	6.5	6.0
3000	2910	3200	3210	3200
% Error	-3.0	6.7	7.0	6.7
4000	3960	4160	4250	4240
% Error	-1.0	4.0	6.3	6.0
5000	5050	5080	5270	5260
% Error	1.0	1.6	5.4	5.2
6000	6080	6000	6300	6290
% Error	1.3	0	5.0	4.8
7000	7110	6950	7330	7390
% Error	1.6	-0.7	4.7	5.6
8000	8150	7910	8370	8360
% Error	1.9	-1.1	4.6	4.5
9000	9180	8900	9420	9410
% Error	2.0	-1.1	4.7	4.6
10000	10200	9850	10480	10460
% Error	2.0	-1.5	4.8	4.6

Average Error, $\overline{X}$: 3.0%

Standard Deviation, σ : 4.3%

Figure L-7

STREETERAMET SCALE CALIBRATION - STATIC LOADING
LOAD ON EACH OF FOUR VERTICAL CHECK ROD: 500 POUNDS

Test Load, Pounds	Location of Test Load on Scale Platform (See Figure L-2)			
	1	3	5	5
1000	850	1130	1110	1140
% Error	-15.0	13.0	11.0	14.0
2000	1760	2230	2220	2210
% Error	-12.0	11.5	11.0	10.5
3000	2780	3270	3320	3310
% Error	-7.3	9.0	10.7	10.3
4000	3850	4190	4370	4390
% Error	-3.8	4.8	9.3	9.8
5000	4950	5100	5420	5420
% Error	-1.0	2.0	8.4	8.4
6000	5990	6010	6440	6450
% Error	-0.2	0.2	7.3	7.5
7000	7020	6930	7470	7500
% Error	0.3	-1.0	6.7	7.1
8000	8060	7850	8500	8510
% Error	0.8	-1.9	6.3	6.4
9000	9100	8790	9570	9560
% Error	1.1	-2.3	6.3	6.2
10000	10140	9750	10590	10580
% Error	1.4	-2.5	5.9	5.8

Average Error, $\overline{X}$: 4.1%

Standard Deviation, σ : 6.6%

Figure L-8

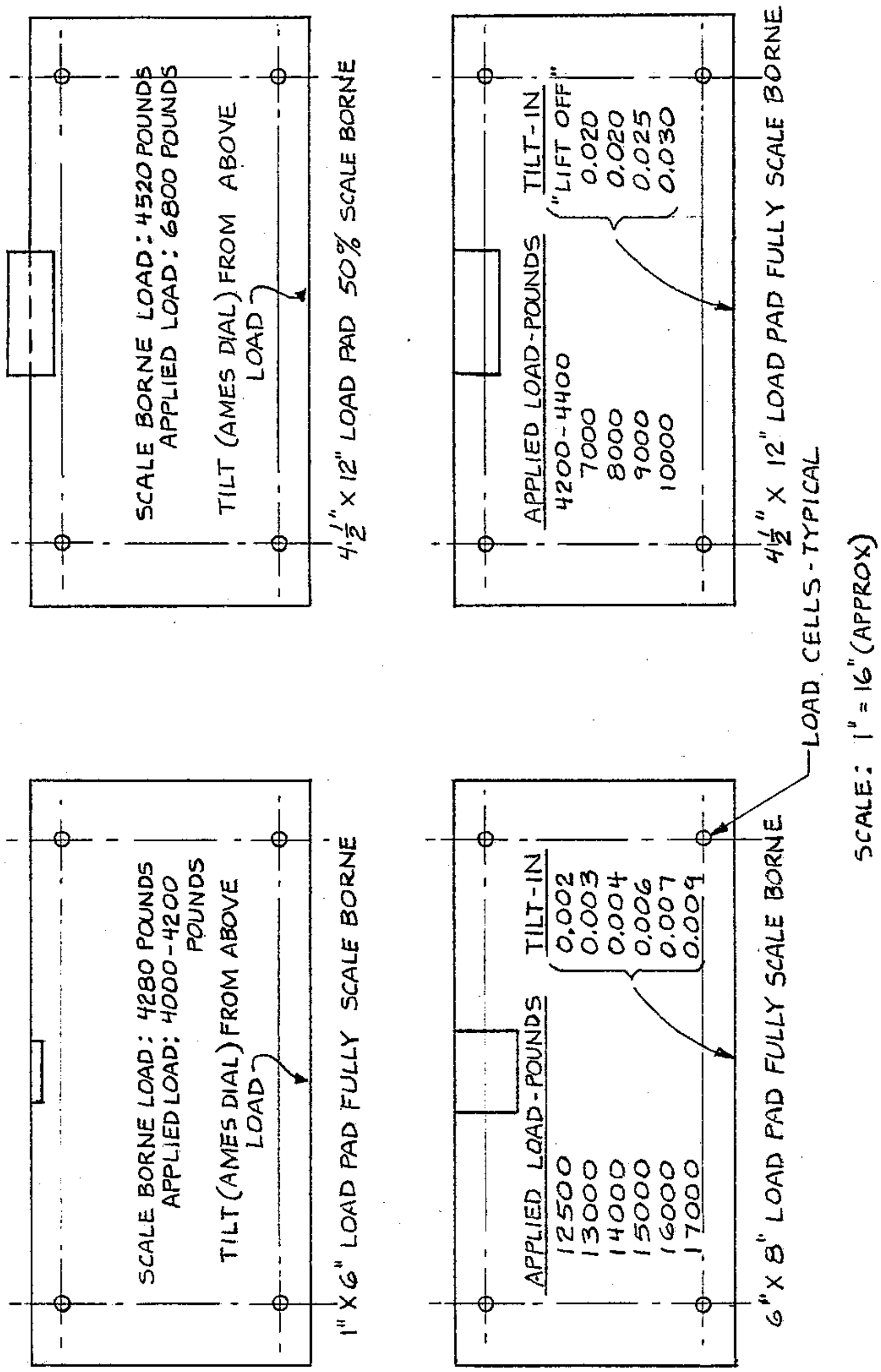
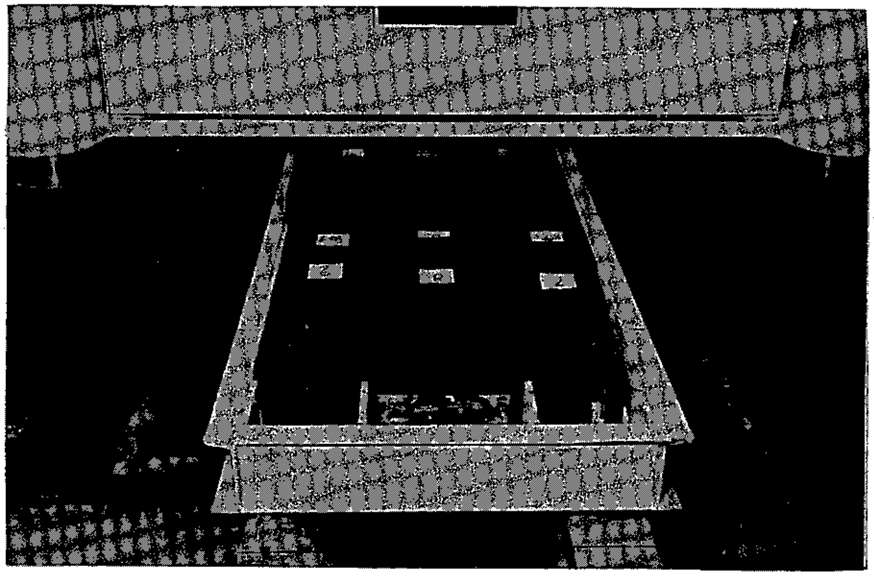
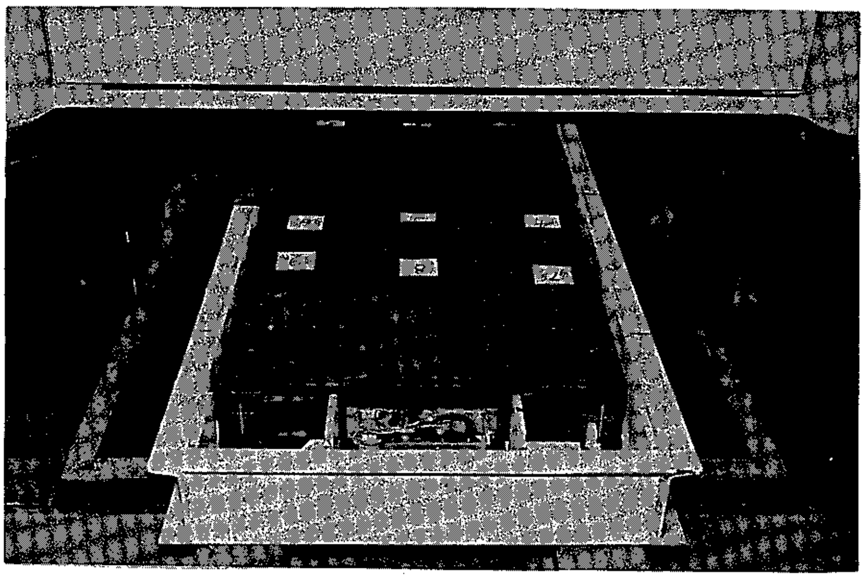

