A PORTABLE ELECTRONIC SCALE FOR WEIGHING VEHICLES IN MOTION

by

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PREFACE

The need for an efficient method of weighing the wheels of moving highway vehicles has become more pressing in recent years, particularly since high-speed, controlled-access highways have become a reality. On roads such as our Interstate Highway System, it is no longer safe nor feasible to stop vehicles on widened shoulders for weighing and measuring.

The research study described in this report was begun in 1963 with the primary objective of developing a portable electronic scale system capable of obtaining weights and dimensions of moving highway vehicles with accuracy sufficient for traffic survey and planning purposes. It was one of the five studies included in the initial Cooperative Research Program of the Center for Highway Research at The University of Texas at Austin, the Texas Highway Department, and the U. S. Bureau of Public Roads.

This final report describes the design, construction, and testing of a system for measuring vehicle speed and length, time of day, number of axles, axle spacing, and wheel weight without impeding normal traffic flow in any way. It also includes a description of required data processing along with appropriately documented computer programs and an analysis of representative data that indicates the order of precision attainable with the system.

The authors acknowledge and extend thanks to the many individuals who have contributed their talents to this research study. George L. Carver and Joe E. Wright, Planning Survey Division, D-10, Texas Highway Department and Henry Bremmer, Bureau of Public Roads served as contact individuals for their respective organizations and gave continuous assistance and advice. Thomas K. Wood, District 14, Austin and his personnel assisted in the field evaluation of the system as did personnel from District 9, Waco. Assistance in data reduction was provided by the Division of Automation, D-19, Hubert A. Henry, Engineer-Director. Machine shop work was performed by Texas Highway Department and The University of Texas employees. Harold H. Dalrymple perfected much of the electronic instrumentation for the system, and Ed Hamilton of

Rainhart Company, Austin, Texas, collaborated on many recent design improvements. Other personnel of The University of Texas and the Texas Highway Department too numerous to mention individually aided immeasurably in this research.

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ABSTRACT

A unique portable electronic scale for weighing each wheel of highway vehicles moving at speeds up to 70 mph has been developed at the Center for Highway Research, The University of Texas at Austin. The scale consists of a pair of special strain gage transducers, each of which is approximately 54 x 20 inches in plan dimensions and about 2-inches thick, connected to conventional electronic recording equipment. The transducers are set side by side in a traffic lane and flush with the pavement surface. Output signals are not affected by tractive forces, tire contact pressure or area, position of the load on the transducer, temperature, nor moisture. Installation of the scale at a new site requires about 4 hours but installation at a previously occupied site takes only 45 minutes.

The system developed for the Texas Highway Department records electrical signals from the two wheel load transducers and from three vehicle detectors in analog form on magnetic tape in the field. These are subsequently converted to digital form for calculating speed and length of the vehicle, time of day, number of axles, axle spacing, vehicle classification, and wheel weights. Computer programs for preparing tabulations and for packing permanent record tapes have been developed. Field evaluation of over 500 vehicle records indicates that the gross weight of trucks determined by the electronic scales is within ±10 percent of the static vehicle weight measured with a loadometer.

The portable electronic scale is a new tool for obtaining vehicle weight data without impeding traffic flow and for research concerned with the dynamics of highway loading.

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CHAPTER 1. INTRODUCTION

General

Rapid advancements in the technology of highway planning, design, and construction suggest the need for parallel and equal advancements in the process of obtaining data required for the design of pavements and other highway structures. At the present time, truck scales (Fig 1.1) are a familiar part of highway operations. These scales indicate the static weight of those vehicles that have not avoided the weighing station and require all trucks that are weighed to stop at the specially constructed sites. The delay, expense, and hazard associated with such operations have directed the attention of engineers to the need for developing a scale system capable of weighing vehicles in motion.

The concept of weighing vehicles in motion is not new. Early attempts at developing such an in-motion weighing system were reported by O. K. Normann and R. C. Hopkins (Refs 1 and 2) in 1952. For their work, a massive reinforced concrete slab about 3 by 10 feet in plan dimensions and 12-inches thick was supported flush with the adjacent road surface by four conventional load cells set in a pit beneath the road, and electrical signals from the load cells were recorded on appropriate instruments. This configuration, with minor modifications, has been used experimentally and commercially both in this country (Refs 3 and 11) and in Europe (Ref 12).

Even though several expensive scales of this type have been installed during the past fifteen years, at least three inherent inadequacies in the basic design have hampered successful operation. The scale location is fixed; therefore, its usefulness is limited to one site. Construction of a pit beneath the pavement is necessary, and even with a good drainage system, moisture in the pit damages the equipment. And finally, the inertia of the heavy slab and its horizontal translation have adverse effects on the response of the system to dynamic loads.

Fig 1.1. Loadometer Station (tire on scale).

Weighing in Motion

A critical analysis of the vehicle weighing problem, performed in the light of experience, makes obvious the need for eliminating the previously mentioned inadequacies in the scale system and for meeting additional requirements if usable results are to be obtained. Certain basic criteria as to the kind and quality of information required must be established before a suitable scale system can be developed. The fundamental question of whether static vehicle weight or dynamic wheel force information is desired must first be answered; then performance criteria for a weighing system can be defined.

Static vehicle weight is generally used for law enforcement and for planning purposes while dynamic wheel force data are used for the structural design of pavements and bridges. In addition to the magnitude of the wheel load, the structural designer needs to know the proximity of the wheel loads, or axle spacing, as well as the number of axles, since closely spaced loads produce overlapping stress patterns in the pavement structure. A relationship exists between static wheel weight and the forces exerted on the pavement by a moving wheel for any given vehicle operating under a specific set of conditions. This relationship is not yet clearly defined. Neither is the relationship precisely known for the general case of mixed traffic operating on different types of roadways. It may be reasoned, however, that the static wheel load will be nearly equal to the dynamic wheel load of a vehicle operating at moderate speed on a perfectly smooth, level surface. From this, it follows that, in a practical sense, wheel loads of a vehicle moving over a smooth pavement can be sensed by a suitable dynamic scale and summed to give a good estimate of the static vehicle weight.

The accuracy with which this estimate can be made is affected by such factors as pavement roughness, tire roundness, vehicle suspension system characteristics, aerodynamic lift, and response characteristics of the weighing device. However, for planning and design purposes, static vehicle weight can probably be estimated from dynamic wheel forces with sufficient precision if a suitable dynamic scale of finite length set flush in a smooth pavement is utilized. The precision of the estimate can undoubtedly be improved either by measuring wheel loads continuously as the wheel moves over some relatively long finite distance or by sampling it several times. In any case, a scale with good and rapid dynamic response is required.

Other criteria to be met for a practical in-motion weighing system include:

Portability. The system should be such that a two-man crew can transport, install, and operate the scale for extended periods of time while using a station wagon or light truck as a working vehicle. Also, a minimum amount of pavement should be removed for installing the scale. This is particularly important when scale platforms or transducers are installed in bridge decks and in rigid pavements.

Reaction to Tractive Forces. The scale system should be insensitive to any tractive forces applied parallel to the roadway surface. Only the component of wheel force acting normal to the pavement surface should affect the scale output signal.

Sensitivity. Since the path of a wheel over the scale platform cannot be predetermined, the sensitivity should be uniform over the entire platform. In other words, the output signal should be the same regardless of the tire position on the scale platform. The output signal should not be affected by the tire print area nor the contact pressure.

Ruggedness and Reliability. This is of prime importance since the system is expected to operate for long periods of time under severe traffic and climatic conditions.

Deflection. The scale platform should deflect in a manner similar to the pavement structure into which it is set so that neither a "bump" nor a "depression" is created in the roadway surface under load. Either of these conditions causes adverse effects on the recorded dynamic forces.

Cost. The cost of owning and operating the system must compare favorably with the cost of procuring vehicle weight information by present techniques if the system is to be considered as a replacement for such techniques.

The only known portable scale used routinely for weighing moving highway vehicles is the one operating in Sweden as described by Stig Edholm (Ref 13). This unit while apparently successful, fails to satisfy all the criteria suggested above in that the load detector is over 4-inches thick and the speed of the vehicles to be weighed is restricted to 12.5 mph. Also, data from the scale are recorded on paper tape in analog form resulting in tedious and expensive interpretation. A transportable scale system is being used in England for research purposes (Refs 16 and 23).

The criteria for an in-motion vehicle weighing system as outlined above are formidable and past experience with in-motion weighing seems somewhat discouraging, but a portable scale system capable of sensing the dynamic forces which are exerted normal to the pavement surface by wheels of highway vehicles moving at normal road speed has been developed through the cooperative research program of the Center for Highway Research at The University of Texas at Austin, the Texas Highway Department, and the U. S. Bureau of Public Roads. In the course of this research study, three major phases of development have been successfully completed. First, a new and unique transportable wheel load transducer has been designed, constructed, field tested, and improved. Second, a mobile instrumentation system for conditioning and recording the signals from a pair of transducers has been specified, purchased, and evaluated under actual traffic conditions. And finally, techniques for computer processing of the traffic data have been developed. The feasibility of in-motion vehicle weighing for the purpose of obtaining design and planning information has been clearly demonstrated.

CHAPTER 2. DEVELOPMENT OF WHEEL LOAD TRANSDUCER

When this study was initiated in 1963, virtually no attention had been given previously to the development of a transportable in-motion vehicle weighing system. The electronic technology needed for recording dynamic force data and for computing associated information had been developed to a high degree, but no suitable wheel load transducer was available. The need for a small, low inertia device that could be transported to different sites and installed with minimum effort was obvious.

The basic configuration for a portable strain gage type wheel load transducer was described in a thesis at Mississippi State College in 1956 (Ref 14). The concepts incorporated in this design were sound, but by 1963 advancements in strain gage technology and machining techniques made the production of an improved transducer possible.

The first portable wheel load transducer was designed for this study in the summer of 1963 and fabricated in the shops of The University of Texas and the Texas Highway Department. This device performed quite satisfactorily in extensive field evaluation tests extending over several months. Two additional transducers of this design were produced by the Philco Corporation for the Texas Highway Department and delivered with an instrument system in July 1966. Certain difficulties with fabrication were indicated by Philco, and problems with the electrical wiring in one transducer were detected before initial installation and again shortly after the unit was subjected to traffic. The second transducer performed well under heavy interstate traffic near Temple, Texas for over nine months before fatigue failure in the sheet-metal cover occurred. Load cells recovered from this unit were found to be operative even though water had intruded through the ruptured cover.

These experiences indicated the need for modifications in sealing details and in fabrication techniques. Cooperative efforts with Ed Hamilton, product designer for Rainhart Company, during 1967 resulted in two improved models of the transducer. Details of the original design and of the two subsequent models constructed for the Texas Highway Department by Rainhart Company are described in this chapter.

Summary of Design Requirements

The wheel load transducer is the load sensing element of the in-motion vehicle weighing system. Its function is to detect the component of wheel force acting normal to the pavement surface and convert this force into a corresponding electrical signal. The principal factors that must be considered in the design of a satisfactory wheel load transducer are summarized below.

Size. The plan dimensions of the transducer must be such that the wheels on each side of a vehicle traveling in a normal traffic lane will pass successively over a transducer and such that each moving wheel will be fully supported for some finite length of time by the transducer. For use in the standard 12-foot lane, two transducers, each approximately 50 by 20 inches in size, set side by side and about 18 inches apart, with their long axis transverse to the direction of traffic, are needed to weigh any conventional vehicle. Two transducers are required for each lane of traffic (see Fig 2.1). See Table 4.2 for the relationship between the effective transducer width and vehicle speed. A minimum effective width of 18 inches is required for adequate sampling of the wheel force signal at the higher vehicle speeds. The overall thickness of the transducer must be less than 3 inches so that it can be installed in either rigid or flexible pavements after removing a minimum of material.

Sensitivity. Since the path of a wheel passing over the transducer cannot be predetermined, the electrical output signal must be the same for any given wheel load regardless of the position of the wheel on the transducer. Neither can the signal be affected by the tire print area nor the contact pressure. Tire contact areas range from about 20 to over 100 square inches, and tire inflation pressures vary from as little as 15 up to 100 pounds per square inch. Tractive forces from the tires of an accelerating or decelerating vehicle must not affect the transducer output signal.

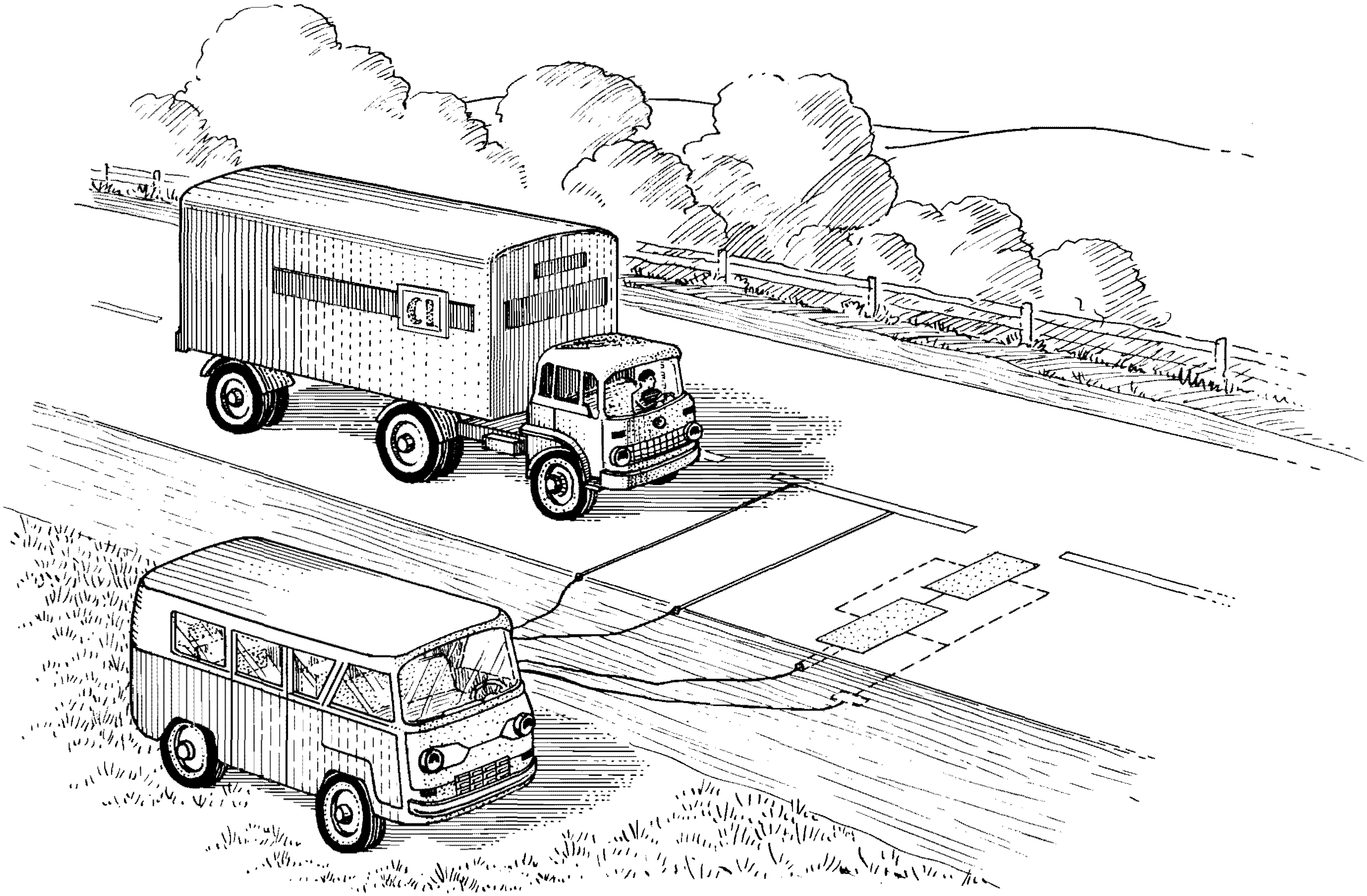


Fig 2.1. Typical installation of portable scale.

Compliance. The transducer must produce an electrical signal which faithfully represents the variation in applied force with respect to time. Since force variations up to 200 Hz are of interest, the resonant frequency of the transducer must be higher than this. The time during which a wheel of a moving vehicle is fully supported by an 18-inch wide transducer might be as short as 3×10^{-3} seconds (see Table 4.2), and wheel forces might change from zero to several thousand pounds in 5×10^{-3} seconds. The mass of the transducer must be kept small so that inertial effects will not affect the electrical signal. Deflection of the transducer under load should be similar to that of the pavement structure into which it is installed so that neither an effective bump nor depression is created. Either of these affects the dynamic behavior of the moving wheel.

Ruggedness. The transducer must withstand thousands of wheel loads that may range up to about 15,000 pounds in magnitude. It must also operate under severe environmental conditions where temperatures may go from well below freezing to as high as 140° F. Finally, the transducer elements must be sealed so that moisture and dirt will have no adverse effects on their operation.

Basic Transducer Design

In the original wheel load transducer designed and fabricated in 1963, a thin metal diaphragm welded to a rectangular steel frame forms the top of the unit (Fig 2.2). Normal forces deflect the diaphragm and are transferred to three structural steel plates that contact the bottom surface of the diaphragm. Tractive forces are transferred by the diaphragm to the rectangular frame and into the pavement and therefore do not affect the output signal. The diaphragm also serves to seal the unit against moisture and foreign matter.

The three structural plates which receive the normal component of the wheel forces are each approximately 18-inches square and are, in effect, supported at each corner. Along the edges of the center plate, a lap-type joint is used so that each plate is simply supported. This arrangement prevents uplift of any adjacent plate when only one plate is loaded. Lateral translation of the plates is prevented by spacers that act against

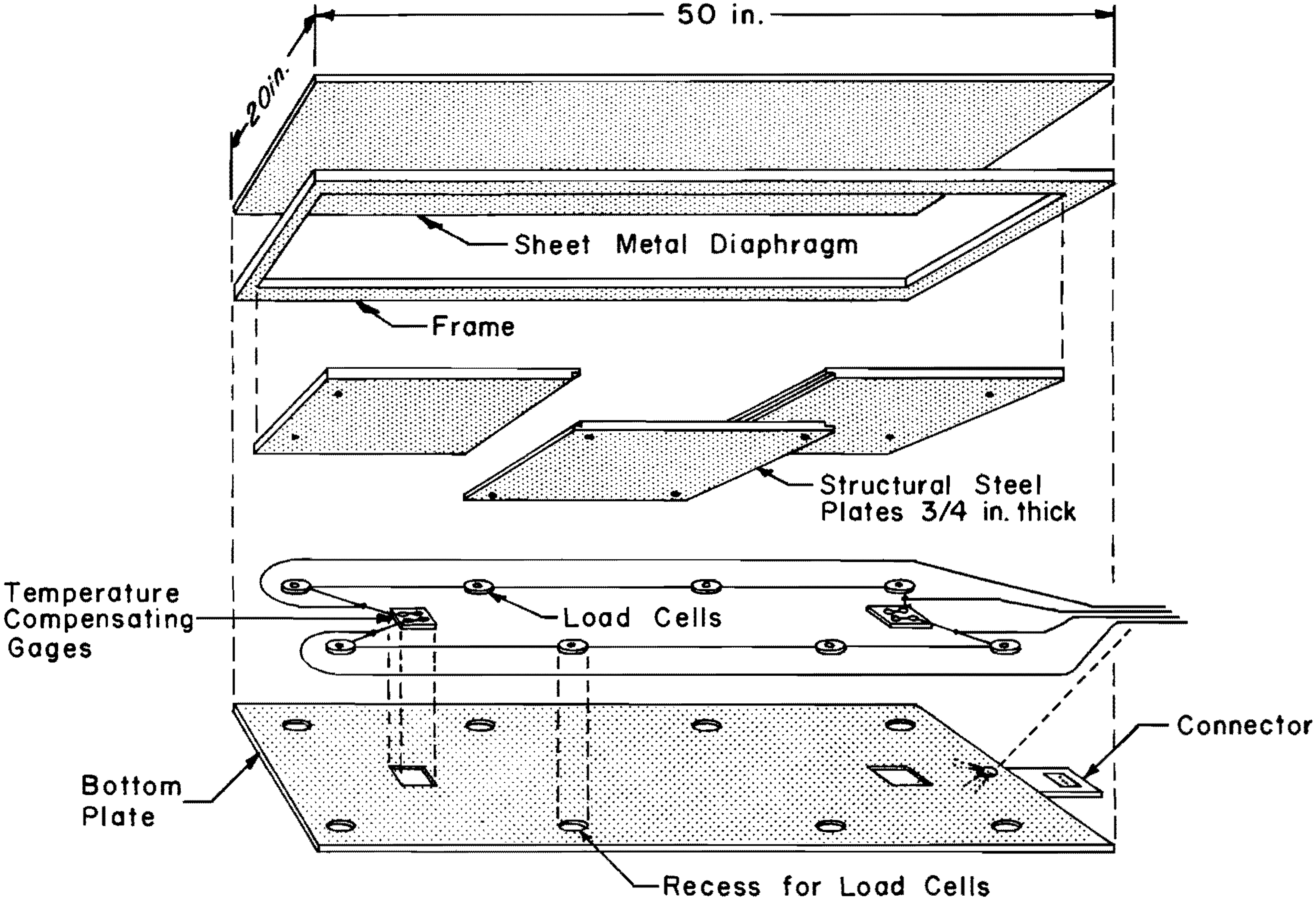


Fig 2.2. Exploded view of wheel load transducer showing arrangements of components.

the frame (see Fig 2.3). The corners of each plate are supported by special load cells. These cells are manufactured in quantities and calibrated individually under static load. The cells are then grouped selectively so that sets of eight cells, all with identical calibration factors, can be used in a single transducer. The design of these cells is unique; therefore, a detailed description will be given in the next section.

It may be noted from Fig 2.2 that all load cells used in the transducer are connected in series. Since all eight cells have the same change in electrical resistance with load, and since the change is linear with load, the total change in resistance in the series-connected set of cells is the same for a given load whether the load is carried by one cell or whether it is distributed among several cells. This arrangement of load cells and plates makes the electrical output signal independent of either load contact area or placement of the load on the transducer and eliminates the problems associated with the random nature of tire contact area and placement of the load.

The load cells measure the magnitude of the load by sensing the change in length of a strain gage cemented to the cell. But since changes in temperature will also result in a change in the length of the gage, the magnitude of indicated load will depend on the temperature conditions existing at the time the load was recorded. To eliminate these temperature effects, eight gages identical to those on the load cells are bonded to two steel plates which are exposed to the same temperature environment as the load cells but which are not loaded in any way. These gages sense temperature-induced strains of the same magnitude as those set up in the load cells. They are connected with the load-cell gages in a Wheatstone-bridge configuration so as to exactly cancel the effects of temperature on the output signal from the transducer. The details of these connections will be described in the next chapter of this report.

The bottom steel plate is 1/4-inch thick and serves to transfer load from the load cells to the pavement into which the transducer is installed. It is bolted around its periphery to the rectangular steel frame with a thin neoprene gasket to effect a waterproof seal. Recesses which accommodate the middle four load cells are provided in the plate and result in small protrusions from the bottom surface, but these are only about 1/2-inch high and

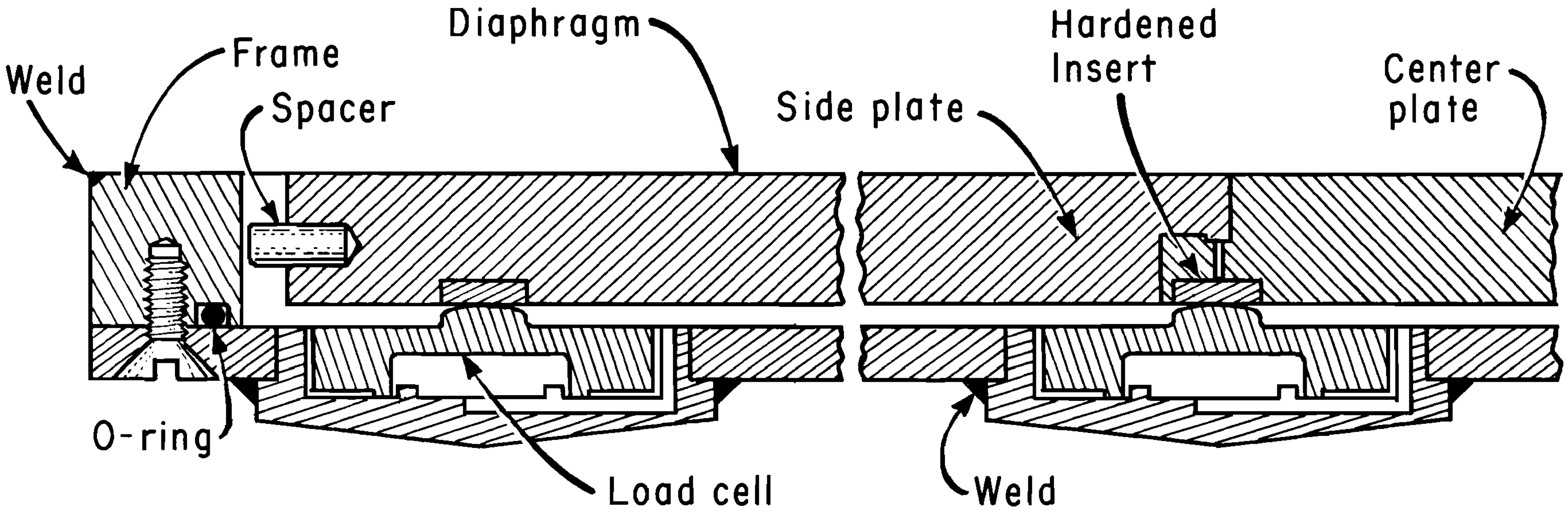


Fig 2.3. Longitudinal section of the wheel load transducer.

3 inches in diameter. Hardened steel inserts are placed to provide a bearing surface for the spherical boss on each load cell. Load cells at the outside corners are recessed into the structural steel plates and bear against hardened inserts in the bottom plate.

Strain gage circuits are notoriously sensitive to moisture. Each strain gage in the transducer is waterproofed by coating it with Di-Jell wax and a layer of room-temperature vulcanizing rubber. All lead-wire terminals are similarly treated, and external access to these lead-wire terminals is provided through gold-plated contacts of a miniature connector which is sealed inside a standard 1/4-inch pipe nipple threaded into the rectangular steel frame. Even the small amount of moisture contained in the air which is trapped inside the transducer can adversely affect the performance of the strain gages if it condenses. Air is therefore purged from the sealed transducer by introducing dry nitrogen through small ports in the frame. These ports are subsequently sealed with special plugs. It is entirely feasible to maintain a small positive pressure in the void space of the transducer and thereby prevent moisture from entering. Lead wires between the transducer and a roadside terminal point are cased in 5/16-inch copper tubing. Nitrogen under pressure can be introduced conveniently into this conduit if moisture in the transducer becomes a problem.

Load Cells

The load cells used in the original wheel load transducer and in the improved models are a special and unique design. The desirable characteristics that have been incorporated into this design are the capability of withstanding relatively large loads, quick response to these loads, and convenient size and shape. Figure 2.4 shows the dimensions of the cell. Basically the cell consists of a circular diaphragm 1.000 inch in diameter and 0.150-inch thick. This diaphragm is made integral with a stiff ring with an outside diameter of 1.980 inches and 0.400-inch height. The diaphragm is loaded through a spherical boss. Graph-mo tool steel, heat treated to Rockwell C-60 hardness, is used as the body of the cell. Top and bottom views of the cell are shown in Fig 2.5. The cell pictured on the left shows the spherical boss centered on top of the diaphragm, and the inverted cell on the right shows the plane surface of the circular

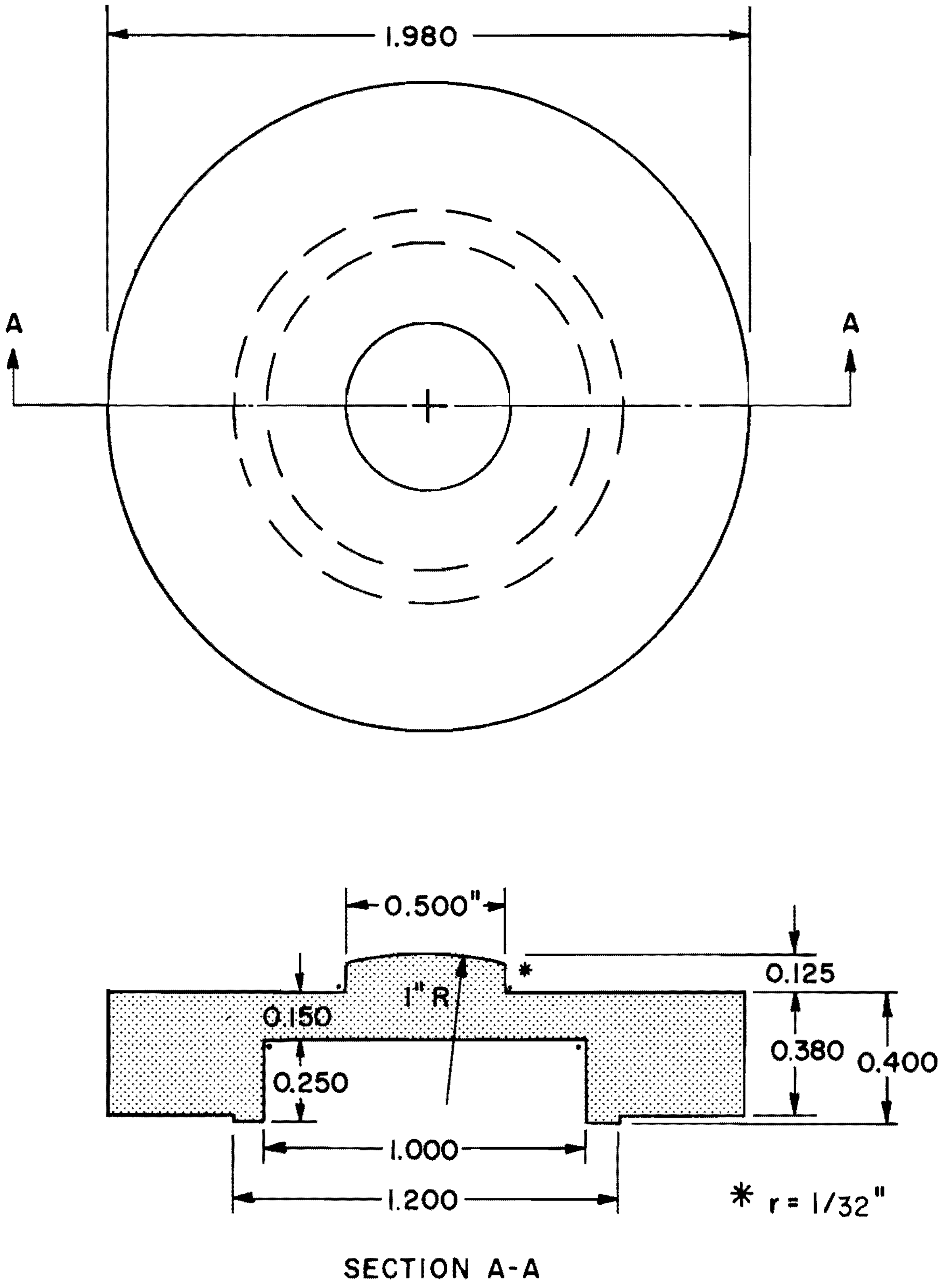


Fig 2.4. Top view and section showing dimensions of load cells.