SCALE BORNE LOAD: 4520 POUNDS
APPLIED LOAD: 6800 POUNDS
TILT (AMES DIAL) FROM ABOVE LOAD
4½" X 12" LOAD PAD 50% SCALE BORNE
SCALE BORNE LOAD: 4280 POUNDS
APPLIED LOAD: 4000-4200 POUNDS
TILT (AMES DIAL) FROM ABOVE LOAD
1" X 6" LOAD PAD FULLY SCALE BORNE
APPLIED LOAD-POUNDS TILT-IN
4200-4400 "LIFT OFF"
7000 0.020
8000 0.020
9000 0.025
10000 0.030
4½" X 12" LOAD PAD FULLY SCALE BORNE
APPLIED LOAD-POUNDS TILT-IN
12500 0.002
13000 0.003
14000 0.004
15000 0.006
16000 0.007
17000 0.009
6" X 8" LOAD PAD FULLY SCALE BORNE
LOAD CELLS - TYPICAL
SCALE: 1" = 16" (APPROX)

Figure L-9



Scale platform tilt test setup. Note that load to be applied through bearing pad is completely scaleborne. Bearing area: 4.5" x 12". (See Figure L-8.)



Scale platform tilt test setup. Note that load to be applied through bearing pad is partially scaleborne. Scale tilted with a scale borne load of 4520 pounds while the total applied load was 6800 pounds. (See Figure L-8.)

APPENDIX M

OUTLINE REQUIREMENTS FOR A WIM SYSTEM

A weigh-in-motion (WIM) system shall automatically identify those trucks in a moving traffic stream which are in weight violation of a State's Vehicle Code as they enter the lane leading to an enforcement weigh station's static scale.

Those trucks that are not in weight violation may be directed through appropriate traffic signals to return to the highway, before they reach the station, and those that are identified as overweight shall be directed through appropriate traffic signals to the weigh station for enforcement weighing on the static scale (see Figure M-8).

The WIM system shall consist of axle scale(s) embedded flush with the pavement surface in the truck scale lane about 800 feet upstream from the weigh station and with appropriate truck presence and loop detectors.

The signals from the above components shall be routed to the weigh station and connected to the WIM instrumentation system installed therein. The system shall process the signals and communicate to the weighmaster those trucks that are in weight violation as each one crosses the WIM scale(s). In addition, the signals shall be processed by the WIM intrumentation system to generate proper outputs for use in a truck traffic management system to 1) direct overweight trucks to the static weigh scale for enforcement weighing, 2) direct non-violators to take the bypass lane back to the highway, and 3) detect violators that have entered the bypass lane.

The minimum components are shown in Figure M-1.

Figure M-2 lists a part of the performance requirements for the WIM system.

WIM Axle Scale

On the static scale approach lane, WIM axle scale(s) shall be embedded flush in the pavement lane to measure the dynamic axle forces on it and, with the associated instrumentation, to derive the (static) weight of the moving axle.

The axle scale may consist of one integral axle scale, or a left-track and a right-track wheel scale. Either one, but not more than two axle scales (in tandem) shall comprise a WIM system. If two axle scales are provided, they shall be separated by about 16.4 feet (5 meters).

The axle scale(s) shall consist of the scale proper and its foundation frame. The transducers within the scale proper shall be sealed against moisture without the use of pressurized gas.

If the axle scale consists of one integral platform, it shall be at least 132 inches wide; if it consists of a left-track and a right-track wheel scale, each scale shall be at least 66 inches wide.

WIM Accuracies

1. The WIM weight accuracy is defined in terms of percent error of the static weight as follows:

$$\% \text{ error} = \frac{\text{WIM Weight} - \text{Static Weight}}{\text{Static Weight}} \times 100.$$

2. The WIM axle spacing accuracy is defined in units of feet of error to the nearest 0.1 feet as follows:

Axle spacing error = WIM axle spacing (ft) - True axle spacing (ft)

3. The WIM speed accuracy is defined in units of miles per hour of error to the nearest 0.1 mph as follows:

Speed error = WIM speed (mph) - True speed (mph)

The required accuracies for WIM axle weights, gross weights, vehicle presence, axle spacings, and speed are set forth in Figure M-2.

Data Display

Data display shall be in two general formats (shown in Figures M-4 and M-6) and selectable by the operator. The proposed format for display shall be submitted for approval.

The WIM system shall retain in memory at least the last 20 trucks weighed and shall be available for reviewing on the CRT by forward and reverse scrolling.

Violation Signal

The WIM system shall provide output signal(s) that a weight violation has occurred. The signal will be used in the truck traffic management system to activate traffic signals to direct violators to the appropriate lane for further processing.

California Vehicle Code (CVC)

The WIM system shall incorporate the sections on "Computation of Allowable Gross Weight" of the state's CVC into the computational software program. The CVC on allowable gross weights are shown in Figure M-3. The display shall be in the general format shown in Figure M-4 to visually communicate to the operator any and all axle and/or gross weight limit violations as listed in Figure M-3.

Listed below are the general requirements for the computer program in accordance with the present CVC sections:

a. Steering (No. 1) axle limited to 12,500 lbs. in all cases.

b. Entry into lookup table (Figure M-3) based on axle spacing (ft.) as determined by Subsection (c) of that section; i.e., tenth values <0.5 ft. will truncate to the foot, and tenth values ≥ 0.5 ft. will increase lookup dimension to the next greater foot.

c. Gross vehicle weight cannot ever exceed 80,000 lbs. Axle group weight can never exceed 40,000 lbs. for the two axles, 60,000 lbs. for three axles, or 80,000 lbs. for four or more axles.

d. Tandem axles will be defined as a limit of 6 feet and Subsection (b) may override the lookup value of allowed weight.

e. Wheel weight limit of 10,500 pounds supporting one end of an axle shall be excluded in the software program.

Any violations shall be communicated to the operator via the general format of Figure M-4, with continuous CRT update display and with a keyboard entry for choice of continuous hard copy printout when desired. Only axle groups with weight violations and/or with axle combinations within a certain percentage of CVC listed weight need be displayed. The WIM system shall be programmable for threshold of 80% to 100% of axle weight limits so that it will display only WIM axle groups that weigh above 80%, 85%, 90%, 95%, or 100% of CVC listed axle weights.

The attached Figure M-4 illustrates the general format required. For example, a hypothetical truck, No. 456, is shown in Figure M-5 listing its axle spacings and axle weights. In accordance with the CVC sections, this truck is overweight for axle groups 2345, 45, and 12345 (gross weight). The overweight violations shall be displayed in the general format as shown in Figure M-4. For this particular dynamic weighing, the threshold was hypothetically set for displaying only trucks weights > 100% of CVC listed weight.