Fig 2.5. Load cell configuration.

restrained-edge diaphragm with a 120-ohm spiral etched-foil strain gage cemented in place. This strain gage detects the tangential strain caused in the surface of the diaphragm by a load acting against the boss on the opposite side. Strain thus detected is evidenced by a change in the electrical resistance of the gage and is related linearly to the applied load.

The design of the load cell is such that it will support up to 12,000 pounds without failure. Each load cell is calibrated to 8,000 pounds after the strain gage is applied (see Figs 2.6 and 2.7). In this range of loads, the change in resistance of the gage is linear with load, and hysteresis effects are very small. The output signal from an initially balanced Wheatstone bridge in which the load cell forms the active arm (120-ohms nominal resistance of each arm) is approximately 0.00037 volts per volt of DC voltage applied to the cell for each 1,000 pounds of load on the cell. The maximum recommended applied voltage is 4 volts per load cell.

Improved Transducer Design

After more than two years of field experience with the original transducer that was fabricated for this study in 1963 and with two additional units of the same design manufactured by the Philco Corporation in 1965-66, the need for modifying manufacture, installation, and performance became evident. The primary problems that were apparent at that time were related to inadequate space for the wiring harness, location of the temperature-compensating gages, and difficulty of fabrication.

To overcome these and other problems associated with the original transducers, a cast-aluminum chassis was substituted for the bottom steel plate and the frame. Details of this modified design are shown in Figs 2.8 and 2.9. One unit was constructed in 1967 by Rainhart Company of Austin, Texas, whose product designer, Ed Hamilton, collaborated in the design changes. The large aluminum casting reduced the total weight of the transducer, made machining easier in some respects, and permitted an electrical junction box to be formed integral with the unit. Also, a more satisfactory arrangement for temperature-compensation was incorporated. The temperature-compensating elements were simply load cells placed adjacent to each active load cell but positioned so that they would never be subjected to load-induced strains.

Fig 2.6. Load cell calibration; loading control.

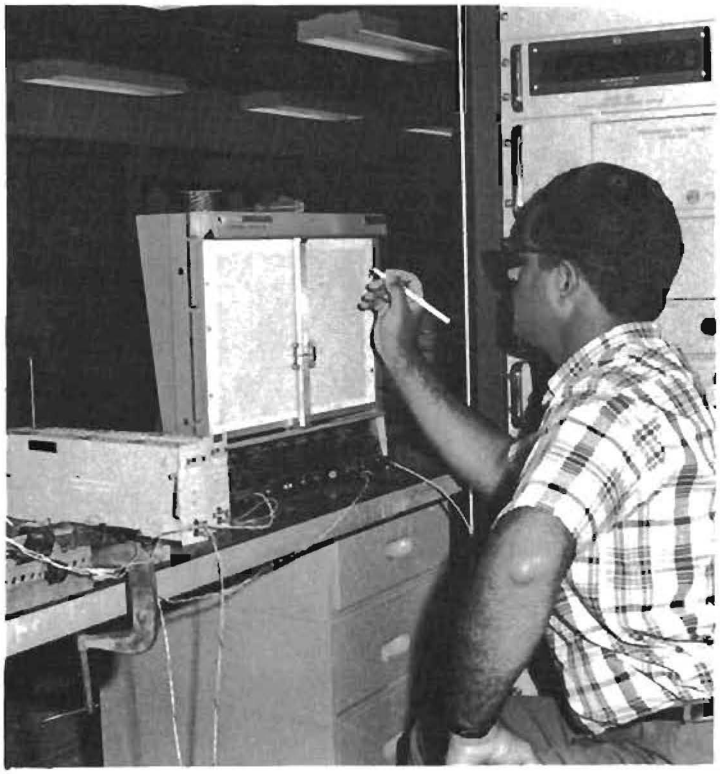


Fig 2.7. Calibration recording on x-y plotter.

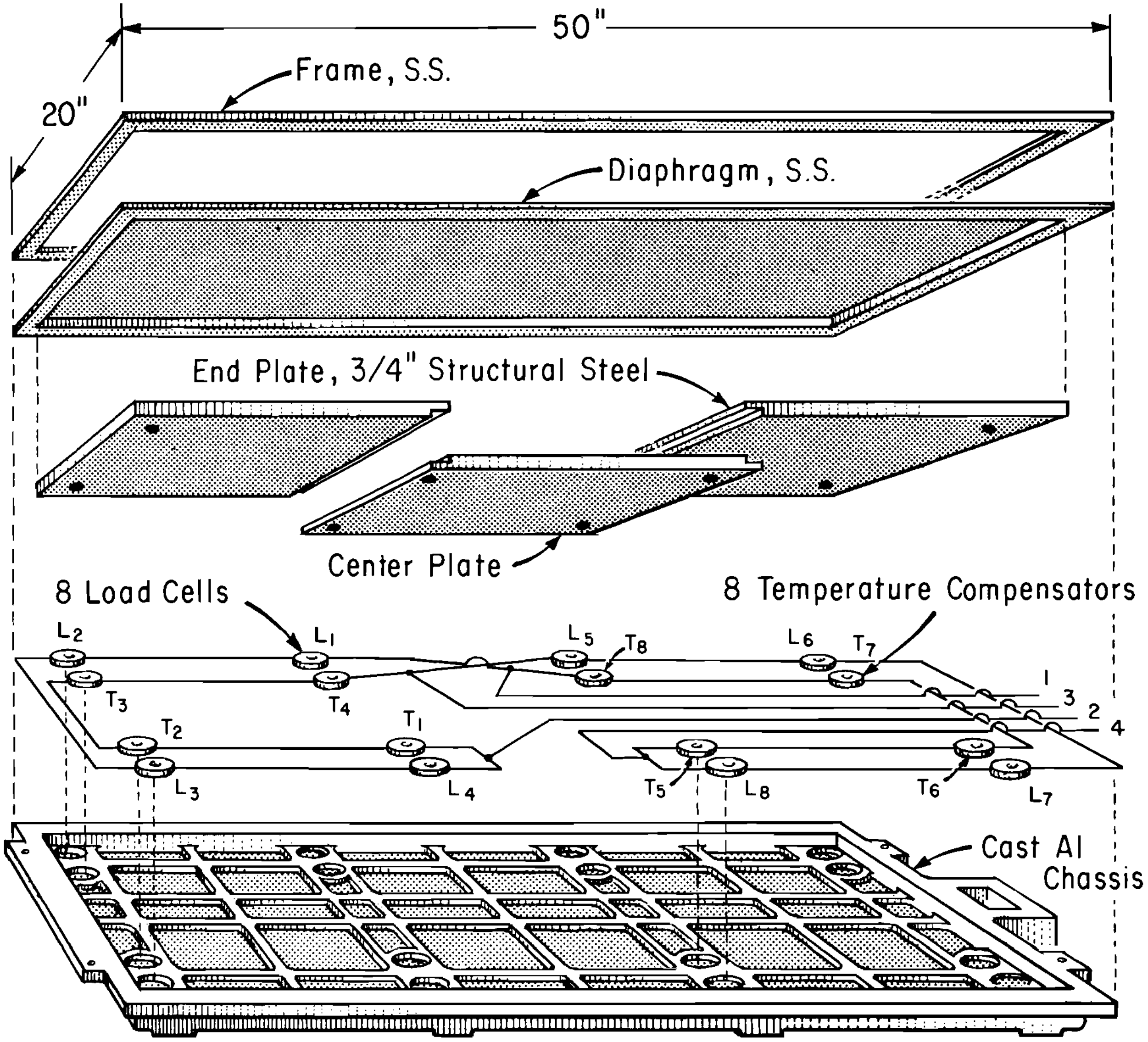


Fig 2.8. Exploded view of modified transducer with cast aluminum chassis.

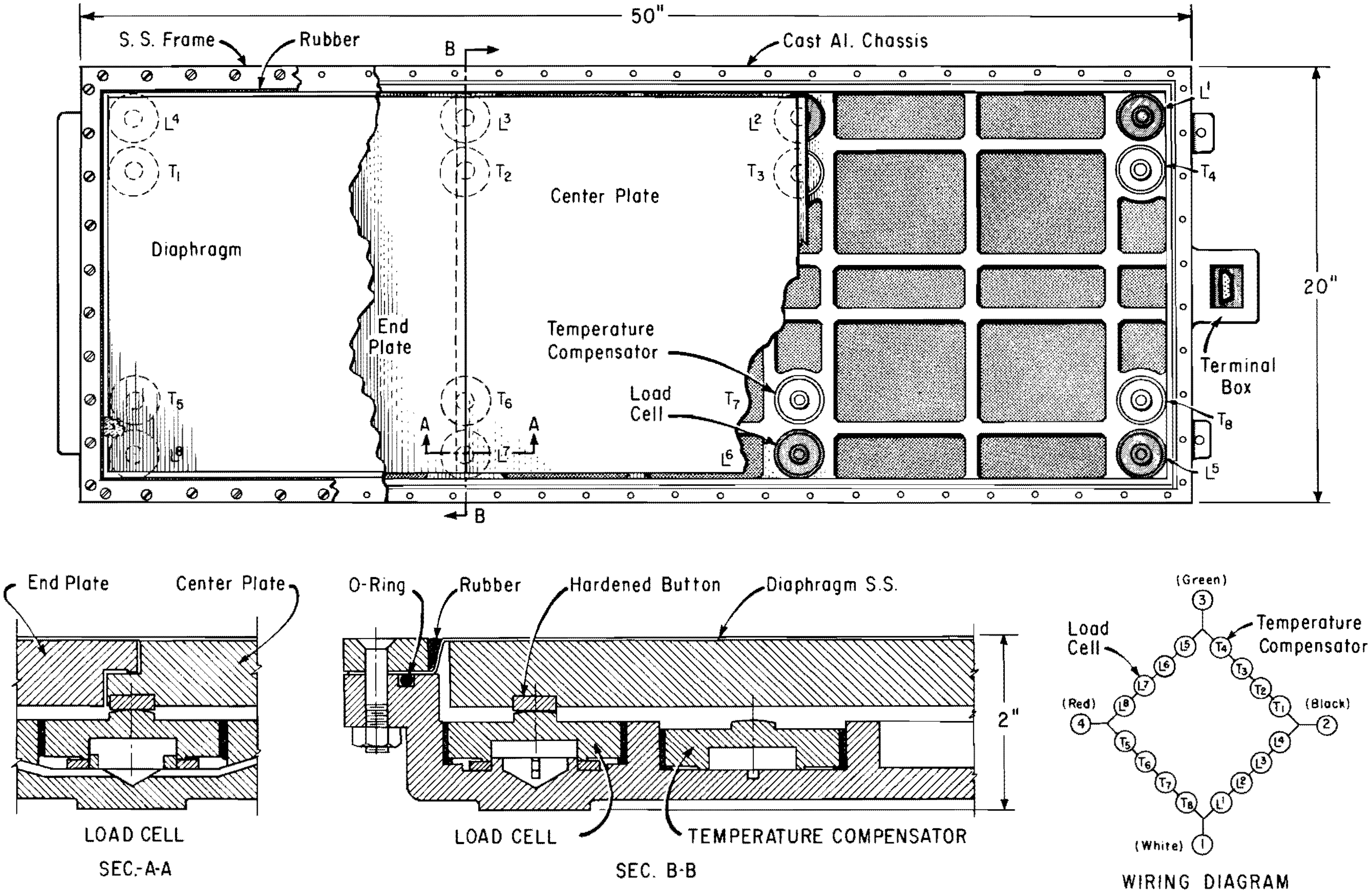


Fig 2.9. Cut-away top view and sections of transducer with cast aluminum chassis.

Even though this design was an improvement over the original, some problems still existed and others were created. Sealing such a large unit against moisture made for tedious and cumbersome machining. Field tests showed that a flat neoprene gasket around the periphery was not an adequate seal and that an O-ring in a machined groove was required. Also, these tests brought out another problem not encountered previously. In installing the transducer, the cast-aluminum chassis was distorted slightly; this caused one of the end structural plates to rock on its supporting load cells. The output signal produced by vehicles traveling faster than about 25 miles per hour indicated force variations of several hundred pounds occurring at about 150 Hz. Laboratory tests of the structural plates showed a predominant resonance at 500 Hz and a secondary at about 150 Hz. When the transducer was reinstalled in such a way that all plates were supported firmly by load cells, the output signals were clean. Evidently a means for insuring contact between all load cells and the structural plates was needed.

Wheel Load Transducer - Model 880

The most recent transducer design, designated as Model 880 by Rainhart Company, incorporates improvements which facilitate manufacture, installation, serviceability, and maintenance. The basic features of the original transducer are preserved, but several obvious modifications are included in the unit shown in Figs 2.10 and 2.11. Significant features of this unit are described below.

Frame and Bearing Pads. A rectangular aluminum frame serves as the skeleton of the transducer. During installation, eight cast-aluminum bearing pads are bolted to the bottom of the frame for positioning in a thin bed of fresh concrete grout. Strips bolted to the top of the frame and extending onto the pavement surface adjacent to the shallow sawed recess align the frame and bearing pads until the grout is set. Bolts are then removed leaving the frame and bearing pads in contact with the hardened grout. Clips covered by the grout at each end secure the frame against uplift, and the bearing pads are free to transfer load from each load cell to the pavement structure. Average unit pressures under each bearing pad are on the order of 60 to 80 psi for a 10,000 pound wheel load on the transducer.

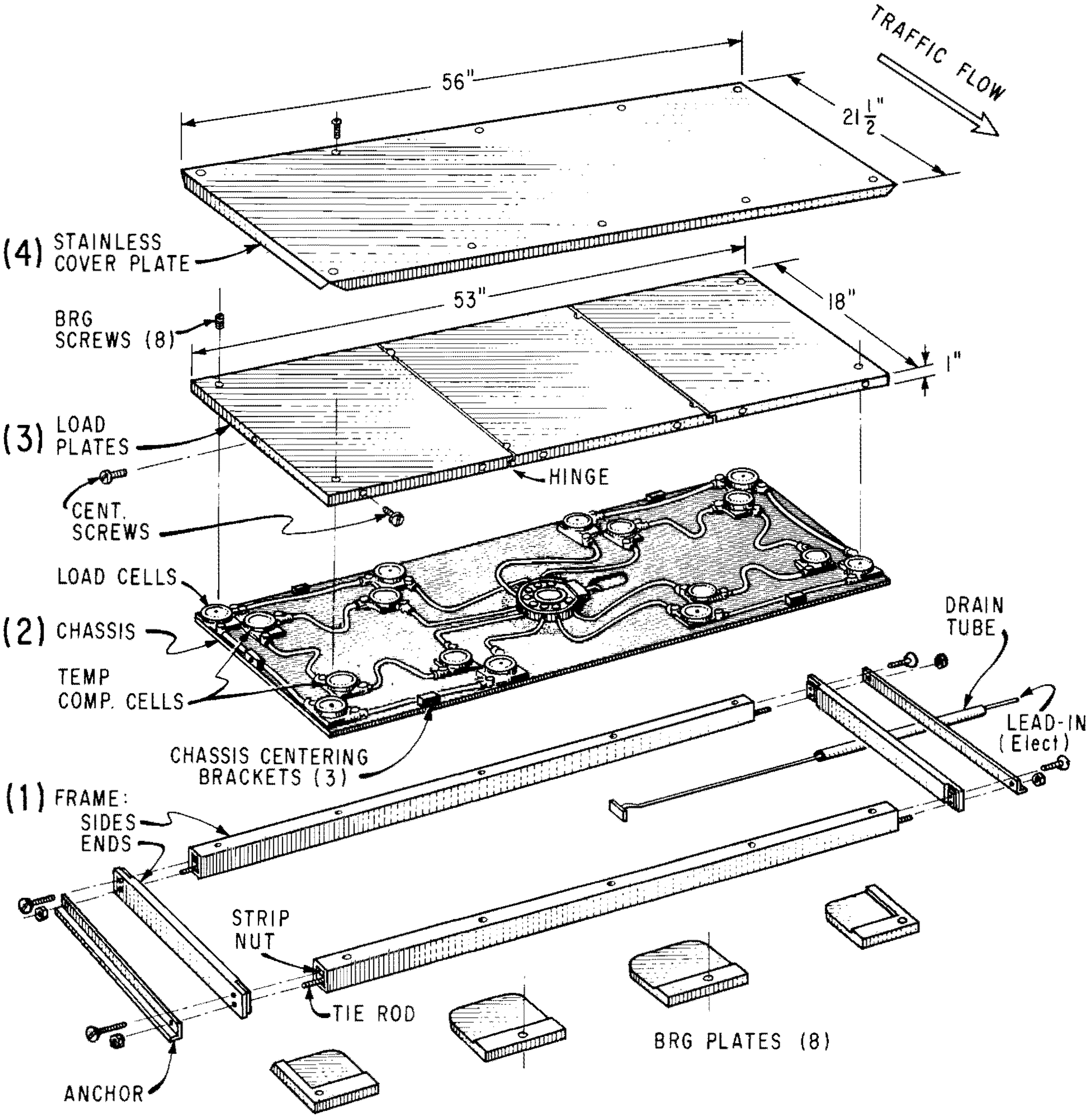


Fig 2.10. Exploded view of model 880 transducer.

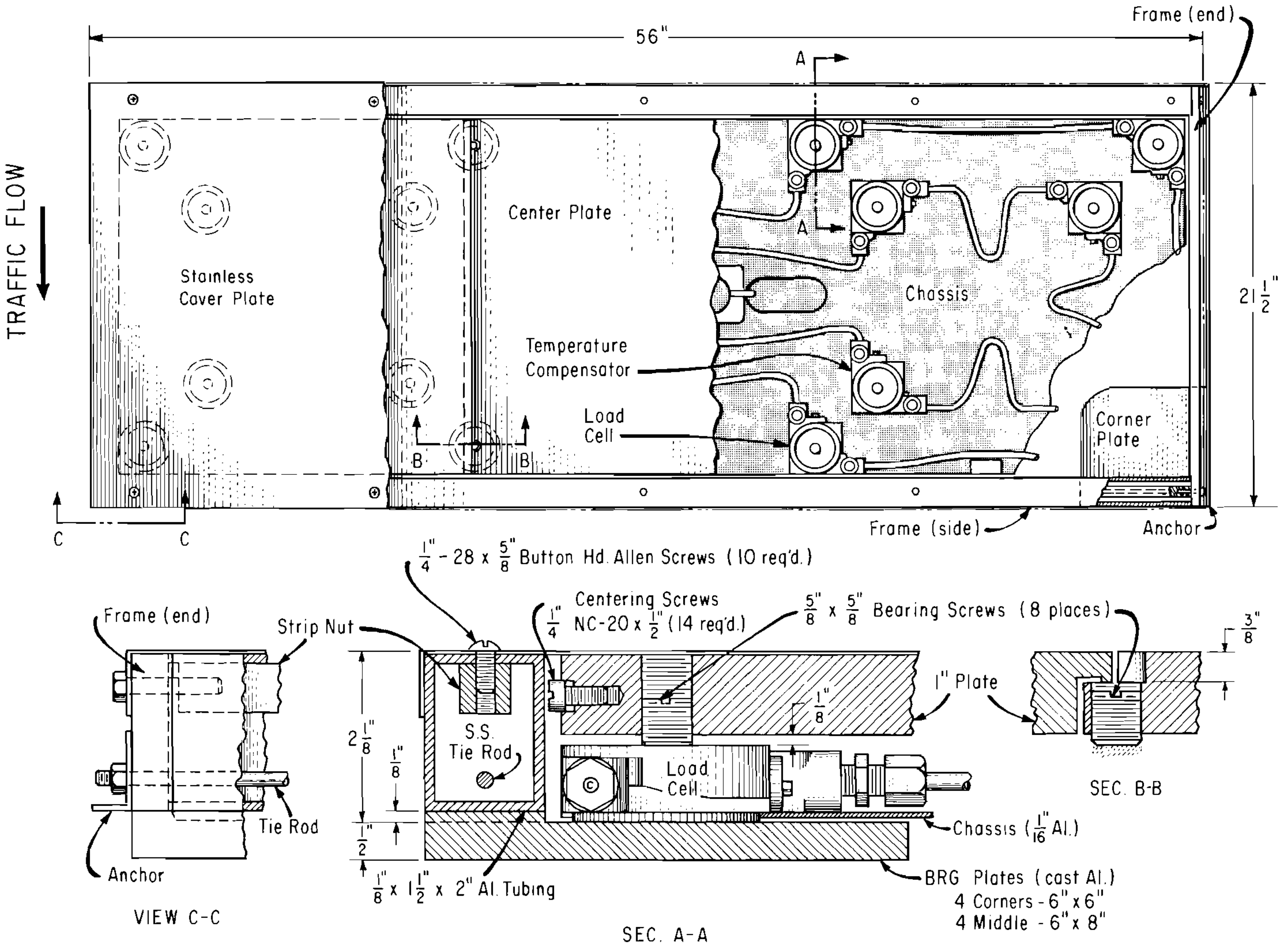


Fig 2.11. Cut-away top view and sections of model 880 transducer.

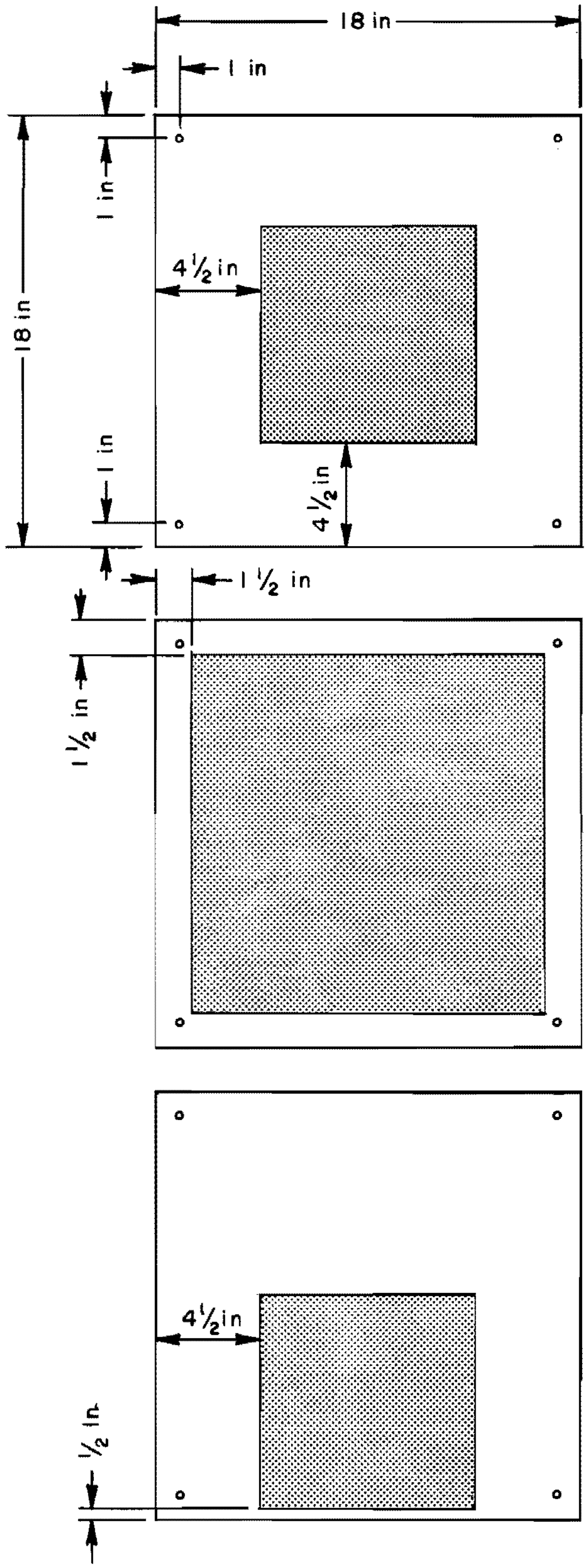
Sealing. No attempt is made to completely seal the entire transducer unit. Rather, a drain to the roadside is provided and each load cell is hermetically sealed in an aluminum casting. Electrical leads pass through the walls of the casting by special sealed connectors, and all wires are housed in copper tubing.

Load-Cell Chassis. The load cells and temperature-compensating cells, sealed in aluminum castings, are fixed to a thin aluminum sheet which positions each cell in its proper horizontal reference to the bearing pads and the frame. The load-cell chassis thus formed can be handled as a unit for installation or for maintenance.

Structural Plates. Rectangular steel plates transfer the load applied to the transducer by the tires of a vehicle to the load cells. The mass of these plates must be small, but they can be neither too stiff nor to limber. Laboratory deflection studies of a 3/4-inch plate from one of the previously described transducers showed a maximum deflection of about 0.065 inch under a 10,000-pound load applied at the center of the plate through a 9 X 9 inch wood block. This deflection was considered to be somewhat large even though no adverse effects from it had been evident in field experiments.

Computer techniques for calculating deflection contours and stress contours in plates have been developed at the Center for Highway Research under Study 3-5-63-56, "Development of Methods for Computer Simulation of Beam-Columns and Grid-Beam and Slab Systems." A computer program identified as DSLAB 3 was used to calculate the deflection and stress contours in an 18 X 18 X 1 inch steel plate for the three loading cases shown in Fig 2.12. Experimental verification of the deflection pattern using the test setup in Fig 2.13 showed the calculated deflections to be within 5 percent of those measured in the laboratory. Results of the computer calculations are summarized in Figs 2.14 through 2.19.

It will be noted that the maximum value of deflection for the 10,000-pound center load was 0.0278 inch at the center with a corresponding maximum stress of 10,200 pounds per square inch in the 1-inch thick steel plate. Stresses and deflections from the other extreme condition loading cases are well within tolerable limits; therefore, the dimensions of the structural plates in Model 880 are 18 X 18 X 1 inches. Each plate weighs 90 pounds, and overlapping joints join the plates.



Case A

10-kip Load on Center
9-in x 9-in Area

Case B

30-kip Load on Center
15-in x 15-in Area

General Dimensions
Same as Case A

Case C

10-kip Load
On 9-in x 9-in Area

General Dimensions
Same as Case A

Fig 2.12. The three loading cases studied.

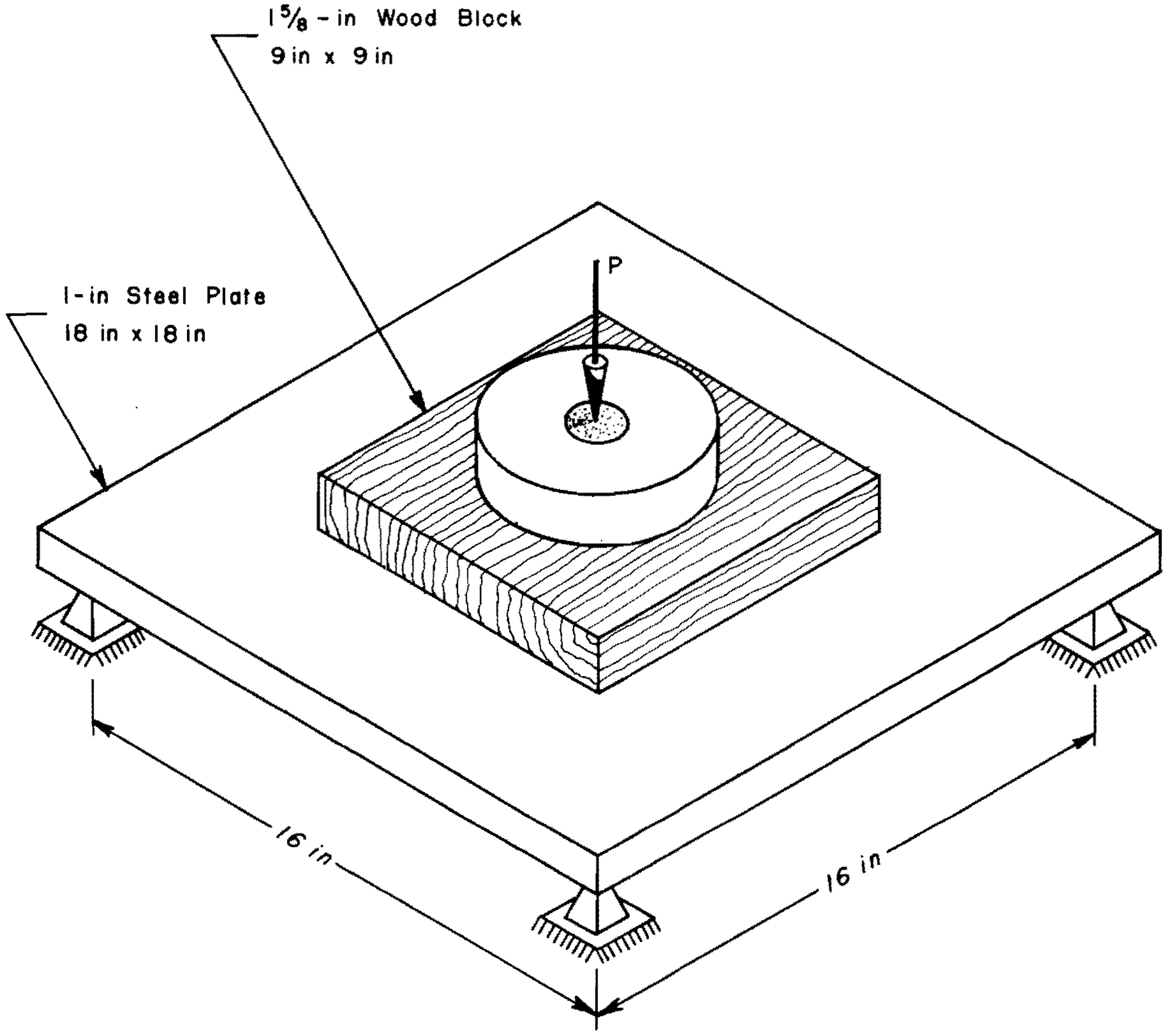


Fig 2.13. Test setup.

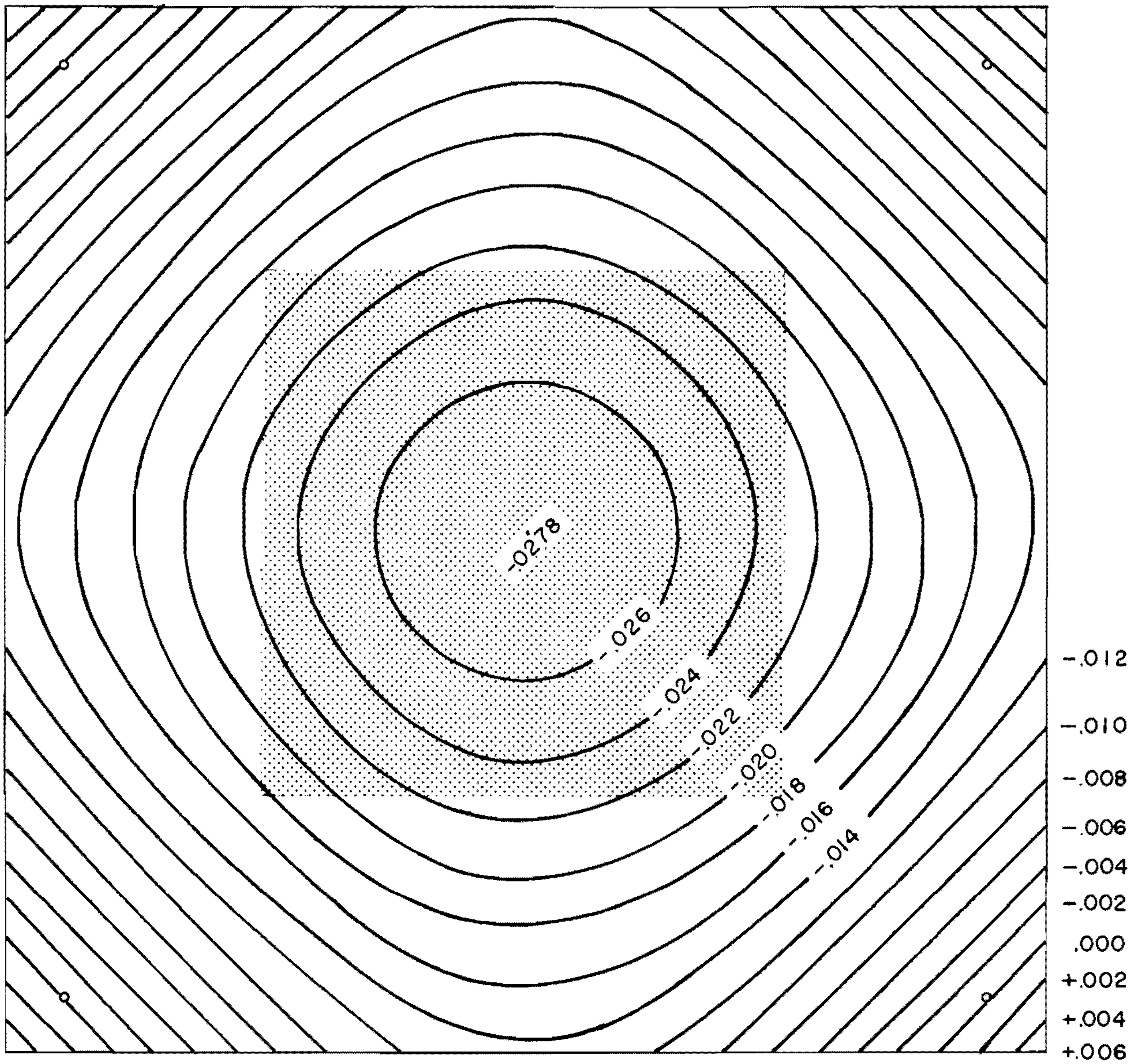


Fig 2.14. Deflection in inches for Case A.

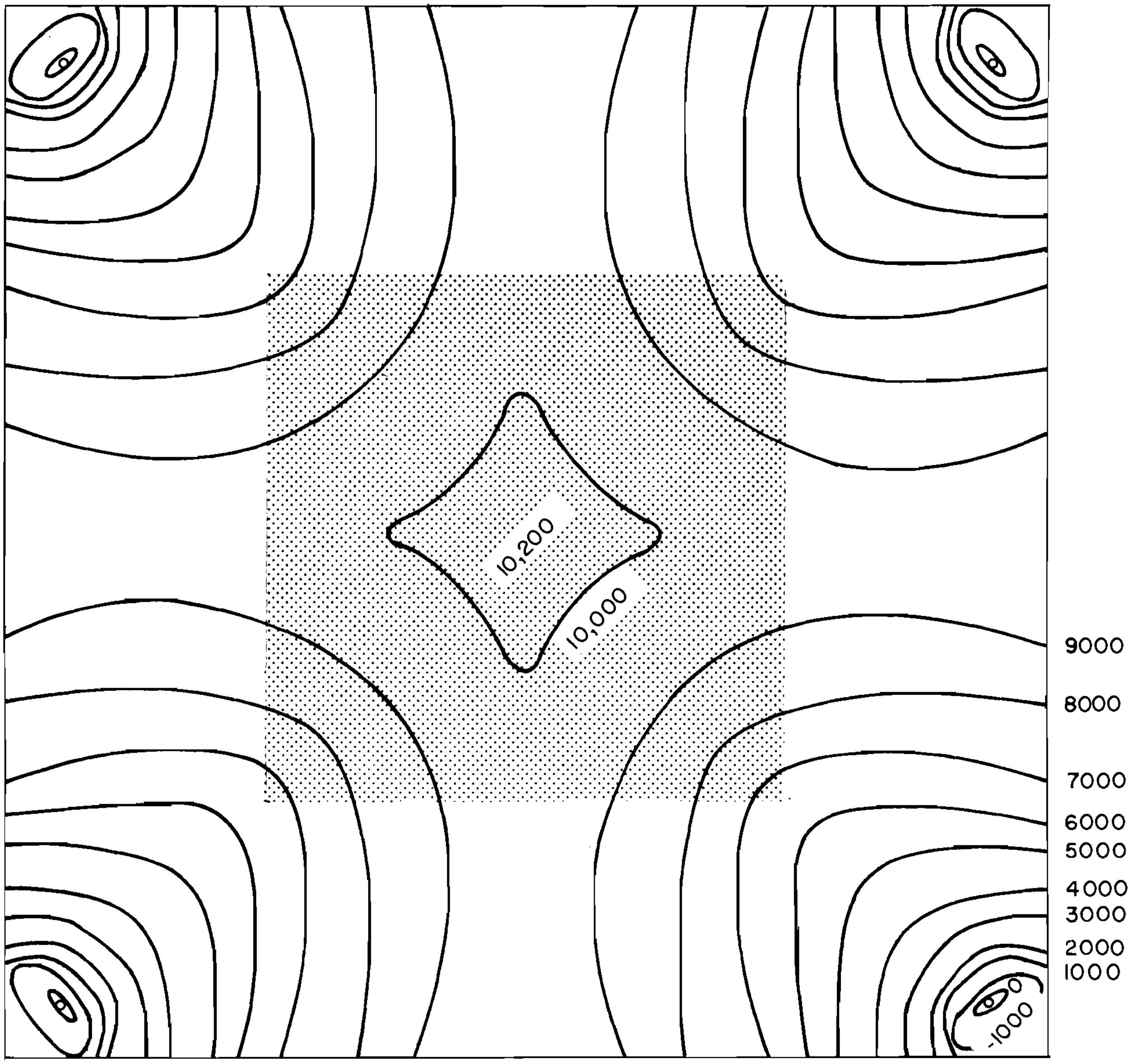


Fig 2.15. Stress in psi for Case A.

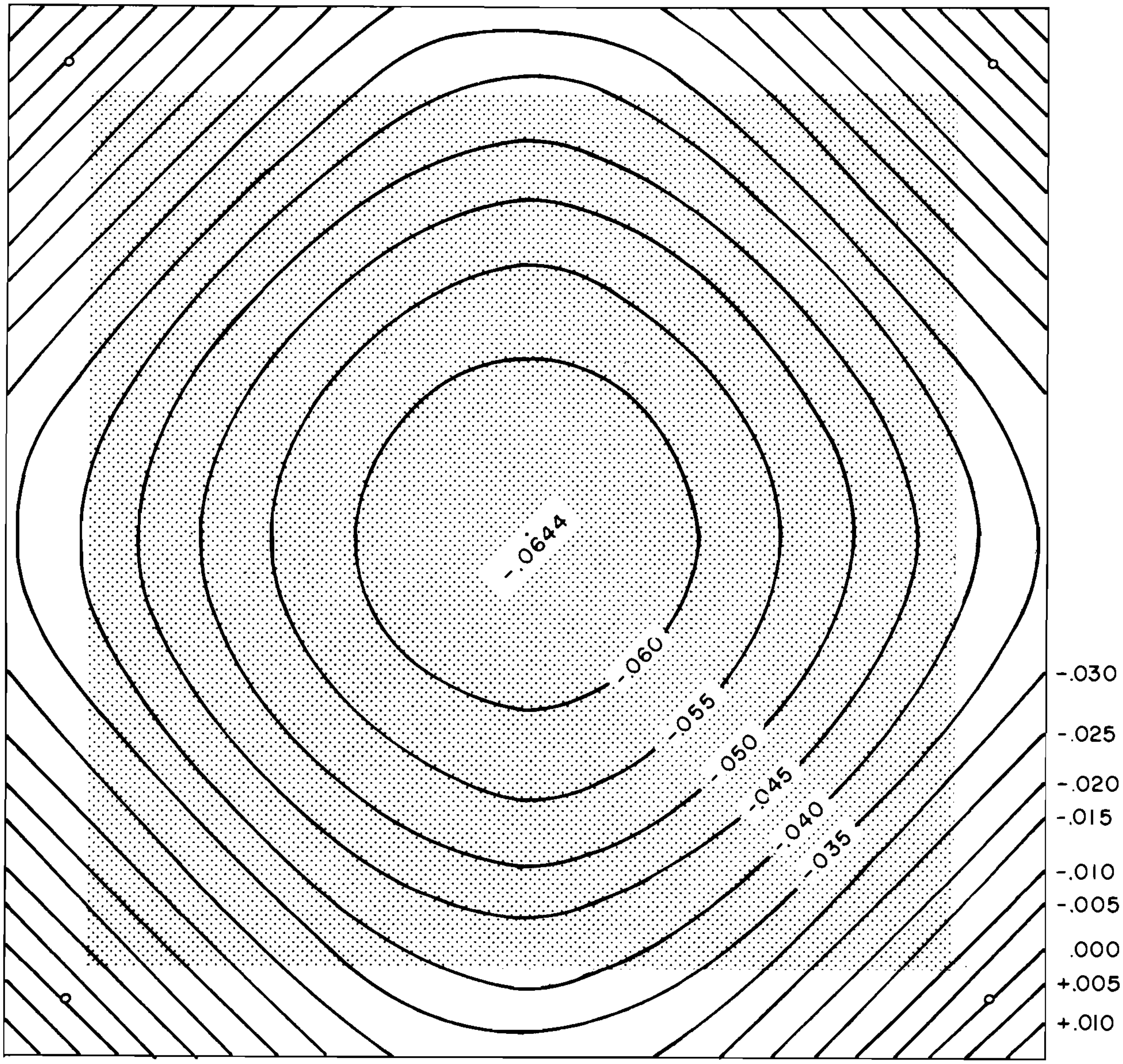


Fig 2.16. Deflection in inches for Case B.

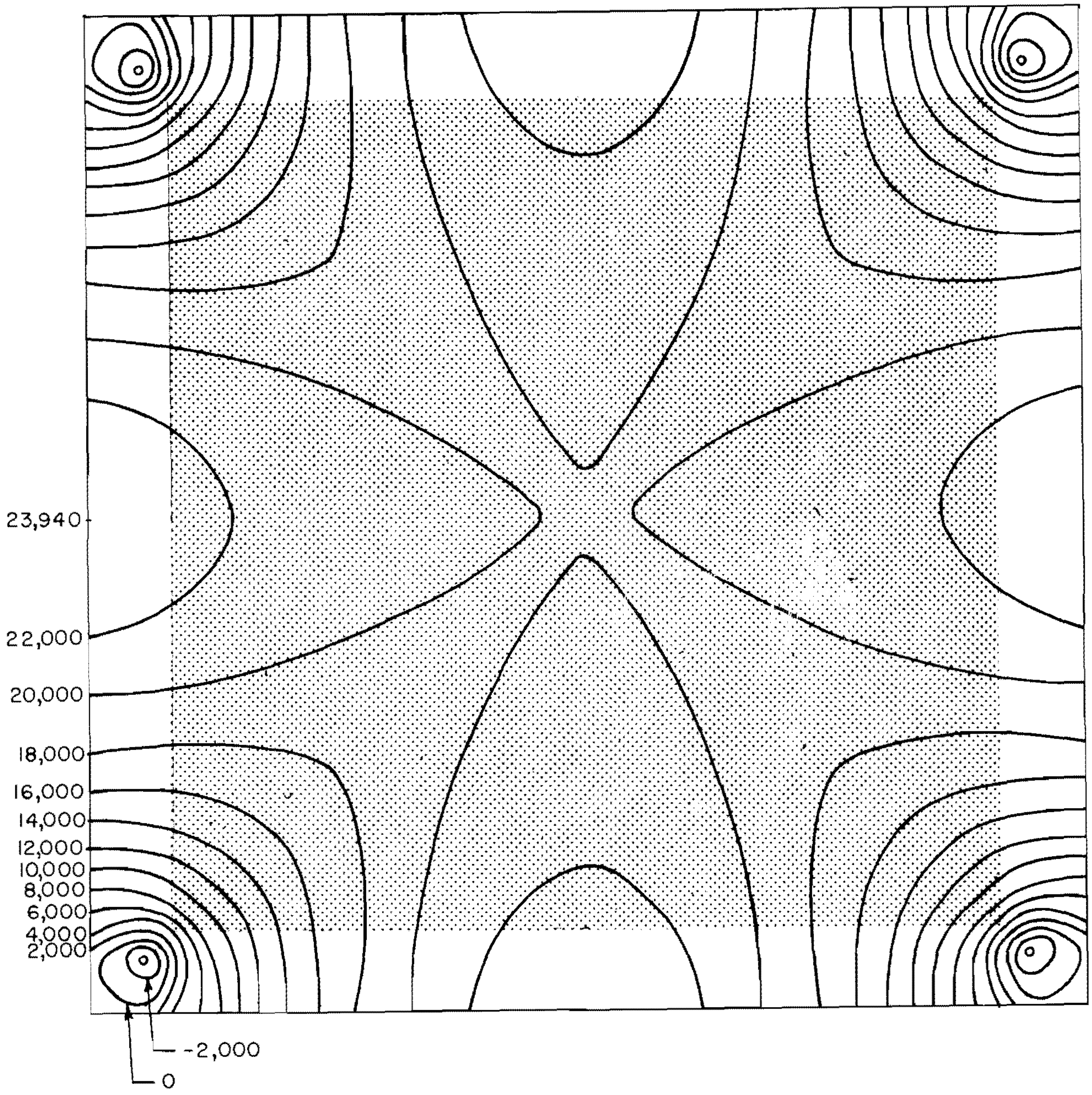


Fig 2.17. Stress in psi for Case B.

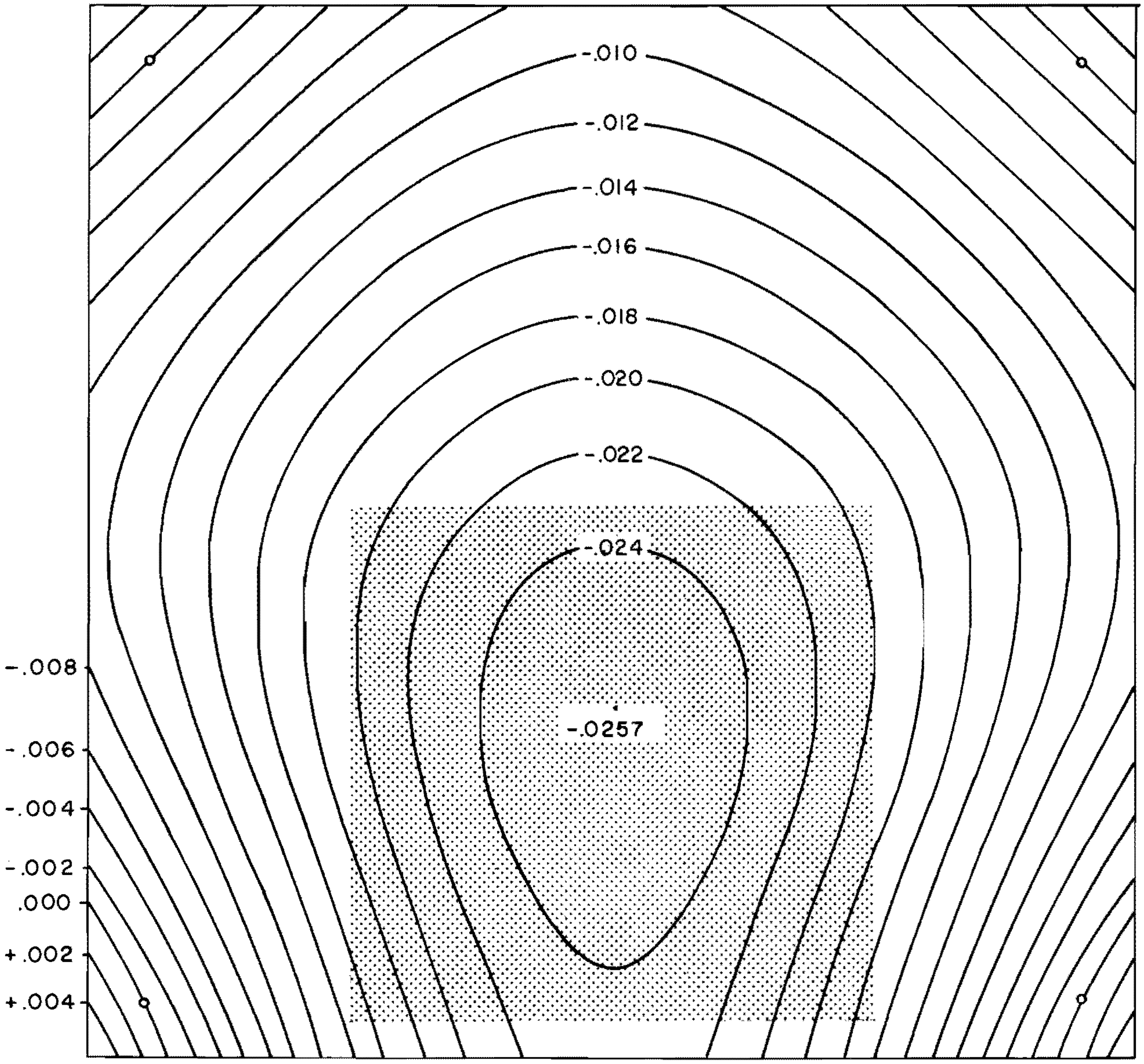


Fig 2.18. Deflection in inches for Case C.

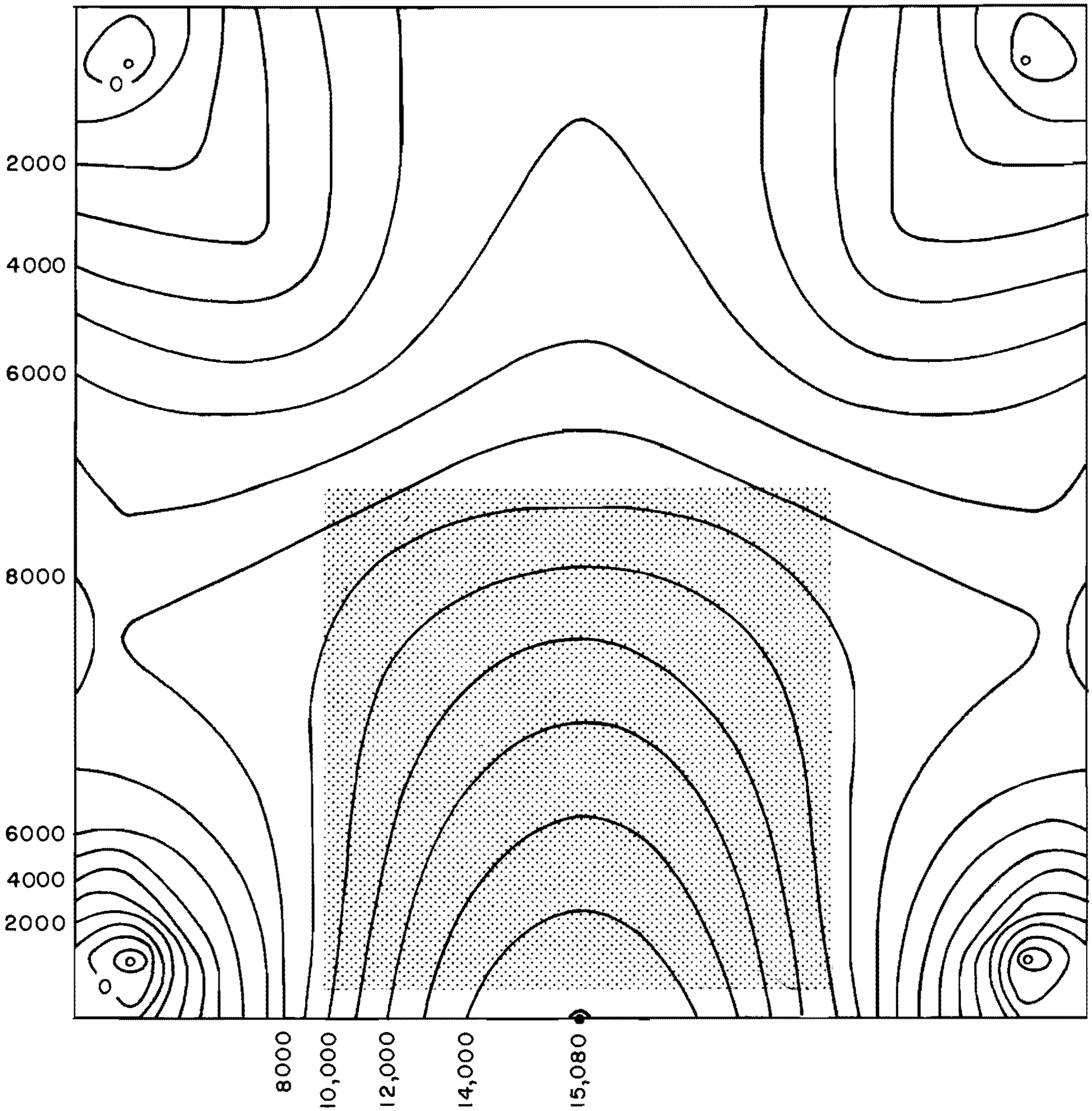


Fig 2.19. Stress in psi for Case C.

Leveling Screws. Hardened steel leveling screws are provided at each corner of the center plate and at the outer corners of the side plates. These screws bear against the spherical boss on the load cell for point-contact load transfer. They provide for vertical positioning of the structural plates with respect to the pavement surface and the load cells. Nylon inserts prevent the screws from turning due to vibration.

Top Cover. A thin stainless-steel cover is placed over the assembled transducer. It serves to transfer tractive forces to the frame and prevents water and debris from entering through the top of the unit.

Installation and Maintenance. As compared with the previous designs, installation and maintenance of Model 880 is significantly easier. The same pavement excavation and grouting techniques are employed, but in this new configuration relatively light components can be installed sequentially by one or two men. Setting tolerances are somewhat less critical since adjustments are available, and it is possible to exchange damaged components for serviceable ones in minimum time. Field experience with the Model 880 unit over the past two months has been entirely satisfactory.

CHAPTER 3. INSTRUMENTATION

General

In preceding chapters, the general requirements for an adequate in-motion weighing system are discussed, and design criteria for a wheel load transducer are presented. Satisfying the basic system requirements as outlined includes providing the electronic instrumentation for conditioning, recording, and processing the system output signals. Rapid advances have been made in electronic data processing techniques in recent years, and sophisticated instruments are commercially available. Since such a variety of equipment is available, the choice of components for any specific system is dictated largely by efficiency and cost.

Signals from the wheel load transducers vary continuously with time and are thus suited for recording directly in analog form. These signals can, of course, be sampled at suitable time intervals, and the sampled information can be recorded in digital form. Each of these forms of recording data has both advantages and disadvantages. Due consideration must be given to the fact that subsequent processing of the data is necessary in order to produce the desired information in a convenient and acceptable form.

Analog-vs-Digital Recording

After examining the suitability of these two forms of recording, it is found that the analog form has the following inherent advantages over the digital form:

(1) Highly sophisticated analog tape recording equipment adaptable for recording the output signals are available at relatively low costs.

(2) Analog records can be observed instantaneously on an oscilloscope or played back at any time. This allows the operator who is monitoring the equipment to detect possible irregularities in the

recorded signals caused by malfunction of the system. Such malfunction can thus be corrected with minimum amount of delay or interruption.

(3) Traces of analog records can be reproduced by playback through a light-beam oscillograph for examination or approximate reduction. This will be discussed later in the chapter.

The major disadvantage of the analog record, however, appears to be in the difficulty and inefficiency of machine processing of large amounts of data, because analog records must first be read and interpreted. The digital form on the other hand is in a form ready for mathematical manipulation and calculation.

It appears then that for the purposes of the weighing in-motion system, the analog form is best suited for recording the signals from the wheel load transducers. For subsequent reduction of extensive data these analog records must be converted to digital form before processing. This choice is believed to be both efficient and economical.

Analog-to-Digital Conversion

The analog-to-digital conversion is needed only in the case of processing large amounts of analog data. Numerous techniques have been developed and equipment is being built for the purpose of analog-to-digital conversion. The several available alternatives for the conversion process are each governed by system specifications, economics, and accuracy considerations as determined by the bit length. In addition, these alternatives are governed by the input and the output rates. The input rate is determined by the maximum number of channels scanned by the multiplexer in any one pass and the time allowable per pass. The output rate on the other hand depends on the output device which is in most cases a computer or a high-speed printer.

After considering the factors involved, an Analog-to-Digital converter was chosen and its operation is discussed later in this report.

Auxiliary Vehicle Detectors

The structural designer, as mentioned earlier, needs to know the proximity of the wheel loads and other classification features of the vehicles using the facility in addition to the magnitude of the wheel loads.

This additional information is of equal importance to the designer as the magnitude of the forces, since closely spaced loads produce overlapping stress patterns in the pavement structures which must be accounted for.

Auxiliary equipments are then needed for acquiring information about speeds, number of axles, axle spacings, and length of the vehicles. Numerous types of detectors can be used for this purpose and each has its own advantages and limitations. The choice of any particular detector depends on its merits and feasibility of incorporation within the overall system. Two types of vehicle detectors were chosen, the pneumatic road tube and loop detector.

Pneumatic Road Tube

This is a popular form of axle-detection devices. It consists of a rubber tube 1/2 x 5/8 inches in diameter which is easily placed transverse to the traffic lane with one end being sealed and the other end connected to a pressure actuated switch. The passage of the wheel over this tube causes a pressure pulse which acts on a diaphragm, thus closing the switch. Two of these pneumatic tubes placed across the traffic lane at a specified distance (Fig 3.1) can serve for the purpose of determining the speed of a passing vehicle. When the front axle passes over the first tube, the resulting switch closure can be used to initiate a voltage change. When the front axle passes over the second road tube it results in opening the circuit switch, thus causing the voltage to return to its initial level. This arrangement, together with a timing signal of known frequency used to determine the period during which the circuit is closed, provides all information needed for determining the speed of the vehicle, or

$$\text{Speed (ft/sec)} = \frac{d}{t}$$

where

d = distance between pneumatic road tubes (ft)

t = time the voltage is on (sec).

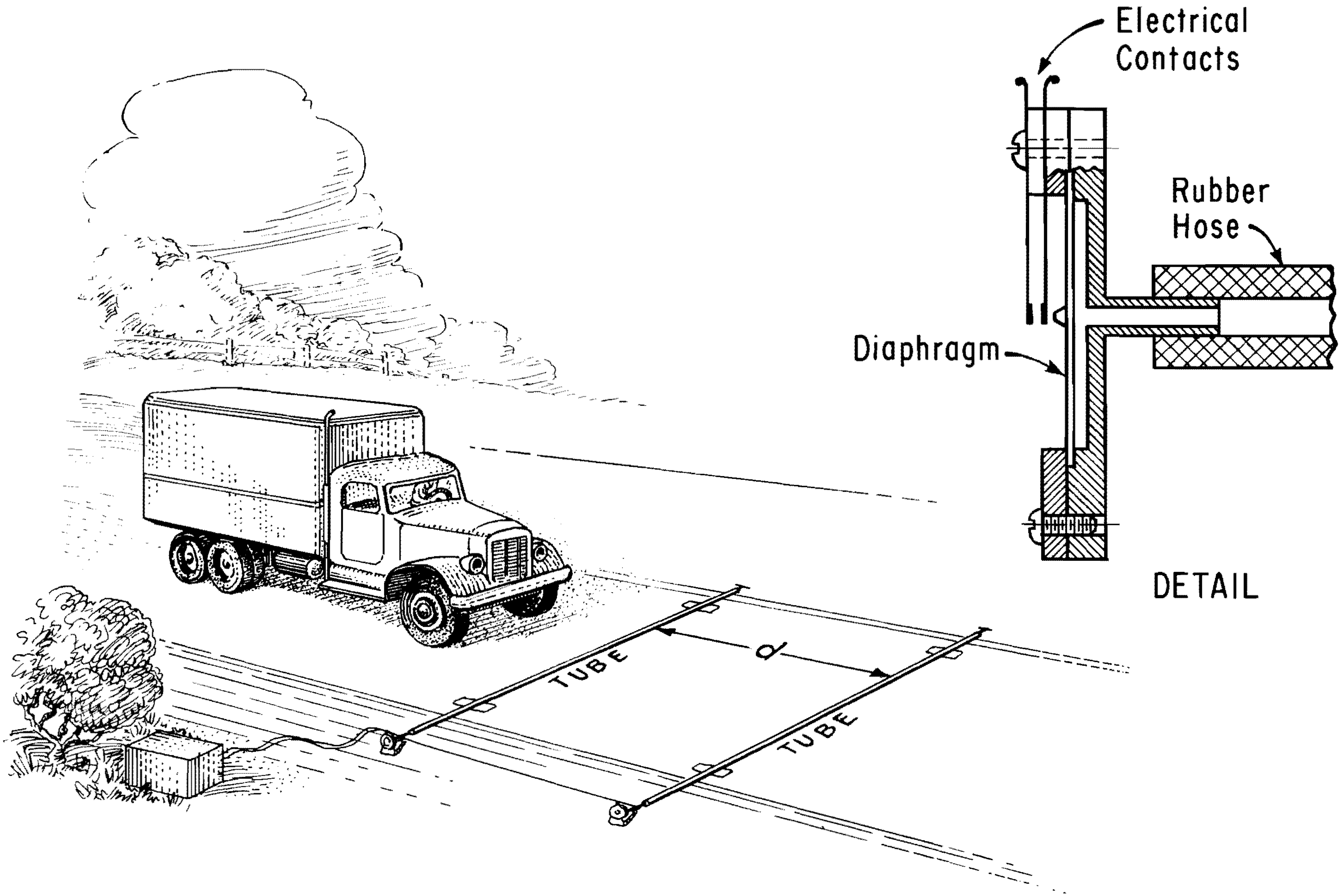


Fig 3.1. Pneumatic road tube.