Program Documentation

The computer program shall be written and the documentation shall be sufficient so that a knowledgeable programmer can modify the coding. The WIM system shall include full program documentation as follows:

1. Program listing with detailed comments to describe operation of each module (subroutine). For assembly language, it shall include, at the minimum, complete source and object statements (code) with comments and with complete symbol and cross-reference table.

2. Detailed flow chart.

3. Functional description of each module.

4. The revision number.

5. Date of last revision.

6. An abstract - a comprehensive explanation of the purpose of each module, clearly describing all paths involved.

7. An English description of each required input, including port numbers and/or memory addresses.

8. The end result of an English description of each output, including port numbers and/or memory addresses.

<u>Factory Performance Test</u>

The Contractor shall factory test the WIM system to ensure its proper functional operation prior to shipment. For the tests, the Contractor, at his option, may simulate the transducer analog outputs of the scales, loop detectors and

d. Tandem axles will be defined as a limit of 6 feet and Subsection (b) may override the lookup value of allowed weight.

e. Wheel weight limit of 10,500 pounds supporting one end of an axle shall be excluded in the software program.

Any violations shall be communicated to the operator via the general format of Figure M-4, with continuous CRT update display and with a keyboard entry for choice of continuous hard copy printout when desired. Only axle groups with weight violations and/or with axle combinations within a certain percentage of CVC listed weight need be displayed. The WIM system shall be programmable for threshold of 80% to 100% of axle weight limits so that it will display only WIM axle groups that weigh above 80%, 85%, 90%, 95%, or 100% of CVC listed axle weights.

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6. An abstract - a comprehensive explanation of the purpose of each module, clearly describing all paths involved.

7. An English description of each required input, including port numbers and/or memory addresses.

8. The end result of an English description of each output, including port numbers and/or memory addresses.

Factory Performance Test

The Contractor shall factory test the WIM system to ensure its proper functional operation prior to shipment. For the tests, the Contractor, at his option, may simulate the transducer analog outputs of the scales, loop detectors and presence detectors. The factory test shall consist of 18 trucks or simulated trucks crossing the WIM scale(s) with individual truck data as listed in Figure M-7. A hard copy printout of the above factory performance test, in the general format of Figure M-4, shall be supplied to the State as evidence of a successful functional operation of the system prior to shipment.

Truck Traffic Management

Figures M-8 and M-9 are outlines of a screening and truck traffic management and identification system. Requirements for such a system are discussed in pages M-20 through M-22.

Acceptance Testing

The acceptance testing period shall be 60 consecutive calendar days. A successful acceptance test shall meet the following:

1. Meet all requirements and that listed in Figure M-2.

Data will be collected to determine that the listed $\bar{x}$ and s for all measurements meet listed errors.

2. The WIM system shall be operational for its intended purpose at least 80% of the time the station is open for static enforcement weighing.

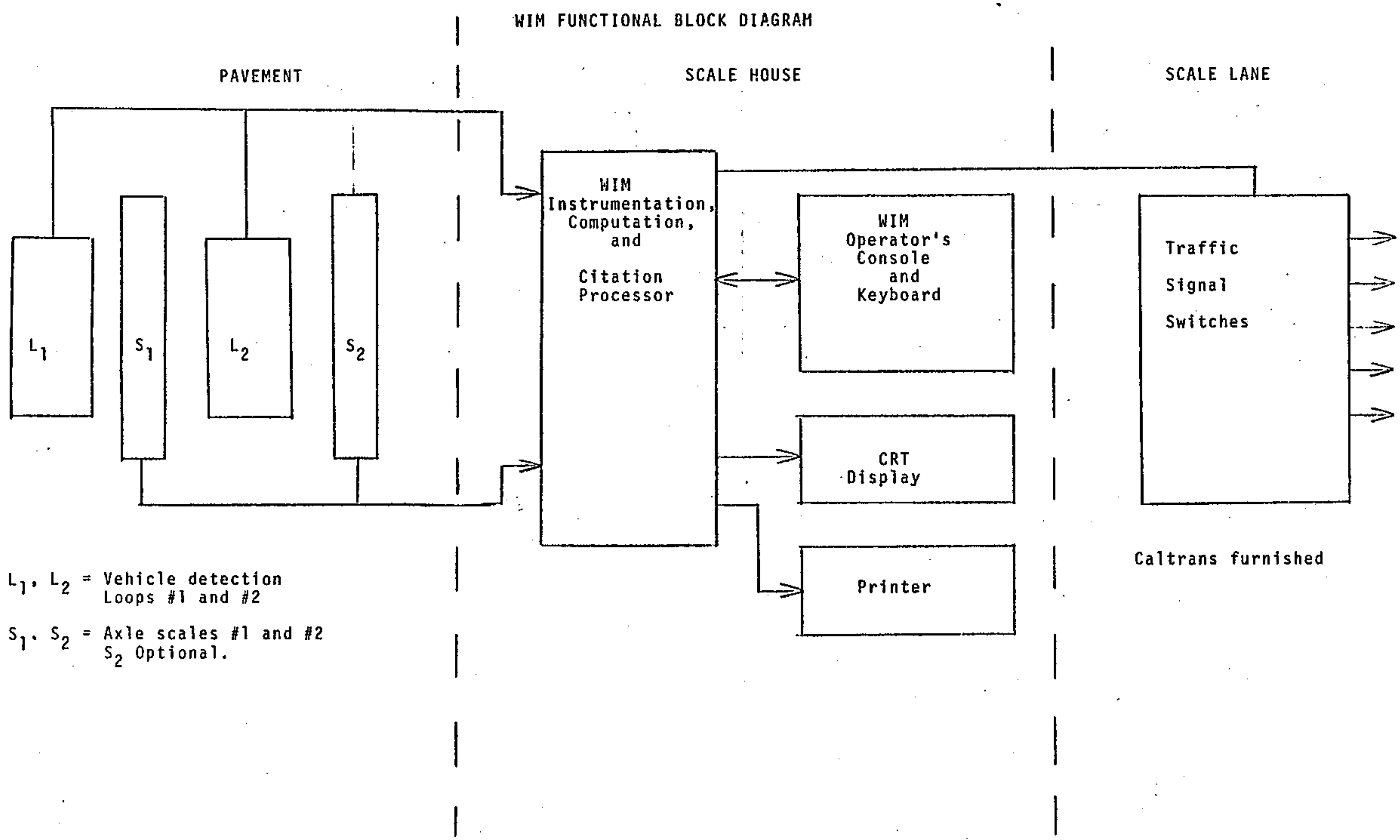
3. Demonstrate the system for on-line production screening and weighing as conceived.

Longevity

The embedded scales shall reliably and correctly perform its weighing function up to 10 million accumulated truck axle loadings, or four (4) years of continuous operation, whichever occurs first.

Figure M-1

WIM FUNCTIONAL BLOCK DIAGRAM



L_1, L_2 = Vehicle detection Loops #1 and #2

S_1, S_2 = Axle scales #1 and #2
S_2 Optional.