Loop Detector

This type of detector consists of four or five loops of insulated conductor buried in a rectangular 1/4-inch-wide groove which is sawed in the pavement for this purpose. The presence of a vehicle is detected by the change in the electrical inductance which causes an electronic switch to be actuated in a manner depending on its intended use. For the purpose of the weighing system under consideration, when the front of the vehicle cuts into the zone of influence (Fig 3.2), it results in closing a circuit thus initiating a change in voltage which returns to its initial condition when the rear-most part of the vehicle leaves the zone of influence. Again by using the same timing signal mentioned in connection with speed calculation, the length of the vehicle can be calculated in the following manner:

$$\text{Length (ft.)} = \text{speed (ft/sec)} \times t_1 - b$$

where

t_1 = time measured by timing signal

b = length of the rectangular loop in the direction of traffic.

Texas Highway Department System

General

The Texas Highway Department "vehicle data recording system" is a portable system which can be installed in the traffic lane for automatically recording and storing on magnetic tape information related to speed, length, number of axles, axle spacing, time of day, and wheel loads of vehicles traveling at speeds up to the maximum legal limit of 70 mph.

The sensing elements of this system are described in the preceding text of this chapter. These elements are mainly, the load transducers, pneumatic rubber tubes, and inductance loop detector. The data signal information is recorded on a portable FM tape recorder which is installed, along with other control systems, in a Dodge van designated for this specific purpose (Fig 3.3). The recording can be accomplished automatically if all vehicle data are desired, or manually if recording is to be done on selective bases.

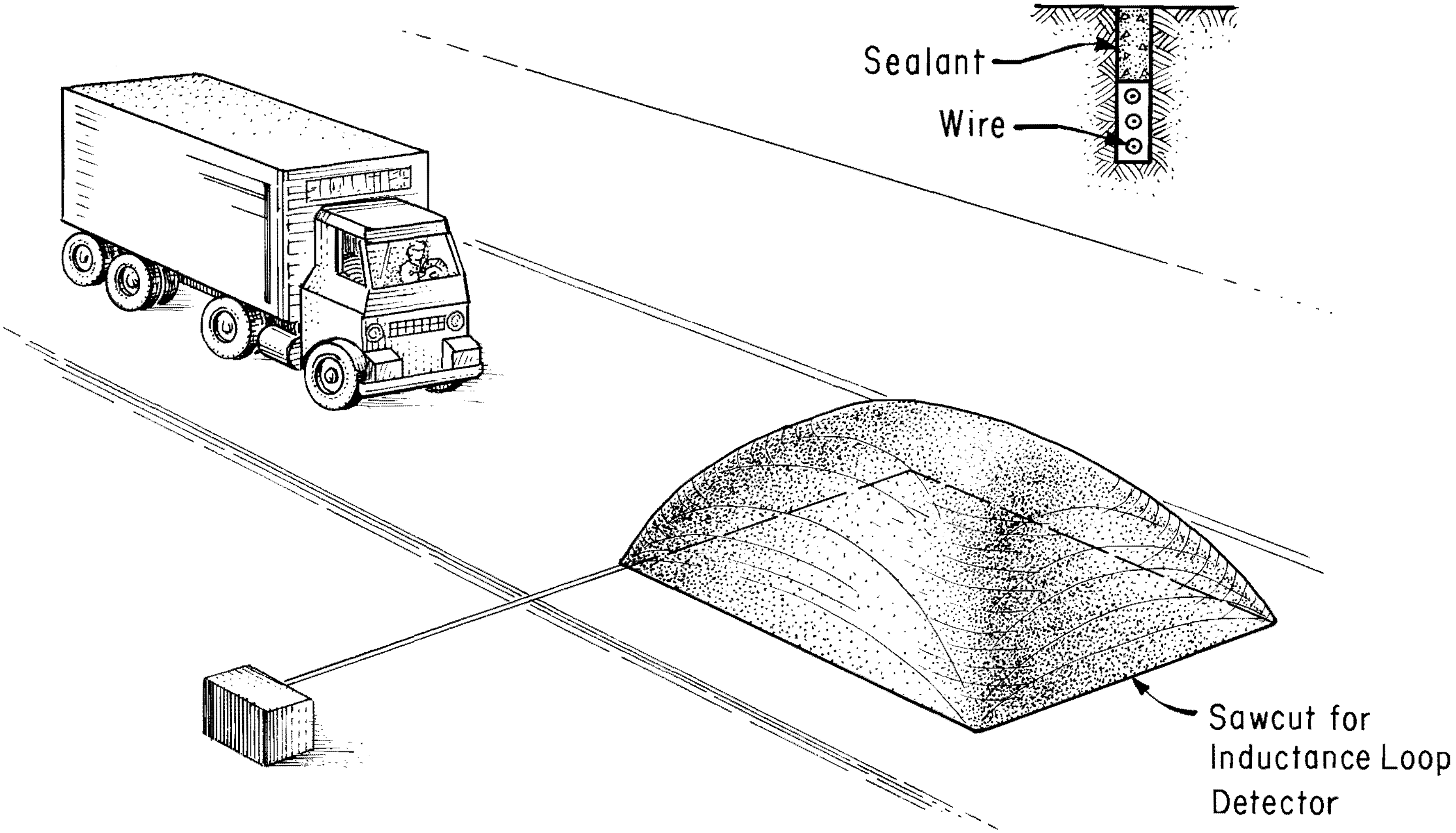


Fig 3.2. Inductance loop detector.

Fig 3.3. Recording system inside Dodge van.

Fig 3.4. Field set-up.

In the former case the tape start switch is triggered by the vehicle from the highway whereas in the latter case it is started by the operator. The data processing on the other hand is performed by a playback analog-to-digital conversion system connected to a 1604 computer which transfers the data from the FM recorder to a digital tape ready for electronic processing. The field setup of the Texas Highway Department system is shown in Fig 3.4.

System Layout

Figure 3.5 shows the field layout and dimensions of the system sensing elements. It is very important that these be installed in the exact positions shown in the figure in order to insure maximum efficiency. A step-by-step procedure for field installation is outlined in the Appendix B of this report. This procedure, if followed systematically and in a coordinated manner, can cut the time of installation operations to 4 hours in a new site and to as low as 30-45 minutes in a previously occupied site. When the transducers are removed, a premix asphalt can be used to fill the grout-lined depressions left in the pavement.

System Recording

Load applied to the surface of the transducer causes a small, but proportional, change in the electrical resistance of the strain gages on the load cells. Under dynamic loading conditions, the magnitude of this change can be measured most conveniently by determining precisely the amount of unbalance in a Wheatstone-bridge circuit. For the experimental work use was made of a half-bridge arrangement in which one arm consisted of eight load cells connected in series while the adjacent arm consisted of eight temperature-compensating gages connected in series. Precision resistors for completing and balancing the bridge were provided outside the transducer. This arrangement caused extra lead wire and temperature-compensating differences. It was decided then to use a full bridge rather than a half bridge inside each transducer because of the inherent advantages of the former over the latter, mainly in providing a more precise temperature compensation.

A full bridge is formed by connecting four load cells in series on each of two opposite arms of the bridge; and four temperature-compensating gages, also connected in series, on each of the remaining opposite arms (Fig 3.6). Each arm of the bridge has a resistance of 480 ohms (120 ohms

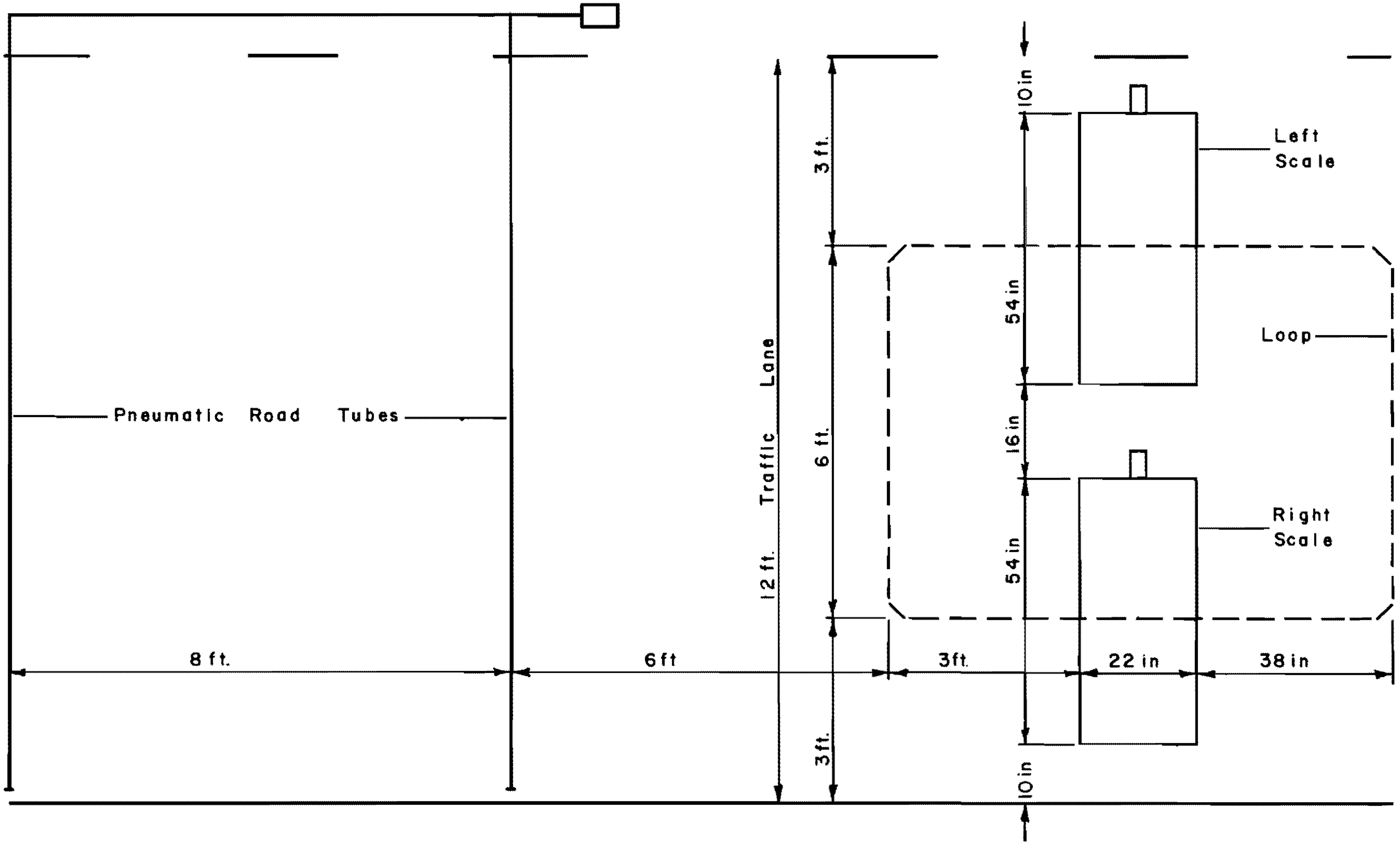


Fig 3.5. Texas Highway Department system layout.

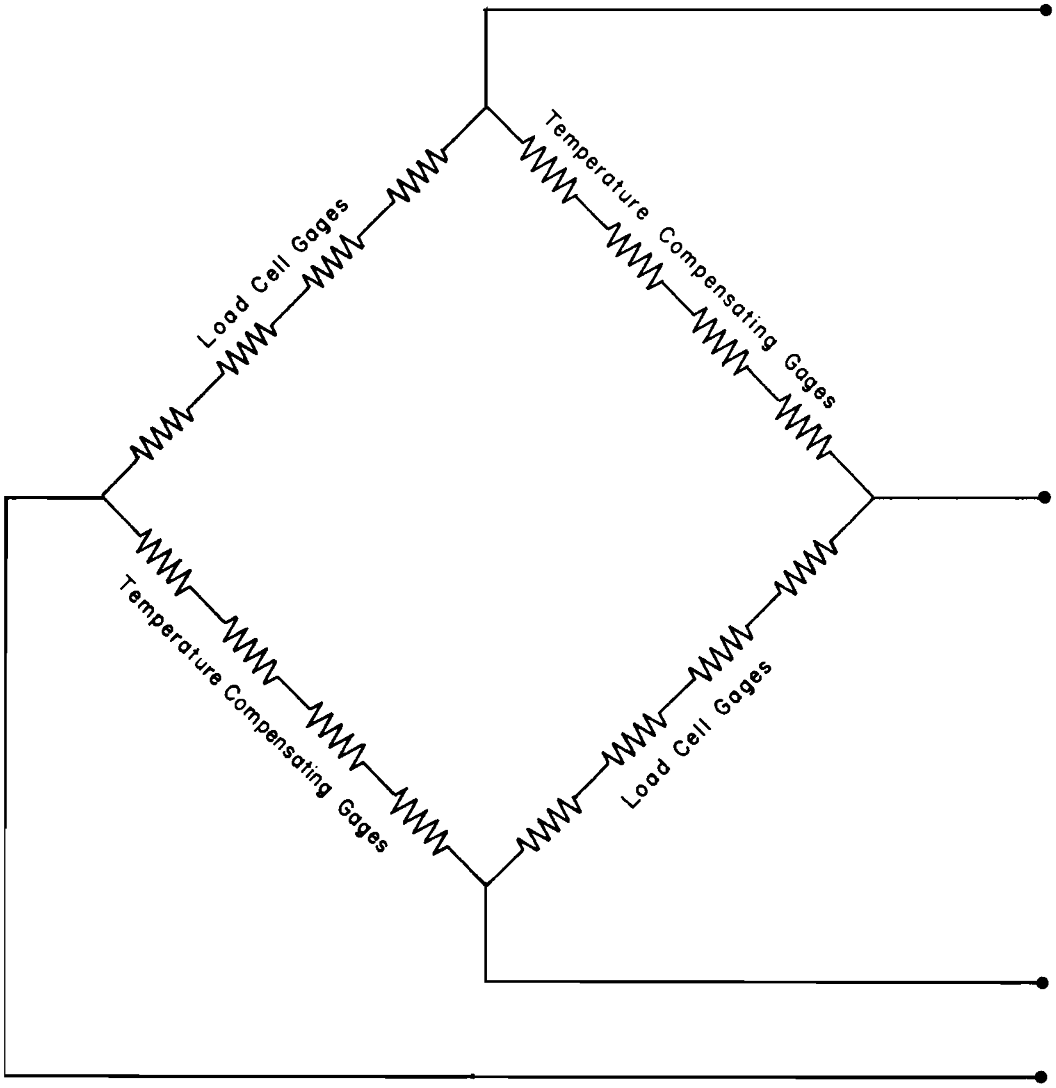


Fig 3.6. Wheatstone bridge circuit.

per cell). Lead wires for the bridge are connected through the water-tight junction box in the center of the measuring-circuit chasis.

The strain gage signals from the two transducers are conditioned by ordinary balancing methods to zero output with no load applied, and shunt calibration is provided. These signals are amplified by a factor of 1000 or 333, depending upon the desired transducer range, and then applied to the input of a Honeywell 8100, 5-channel FM magnetic tape recorder.

The 5 channels of the FM magnetic tape recorder are each used in the following manner to record a specific signal of information from the system:

Channel 1. Records the signal and shunt calibration from the right transducer.

Channel 2. Records the signal and shunt calibration from the left transducer.

Channel 3. Records the signals from a transistor logic module initiated by the pneumatic road tube and loop detector which, as mentioned earlier, provides information for calculating speed and length of the vehicle. This same logic initiates the timing signal on Channel 5 and provides shunt calibration at the end of each vehicle record.

Channel 4. Records pulses of either 0^V or $+6^V$ magnitude and of proper duration to indicate a code for the time of day the vehicle passed and may be preset from a specified time reference. These pulses are generated by an electronic clock circuit within the recording equipment rack housed in the Dodge van.

Channel 5. Records a sine-wave timing signal generated by a 2400 H_z constant-frequency oscillator providing a time base for all the other channels. This signal begins when the front axle of the vehicle closes the diaphragm-switch contact on the forward pneumatic tube and terminates approximately 0.100 second after the loop-detector switch contacts open.

Figure 3.7 shows a block diagram of the data recording process described above.

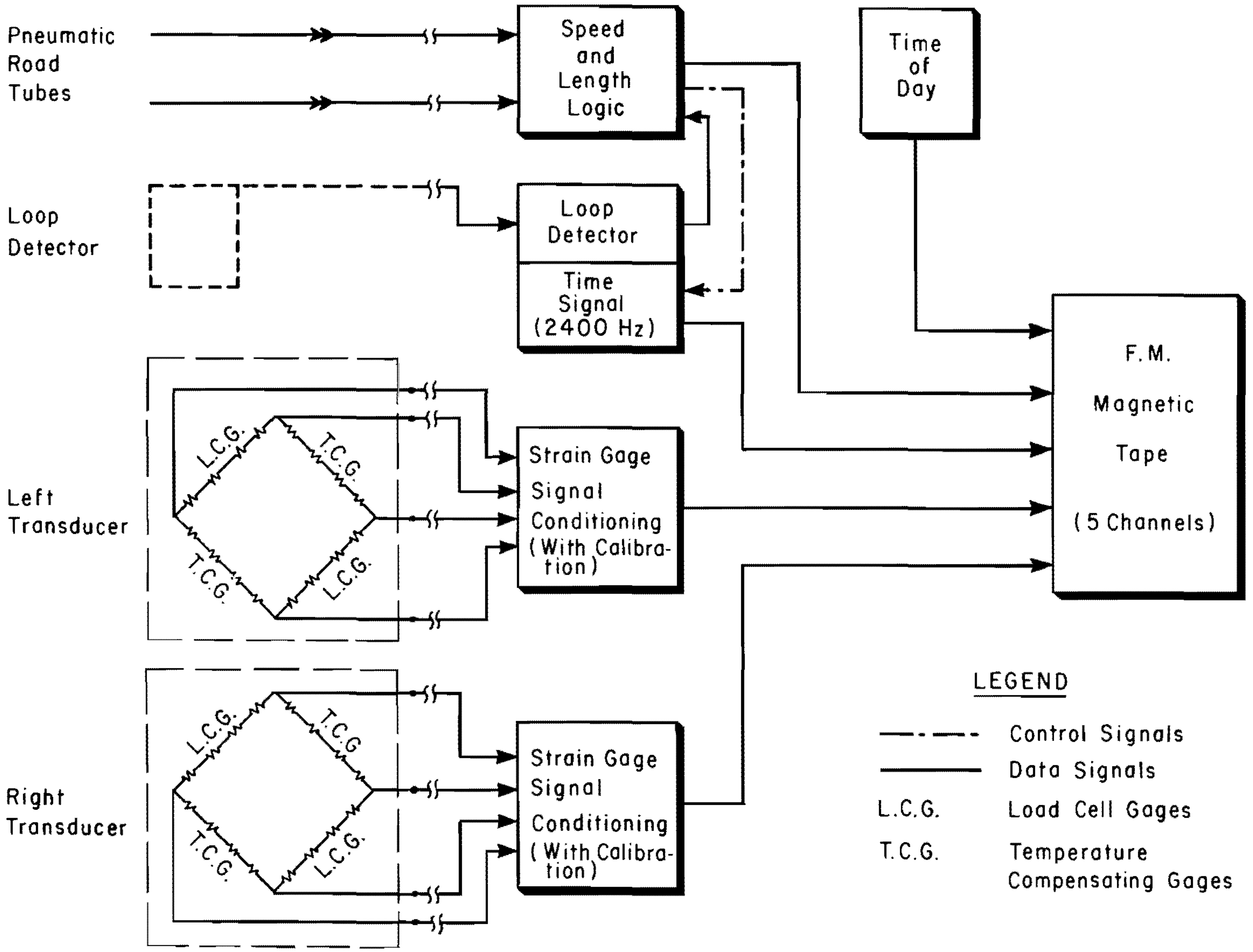


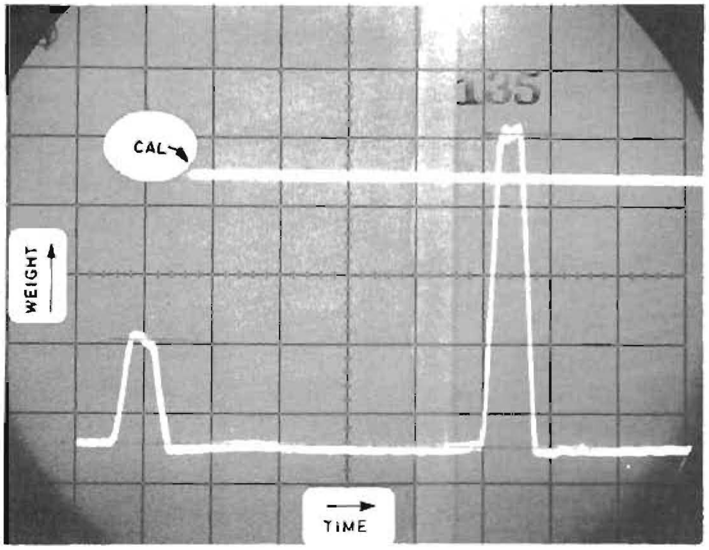
Fig 3.7. Recording logic block diagram.

System Playback

Field Analog Record. Data recorded in the field may be observed instantaneously during or after the recording process with no additional equipment by utilizing the small built-in oscilloscope in the 8100 tape recorder. This feature allows checking signal-to-noise, presence of the transducer signals, and other logic data. Due to the limited versatility of the built-in oscilloscope accurate scaling is not possible.

For more accurate scaling and time measurements, a laboratory oscilloscope such as the Tektronix type 564 is found to be of great advantage even during the field work.

During the early stages of the investigation and design of this system an oscilloscope with a high-gain direct-current amplifier was used. The light beam of the oscilloscope was caused to sweep horizontally at a precisely controlled speed to form a time reference, and the beam was deflected vertically by the voltage across the unbalanced bridge circuit of the transducer. The horizontal sweep of the beam was initiated when the front wheels of a vehicle actuated a pneumatic-tube detector placed at a given distance in advance of the transducer. Figure 3.8, a photograph of the face of the oscilloscope, shows a typical trace produced by the wheels of a two-axle vehicle moving at a speed of approximately 35 mph. The front axle of this vehicle weighed 2500 pounds and a rear axle weighed 7700 pounds. A calibration trace which represents 6600 pounds was superimposed on the photograph for reference purposes. The horizontal-sweep speed of 50 milliseconds per centimeter was selected so that the electrical signals produced by all the wheels of the vehicle would be displayed sequentially as shown. From this display vehicle speed, axle spacing, and wheel loads can be determined. Speed is determined by dividing the known distance between the pneumatic detector and the wheel load transducer by the time required for the front wheel of the vehicle to travel this distance (trace start to beginning of first load pulse). Wheel load is of course represented by the height of the trace on the oscilloscope display. This arrangement used in the experimental stages differs from the Texas Highway Department system arrangement, but signals from this system can be displayed, and calculations can be performed using the same principles.



Horizontal Sweep Speed
50 ms/cm

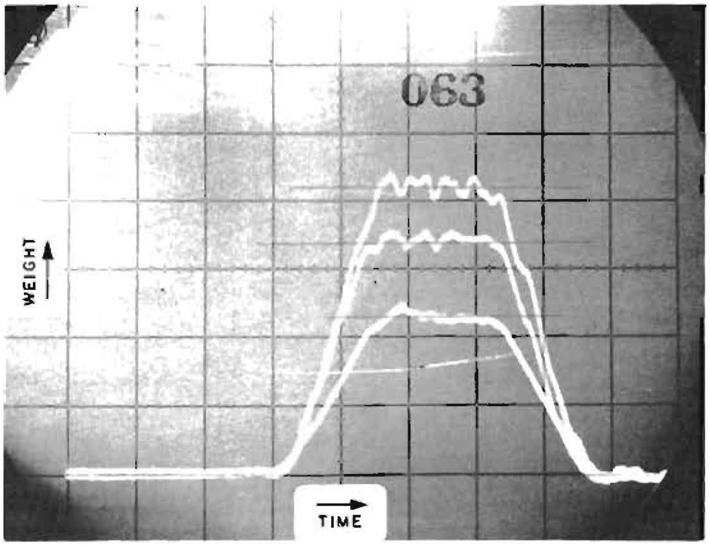
Vertical Sensitivity
0.1 - 1.0 mv/cm

Calibration Trace = 6600 lbs
Front Wheel Wt = 2500 lbs
Rear Wheel Wt = 7700 lbs
Axle Spacing = 14.1 ft
Vehicle Speed = 35 mph

I-35 Belton - Temple, Texas

31 July 1964

Figure 3.8. TYPICAL TRACE ON OSCILLOSCOPE FOR 2-AXLE VEHICLE



Horizontal Sweep Speed
10 ms/cm

Vertical Sensitivity
0.50-1.0 mv/cm

I-35 Belton - Temple, Texas

31 July 1964

Figure 3.9. OSCILLOSCOPE TRACE SHOWING SUPERIMPOSED PATTERN FOR 3-AXLE VEHICLE

Furthermore, by increasing the horizontal-sweep speed, wheel load traces can be superimposed in the manner shown for a three-axle vehicle in Fig 3.9. This form of display yields more information about the high-frequency variation in load, but axle spacing cannot be determined. It may be noted from this figure that the inertial effects of the transducer are negligible and that there is a rapid, but small, variation in the magnitude of the wheel load during the time it is on the transducer. It may also be seen that the speed of the vehicle was constant.

Manual reduction of the data is also made possible by using 5-channel light-beam oscillograph reproductions with sufficient accuracy. The 5-channel time analog record displayed in this manner allows scaling transducer readings, speed, length, number of axles, and axle spacings of each vehicle.

Figure 3.10 shows the form of a typical vehicle field analog record of the Texas Highway Department system. The duration of a complete vehicle record is directly proportional to the length and inversely proportional to the speed. The duration ranges from approximately 0.50 seconds for a passenger car moving at 70 mph to about 1.80 seconds for a "2S1-2" of length 65 feet moving at 35 mph. A glance at this analog record gives comprehensive qualitative information about the classification features of the vehicle.

The data reduction, made possible by the analog form, in this manner is ideal and convenient for limited amounts of field data. Due to this convenience and other inherent advantages in the analog form of recording, the Texas Highway Department system was designed as an analog-digital system rather than a pure digital system.

Analog-to-Digital Conversion. For situations involving large quantities of field data and more demand for precision, it is more economical to use electronic data processing. It is then desirable, as mentioned earlier in this chapter, to digitize the analog data before feeding it to computer for arithmetic processing.

Since the Texas Highway Department system is intended for handling small and large amounts of data, as the case may be, an Analog-to-Digital converter is included with the system. This Analog-to-Digital converter is so designed and specified in order to be used in conjunction with the CDC 1604 computer that the Texas Highway Department had at the time the system was designed. Figure 3.11 shows a view of the Analog-to-Digital converter

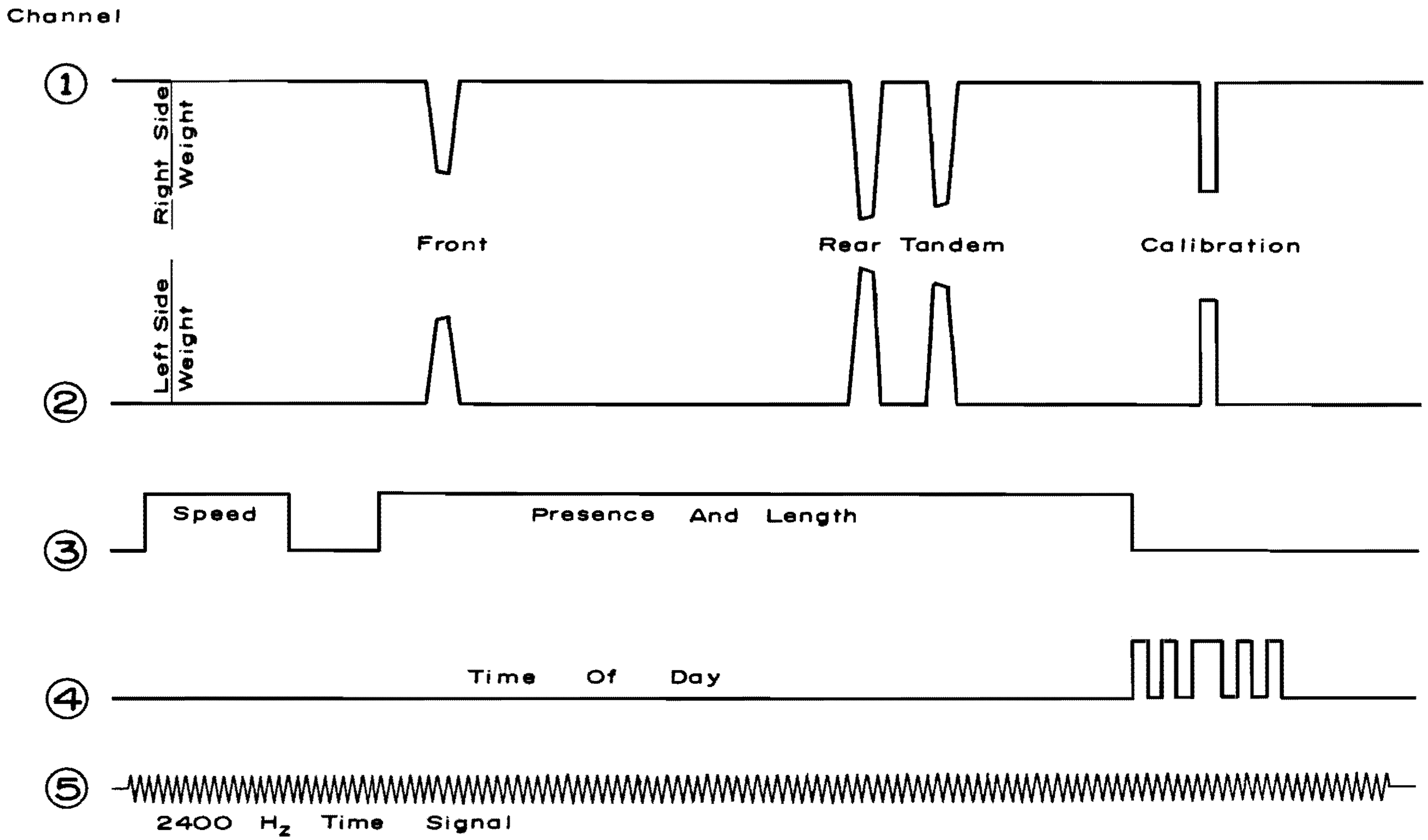


Fig 3.10. Analog record on magnetic tape.

Fig 3.11. Tape recorder and analog-to-digital converter.

set up at the Texas Highway Department Automation Division. The tape recorder appears at the top of the converter.

The block diagram of the conversion process is shown in Fig 3.12. In this process, the transducers data contained on Channels 1 and 2 of the tape recorder are fed to a 2-channel multiplexer which is triggered by the 2400 H_z timing signal on Channel 5. The multiplexer output is digitized by the Analog-to-Digital converter so that Channels 1 and 2 are sampled alternately and fed to the 1604 computer. Speed and length data from Channel 3, as well as the time of day from Channel 4 of the tape recorder, are processed by a digital logic circuit in the conversion unit and fed to the computer input at the same time. The total incoming data is transferred to a digital magnetic tape ready for arithmetic processing. Proper timing and synchronization of data flow in this process are provided by control lines to and from the computer.