Figure M-2

DATA AND ACCURACY REQUIREMENTS FOR WEIGH-IN-MOTION SYSTEM

Measurand	Range	Resolution	Error $\overline{X}$	Error S	n	Speed, mph	Sensor	Signal
Single Axle Weight	20,000 pounds	100 pounds	- ±4% 4 4 4 4	1 7 7 7 7 7	30 40 160 160 40 400	Static 10 - 19.9 20 - 29.9 30 - 39.9 40 - 49.9 All Speeds	Axle Scale(s)	dc analog signal
Tandem Weight	40,000 pounds	100 pounds	±4% 4 4 4 4	5 5 5 5 5	20 80 80 20 200	10 - 19.9 20 - 29.9 30 - 39.9 40 - 49.9 All Speeds	Axle Scale(s)	dc analog signal
Gross Weight	100,000 pounds	100 pounds	±4% 4 4 4 4	4 4 4 4 4	20 80 80 20 200	10 - 19.9 20 - 29.9 30 - 39.9 40 - 49.9 All Speeds	Axle Scale(s)	dc analog signal
Vehicle Presence	Yes or No	--	-	-			Detection Loops	Logic signal (level)
Vehicle Speed	10-50 mph	0.1 mph	±0.2 mph	0.2 mph	--	--		Computed
Axle Spacing	70 ft.	0.1 ft.	±0.15 ft	0.15 ft	--	--		Computed
Axle Count	2 - 10	1	-	-	--	--	Axle Scale(s)	dc analog signal
Time, Date	24-hour clock, day, month, year	1 sec.	-	-	--	--	Digital	Logic

NOTES: $\overline{X}$ = Average error (% or unit)
S = Standard Deviation
n = Minimum sample size for calculating $\overline{X}$ and S

Reliability: The embedded scales shall correctly perform its weighing function up to 10 million truck axle loadings or four years of continuous operation, whichever occurs first.

Vehicle Speed Change: Requirements as setforth in Figure N-1 "Axle Spacing Measurement Error with Speed Change".

MAXIMUM WEIGHT ON SINGLE AXLE OR WHEELS

(a) The gross weight imposed upon the highway by the wheels on any one axle of a vehicle shall not exceed 20,000 pounds and the gross weight upon any one wheel, or wheels, supporting one end of an axle, and resting upon the roadway, shall not exceed 10,500 pounds, except that the gross weight imposed upon the highway by the wheels on any front steering axle of a motor vehicle shall not exceed 12,500 pounds.

(b) The gross weight limit provided for weight bearing upon any one wheel, or wheels, supporting one end of an axle shall not apply to vehicles the loads of which consist of livestock.

(c) The following vehicles are exempt from the front axle weight limits specified in this section:

(1) Trucks transporting vehicles.

(2) Trucks transporting livestock.

(3) Dump trucks.

(4) Cranes.

(5) Buses.

(6) Transit mix concrete or cement trucks, and trucks that mix concrete or cement at, or adjacent to, a jobsite.

(7) Motor vehicles that are not commercial vehicles.

(8) Vehicles operated by any public utility furnishing electricity, gas, water, or telephone service.

(9) Trucks or truck tractors with a front axle at least four feet to the rear of the foremost part of the truck or truck tractor, not including the front bumper.

(10) Trucks transporting garbage, rubbish, or refuse.

(11) Trucks equipped with a fifth wheel when towing a semitrailer.

(12) Tank trucks which have a cargo capacity of at least 1,500 gallons.

(13) Trucks transporting bulk grains or bulk livestock feed.

COMPUTATION OF ALLOWABLE GROSS WEIGHT

(a) Except as otherwise provided in this section or Section the total gross weight in pounds imposed on the highway by any group of two or more consecutive axles shall not exceed that given for the respective distance in the following table:

Distance in feet between the extremes of any group of 2 or more consecutive axles	2 axles	3 axles	4 axles	5 axles	6 axles
4	34,000	34,000	34,000	34,000	34,000
5	34,000	34,000	34,000	34,000	34,000
6	34,000	34,000	34,000	34,000	34,000
7	34,000	34,000	34,000	34,000	34,000
8	34,000	34,000	34,000	34,000	34,000
9	39,000	42,500	42,500	42,500	42,500
10	40,000	43,500	43,500	43,500	43,500
11	40,000	44,000	44,000	44,000	44,000
12	40,000	45,000	50,000	50,000	50,000
13	40,000	45,500	50,500	50,500	50,500
14	40,000	46,500	51,500	51,500	51,500
15	40,000	47,000	52,000	52,000	52,000
16	40,000	48,000	52,500	52,500	52,500
17	40,000	48,500	53,500	53,500	53,500
18	40,000	49,500	54,000	54,000	54,000
19	40,000	50,000	54,500	54,500	54,500
20	40,000	51,000	55,500	55,500	55,500
21	40,000	51,500	56,000	56,000	56,000
22	40,000	52,500	56,500	56,500	56,500
23	40,000	53,000	57,500	57,500	57,500
24	40,000	54,000	58,000	58,000	58,000
25	40,000	54,500	58,500	58,500	58,500
26	40,000	55,500	59,500	59,500	59,500
27	40,000	56,000	60,000	60,000	60,000
28	40,000	57,000	60,500	60,500	60,500
29	40,000	57,500	61,500	61,500	61,500
30	40,000	58,500	62,000	62,000	62,000
31	40,000	59,000	62,500	62,500	62,500
32	40,000	60,000	63,500	63,500	63,500
33	40,000	60,000	64,000	64,000	64,000
34	40,000	60,000	64,500	64,500	64,500
35	40,000	60,000	65,500	65,500	65,500
36	40,000	60,000	66,000	66,000	66,000

(CONT)

37	40,000	60,000	66,500	66,500	66,500
38	40,000	60,000	67,500	67,500	67,500
39	40,000	60,000	68,000	68,000	68,000
40	40,000	60,000	68,500	70,000	70,000
41	40,000	60,000	69,500	72,000	72,000
42	40,000	60,000	70,000	73,280	73,280
43	40,000	60,000	70,500	73,280	73,280
44	40,000	60,000	71,500	73,280	73,280
45	40,000	60,000	72,000	76,000	80,000
46	40,000	60,000	72,500	76,500	80,000
47	40,000	60,000	73,500	77,500	80,000
48	40,000	60,000	74,000	78,000	80,000
49	40,000	60,000	74,500	78,500	80,000
50	40,000	60,000	75,500	79,000	80,000
51	40,000	60,000	76,000	80,000	80,000
52	40,000	60,000	76,500	80,000	80,000
53	40,000	60,000	77,500	80,000	80,000
54	40,000	60,000	78,000	80,000	80,000
55	40,000	60,000	78,500	80,000	80,000
56	40,000	60,000	79,500	80,000	80,000
57	40,000	60,000	80,000	80,000	80,000
58	40,000	60,000	80,000	80,000	80,000
59	40,000	60,000	80,000	80,000	80,000
60	40,000	60,000	80,000	80,000	80,000

(b) In addition to the weights specified in subdivision (a), two consecutive sets of tandem axles may carry a gross weight of 34,000 pounds each if the overall distance between the first and last axles of such consecutive sets of tandem axles is 36 feet or more. The gross weight of each set of tandem axles shall not exceed 34,000 pounds and the gross weight of the two consecutive sets of tandem axles shall not exceed 68,000 pounds.

(c) The distance between axles shall be measured to the nearest whole foot. When a fraction is exactly six inches, the next larger whole foot shall be used.

(d) Nothing contained in this section shall affect the right to prohibit the use of any highway or any bridge or other structure thereon in the manner and to the extent specified in Article (commencing with Section .) and Article (commencing with Section) of this chapter.

(e) The gross weight limits expressed by this section and Section shall include all enforcement tolerances.

FIGURE M-4

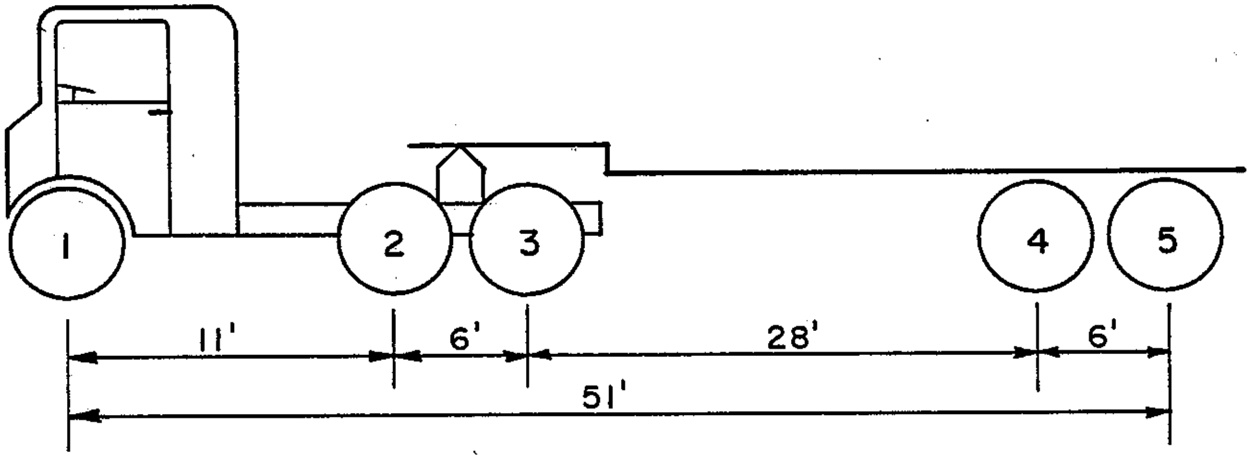
WIM SYSTEM

DISPLAY FORMAT FOR HYPOTHETICAL TRUCK CVC VIOLATION

Date	Truck No.	Axles	Axle Group	Spacing	Allowable	WIM Wt.	Diff.	Stop
5-27-81	456	4	25	40	68.5	70.0	+1.5	
5-27-81	456	2	45	6	34.0	36.0	+2.0	
5-27-81	456	5	15	51	80.0	82.5	+2.5	

FIGURE M-5

A HYPOTHETICAL TRUCK AXLE WEIGHTS AND SPACING



Axles	CVC 35550 & 35551 Weight Limit	Weight	Violation	Axle Spacing
1	12500	12500	-	-
2	20000	20000	-	-
3	20000	14000	-	-
4	20000	20000	-	-
5	20000	16000	-	-
12	32500	32500	-	11'
123	46500	46500	-	17'
23	34000	34000	-	6'
234	60000	54000	-	34'
2345	68500	70000	+1500	40'
345	60000	50000	-	34'
45	34000	36000	+2000	6'
12345	80000	82500	+2500	51'
1234	72000	66500		45'
34	40000	34000		28'

1 axle limited to 12,500 pounds at all times in the software program. There are 13 exceptions which the weighmaster will qualify in determining final compliance.

Figure M-6

0113 7-29-81-1515	SP: 12.5		GW: 27.2			TL: 57.2		AX: 5		
	AW:	8.3		6.6		6.3		2.8		3.2
	TW:				12.9				6.0	
	AS:		15.8		4.6		32.3		4.5	
0114 7-29-81-1518	SP: 10.1		GW: 11.4			TL: 16.0		AX: 3		
	AW:	5.4		3.2		2.8				
	TW:				6.0					
	AS:		11.6		4.4					
0001 7-30-81-0800	SP: 22.5		GW: 75.4			TL: 63.2		AX: 5		
	AW:	8.3		17.7		18.3		17.5		13.6
	TW:									
	AS:		14.9		15.4		17.0		15.9	

SYMBOLS

SP: Speed in miles per hour
GW: Truck gross weight in Kips (1,000 pounds)
TL: Total truck length between outer axles in feet.
AX: Number of axles
AW: Axle wieght in Kips (1,000 pounds)
TW: Tandem axle weight in Kips (1,000 pounds)
AS: Axle spacing in feet.

Figure M-7

TRUCKS WITH VARIOUS WEIGHT VIOLATIONS PER CVC 35550 AND 35551

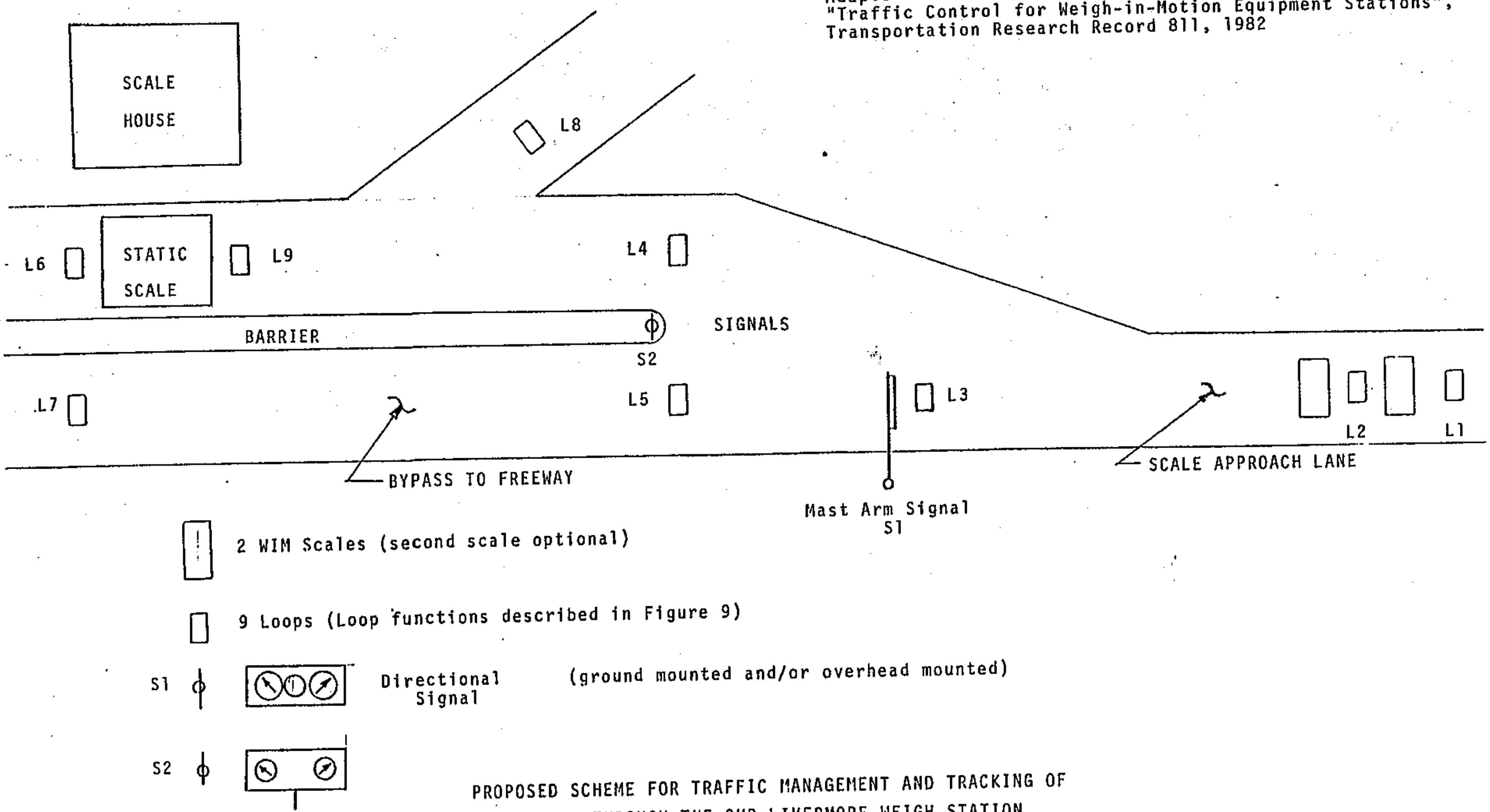
Truck No.	Axle 1 (lbs)	S1	Axle 2 (lbs)	S2	Axle 3 (lbs)	S3	Axle 4 (lbs)	S4	Axle 5 (lbs)	S5	Axle 6 (lbs)	Axle Group Violation Axles	Axle Group Violation Violation (lbs)	Gross Weight
458 V	13,000 500	12.0	20,000											33,000
459 V	11,500	11.5	20,000	28.0	20,500 500							23	500	52,000
460 V	11,000	15.0	20,000	9.0	20,000							23	1,000	51,000
461 V	13,000 500	11.0	19,000	30.0	22,000 2,000							23	1,000	54,000 1,500
462 V	9,000	30.0	20,000	4.0	20,000							23	6,000	49,000 2,500
463 V	10,000	27.0	19,000	9.0	20,000	33.0	21,000 1,000					34	1,000	70,000
464 V	9,000	12.0	18,000	35.0	17,000	4.0	17,000							61,000
465 V V V	12,500	16.0	20,000	4.5	20,000	32.0	20,000					23 123 234	6,000 6,000 6,000*	72,500 6,000*
466 V	10,000	27.0	16,000	34.0	17,000	5.0	17,000							60,000
467 V	12,000	9.0	18,000	27.0	20,000	10.0	20,000	20.0	20,000					90,000 10,000
468 V	13,000 500	24.0	19,000	12.0	20,000	34.0	15,000	5.0	15,000					82,000 2,000
469 V	10,000	36.0	18,000	4.0	18,000	10.0	17,000	30.0	17,000			23	2,000	80,000
470 V	12,000	20.0	17,000	4.0	17,000	30.0	18,000	4.0	18,000			45	2,000	82,000 2,000
471 V	12,000	12.0	20,000	31.0	12,000	4.0	12,000	4.0	12,000			345	2,000	68,000
472 V	9,000	12.0	12,000	4.0	12,000	20.0	17,000	6.0	18,000	20.0	16,000	45	1,000	84,000 4,000
473 V	8,000	20.0	13,000	4.0	13,000	9.0	21,000 1,000	23.0	12,000	4.0	12,000	234	1,500	79,000
474 V	8,000	14.0	14,000	4.0	14,000	20.0	16,000	4.0	16,000	20.0	15,000			83,000 3,000
475 V V	8,000	15.0	18,000	4.0	18,000	30.0	12,000	4.0	12,000	4.0	12,000	23 456	2,000 2,000	80,000