Finally, it must be mentioned that aside from the FM 8100 tape recorder designed by Philco, the circuits generating the time-of-day signals, multiplexer, Analog-to-Digital converter, and other associated logic circuitry used in the recording and playback systems employ Standard Navigational Computer Corporation logic circuitry.

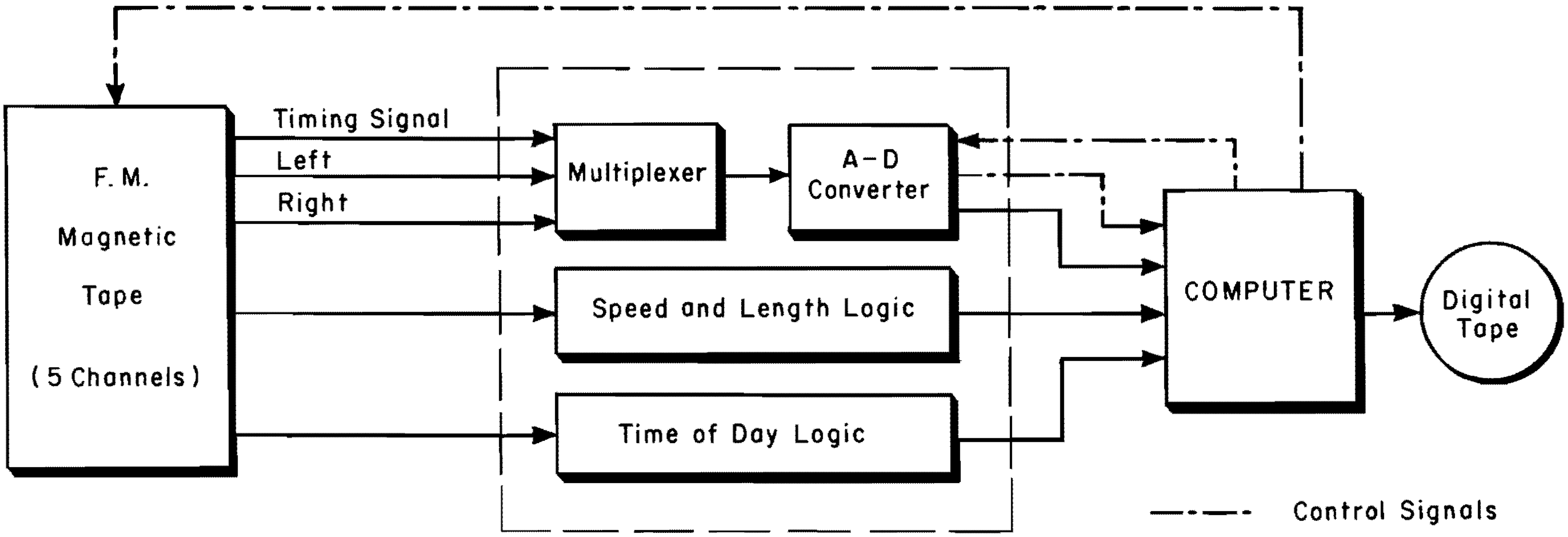


Fig 3.12. Analog-to-digital conversion block diagram.

CHAPTER 4. OPERATION AND DATA PROCESSING

System Operation

The step-by-step operation procedure for the Texas Highway Department system is outlined in detail in the manual entitled, "Instrumentation to Record and Recover Vehicle Weight Data, Instruction Manual" which was prepared by Philco Corporation (Philco 4392, July 1966), under contract No. P037319 for the Texas Highway Department. This manual includes the following:

(1) general description and specifications of THD system,
(2) operating instructions including a description and the detailed calibration procedure of the recording and playback systems,
(3) procedure for data recording,
(4) procedure for data playback,
(5) brief discussion of principles of operation as related to power circuits, automatic and manual tape control, speed and length recording circuits, scale processors, time-of-day generator and readout, and timing channel for the recording system in addition to similar principles for the playback system, and
(6) system diagrams.

Since the Philco manual rather than this report is going to be followed for operating the THD system, it would be sufficient to refer to this manual without any detailed elaboration. In order to insure efficient and sound operation of the system, the procedures outlined in the manual in connection with logic calibration, data recording, or data playback must be followed very closely.

Data Processing

Computer programs were written for handling the different phases of data processing which are mainly analog-to-digital conversion, data listing, and arithmetic processing. Table 4.1 presents a summary of these programs, and the complete listing of these programs along with appropriate flow charts are included in Appendix A of this report.

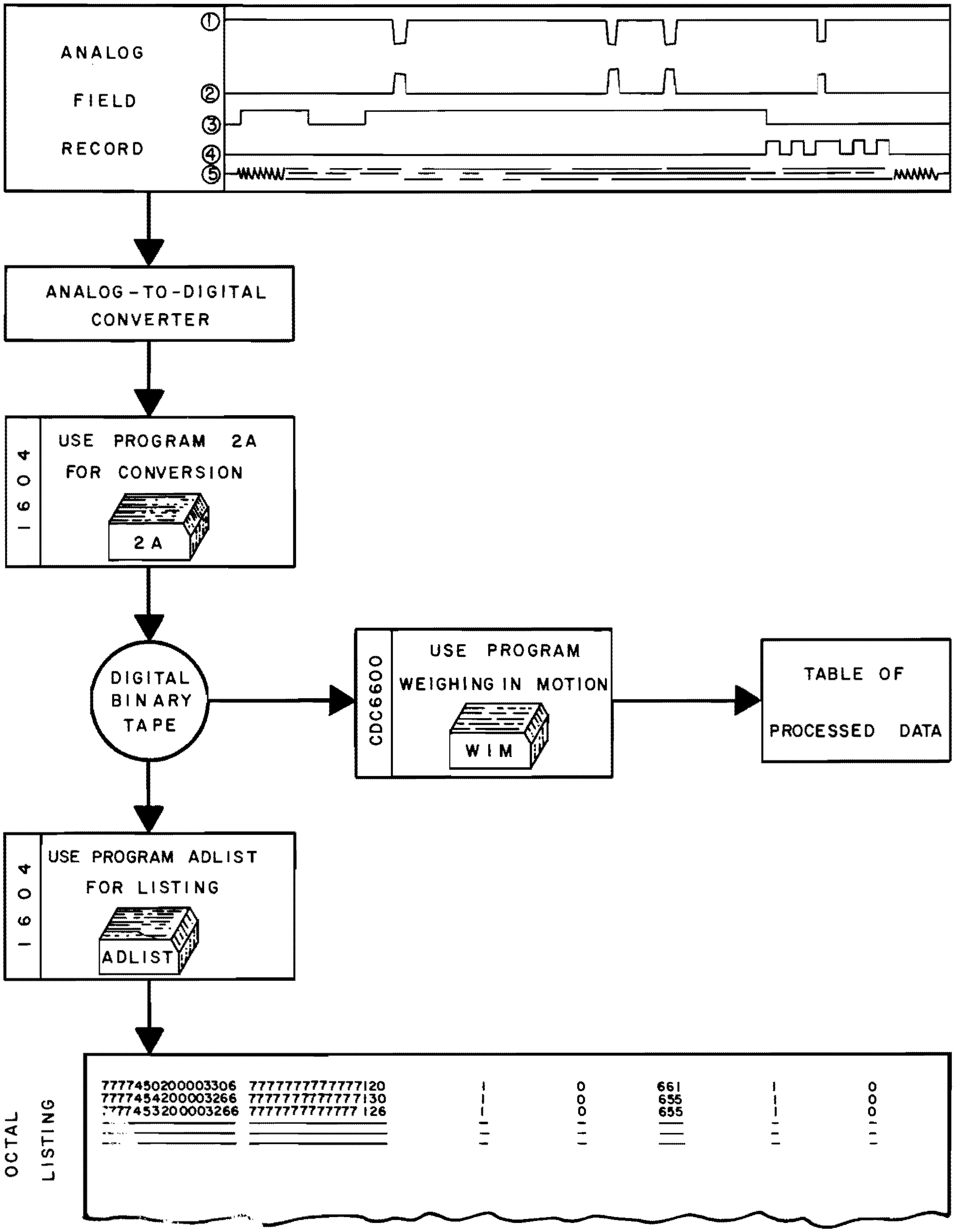
TABLE 4.1. COMPUTER (1604) PROGRAMS

Program Name	Language	Purpose
2A	codap	A/D conversion (builds binary tape)
1A	codap	A/D conversion (builds BCD tape)
1B	FORTRAN	List BCD data tape
ADLIST	FORTRAN	List binary tape
WIM	FORTRAN	Arithmetic processing of binary digital data (contains main driver and 15 subroutines)

In order to avoid any possible confusion in the data processing, due to the multiplicity of programs, the block diagram shown in Fig 4.1 may be used as a guide for the data processing operation. It must be noticed that program WIM (Weighing in Motion) employs the binary data tape as input. However, if the data are to be examined in the BCD form, shown at the bottom of Fig 4.2, the programs indicated in this figure must be followed, namely program "1A" for A/D conversion and program "1B" for listing.

Arithmetic Processing and Calculations. The mathematical processing of the data entails calculation and determination of the following vehicle information: (1) speed, (2) length, (3) wheel loads, (4) number of axles, (5) axles spacings, (6) wheel base, (7) vehicle classification, and (8) time of day.

Initially, program "WIM" was written as one routine that performs the necessary operations for determining these values, but later the program was broken into a main driver program and 15 subroutines, with each subroutine designed to handle calculation of any particular information. This is believed to be of great help in case any adjustment or a change in a subroutine is needed. The adjustment can be done without affecting the logic of the remaining subroutines.



```
7777450200003306  7777777777777120      1      0      661      1      0
7777454200003266  7777777777777130      1      0      655      1      0
7777453200003266  7777777777777 126     1      0      655      1      0
```

Fig 4.1. Processing block diagram (binary).

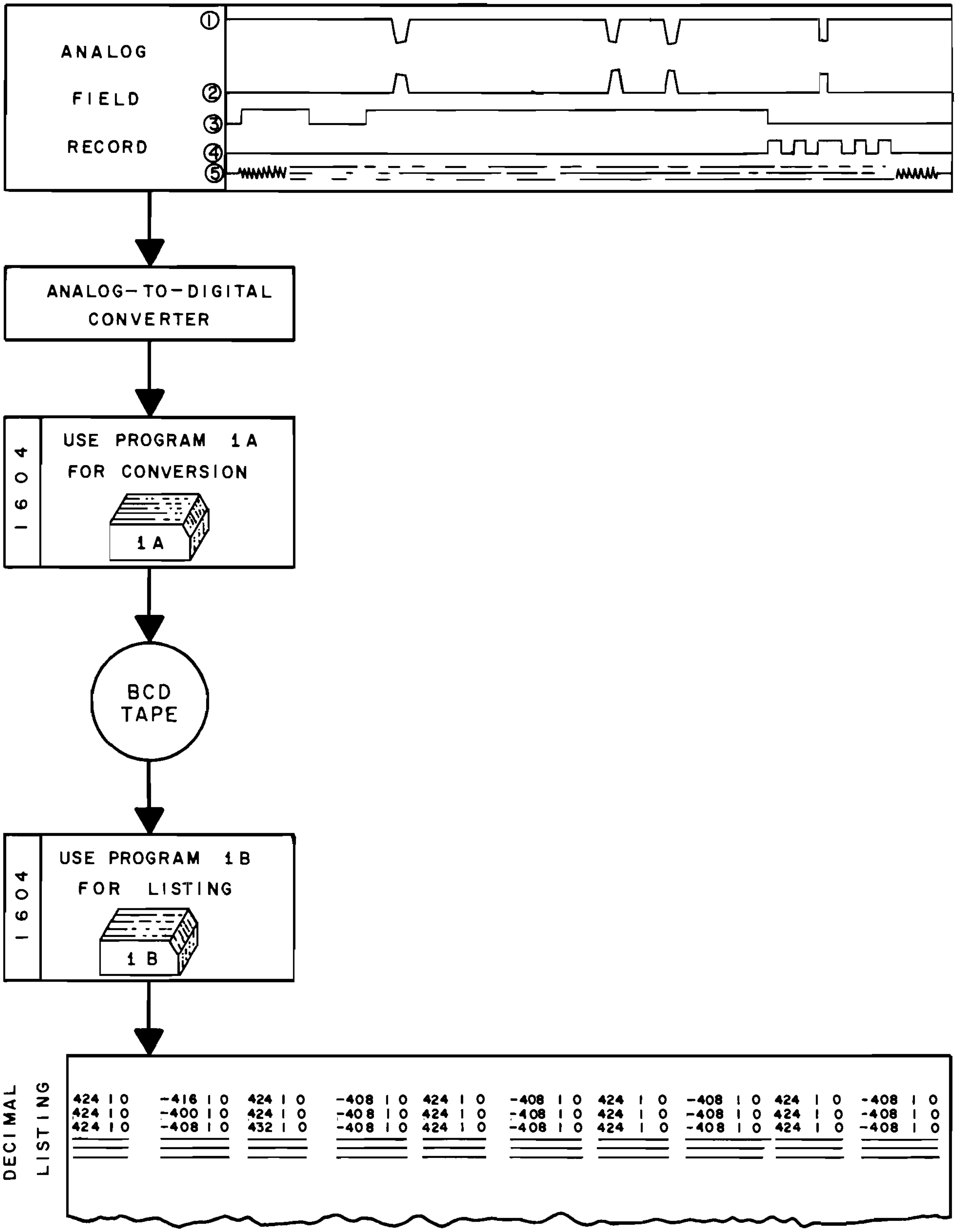


Fig 4.2. Processing block diagram (BCD).

The principles of the mathematical manipulations used in these subroutines for determining speeds, lengths, and the rest of the vehicles information are described in the following paragraphs.

Speed Calculation. The number of samples included within a speed pulse is divided by the sampling frequency (2400 H_z) in order to find the time, t, in seconds, during which the front axle of the vehicle traveled the distance between the pneumatic-road-tube detectors (8 feet). The speed follows as:

$$\text{speed} = \frac{8}{t}$$

Example:

Assume number of samples in the speed pulse = 291 samples

$$\text{therefore } t = \frac{291 \text{ samples}}{2400 \text{ samples/sec}}$$

$$= 0.121 \text{ sec}$$

$$\text{therefore speed} = \frac{8}{0.121} = 66 \text{ ft/sec}$$

$$\text{or speed} = 45 \text{ mph.}$$

Length Calculations. The number of samples in the length pulse are counted, and again using the sampling frequency, the corresponding time, t_1, in seconds, is determined. This time, t_1, represents the elapsed time between the moment when the front of the vehicle cut into the zone of influence of the inductance loop detector (Fig 3.2, p 38) until the rear of the vehicle leaves that influence zone. Distancewise, this time corresponds to the length of the vehicle (L) plus the width of the rectangular loop in the direction of traffic (loop width = 8 ft, see Fig 3.5).

Example:

Assume number of samples included in the length loop = 1020 samples

duration t_1 = 1020/2400 = 0.425 sec

speed calculated above = 66 ft/sec

therefore L + 8 = 66 (ft/sec) × 0.425 (sec)

= 28 ft

L = 20 ft.

Weight Calculation. The wheel load is represented by the height of the pulse trace in the analog record (Fig 3.10, p 48). Each pulse consists of a rise portion, maximum attained level, and a fall portion. The rise corresponds to the wheel starting gradual contact with the transducer whereas the maximum level and the fall of the pulse corresponds, respectively, to the wheel fully supported by the transducer and then gradually loosing contact with it. It appears then, that the central portion of the pulse is the portion of interest in load calculation. Figure 4.3 shows a typical weight pulse. The duration of the maximum-level portion depends on the tire contact and the speed of the vehicle. Different values of durations are given in Table 4.2. Based on the preceding the weight subroutines were written to find the pulse, establish the central half portion, and arithmetically average the sampled voltage readings. This average is then scaled using the calibration factor indicated by the shunt-calibration pulse, in order to determine the weight in pounds.

Number of Axles and Axle Spacing Calculation. The number of axles is determined simply by counting the number of load pulses. The axle spacing, on the other hand, is determined by the distance between the starts, ends, or centers of adjacent load pulses. This is done by counting the number of samples between these points, then using the sampling frequency (1200 H_z for each transducer) the time, t_1 , in seconds, is determined. The axle-spacing follows as the product of t_1 times the speed of the vehicle.

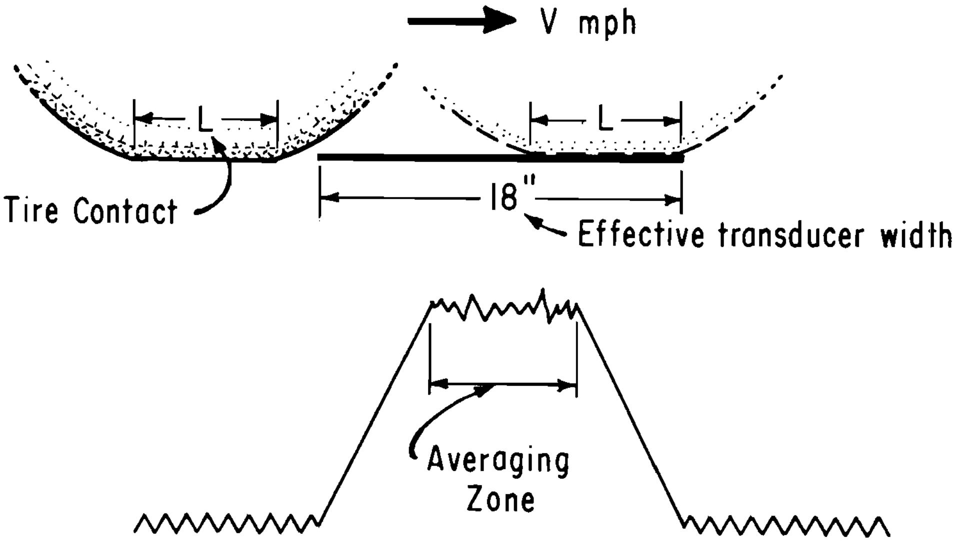


Fig 4.3. Typical weight pulse.

TABLE 4.2. DURATION OF MAXIMUM LEVEL OF PULSE
(Effective width of transducer = 18 inches)

Tire Contact	Durations in sec. for Vehicle Speeds (mph)							
L	10	20	30	40	50	60	70	80
9.0	.0511	.0255	.0170	.0127	.0102	.0085	.0073	.0063
10.0	.0454	.0227	.0151	.0113	.0090	.0075	.0064	.0056
11.0	.0397	.0198	.0132	.0099	.0079	.0066	.0056	.0049
12.0	.0340	.0170	.0113	.0085	.0068	.0056	.0048	.0042
13.0	.0284	.0142	.0094	.0071	.0056	.0047	.0040	.0035
14.0	.0227	.0113	.0075	.0056	.0045	.0037	.0032	.0028

Example:

Assume that the number of samples between two consecutive load pulses = 218 samples

$$\text{therefore } t_1 = \frac{218}{1200} = 0.182 \text{ sec}$$

$$\text{therefore spacing} = 0.182 \text{ (sec)} \times 66 \left(\frac{\text{ft}}{\text{sec}}\right)$$

$$= 12 \text{ ft.}$$

Once the number of axles and the axle spacings are determined, the wheel base and the vehicle classification can follow without any difficulty.

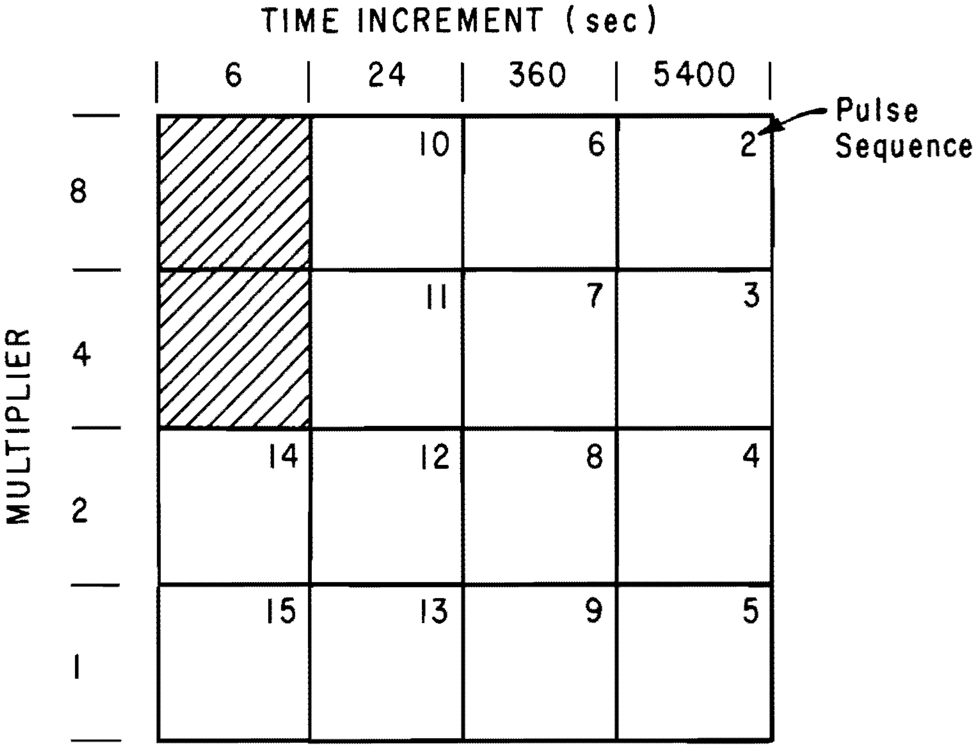
Time-of-Day Calculations. It was mentioned earlier that the time-of-day pulses are generated by an electronic logic circuit and are recorded on Channel 4 of the FM recorder. The Analog-to-Digital converter samples the voltage on the "Time of Day" channel once every $\frac{1}{2400}$ second and receives its command to sample from the 2400 H_z signal recorded on Channel 5, voice channel, of the magnetic analog tape. The digital record from the A/D converter will contain approximately 16 samples for each time-of-day pulse showing a "0" for no pulse present and "1" for a pulse present. A total of 15 pulses makes up each time-of-day signal sequence.

The time represented by these pulses and subsequent calculations is based on a digital clock shown in Fig 4.4. The total time count possible is 24 hours; the least increment of time is 0.1 minute or 6 seconds.

The first pulse in the time-of-day sequence is always a "1" indicating the presence of the time pulses and does not enter into the time calculation. The calculation of time-of-day is performed in the following manner:

(1) Test for "1" or "0" near center of pulse. The exact number of samples in a pulse may vary from 13 to 19, i.e., 16 ± 3.

(2) Use the following values for test zones in the calculation (16 ± 4):



MULTIPLIER	TIME INCREMENT (sec) 6	24	360	5400
8	▨	10	6	2
4	▨	11	7	3
2	14	12	8	4
1	15	13	9	5

Fig 4.4. Digital time clock.

Pulse No.	Test Zone for Pulse Presence (Sample No.)
1	1 - 12
2	20 - 28
3	36 - 44
4	52 - 60
5	68 - 76
6	84 - 92
7	100 - 108
8	116 - 124
9	132 - 140
10	148 - 156
11	164 - 172
12	180 - 188
13	196 - 204
14	212 - 220
15	228 - 236

(3) Multiply the increment (seconds) by the multiplier for each pulse present and accumulate.

(4) Convert time in seconds to hours, minutes, and seconds.

Example:

Assume a time-of-day signal represented in Fig 4.5 (presence indicated by "1", absence by "0").

Pulse No.	Presence	Increment	Multiplier	Time (sec)
1	1	---	-	---
2	0	5400	8	0
3	1	5400	4	21600
4	0	5400	2	0
5	1	5400	1	5400
6	1	360	8	2880
7	0	360	4	0
8	1	360	2	720
9	1	360	1	360
10	1	24	8	192

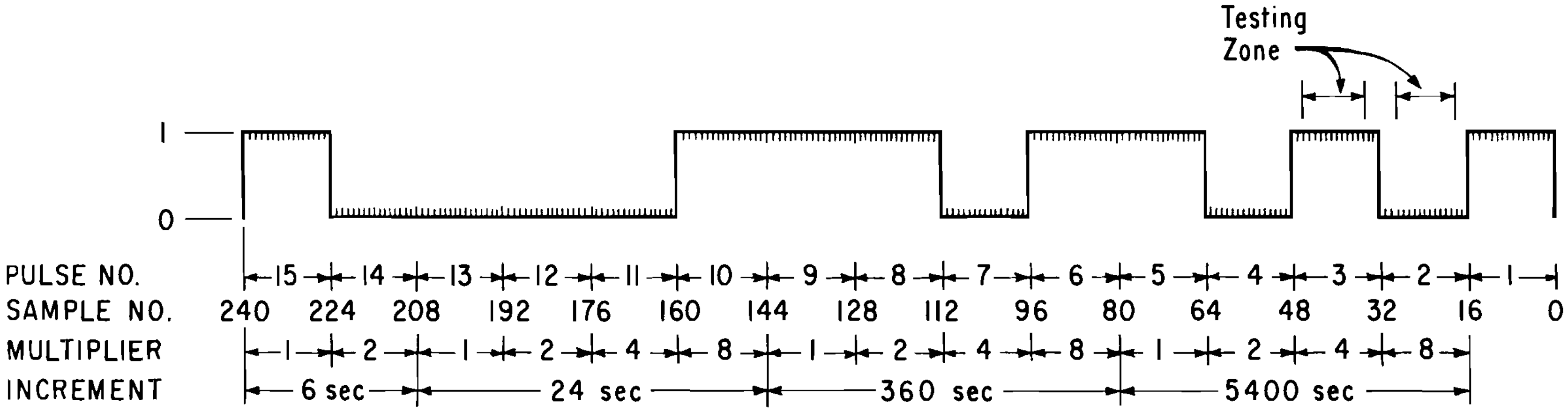


Fig 4.5. Typical time-of-day digital.

Pulse No.	Presence	Increment	Multiplier	Time (sec)
11	0	24	4	0
12	0	24	4	0
13	0	24	2	0
14	0	6	2	0
15	1	6	1	6
			Total seconds	31158

This time is equivalent to 8 hours, 39 minutes, and 18 seconds from the time reference at which the clock is set.

These calculations are handled by a special subroutine in program WIM.

CHAPTER 5. EXPERIMENTAL EVALUATION

Transducer Testing

A single wheel load transducer was used in a series of laboratory and field experiments designed to evaluate its response to static and dynamic loads. In the laboratory, the transducer was supported on the lower platen of a hydraulic testing machine in a box of sand, and load was applied at different positions on the surface through wooden blocks with approximately the same contact area as typical vehicle tires. The output signal was affected by neither the contact area nor the position of the load. A relationship between applied load and electrical response under static loading conditions was developed from these tests.

The transducer was then installed successively at three different field sites. Each installation involved removing about 1-1/2 inches of flexible pavement, setting the transducer in a thin layer of fresh cement-sand grout, and pressing it flush with the pavement surface. Conventional hand tools were used for removing the pavement material, and the installation took between two and three hours at each site. Power equipment would of course facilitate this work and reduce the time required for initial installation.

The site selected for the first series of field studies was on a four-lane farm-to-market road near Austin and was conveniently located adjacent to a Texas Highway Department maintenance warehouse. The pavement on this road was a double-surface treatment with good riding qualities. Precise elevations of the pavement surface were determined at 1-foot grid intersections with a Wild level for 200 feet in advance of the detector; the elevations varied no more than about 0.02 foot between adjacent points. The pavement was considered to be reasonably smooth. Even though truck traffic was rather heavy, the significiant experimentation was confined to studying the static and dynamic loads produced by a series of test vehicles. These vehicles were loaded to represent typical operating conditions, weighed on a loadometer, and driven at various speeds across the transducer.

Some tests involved stopping the vehicle on the transducer, and speeds ranged up to 70 mph.

During the eight months following the first field installation, test vehicles, which ranged from passenger cars and two-axle trucks to multiaxle vehicles and front-end loaders, made several hundred trips across the transducer. A systematic study was made of the effects of vehicle speed, load placement on the transducer, tire inflation pressure, vehicle acceleration, braking, and other factors. The transducer responded satisfactorily under all conditions. Speed, load placement on the transducer, nor tire inflation pressure affected the magnitude of the output signal. Acceleration and braking caused a transfer of load among the wheels of the test vehicles; this transfer of load was expected and was indicated by the studies. The transducer withstood the traffic and the winter environment without adverse effects.

The second series of tests conducted during the summer of 1964 subjected the scale to heavy traffic on Interstate 35 near Temple, Texas. The transducer was placed in the outer lane and was positioned to weigh the wheels on the right side of all vehicles. Figure 5.1 shows this installation. The site was about a mile downstream from the loadometer station which is operated periodically by the Planning Survey Division of the Texas Highway Department. The normal operating schedule called for occupancy of the loadometer station for four hours on the first and last day of July. The portable scale was operated during these periods in order to obtain comparable data on the static weight and the dynamic weight of a large variety of commercial vehicles. Walkie-talkie radios were used to coordinate weighing operations at the two sites, and wheel weights for over 200 vehicles were recorded. The vehicles which were weighed while moving were traveling at speeds ranging from about 35 to 60 mph. Polaroid photographs were used to make permanent records of the oscilloscope traces.

Wheel load data were scaled from these photographs and transferred to punched cards for machine processing. Likewise, wheel load data procured by loadometer weighing were punched on cards. A computer was used to plot these data in the form shown in Figs 5.2 through 5.7. The regression lines shown through the points on these figures are the straight lines of best fit as determined by a least-square technique. If there were perfect agreement between the loadometer weights and the portable scale weight, all data

Fig 5.1. Portable scale installation on Interstate 35 at Temple-Belton, Texas.

points would lie along a straight line inclined at 45° F. It may be noted from Fig 8 that the line of best fit is inclined at approximately 45° F but that the data points are somewhat scattered about this line. In some cases, the portable scale weights for the sum of the wheel loads on each vehicle are higher than the loadometer weights while in other cases they are lower. In virtually all cases the portable scale weights are within 10 percent of the loadometer weights, and the scatter is approximately equally distributed on the high side and on the low side.

Figure 5.3 shows the relationship between the loadometer weights and the portable scale weights for the right front wheel of each vehicle. The portable scale weights are, on the average, lighter than the loadometer weights, and the variation of the dynamic weight from the static weight is as much as 40 percent in a few cases. Most of the data points agree within about 15 percent, however.

Since many of the vehicles were accelerating when they passed over the portable scale, it is logical that a part of the normal front-axle load might have been transferred to other axles. For certain axles, as shown in Figs 5.4 through 5.7, the wheel weights determined by the portable scale are higher than those measured statically while for other axles they are lower. It may also be seen that the scatter in the data is somewhat larger when considering individual wheel loads than when considering the sum of the wheel loads for each vehicle. The scatter is, however, approximately equally distributed on the high and low side for every case.

The third site at which the portable scale was installed was also adjacent to a loadometer station operated by the Texas Highway Department near Luling, Texas. Truck traffic during the four-hour weighing period was very light, and this installation served more to demonstrate the portability of the scale than to provide data. As a matter of fact, only thirteen commercial vehicles were weighed during the four-hour period. This installation took only two hours to complete.