V = Axle, axle group and gross weight violation in pounds

S = Axle spacing in feet.

* = Omit in computer program.

Adapted from Lee, C. E. and Machemehl, R. B., "Traffic Control for Weigh-in-Motion Equipment Stations", Transportation Research Record 811, 1982



PROPOSED SCHEME FOR TRAFFIC MANAGEMENT AND TRACKING OF TRUCKS THROUGH THE CHP LIVERMORE WEIGH STATION

Scale: None

Figure M-9

PROPOSED LOOP FUNCTIONS FOR A TRAFFIC MANAGEMENT SCHEME

Loop	Function
1	Detects truck presence for WIM Scale No. 1.
2	Detects truck presence for optional WIM Scale No. 2.
3	Control directional signal to direct truck to static scale or to bypass lane. Synchronize with L4 or L5 to update directional signal. Returns S1 signal control to WIM microprocessor for next following truck.
4	Detects truck in static lane and beyond sight of directional signal. Synchronize with L3 and update directional signal for next following truck.
5	Detects truck in bypass lane and beyond sight of directional signal. Synchronize with L3 and update directional signal for next following truck. Identify violator in bypass lane.
6	Detects truck passed static scale. Update operator's WIM display for the next following truck in the scale lane.
7	Detects truck beyond scale house in the bypass lane. Update operator's WIM display for the next following truck in the scale lane.
8	Detects truck returning to static scale for reweighing.
9	Switch for delayed operator display of truck approaching static scale.

State of the Art Signal Systems

A state of the art method for managing truck traffic at a weigh station, where WIM scales are used for screening in advance of the static scale, calls for two overhead signals, having a red X or a green arrow under control of the WIM scale. When trucks bunch up, this type of signal system can easily be misread. Lee and Machemehl (ref 16) have suggested an improved signal system consisting of a three- section signal face (S1, Fig M-8), mast-arm mounted, and 250 feet upstream from the WIM screening scale followed by a two-section signal (S2), ground mounted, in the gore between the bypass and static scale lanes. The green ball at S1 is continuously illuminated to keep traffic moving while directional green arrows tell the drivers which lane to take.

Deficiencies

Queuing

At high-volume weigh stations, headways tend to shorten and intervals between trucks tend to close as peaking occurs. Queuing in the static scale lane will occur at peak periods when demand is greater than capacity. Two studies in California have pegged the maximum flow rate for a single static scale at 140 to 150 vehicles per hour thus averaging 24 to 26 seconds for each truck.

Current weigh-in-motion state of the art is deficient when queuing occurs because the operation cannot identify the data displayed on the video screen in the scale house with its associated truck backed up to the queue. Weight data should not be displayed in the scale house the instant a truck crosses the WIM scale. To avoid confusion, data should be held in computer memory and shown on the video screen just moments before a truck rolls up on the static scale so the operator can match the truck with its own weight data. WIM scale violation should be highlighted (blinking characters) for quick comparison with the static scale readout.

Violator Bypass

State of the art systems requires further development and refinement to alert the operator when a violator (intentionally or unintentionally) gets into the bypass lane.

Safety Inspections

The operator should have some means of randomly selecting legal vehicles from the traffic stream for safety inspections. Some weigh stations in California are fully equipped with covered inspection sheds for conducting comprehensive safety checks. At others, a critical item safety check is conducted on a routine basis.

Proposal

Figures M-8 and M-9 outline a proposal for a truck traffic management and identification system that addresses the deficiencies mentioned above.

The problem of identifying trucks in a queue can be overcome by delaying the operator display until the truck crosses loop L9.

Violators in the bypass lane can be detected by computer logic and by loops L5 and L7 causing an audio or video signal to flash in the scale house.

Random selection of trucks for safety inspections can be accomplished by computer logic and/or operator override of the signal system. In either case, a legal vehicle can be directed away from the bypass lane, across the static scale, and around back of the scale house to the inspection area.

APPENDIX N

ERRORS IN IN-MOTION AXLE SPACING MEASUREMENTS

In-motion axle spacing measurements must be accurate to 0.5 foot. The California Vehicle Code Section 35551 requires that "The distance between axles shall be measured to the nearest whole foot. When a fraction is exactly six inches, the next larger whole foot shall be used."

The attainment of the above accuracy, i.e., 0.5 foot, is very dependent on the truck in question crossing a speed trap* at a constant speed.

Figure N-1 tabulates limits of allowable speed changes to stay within 0.5 foot spacing error measurement. It is a compilation of Figures N-2 through N-5. For example, it shows that for a speed of 32 mph, a truck must maintain this speed to within ±4 mph in order to measure a 4-foot axle spacing to within ±0.5 foot. For a 60-foot axle spacing (say, a steering axle to last axle), at the same speed, it must maintain speed to within ±0.26 mph to measure the 60-foot spacing to within ±0.5 foot. Thus, for increasing axle spacing, at a given speed, the magnitude of speed changing becomes more critical. Figure N-1 also

*The speed trap for the PAT system were the two axle weight scales and for the StreeterAmet system the two vehicular loop detectors.

indicates that the combination of lower truck speeds and larger axle spacings can tolerate relatively little speed changes. For a truck speed of 20 mph and an axle spacing of 60-foot, the limit of speed change is 0.17 mph to stay within a 0.5 foot measurement error.