Texas Highway Department System Field Testing

The first series of field testing of the Texas Highway Department system involved static calibration of the two transducers. A 10-kip load cell along with an 8-ton hydraulic jack was used. The transducers were

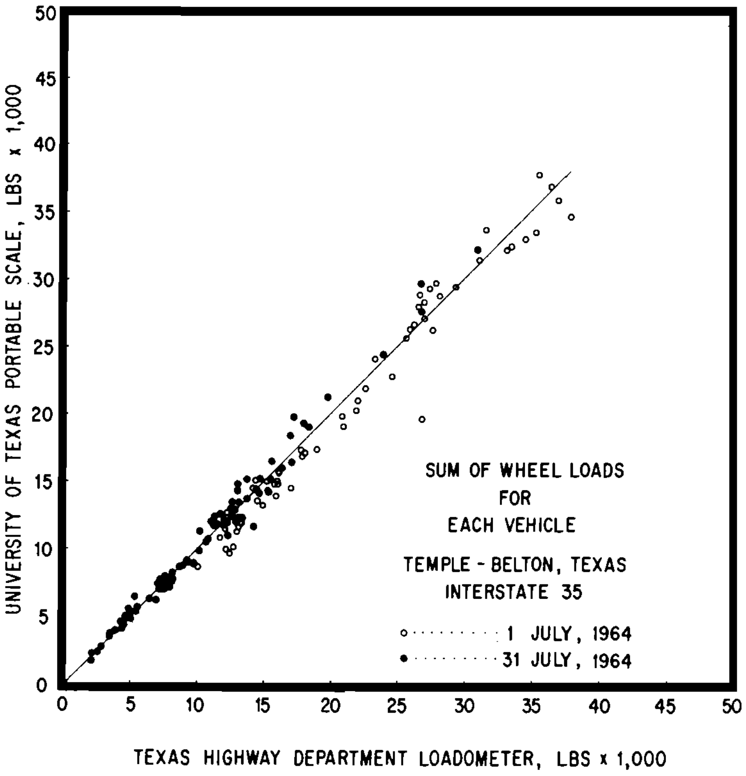


Fig 5.2. Loadometer weights vs portable weights.

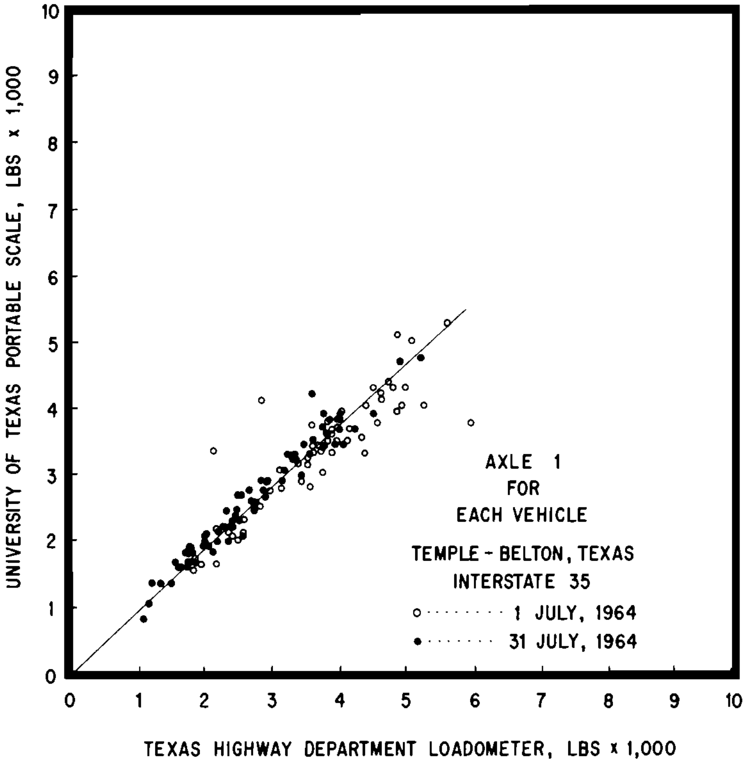


Fig 5.3. Loadometer weights vs portable weights.

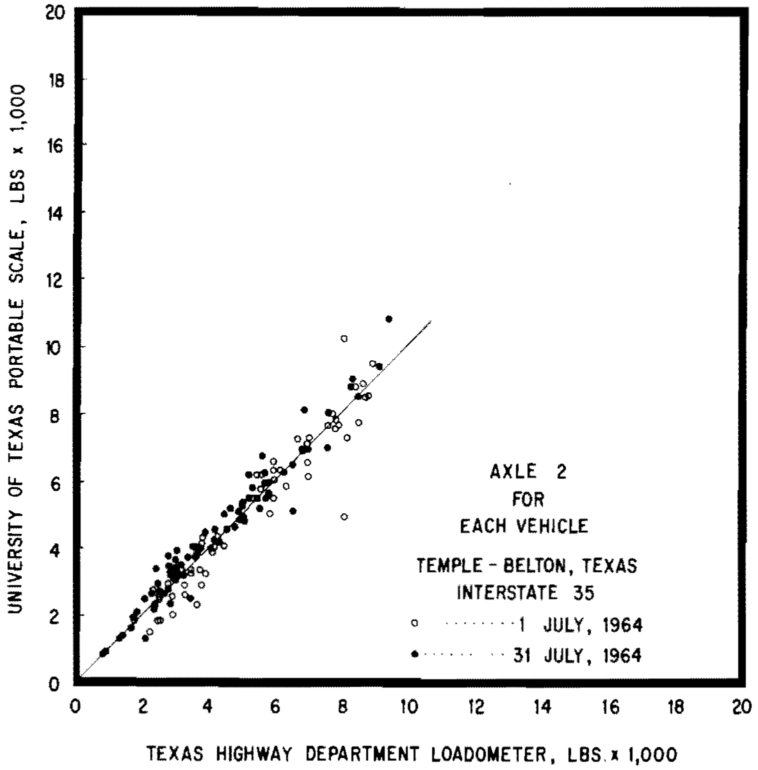


Fig 5.4. Loadometer weights vs portable weights.

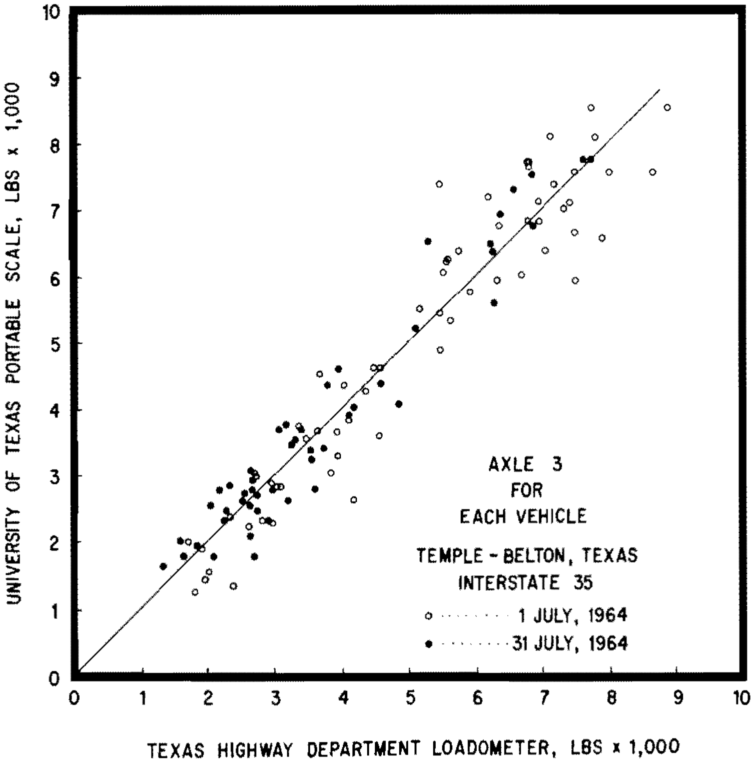


Fig 5.5. Loadometer weights vs portable weights.

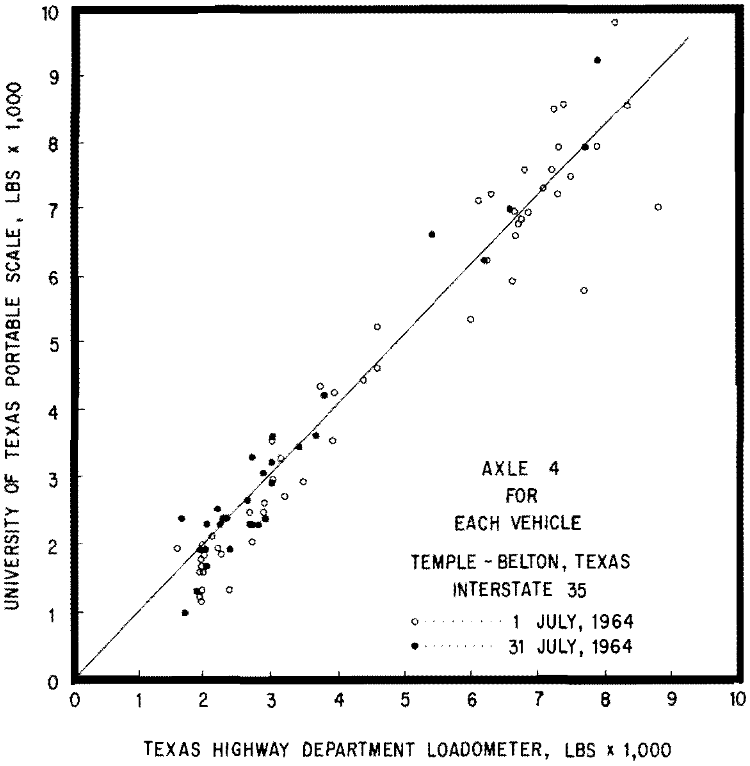


Figure 5.6. LOADOMETER WEIGHTS vs PORTABLE WEIGHTS

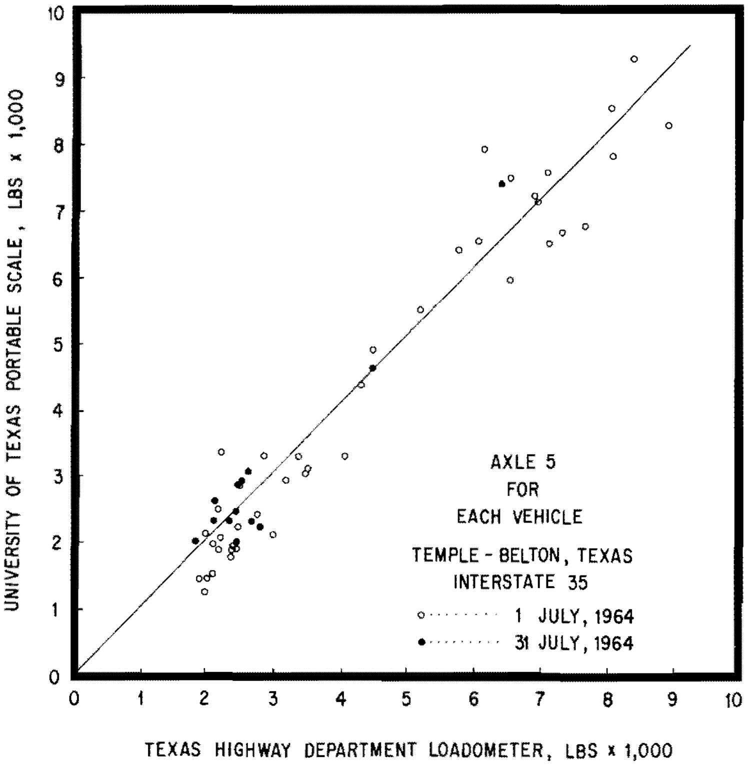


Figure 5.7 LOADOMETER WEIGHTS vs PORTABLE WEIGHTS

loaded separately at three positions across the surface and information relating the shunt-calibration dial setting to the equivalent load was obtained. It was decided to use the index settings that correspond to 5000 pounds for each transducer to serve as a starting calibration for data reduction. The Texas Highway Department system was then installed at different sites including a four-lane farm-to-market road near Austin and then on Interstate 35 near Temple, Texas, in the outer lane of the northbound. The transducers were subjected to heavy traffic for several months and data was recorded at different times. Unfortunately, unforeseen difficulties in the development of the computer program delayed processing of the data but when the program was completed more than two hundred vehicles were processed. Approximately sixty-five of these vehicles were weighed by the loadometer station which is operated by the Planning Survey Division of the Texas Highway Department. These loadometer weights provided a check for the scale weights. The portable scale values were plotted against the loadometer values for these vehicles (Figs 5.8 through 5.10).

The points were scattered around the fitted straight line and few extreme points showed variation as much as 50 percent or more. These points represent vehicles partially passing over the scale transducers, thus resulting in signals corresponding to part rather than the total wheel loads. Other than these extreme points the curve fit showed the following observations:

(1) Gross weights. The portable scale values were generally lower than the Texas Highway Department values by about 5 percent.

(2) Sum of right wheels. The portable scale values were generally higher than the Texas Highway Department loadometer values by about 7 percent.

(3) Sum of left wheels. The portable scale values were generally lower than the Texas Highway Department loadometer values by about 12 percent.

The variations between the portable scale weights and the Texas Highway Department weights are attributed to the following reasons:

(1) The portable scale weights were calculated on the basis of static calibration and the value of 5000 pounds for the shunt calibration was approximate pending further analysis.

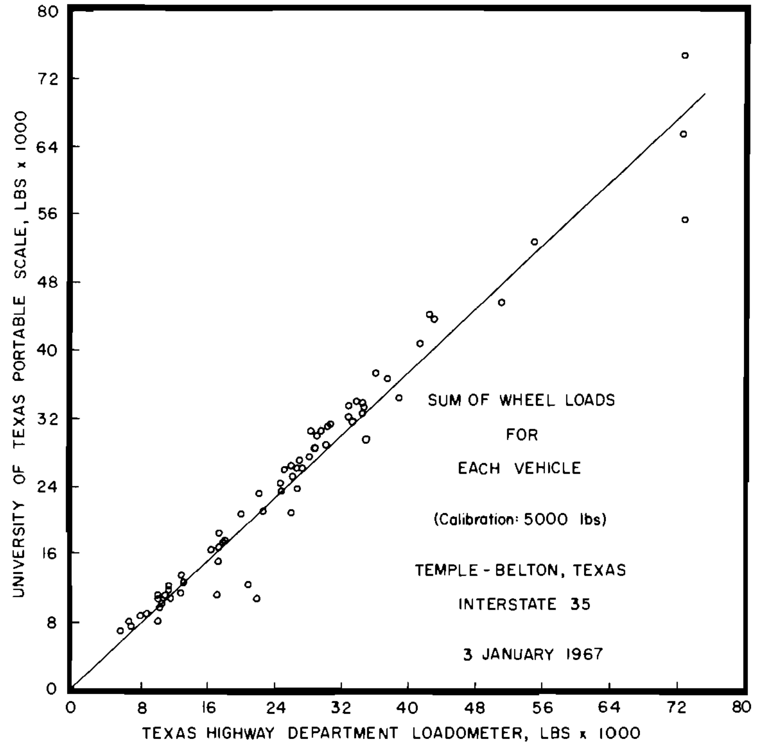


Fig 5.8. Portable scale weights vs loadometer weights.

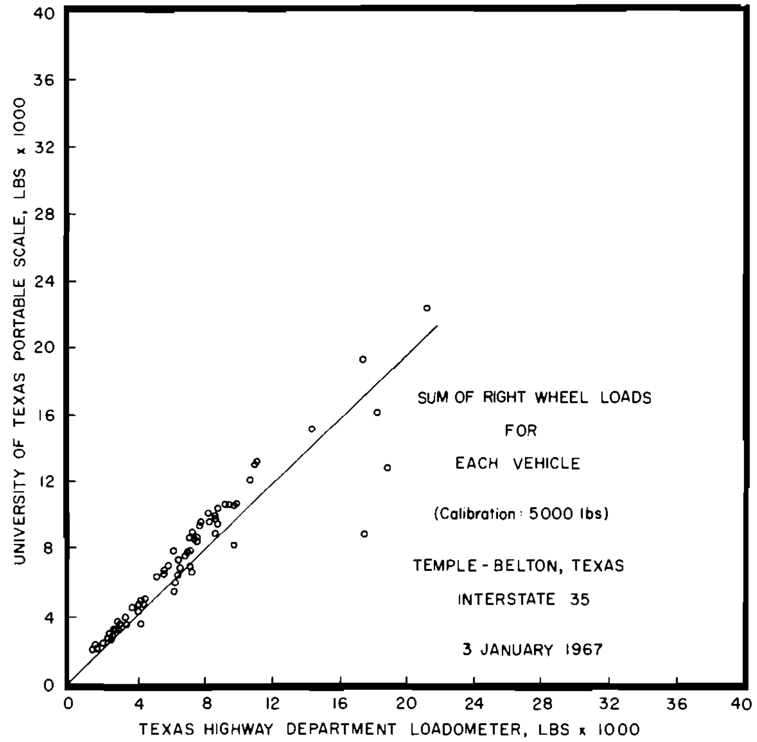


Fig 5.9. Portable scale weights vs loadometer weights.

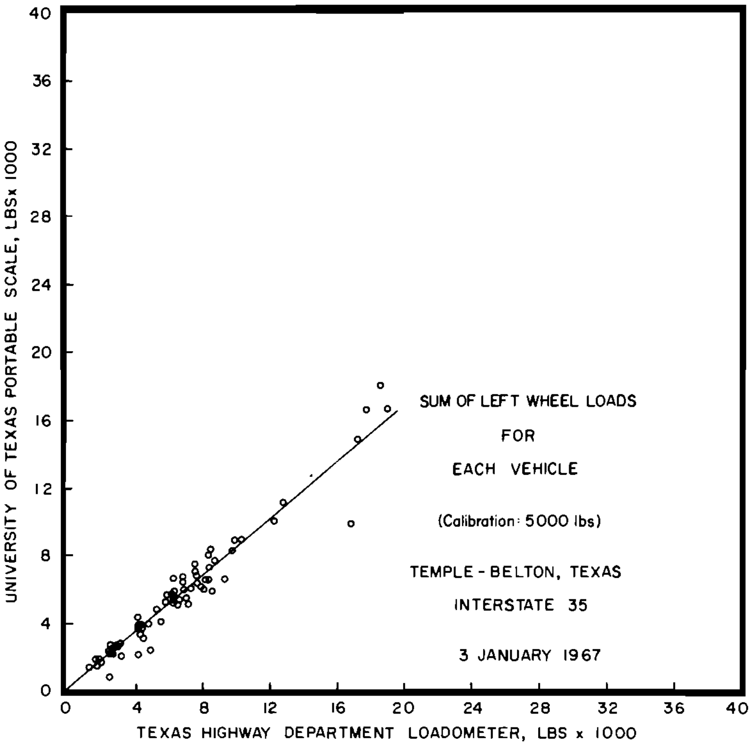


Fig 5.10. Portable scale weights vs loadometer weights.

(2) The portable scale weights were dynamic weights while the Texas Highway Department weights were static. The variation between these weights are due to a number of factors with varying degrees of criticality. Some of these factors, as mentioned earlier in this report, are vehicle speed, surface roughness, profile, vehicle response to aerodynamic effects, and last, but certainly not least, the vehicle suspension characteristics.

Based on the above observed variations, it was decided to normalize the data in such a manner to make the portable scale weights approximate as much as possible the static weights. This was done by increasing the calibration factor of the left transducer by 18 percent and decreasing the corresponding calibration factor for the right side by 7 percent. This entailed using 6100 pounds for the left shunt calibration and 4680 pounds for the right instead of the equal value of 5000 pounds for each. The computer program was then modified to account for these two changes and the same data was processed.

Tables 5.1 through 5.3 show simple printout of the vehicles data and Tables 5.4 and 5.5 give a legend for the different variables and an explanation for the code used in connection with the classification system as used by the Texas Highway Department.

The portable scale weights were plotted against the Texas Highway Department loadometer weights in order to see the degree of comparison for the following:

(1) the gross weight or the sum of wheel loads for each vehicle (Fig 5.11),
(2) axle 1 for each vehicle (Fig 5.12),
(3) axle 2 for each vehicle (Fig 5.13),
(4) sum of left wheel loads for each vehicle (Fig 5.14), and
(5) sum of right wheel loads for each vehicle (Fig 5.16).

In each of the above curves one can notice that scatter still exists, but a closer correspondence between the portable scale weights and the loadometer weights resulted after the adjustment of the calibration factors.

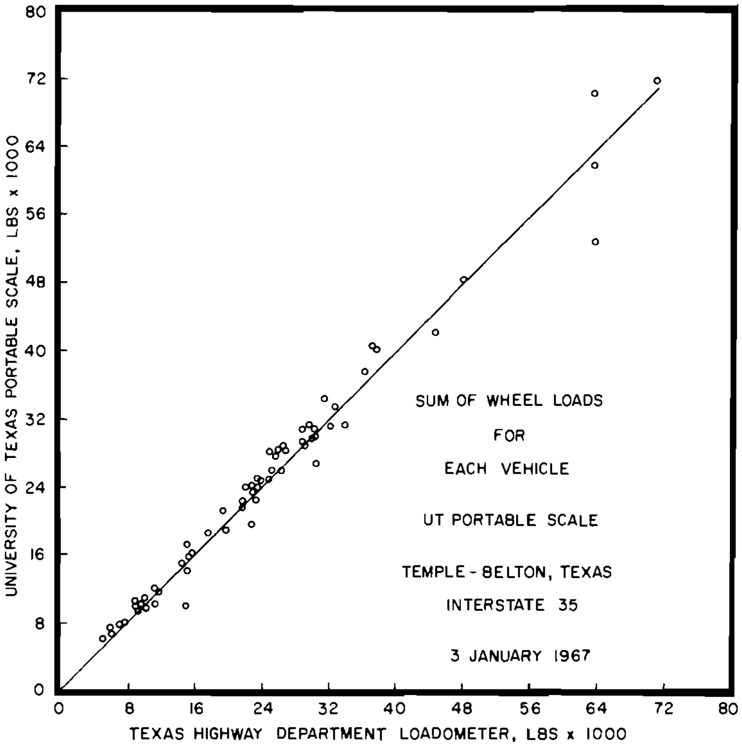


Fig 5.11. Loadometer weights vs portable weights.

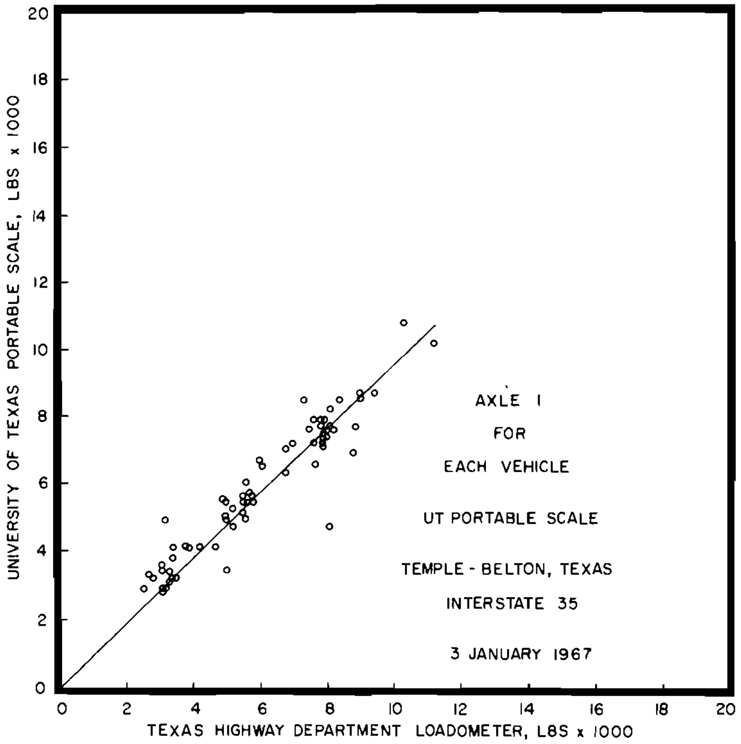


Fig 5.12. Loadometer weights vs portable weights.

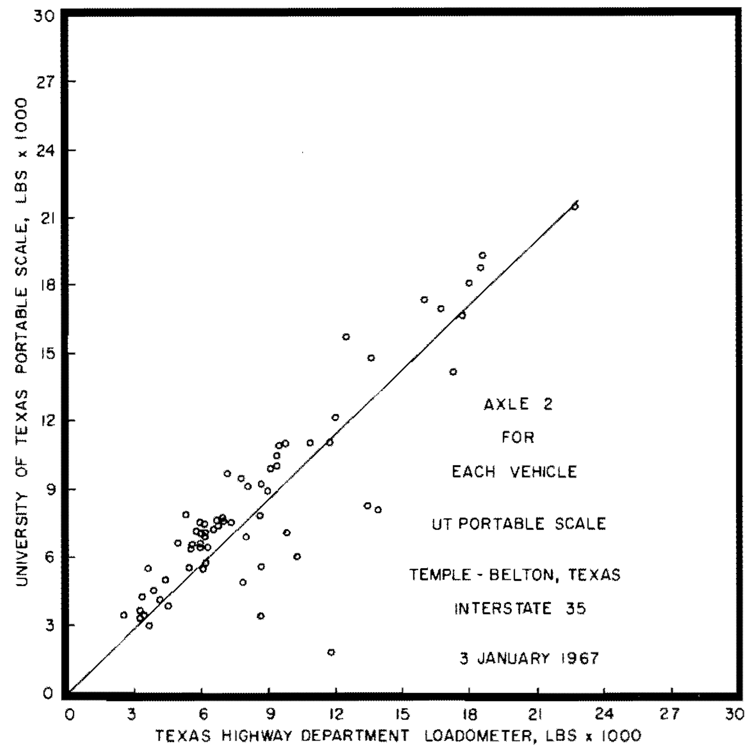


Fig 5.13. Loadometer weights vs portable weights.

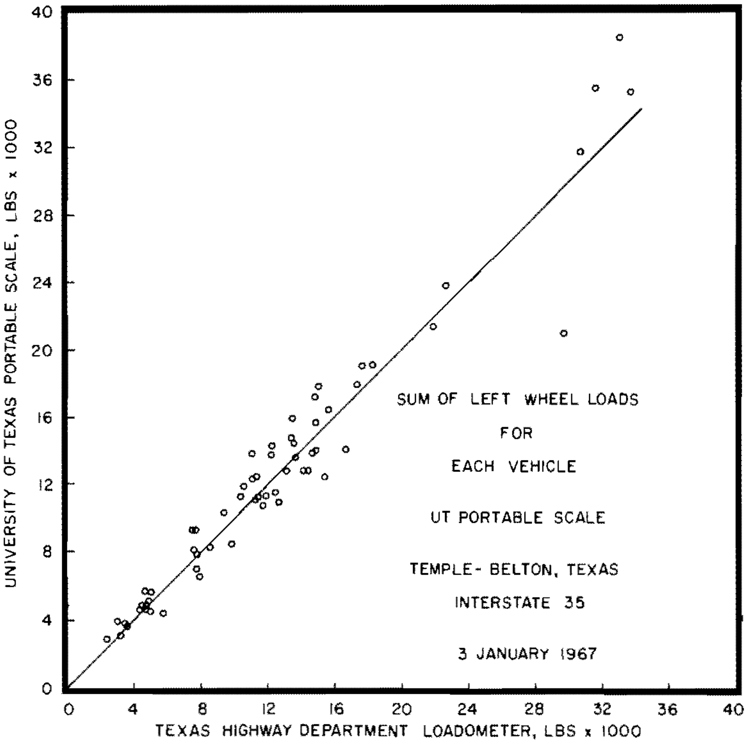


Fig 5.14. Loadometer weights vs portable weights.

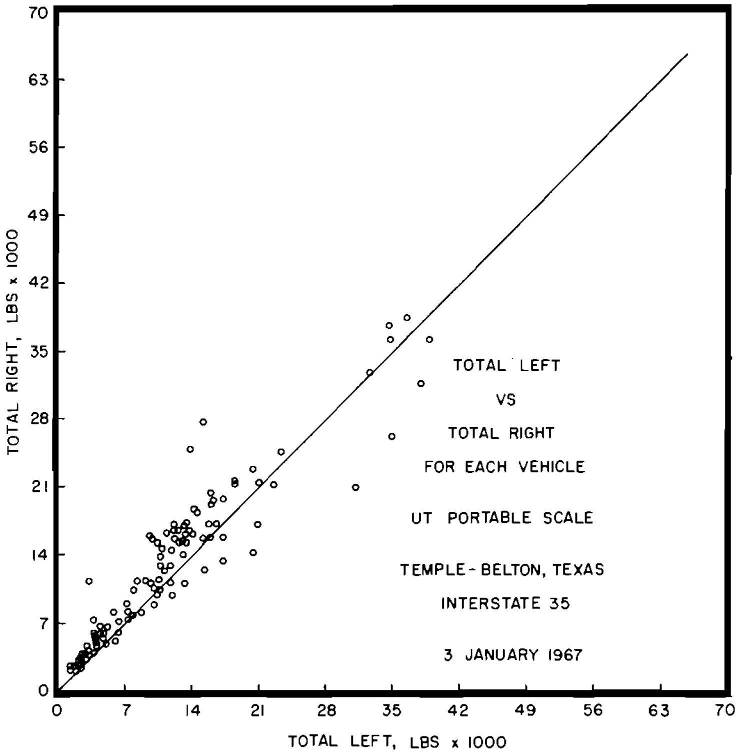


Fig 5.15. Loadometer weights vs portable weights.

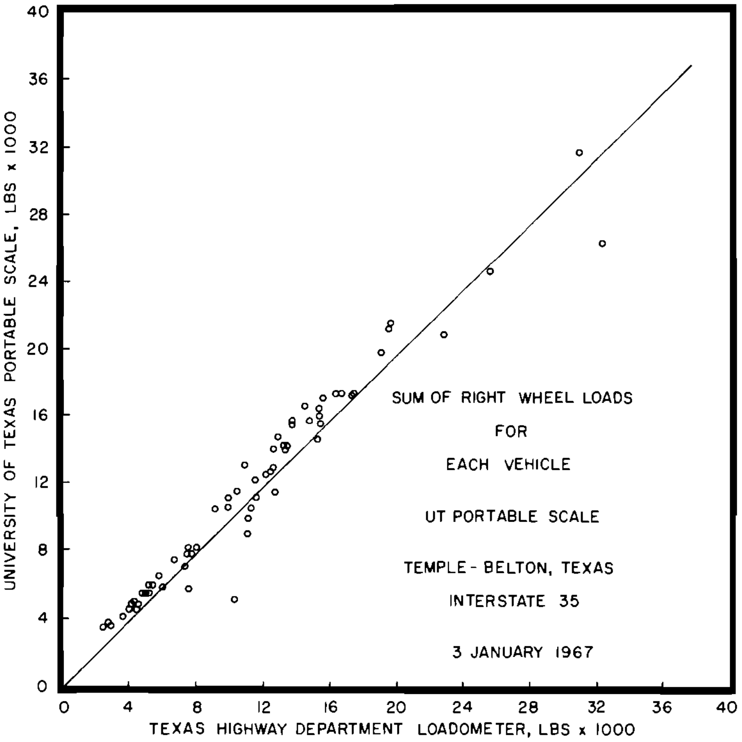


Fig 5.16. Loadometer weights vs portable weights.