Figure N-1

Axle Spacing Measurement Error
With Speed Change

Truck Speed (MPH)	Axle Spacing (Feet) 4.0	15.0	30.0	60.0
60	7.50	2.00	1.00	0.50
55	6.88	1.83	0.92	0.46
40	5.00	1.33	0.67	0.33
*32	4.00	1.06	0.54	0.26
20	2.50	0.67	0.33	0.17

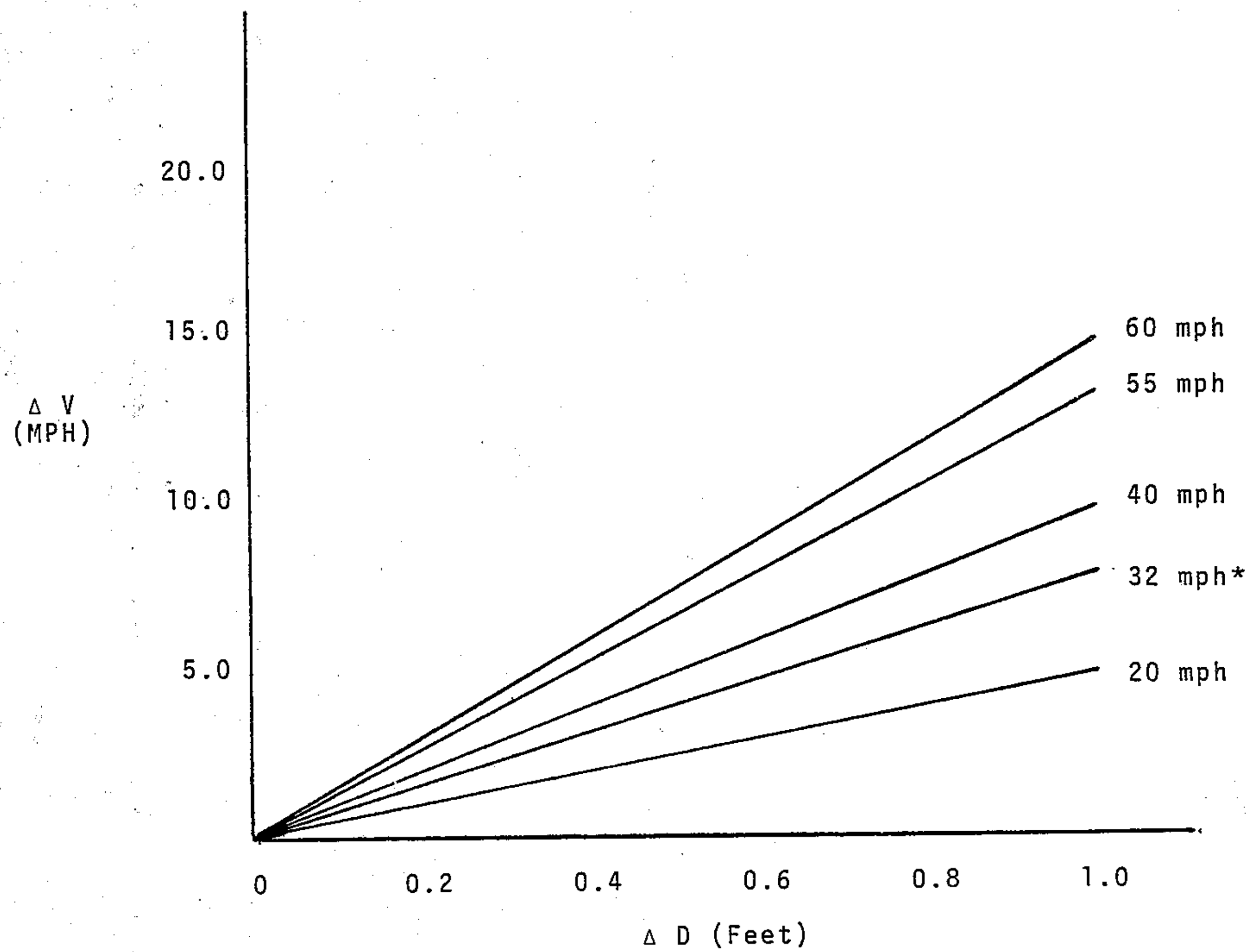
Speed Change - ΔV (MPH)

Allowable Speed Change (MPH) for
0.5 feet axle spacing error

* Average truck speed crossing WIM scales at Antelope Weigh Station

Figure N-2

Axle Spacing Error (ΔD)
vs.
Speed Change (ΔV)
at D = 4 Feet



*Average truck speed at Antelope Weigh Station

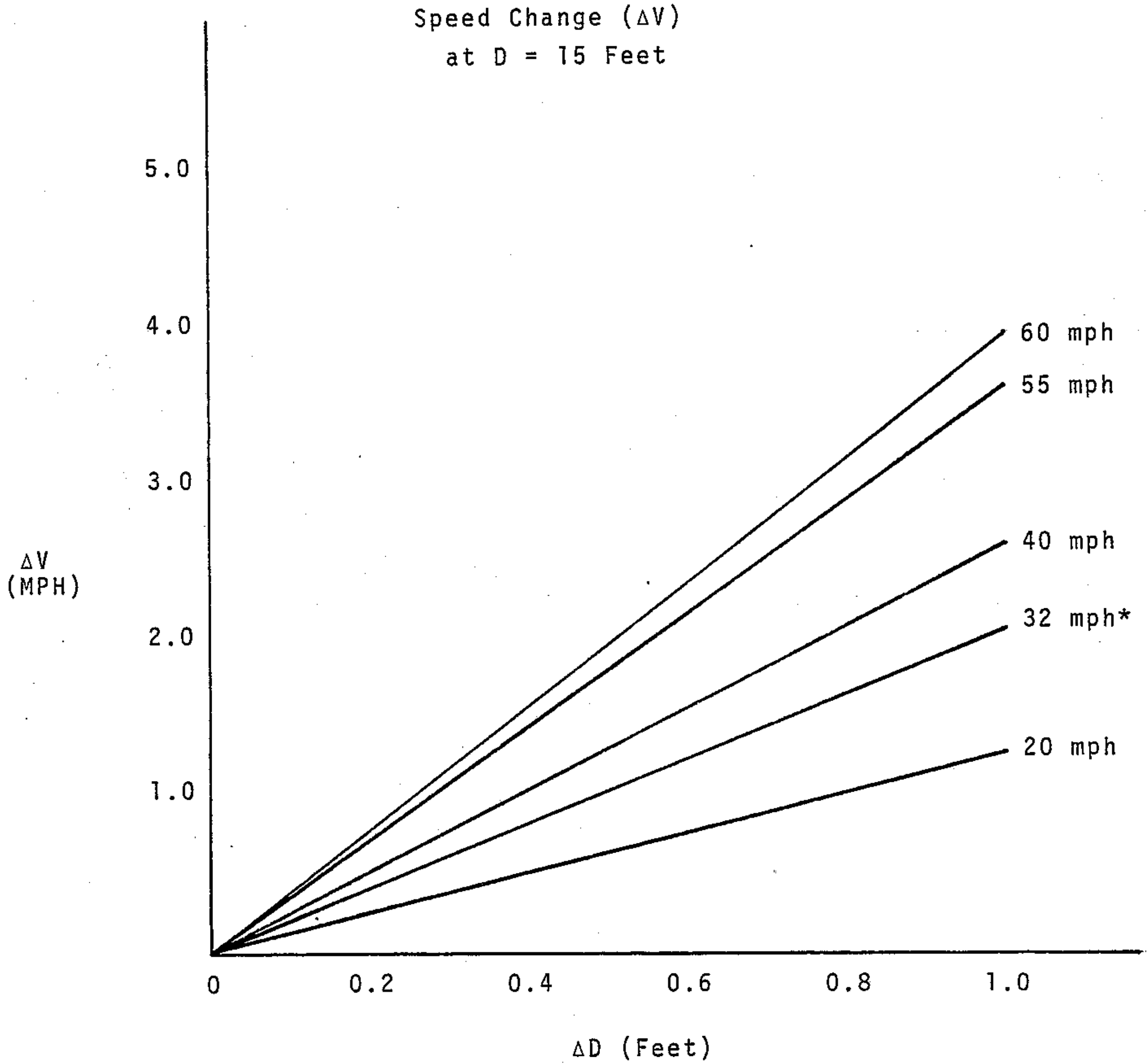
Figure N-3

Axle Spacing Error (ΔD)

vs.

Speed Change (ΔV)

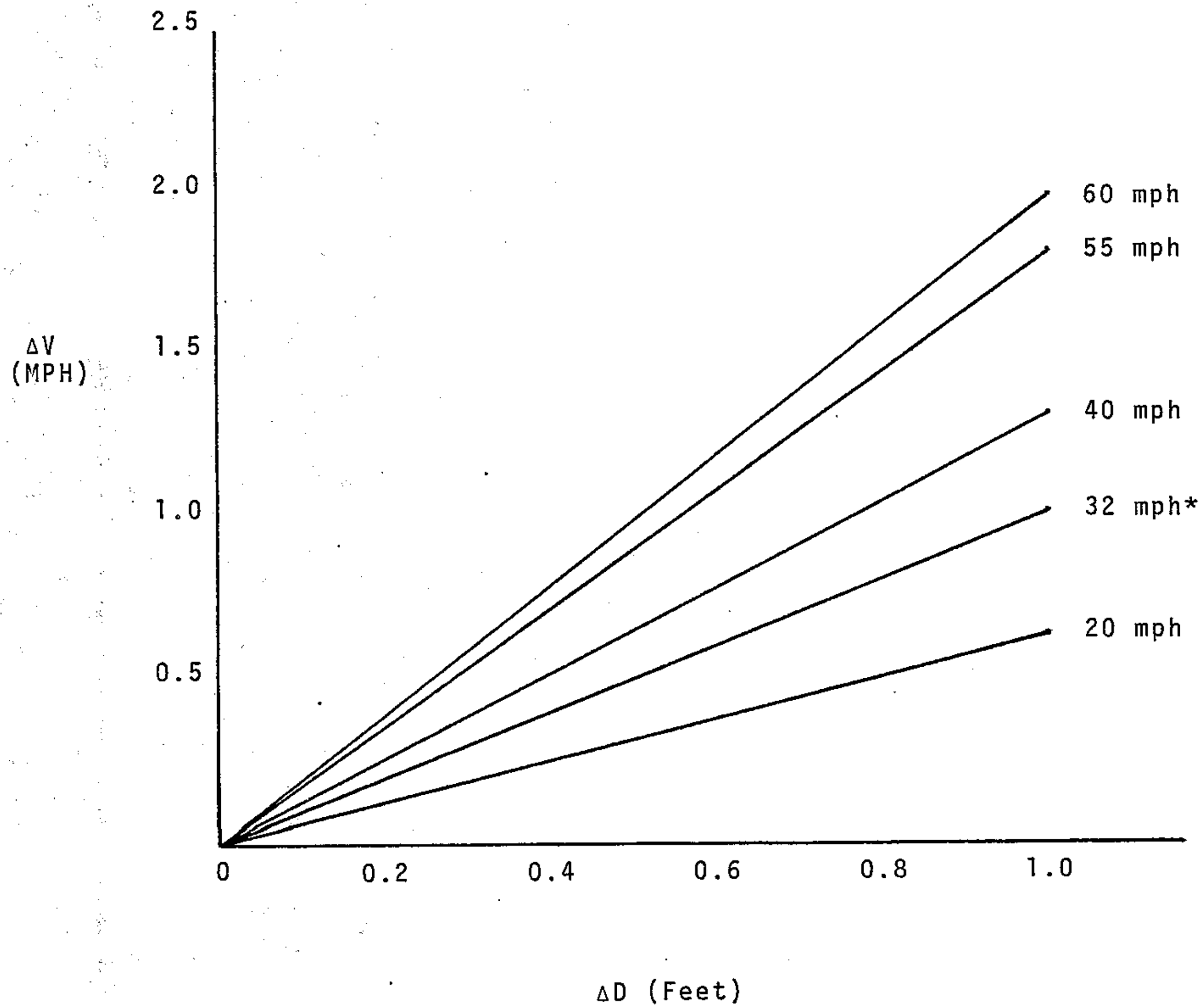
at D = 15 Feet



*Average truck speed at Antelope Weigh Station

Figure N-4

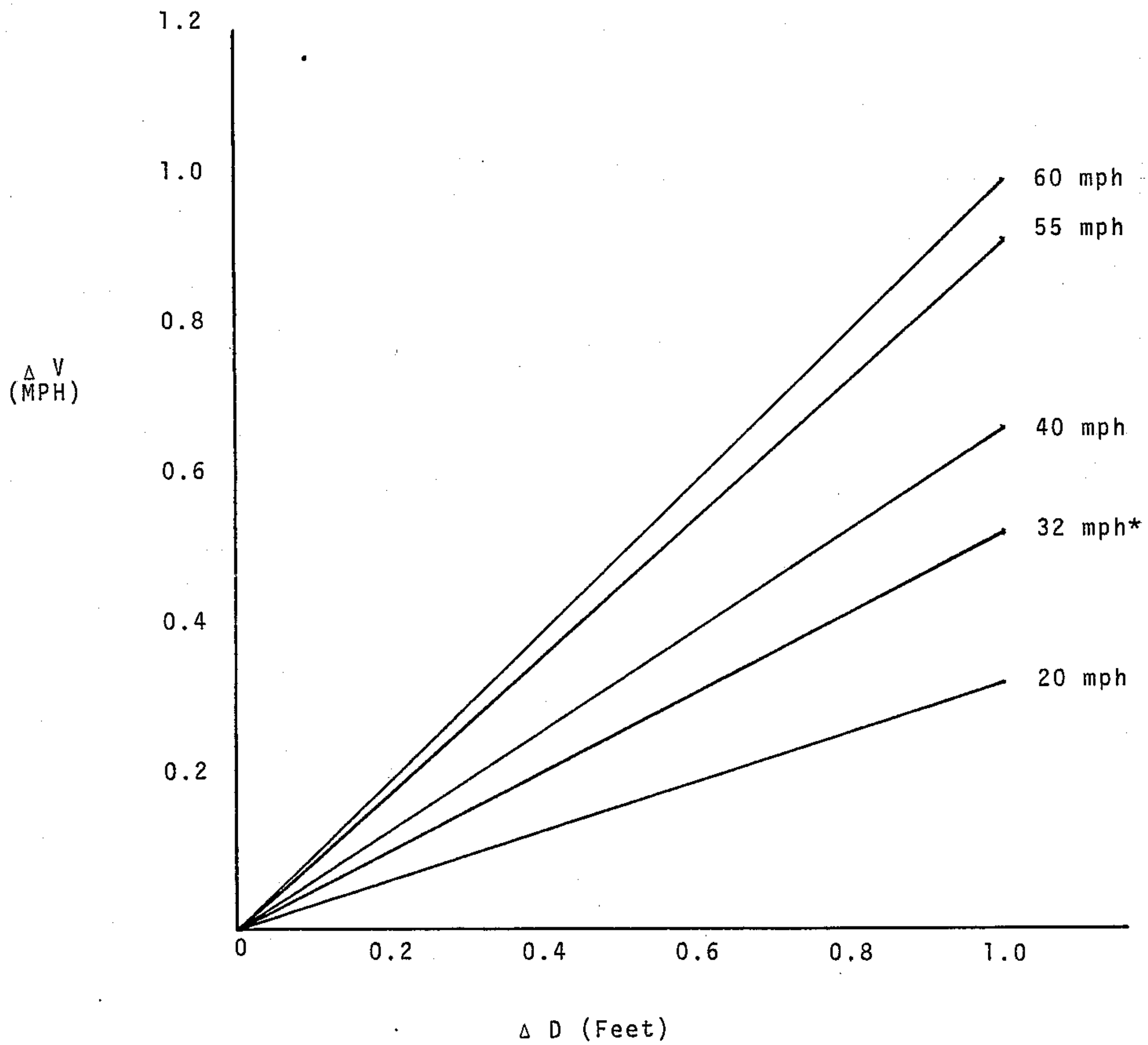
Axle Spacing Error (ΔD)
vs.
Speed Change (ΔV)
at D = 30 Feet



*Average truck speed at Antelope Weigh Station

Figure N-5

Axle Spacing Error (ΔD)
vs.
Speed Change (ΔV)
at D = 60 Feet



*Average truck speed at Antelope Weigh Station