DATA TAKEN AT TEMPLE-BELTCN STATICN - I35 NORTHBOUND
DATE - TUESDAY JAN. 3,1967

TIME	VT	VS	LTOT	RTOT	GROS	N	AB	BC	CD	DE	EF	FG	GH	WB	VL	AR	AL	A	BR	BL	B	CR	CL	C	DR	DL	D	ER	EL	E	FR	FL	F	GR	GL	G	HR	H
13912	22	29	356	263	618	4	15	18	4	0	0	0	0	37	42	36	42	79	87	128	215	68	91	159	71	94	165	0	0	0	0	0	0	0	0	0	0	
14036	21	42	136	134	289	3	9	35	0	0	0	0	0	44	54	34	38	72	64	47	111	56	51	107	0	0	0	0	0	0	0	0	0	0	0	0	0	
14130	13	46	36	45	81	2	15	0	0	0	0	0	0	15	19	17	15	31	28	21	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
14248	13	34	66	51	117	2	10	0	0	0	0	0	0	10	15	15	19	34	36	47	83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
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0	99	49	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
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20830	13	55	24	19	42	2	10	0	0	0	0	0	0	10	20	11	13	23	8	11	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
20900	13	52	29	25	54	2	10	0	0	0	0	0	0	10	22	12	14	27	13	15	27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
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21430	24	48	134	316	450	5	9	4	28	4	0	0	0	45	51	83	44	127	49	23	72	75	31	106	60	21	81	49	15	64	0	0	0	0	0	0	0	
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21848	22	42	137	141	277	4	12	19	4	0	0	0	0	36	47	31	39	70	53	55	109	23	14	38	33	29	62	0	0	0	0	0	0	0	0	0	0	
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22318	21	35	117	124	241	3	12	29	0	0	0	0	0	41	50	23	24	47	52	47	99	49	46	95	0	0	0	0	0	0	0	0	0	0	0	0	0	
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22806	13	35	57	65	121	2	10	0	0	0	0	0	0	10	17	25	26	52	39	30	69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22830	13	55	45	54	98	2	15	0	0	0	0	0	0	15	26	17	15	32	36	30	66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22936	13	48	79	74	153	2	16	0	0	0	0	0	0	16	26	27	26	54	46	53	99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
23012	13	41	57	49	106	2	13	0	0	0	0	0	0	13	20	17	23	41	31	34	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
23054	65	34	668	508	1176	6	14	5	34	4	4	0	0	60	65	59	71	129	90	124	214	89	124	213	90	121	211	90	112	202	90	117	207	0	0	0	0	
23248	21	35	215	208	422	3	13	14	0	0	0	0	0	28	31	25	26	51	91	102	193	92	86	178	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
23436	14	42	93	81	174	3	16	4	0	0	0	0	0	20	30	24	31	55	27	27	55	30	34	64	0	0	0	0	0	0	0	0	0	0	0	0	0	
24024	24	35	115	146	261	5	9	4	27	4	0	0	0	45	50	37	35	72	33	31	64	30	18	47	18	19	37	28	12	41	0	0	0	0	0	0	0	
132424	14	31	352	93	446	3	11	4	0	0	0	0	0	16	27	24	87	111	29	133	163	40	132	172	0	0	0	0	0	0	0	0	0	0	0	0	0	
24342	21	46	123	128	251	3	12	32	0	0	0	0	0	44	50	37	39	75	53	48	100	39	37	75	0	0	0	0	0	0	0	0	0	0	0	0	0	
24548	24	44	139	170	309	5	9	4	24	4	0	0	0	41	49	36	49	85	22	20	41	37	28	65	27	12	39	47	31	78	0	0	0	0	0	0	0	

TABLE 5.1 PRINTOUT OF THE VEHICLE DATA

DATA TAKEN AT TEMPLE-BELTON STATION - I35 NORTHBOUND
DATE - TUESDAY JAN. 3,1967

TIME	VT	VS	LTOT	RTOT	GROS	N	AB	BC	CD	DE	EF	FG	GH	WB	VL	AR	AL	A	BR	BL	B	CR	CL	C	DR	DL	D	ER	EL	E	FR	FL	F	GR	GL	G	HR	H
24712	24	47	178	134	311	5	15	4	32	4	0	0	0	56	68	31	34	65	36	45	81	30	39	69	21	22	44	16	38	53	0	0	0	0	0	0	0	
24900	24	40	191	215	406	5	11	4	19	4	0	0	0	38	44	28	26	54	54	51	105	42	36	78	40	29	70	50	49	99	0	0	0	0	0	0	0	
25030	14	45	143	139	282	3	11	4	0	0	0	0	0	15	28	49	59	108	53	44	97	37	39	77	0	0	0	0	0	0	0	0	0	0	0	0	0	
25324	21	50	111	114	225	3	12	32	0	0	0	0	0	44	52	26	30	56	48	45	92	40	36	76	0	0	0	0	0	0	0	0	0	0	0	0	0	
25500	22	43	140	159	299	4	12	18	4	0	0	0	0	34	43	24	25	49	57	53	110	36	31	67	43	32	74	0	0	0	0	0	0	0	0	0	0	
25742	13	56	28	31	58	2	10	0	0	0	0	0	0	10	21	16	15	30	15	13	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
25800	13	45	23	23	46	2	10	0	0	0	0	0	0	10	21	12	11	23	11	11	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
25824	24	47	144	164	308	5	11	4	27	4	0	0	0	46	54	38	40	77	39	33	71	33	25	58	28	21	49	26	26	53	0	0	0	0	0	0	0	
25824	13	49	19	21	40	2	10	0	0	0	0	0	0	10	20	11	11	21	10	9	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
25830	13	49	21	24	45	2	10	0	0	0	0	0	0	10	21	12	11	23	12	10	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
43130	24	31	318	210	528	5	9	4	24	4	0	0	0	42	56	32	42	74	51	94	145	42	69	111	32	40	72	53	72	126	0	0	0	0	0	0	0	
43324	24	46	148	141	289	5	11	4	28	4	0	0	0	47	53	37	39	77	34	44	78	25	18	42	21	18	39	24	29	53	0	0	0	0	0	0	0	
43330	13	54	32	30	62	2	10	0	0	0	0	0	0	10	22	13	14	27	17	18	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	99	54	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	99	55	0	0	0	0	0	0	0	0	0	0	0	0	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
43800	24	43	157	156	313	5	10	4	28	4	0	0	0	46	52	40	45	85	36	36	72	30	37	67	24	18	42	26	21	47	0	0	0	0	0	0	0	
43942	24	36	354	363	717	5	12	4	24	4	0	0	0	44	49	44	41	85	70	78	148	84	87	172	81	74	155	84	73	157	0	0	0	0	0	0	0	
44024	13	59	44	57	101	2	15	0	0	0	0	0	0	15	25	24	16	41	33	27	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
44136	22	39	191	211	402	4	12	20	4	0	0	0	0	36	41	28	26	54	81	89	170	47	35	82	54	42	96	0	0	0	0	0	0	0	0	0	0	
44254	22	44	128	156	284	4	12	20	4	0	0	0	0	36	45	30	26	56	55	55	110	35	19	54	35	29	64	0	0	0	0	0	0	0	0	0	0	
44436	24	42	109	153	262	5	8	4	28	4	0	0	0	45	51	33	35	67	23	15	38	44	28	72	20	13	33	34	18	52	0	0	0	0	0	0	0	
44518	13	48	44	39	83	2	15	0	0	0	0	0	0	15	35	24	25	49	15	19	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
44554	13	49	29	34	63	2	10	0	0	0	0	0	0	10	18	17	12	29	17	17	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	99	82	0	0	0	0	0	0	0	0	0	0	0	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
44642	13	44	46	48	94	2	13	0	0	0	0	0	0	13	22	15	13	28	33	33	66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
44742	24	52	113	130	243	5	12	4	23	4	0	0	0	44	49	27	23	50	32	24	57	24	27	52	12	10	22	35	28	63	0	0	0	0	0	0	0	
45000	21	46	119	121	240	3	10	26	0	0	0	0	0	36	45	36	42	79	50	45	95	35	32	67	0	0	0	0	0	0	0	0	0	0	0	0	0	
45006	13	55	49	54	103	2	13	0	0	0	0	0	0	13	22	20	19	38	34	30	64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
45130	13	44	107	89	196	2	13	0	0	0	0	0	0	13	18	25	29	54	64	79	142	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
45618	24	36	210	144	355	5	11	4	26	4	0	0	0	45	50	13	56	69	42	39	81	41	42	84	15	40	55	33	33	66	0	0	0	0	0	0	0	
0	99	40	0	0	0	0	0	0	0	0	0	0	0	0	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
45624	13	44	21	20	42	2	10	0	0	0	0	0	0	10	19	11	11	22	10	10	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
45718	13	51	81	81	163	2	15	0	0	0	0	0	0	15	27	20	20	41	61	61	122	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
45724	21	41	214	170	385	3	11	14	0	0	0	0	0	26	30	25	29	53	82	104	186	64	82	145	0	0	0	0	0	0	0	0	0	0	0	0	0	
45854	21	41	83	104	187	3	12	28	0	0	0	0	0	40	48	24	25	49	40	34	73	40	25	65	0	0	0	0	0	0	0	0	0	0	0	0	0	
50030	24	46	124	145	269	5	10	4	26	4	0	0	0	44	51	38	38	76	32	24	56	25	27	52	22	8	31	28	26	54	0	0	0	0	0	0	0	
50424	22	40	172	172	344	4	11	24	4	0	0	0	0	39	50	42	44	87	76	80	157	34	21	55	19	27	46	0	0	0	0	0	0	0	0	0	0	
50600	22	44	38	113	151	4	16	17	4	0	0	0	0	37	46	37	10	47	30	19	49	25	9	34	21	0	21	0	0	0	0	0	0	0	0	0	0	
50806	24	47	128	165	293	5	11	4	23	4	0	0	0	42	49	37	35	73	41	32	74	37	27	64	21	12	33	28	22	49	0	0	0	0	0	0	0	
51442	13	42	49	46	96	2	11	0	0	0	0	0	0	11	18	18	14	32	30	34	64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
51506	13	45	53	55	109	2	11	0	0	0	0	0	0	11	17	16	18	35	39	35	74	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
51854	21	35	148	161	309	3	11	24	0	0	0	0	0	35	44	20	21	41	61	59	120	80	68	148	0	0	0	0	0	0	0	0	0	0	0	0	0	
52048	22	46	101	158	259	4	12	25	4	0	0	0	0	41	52	39	35	74	55	42	96	32	10	42	32	14	46	0	0	0	0	0	0	0	0	0	0	
52236	24	46	152	184	336	5	13	4	27	4	0	0	0	49	55	37	34	72	44	34	78	43	43	86	37	20	58	22	21	42	0	0	0	0	0	0	0	
52418	24	46	165	158	323	5	9	4	24	4	0	0	0	41	51	39	47	86	23	20	43	38	39	77	32	25	57	27	33	60	0	0	0	0	0	0	0	
52806	13	50	31	35	66	2	11	0	0	0	0	0	0	11	20	13	13	26	22	19	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
53042	21	42	232	212	444	3	13	14	0	0	0	0	0	28	32	27	25	52	92	108	200	93	99	192	0	0	0	0	0	0	0	0	0	0	0	0	0	
53200	21	59	89	113	201	3	11	31	0	0	0	0	0	42	53	37	45	82	39	28	67	37	15	52	0	0	0	0	0	0	0	0	0	0	0	0	0	
53418	24	49	105	156	261	5	9	4	27	4	0	0	0	45	52	40	35	76	35	20	56	28	23	50	34	15	49	19	12	30	0	0	0	0	0	0	0	

TABLE 5.2. PRINTOUT OF THE VEHICLE DATA

DATA TAKEN AT TEMPLE-BELTON STATION - I35 NORTHBOUND
DATE - TUESDAY JAN. 3,1967

TIME	VT	VS	LTOT	RTOT	GROS	N	AB	BC	CD	DE	EF	FG	GH	WB	VL	AR	AL	A	BR	BL	B	CR	CL	C	DR	DL	D	ER	EL	E	FR	FL	F	GR	GL	G	HR	H
53554	24	46	149	187	336	5	15	4	32	4	0	0	0	56	68	33	28	62	49	44	94	39	28	67	30	20	50	35	29	64	0	0	0	0	0	0	0	
53630	13	50	44	54	98	2	11	0	0	0	0	0	0	11	26	23	16	39	31	28	59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
53736	24	48	119	162	281	5	10	4	28	4	0	0	0	46	51	43	33	76	20	12	33	46	36	81	24	17	40	29	22	51	0	0	0	0	0	0	0	
53900	14	44	128	122	250	3	15	4	0	0	0	0	0	19	29	38	41	79	44	45	89	40	41	81	0	0	0	0	0	0	0	0	0	0	0	0	0	
54036	13	46	64	81	145	2	15	0	0	0	0	0	0	15	24	30	25	55	51	39	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
54242	24	43	166	192	358	5	15	4	33	4	0	0	0	56	69	31	33	64	64	61	125	25	27	52	38	14	51	35	31	66	0	0	0	0	0	0	0	
0	0	66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
54500	24	43	167	195	363	5	15	4	32	4	0	0	0	55	68	37	34	70	42	32	75	49	52	101	35	20	55	33	30	63	0	0	0	0	0	0	0	
54718	24	32	395	362	757	5	13	4	25	4	0	0	0	47	52	33	35	68	93	125	218	69	65	134	81	80	161	87	90	177	0	0	0	0	0	0	0	
54800	13	39	54	53	108	2	11	0	0	0	0	0	0	11	21	16	16	33	37	38	75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
54848	24	42	166	204	370	5	11	4	26	4	0	0	0	45	51	47	47	94	43	33	77	37	30	67	27	20	46	50	35	86	0	0	0	0	0	0	0	
54954	13	41	118	126	244	2	15	0	0	0	0	0	0	15	25	35	31	67	90	87	177	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
55006	13	51	36	32	69	2	11	0	0	0	0	0	0	11	19	16	19	34	16	18	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
55118	22	43	210	229	438	4	11	21	4	0	0	0	0	36	49	42	40	82	87	87	174	46	36	82	55	46	100	0	0	0	0	0	0	0	0	0	0	
55230	24	49	131	164	295	5	9	4	28	4	0	0	0	46	53	38	33	71	36	26	62	35	28	63	28	24	52	27	21	47	0	0	0	0	0	0	0	
55300	13	51	62	59	121	2	15	0	0	0	0	0	0	15	25	20	20	40	39	42	81	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	99	45	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
55948	21	42	99	114	213	3	12	28	0	0	0	0	0	40	48	24	24	48	48	40	89	42	35	77	0	0	0	0	0	0	0	0	0	0	0	0	0	
73136	13	43	52	59	111	2	13	0	0	0	0	0	0	13	22	19	17	36	40	35	75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
73206	13	39	84	79	164	2	15	0	0	0	0	0	0	15	24	28	30	58	51	54	105	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
73213	21	41	79	83	162	3	13	16	0	0	0	0	0	29	37	20	18	38	29	32	61	33	30	63	0	0	0	0	0	0	0	0	0	0	0	0	0	
73324	24	34	332	328	659	5	13	4	23	4	0	0	0	45	51	42	45	87	83	98	181	70	65	134	55	53	107	78	71	149	0	0	0	0	0	0	0	
73348	13	42	50	67	118	2	17	0	0	0	0	0	0	17	27	24	20	44	43	30	74	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
73548	13	50	35	39	74	2	13	0	0	0	0	0	0	13	21	15	15	31	23	20	43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
73648	13	41	94	90	184	2	15	0	0	0	0	0	0	15	29	35	37	71	55	57	112	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
73724	13	45	45	52	98	2	15	0	0	0	0	0	0	15	25	19	18	37	34	27	61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
73930	21	46	106	106	213	3	11	34	0	0	0	0	0	45	52	29	29	59	45	46	91	32	31	63	0	0	0	0	0	0	0	0	0	0	0	0	0	
74154	24	37	371	385	756	5	10	4	24	4	0	0	0	42	47	44	41	85	86	87	173	88	88	175	77	69	146	91	86	177	0	0	0	0	0	0	0	
74224	13	46	52	51	103	2	14	0	0	0	0	0	0	14	24	15	12	27	36	40	76	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
74300	13	50	69	60	129	2	15	0	0	0	0	0	0	15	25	21	26	46	39	44	83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	99	52	0	0	0	0	0	0	0	0	0	0	0	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
74412	14	42	178	158	336	3	13	4	0	0	0	0	0	17	26	34	35	69	31	38	70	93	105	197	0	0	0	0	0	0	0	0	0	0	0	0	0	
74630	24	35	258	277	535	5	14	4	21	4	0	0	0	43	49	41	40	81	83	87	170	38	41	79	56	49	105	59	41	100	0	0	0	0	0	0	0	
74718	14	40	216	213	429	3	15	4	0	0	0	0	0	19	27	45	47	92	84	82	166	84	87	171	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
74724	13	45	27	24	52	2	10	0	0	0	0	0	0	10	21	11	13	24	13	14	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
74800	13	40	56	62	118	2	15	0	0	0	0	0	0	15	26	20	18	38	42	38	79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
75000	24	34	354	377	730	5	11	4	22	4	0	0	0	42	47	41	41	82	91	76	168	83	73	156	81	78	159	80	85	165	0	0	0	0	0	0	0	
75042	24	49	133	152	285	5	14	4	21	4	0	0	0	44	49	40	41	81	36	32	68	31	29	60	27	16	43	18	16	34	0	0	0	0	0	0	0	
75142	13	45	47	55	101	2	15	0	0	0	0	0	0	15	25	15	12	28	39	34	74	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
75300	21	32	78	91	169	3	9	26	0	0	0	0	0	35	42	23	22	45	32	35	66	36	21	57	0	0	0	0	0	0	0	0	0	0	0	0	0	
75348	22	45	109	153	262	4	12	24	4	0	0	0	0	40	52	39	40	80	46	45	91	26	1	27	42	23	64	0	0	0	0	0	0	0	0	0	0	
75518	24	45	138	153	291	5	9	4	28	4	0	0	0	45	51	41	45	86	19	11	30	44	38	82	27	22	49	22	21	43	0	0	0	0	0	0	0	
160106	13	46	49	56	105	2	11	0	0	0	0	0	0	11	15	22	19	41	35	30	64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	99	42	0	0	0	0	0	0	0	0	0	0	0	0	-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

TABLE 5.3. PRINTOUT OF THE VEHICLE DATA

TABLE 5.4. LEGEND FOR THE VEHICLE DATA

Time	Time vehicle passed over system - e. g. 13912 means 01 hr. 39 min. and 12 sec. from known reference time of day
VT	Vehicle type - classification code
VS	Vehicle speed - (mph)
LTOT	Left-side total weight (100 lb)
RTOT	Right-side total weight (100 lb)
GROS	Gross weight of the vehicle (100 lb)
N	Number of axles
AB	Axle spacing between first and second axles (ft)
BC	Axle spacing between second and third axles (ft)
CD	Axle spacing between third and fourth axles (ft)
DE	Axle spacing between fourth and fifth axles (ft)
EF	Axle spacing between fifth and sixth axles (ft)
FG	Axle spacing between sixth and seventh axles (ft)
GH	Axle spacing between seventh and eighth axles (ft)
WB	Wheel base (ft)
VL	Vehicle length (ft)
AR	Weight of front-axle right tire (100 lb)
AL	Weight of front-axle left tire (100 lb)
A	Weight of front axle
BR	Weight of second-axle right tire (S) (100 lb)
BL	Weight of second-axle left tire (S) (100 lb)
B	Weight of second axle Similarly the same for axles C, D, E, F, G, and H (Provision is made for a maximum of 8 axles.)

TABLE 5.5. VEHICLE CLASSIFICATION CODE

VEHICLE CLASSIFICATION CODE

CODE		DESCRIPTION
13	2D	TWO-AXLE SINGLE UNIT TRUCK (WITH SPACING 9-16FT BETWEEN THE TWO AXLES.
14	3A	THREE-AXLE SINGLE UNIT TRUCK (WITH SPACING 12-20 FT BETWEEN FIRST TWO AXLES AND 3.2-5FT BETWEEN SECOND AND THIRD AXLES
21	2S1	THREE-AXLE TRACTOR TRUCK SEMI-TRAILER COMBINATION (WITH SPACING 8-16FT BETWEEN FIRST AND SECOND AXLES AND 13-33FT BETWEEN SECOND AND THIRD AXLES)
22	2S2	FOUR-AXLE TRACTOR TRUCK SEMI-TRAILER COMBINATION (WITH SPACING 8-16FT BETWEEN FIRST AND SECOND AXLES,13-33FT BETWEEN THE SECOND AND THIRD AXLES, AND 3.2-5FT BETWEEN THE THIRD AND FOURTH AXLES)
23	3S1	FOUR AXLE TRACTOR TRUCK SEMI-TRAILER COMBINATION (WITH SPACING 8-16FT BETWEEN FIRST AND SECOND AXLES,3.2-5FT BETWEEN SECOND AND THIRD AXLES, 13-33FT BETWEEN THIRD AND FOURTH AXLES)
24	3S2	FIVE AXLE TRACTOR TRUCK SEMI-TRAILER COMBINATION (WITH SPACING 8-16FT BETWEEN FIRST AND SECOND AXLES, 3.2-5FT BETWEEN SECOND AND THIRD AXLES, 13-33FT BETWEEN THIRD AND FOURTH AXLES, AND 3.2-5FT BETWEEN FOURTH AND FIFTH AXLES)
52	2S1-2	FIVE AXLE TRACTOR TRUCK SEMI-TRAILER-TRAILER COMBINATION (WITH SPACING 8-16FT BETWEEN FIRST AND SECOND AXLES, 13-33FT BETWEEN SECOND AND THIRD AXLES, 8-11FT BETWEEN THIRD AND FOURTH AXLES, AND 13-33FT BETWEEN FOURTH AND FIFTH AXLES)
53	2S1-3	SIX AXLE TRACTOR TRUCK SEMI-TRAILER - TRAILER COMBINATION (WITH SPACING 8-16FT BETWEEN FIRST AND SECOND AXLES, 13-33FT BETWEEN SECOND AND THIRD AXLES, 8-11FT BETWEEN THIRD AND FOURTH AXLES,13-33FT BETWEEN FOURTH AND FIFTH AXLES, AND 3.2-5FT BETWEEN FIFTH AND SIXTH AXLES)
56	2S2-2	SIX AXLE TRACTOR TRUCK SEMI-TRAILER - TRAILER COMBINATION (WITH SPACING 8-16FT BETWEEN FIRST AND SECOND AXLES, 13-33FT BETWEEN SECOND AND THIRD AXLES, 3.2-5FT BETWEEN THIRD AND FOURTH AXLES, 8-11FT BETWEEN FOURTH AND FIFTH AXLES, AND 13-33FT BETWEEN FIFTH AND SIXTH AXLES)
57	2S2-3	SEVEN AXLE TRACTOR TRUCK SEMI-TRAILER - TRAILER COMBINATION (WITH SPACING 8-16FT BETWEEN FIRST AND SECOND AXLES, 13-33FT BETWEEN SECOND AND THIRD AXLES, 3.2-5FT BETWEEN THIRD AND FOURTH AXLES, 8-11FT BETWEEN FOURTH AND FIFTH AXLES, 13-33FT BETWEEN FIFTH AND SIXTH AXLES, AND 3.2-5FT BETWEEN SIXTH AND SEVENTH AXLES)
65	3S1-2	SIX AXLE TRACTOR TRUCK SEMI-TRAILER - TRAILER COMBINATION (WITH SPACING 8-16FT BETWEEN FIRST AND SECOND AXLES, 3.2-5FT BETWEEN SECOND AND THIRD AXLES, 13-33FT BETWEEN THIRD AND FOURTH AXLES, 8-11FT BETWEEN FOURTH AND FIFTH AXLES, AND 13-33FT BETWEEN FIFTH AND SIXTH AXLES)
66	3S1-3	SEVEN AXLE TRACTOR TRUCK SEMI-TRAILER - TRAILER COMBINATION (WITH SPACING 8-16FT BETWEEN FIRST AND SECOND AXLES, 3.2-5FT BETWEEN SECOND AND THIRD AXLES, 13-33FT BETWEEN THIRD AND FOURTH AXLES, 8-11FT BETWEEN FOURTH AND FIFTH AXLES, 13-33FT BETWEEN FIFTH AND SIXTH AXLES, AND 3.2-5FT BETWEEN SIXTH AND SEVENTH AXLES)
69	3S2-2	SEVEN AXLE TRACTOR TRUCK SEMI- TRAILER - TRAILER COMBINATION (WITH SPACING 8-16FT BETWEEN FIRST AND SECOND AXLES, 3.2FT-5FT BETWEEN SECOND AND THIRD AXLES 13FT-33FT BETWEEN THIRD AND FOURTH AXLES, 3.2FT-5FT BETWEEN FOURTH AND FIFTH AXLES,
71	3S2-3	EIGHT AXLE TRACTOR TRUCK SEMI-TRAILER - TRAILER COMBINATION WITH SPACING 8-16FT BETWEEN FIRST AND SECOND AXLES, 3.2-5FT BETWEEN SECOND AND THIRD AXLES, 13-33FT BETWEEN THIRD AND FOURTH AXLES, 3.2-5FT BETWEEN FOURTH AND FIFTH AXLES, 8-11FT BETWEEN FIFTH AND SIXTH AXLES, 13-33FT BETWEEN SIXTH AND SEVENTH AXLES AND 3.2-5FT BETWEEN SEVENTH AND EIGHTH AXLES.

The least-square-method curve shows that the slopes of the lines for the different curves are as follows:

The gross weight	.99
Axle 1	.95
Axle 2	.94
Sum of left wheels	1.01
Sum of right wheels	.98

In addition to the above mentioned curves, the portable scale total left-wheel loads for each vehicle were plotted against the total right-wheel loads as shown in Fig 5.15. The least-square-method curve fit shows that the right side was generally heavier than the left side.

CHAPTER 6. EXTENDED APPLICATIONS OF PORTABLE SCALE

The wheel load transducers are one component of the system used to sample highway traffic characteristics needed for planning and design purposes. These transducers, however, are found to be ideal and convenient for applications other than those mentioned in the preceding chapters. These include applications in the field of research, classification and enforcement, and commercial use.

Application in Research

Highway pavement systems are designed to carry vehicular traffic and to withstand severe environmental and other ambient conditions for the design life of several years with minimum maintenance or major replacements. During the design life of the pavement, the structure is subjected to millions of repetitions of dynamic loads which vary in magnitude, duration, and frequency. Knowledge of the characteristics of these loads is a prime prerequisite to a good and sound structural design.

Present structural design procedures utilize static strength tests on materials and attempt by design to balance the strength of the material with the stress to which the material will be subjected when loaded. A safety factor or impact factor is normally applied to account for the effects of dynamic loading. Since there is no real knowledge as to the magnitude, duration, and frequency of dynamic loads to which highway structures are subjected, nor an adequate understanding of the response of these structures to dynamic and static loads, precise or optimum designs are impossible. Even though most highway structures have proved to be structurally adequate, many failures have occurred prematurely or unexpectedly. The results of the recently terminated AASHO Road Test indicate rather dramatically the need for improved design procedures which realistically account for many complex factors including the effects of dynamic loading by mixed traffic. Measuring and defining the spectrum of traffic loads to which highway structures are subjected will be a significant contribution to the knowledge needed for improving pavement and bridge design methods.

Before the development of this wheel load transducer, there has been no good way to measure the forces applied to highway structures through the wheels of the moving vehicles. The transducer can be installed at virtually any location on a highway, thus providing a new research tool for investigating these dynamic wheel loads and the distribution among the lanes of multi lane facilities. Furthermore, the operating characteristics of loaded vehicles are different from those of empty or lightly loaded ones. Weight sensors capable of detecting moving wheel loads must be installed in each lane in order to determine which lanes are used by vehicles in different weight classes.

The Center for Highway Research at The University of Texas is currently conducting research for the Texas Highway Department in cooperation with the U. S. Bureau of Public Roads in which twelve wheel load transducers are being used to study the dynamics of highway loading.

A typical view of a field installation at one of the study sites is shown in Fig 6.1. This site is one of several other sites each with different type and texture of pavement surface which is one of the several parameters under study.

Classification of Moving Vehicles According to Weight

Traffic Control. Loaded vehicles have different operating characteristics than empty ones and heavy vehicles accelerate at a slower rate than passenger cars. Sophisticated traffic control systems, such as the ramp metering equipment developed by Automatic Signal for Texas Transportation Institute for use on the Gulf Freeway in Houston, project the position of an accelerating vehicle on an entrance ramp in time so that an acceptable gap, as sensed by vehicle presence detectors, will be available in the freeway traffic stream when the ramp vehicle arrives at the end of the ramp. Scales installed in the ramp in advance of the ramp metering point can supply pertinent information necessary for classifying each ramp vehicle according to weight and size and thus permits a good projection of its position with respect to time during acceleration on the ramp.

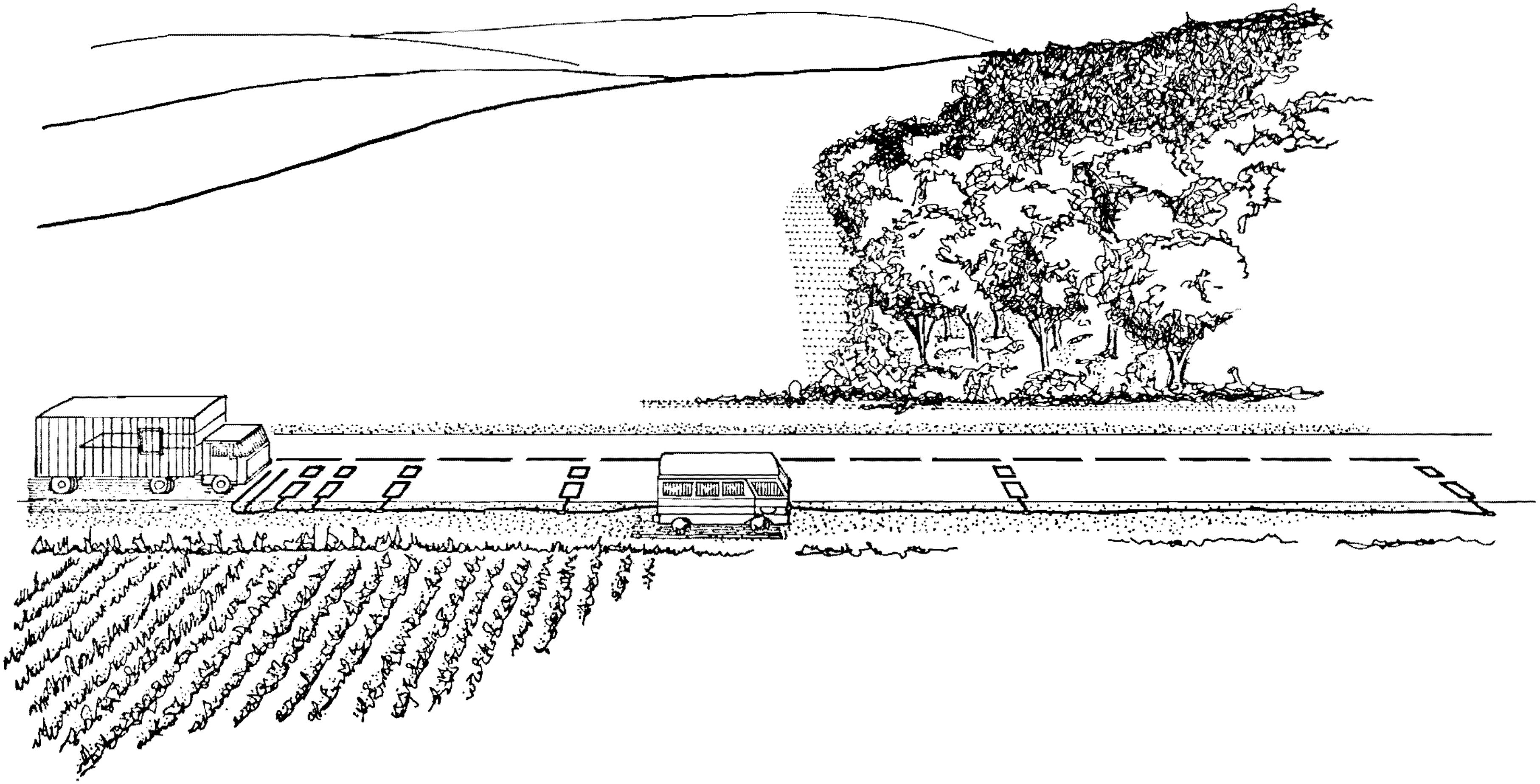

Fig 6.1. Typical dynamics field study.

Legal Weight Limits Enforcement. At the present time most commercial vehicles are being stopped at weighing stations for weight limits enforcement. Enforcement is based on static axle loads, but it is possible, as mentioned before, to estimate static axle weight from samples of dynamic wheel loads with reasonable precision under given conditions. Electronic scales installed in the traffic lanes in advance of a weight enforcement station can be used to sort out those vehicles suspected of being overloaded and allow vehicles with wheel loads obviously within the legal limits to pass over the transducers and continue their journey uninterrupted. This operation can be achieved by setting up an alarm circuit arranged to illuminate a sign that directs suspects into the weighing station for further weight check. The weight level at which this alarm will be triggered can be selected to account for the difference in the dynamic and static wheel load that is likely to be involved when vehicles are weighed while moving at normal road speeds. Since the various factors discussed previously in this report influence the dynamic loads, an extremely high degree of precision is impossible, but for this application it is probably unnecessary. For each installation, the weight level for triggering the alarm can be determined by trial. A low weight level can be selected at first, and then if a significant number of vehicles are weighed, other levels can be established. Such application of the transducers will eliminate unnecessary weighing and delay of vehicles operating within the legal weighing limits.

Commercial Applications

Field weighing is one of the major problems associated with construction industry. This includes weighing of earth moving and other construction equipments which is important both to the manufacturer and to the contractor (Ref 18). The manufacturer is interested in finding the loading abilities of the machines and their performance on the job, and also in determining the tire and axle weight distribution. The contractor, on the other hand, is interested in measuring quantities, optimizing loading size-loading time relationships, and putting the job on a better paying basis.

For the past two decades, engineers have been trying to see solutions for the numerous problems encountered in the field weighing. The present methods, in spite of the progress achieved, are still not very satisfactory in as far as their effectiveness and efficiency.

The wheel load transducer offers an ideal solution to many of these encountered problems. It has already been mentioned that forces transmitted by a slow moving wheel (1-10 mph) to a transducer placed in a relatively smooth pavement can approximate the static weight of the wheel to probably within 1 percent. This is made possible by negligible effects of bouncing at low speeds.

The following are some specific examples of possible applications in this area:

(1) Weighing construction materials or products such as aggregates, asphalt, cement, lime, and water at: (a) plant or quarry and (b) construction site.

(2) Production control and determining whether haul vehicles are loaded to rated capacity. Here either overloading or underloading results in inefficiency.

(3) Checking overloading during construction. Haul vehicles or erection devices (cranes, form trucks, etc.) might overload partially-curved concrete structures (bridges or pavements) during the first few weeks after placement. Installation of portable transducers with overload alarm could discourage this practice.

(4) Aid to enforcement. The weighing of vehicles at sites selected for enforcement can be expedited by weighing each axle as vehicles pass over transducer and then printing or otherwise displaying a record of weights at a remote location beyond weighing point. This arrangement can be used either in a permanent or portable setup.

(5) The same transducer design can be used for transportable scales to weight aircraft and other large machines.

Finally, weighing tables of almost any practicable size can be made by using the principles of design employed in the wheel load transducer.

CHAPTER 7. CONCLUSIONS

Summary

The portable electronic scale which has been developed at the Center for Highway Research, The University of Texas, consists of a pair of wheel load transducers and associated detecting and recording instruments, all making up the vehicle data recording system. The transducers, each of which is 54 x 20 inches in plan dimensions and about 2-inches thick, are simple in design, rugged, and portable. Inertial effects in the transducers are negligible, and the electrical output signals depend only upon the magnitude of the load applied normal to the surface. Since only 2-1/2 inches of pavement must be removed, the transducers can be installed in any smooth roadway surface including rigid pavements and bridge decks. Initial installation requires approximately 4 hours, but subsequent installations at a previously occupied site requires only about 45 minutes.

During the experimental stage of the scale development, basic electronic equipment was used. Signals were displayed in the screen of an oscilloscope and Polaroid photographs were made for permanent records. Later an instrument system, including an analog FM tape recorder and other associated logic circuitry, was constructed under a contract by Philco Corporation and was used to record on tape in analog form information regarding vehicle speed, vehicle length, time of day, number of axles, axle spacing, and wheel weight.

Analysis of data on nearly 500 different vehicles, each of which was weighed both statically by a conventional loadometer and while moving at normal highway speeds by the portable electronic scale, indicate that static vehicle weight can be estimated from the weights obtained by the portable scale within 10 percent precision which is sufficient for planning and design purposes. The precision of the estimate can undoubtedly be improved by using more than one pair of transducers for sensing the moving wheel loads.

There are many potential uses for the portable electronic scale in highway planning, design, and operation. Routine statistical data procurement without stopping or delaying traffic has been described. Computer programs for processing were presented. Vehicles can be classified automatically into groups according to the number of axles per vehicle or wheel weight. Lane use by various classes of vehicles can be studied. Traffic control devices can be operated. Unnecessary delay to vehicles which are within the legal weight limits can be eliminated by using the electronic scale as a sorting device at static weight enforcement stations. Research leading to a better understanding of the behaviour of highway structures and pavements subjected to repeated dynamic loads can be initiated. Contractors will find the scale convenient for field weighing on construction jobs. Finally, several other uses of this dynamic weighing device must be left to the imagination of engineers.

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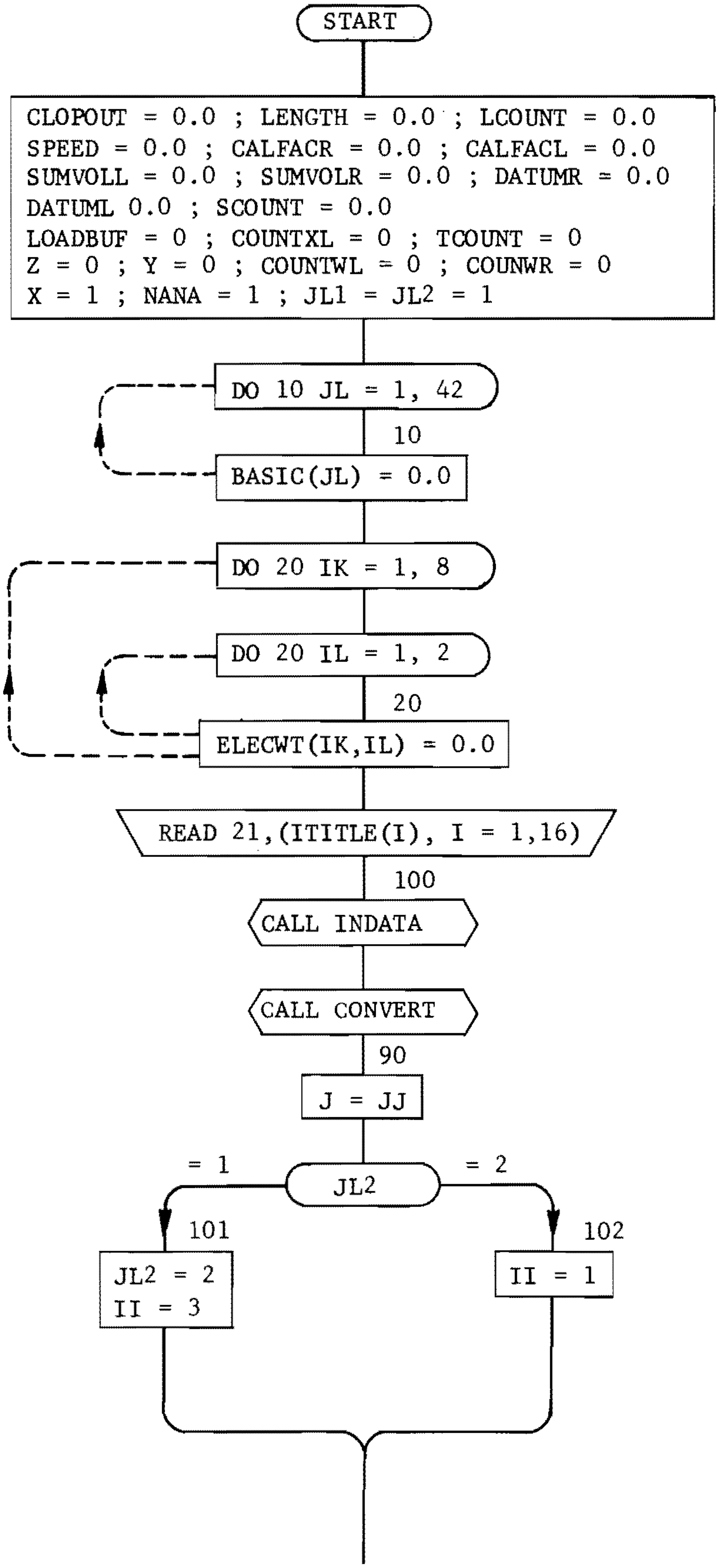
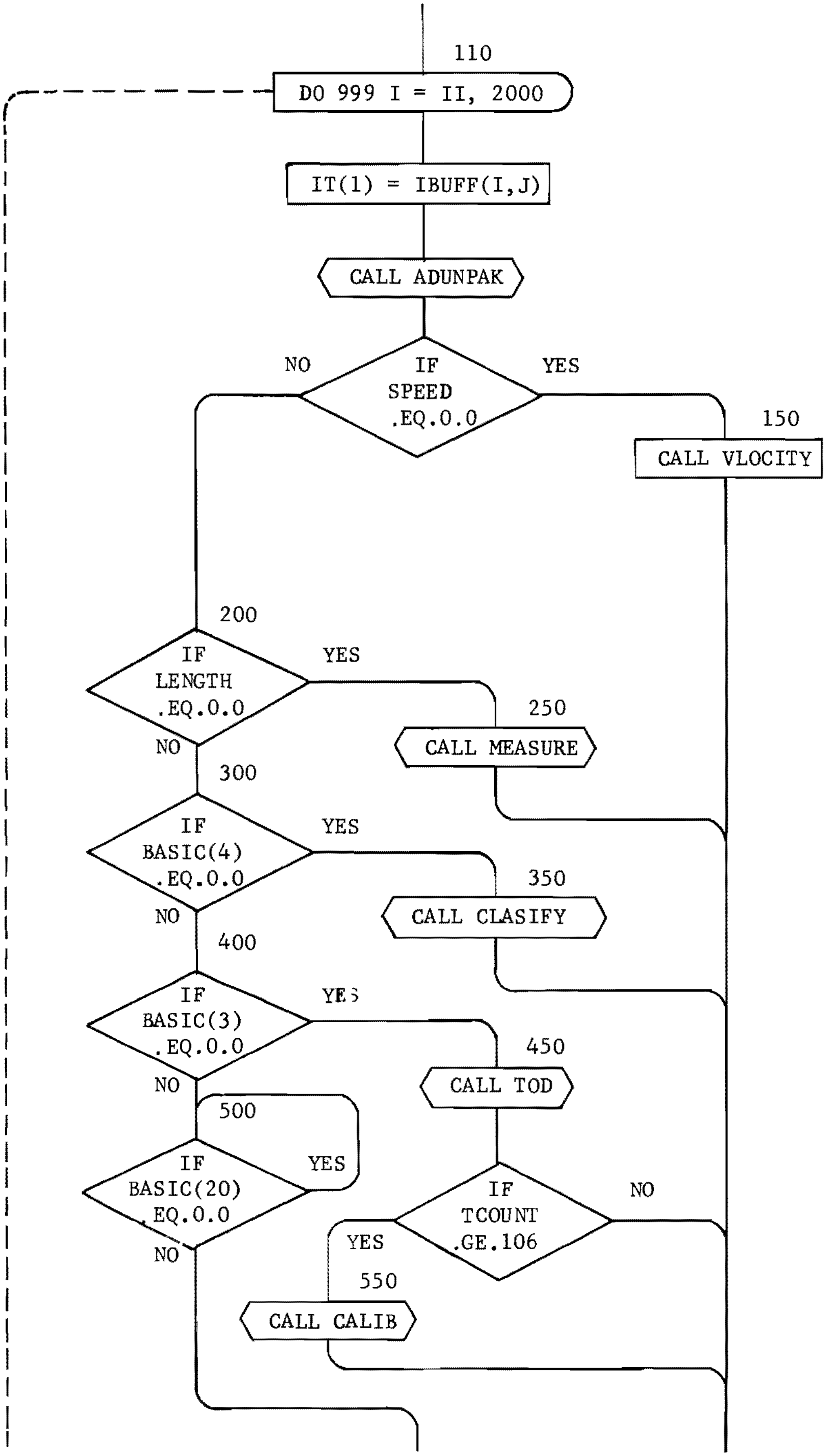
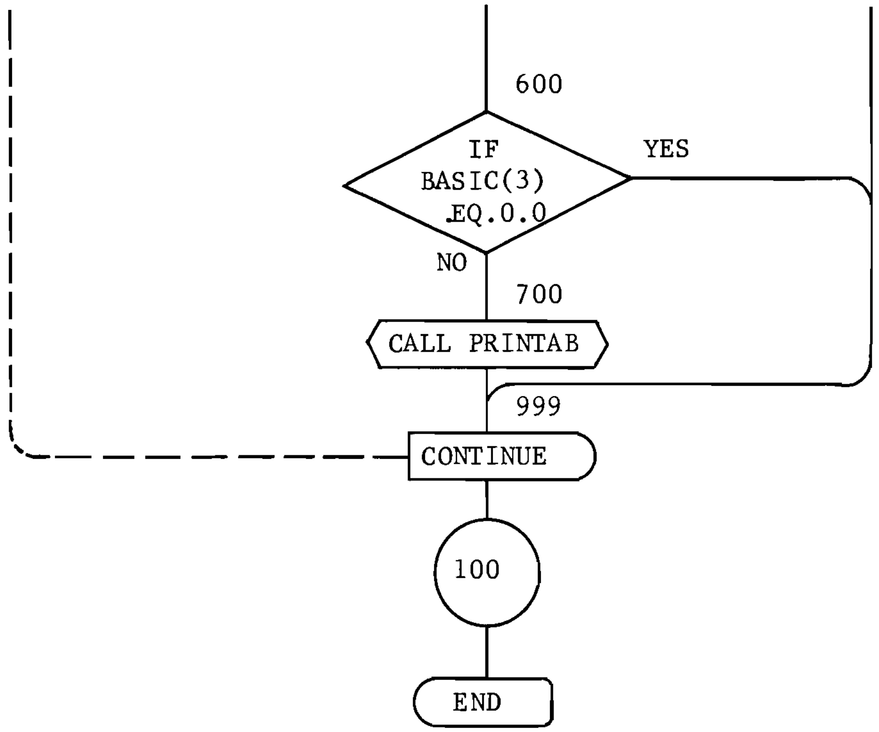
APPENDIX A

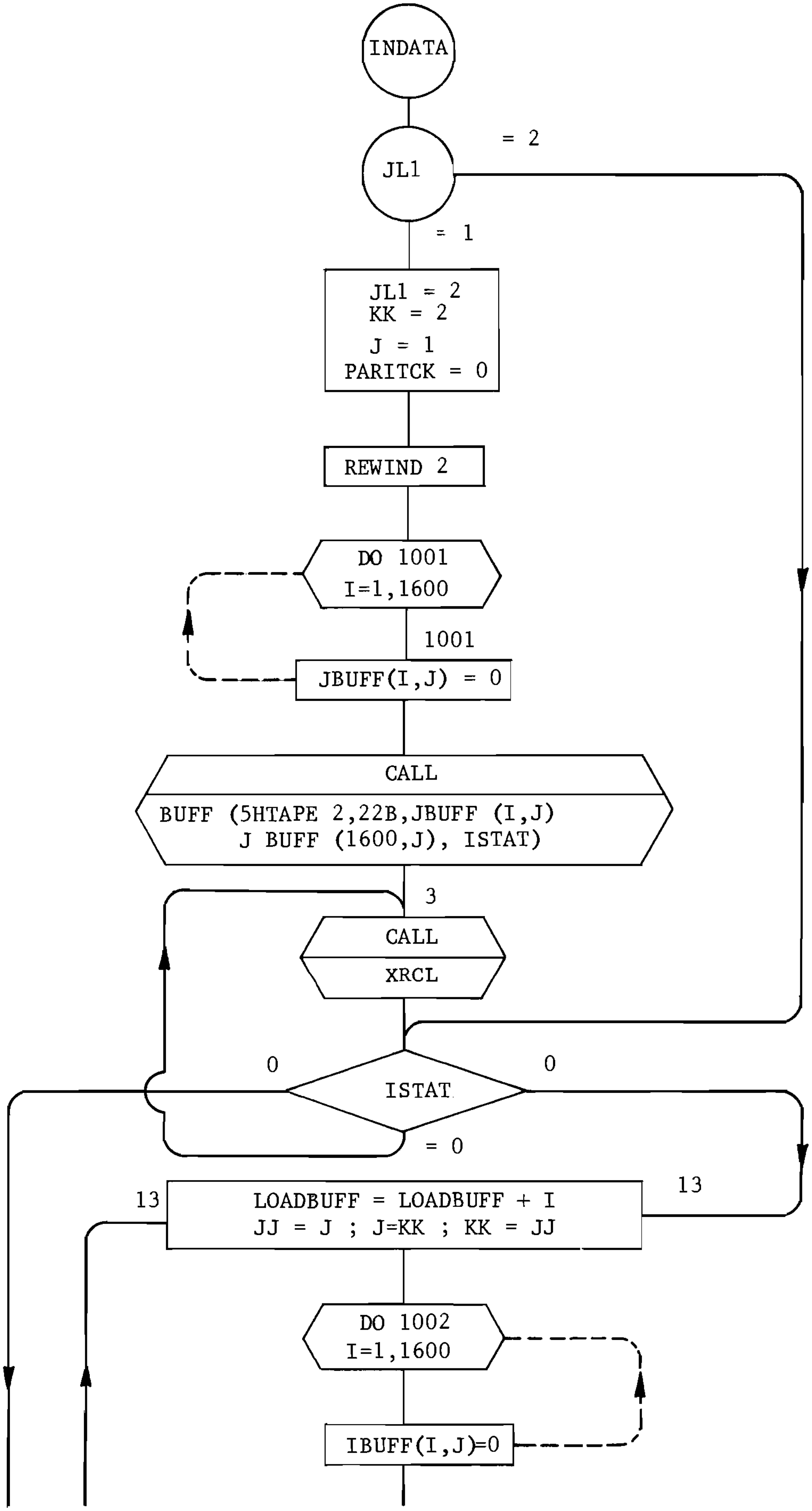
COMPUTER PROGRAMS

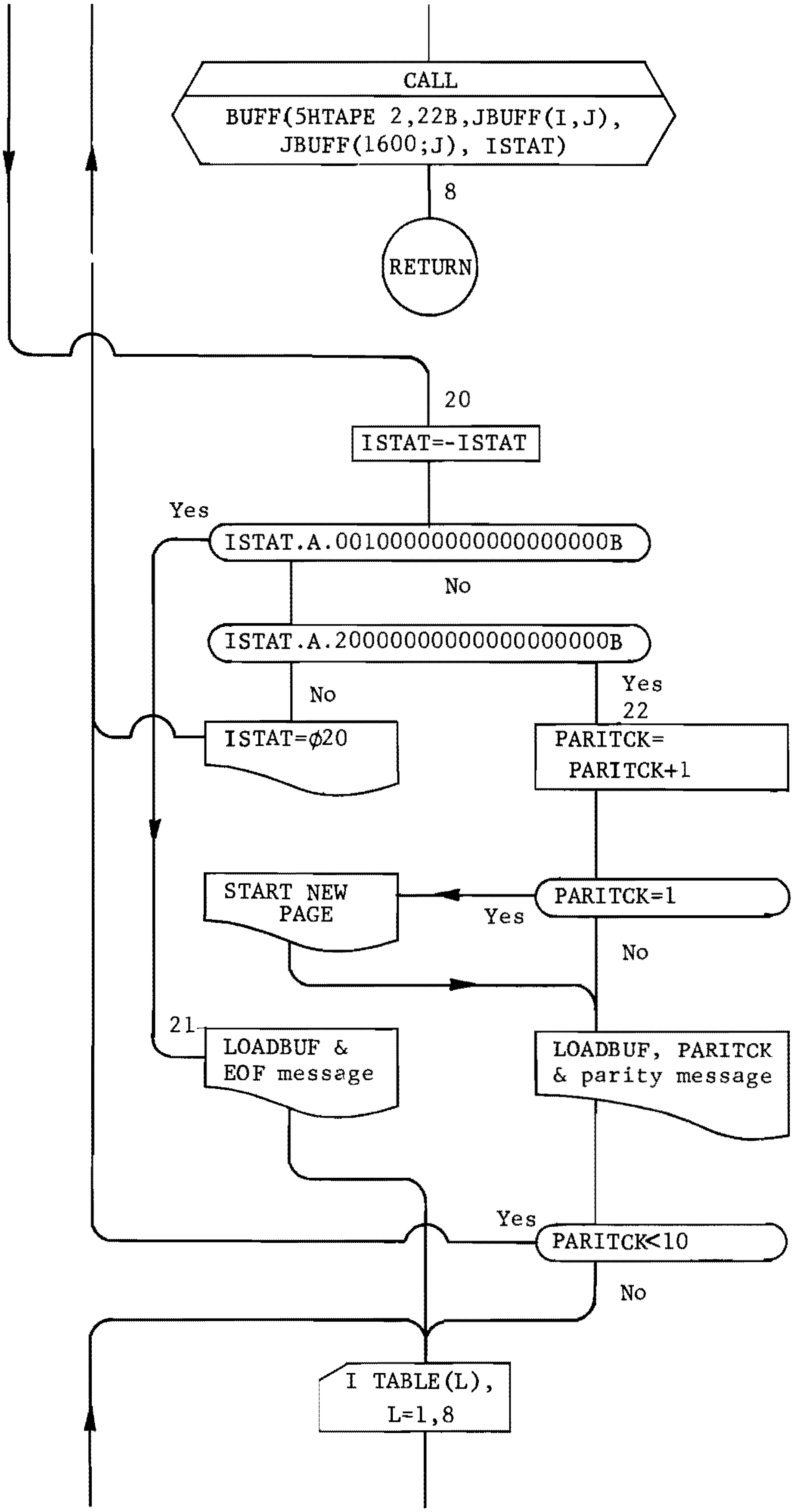
DRIVER PROGRAM

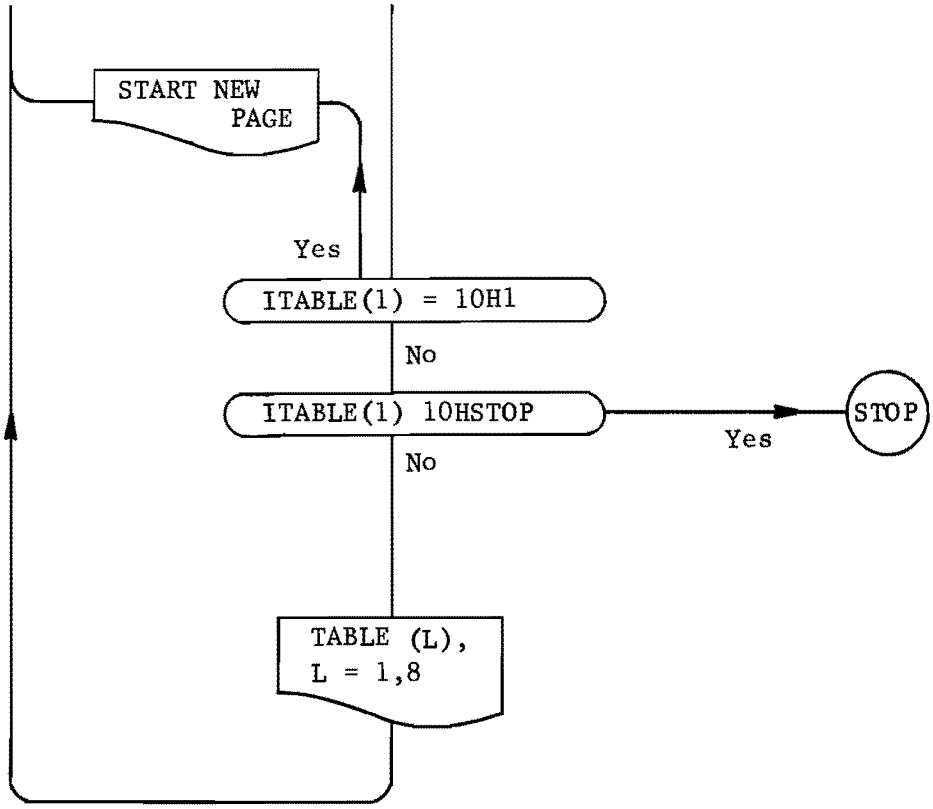



110
DO 999 I = II, 2000
IT(1) = IBUFF(I,J)
CALL ADUNPAK
NO
IF SPEED .EQ.0.0
YES
150
CALL VLOCITY
200
IF LENGTH .EQ.0.0
YES
250
CALL MEASURE
NO
300
IF BASIC(4) .EQ.0.0
YES
350
CALL CLASIFY
NO
400
IF BASIC(3) .EQ.0.0
YES
450
CALL TOD
NO
500
IF BASIC(20) .EQ.0.0
YES
NO
IF TCOUNT .GE.106
NO
YES
550
CALL CALIB

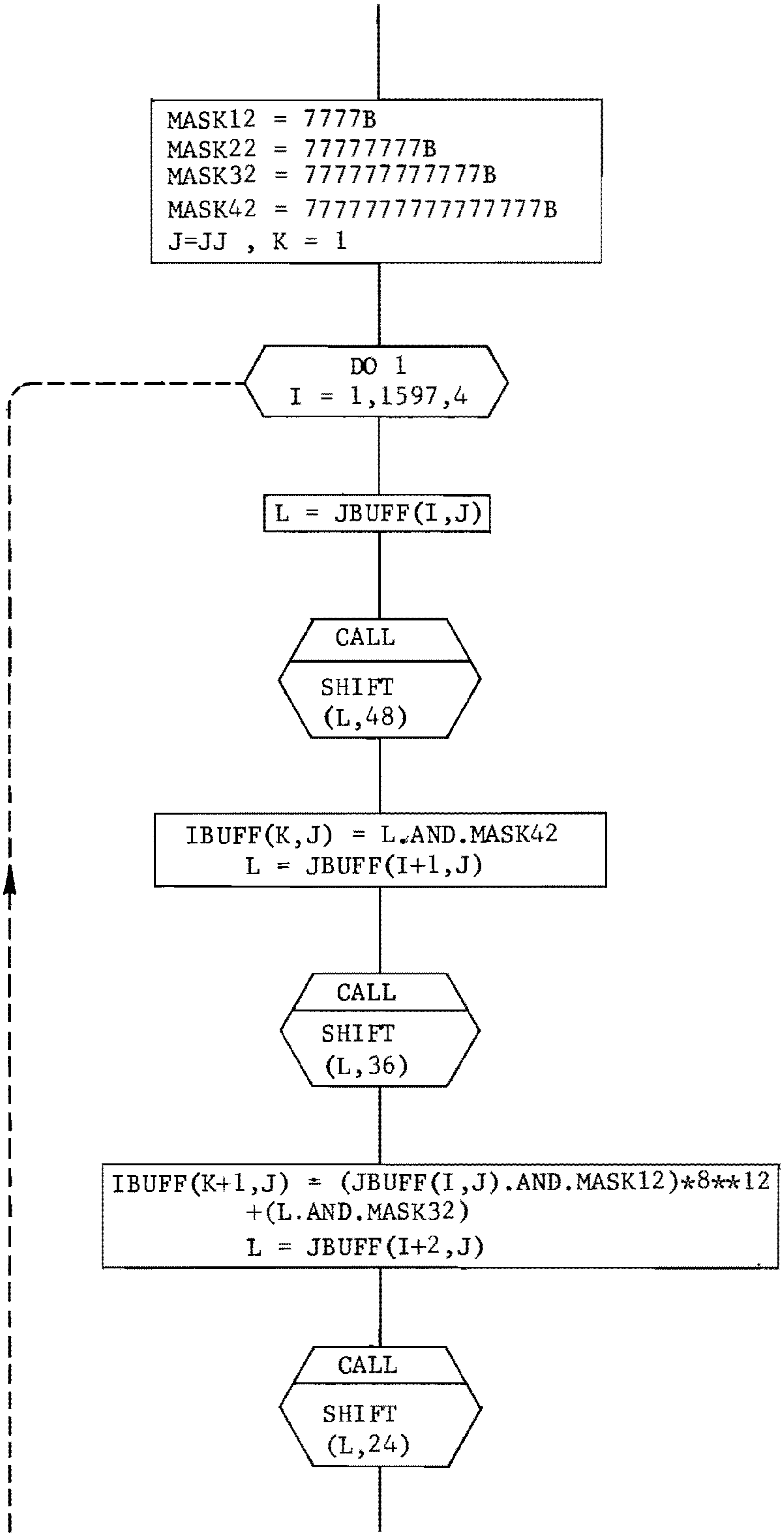

600
IF
BASIC(3)
.EQ.0.0
YES
NO
700
CALL PRINTAB
999
CONTINUE
100
END

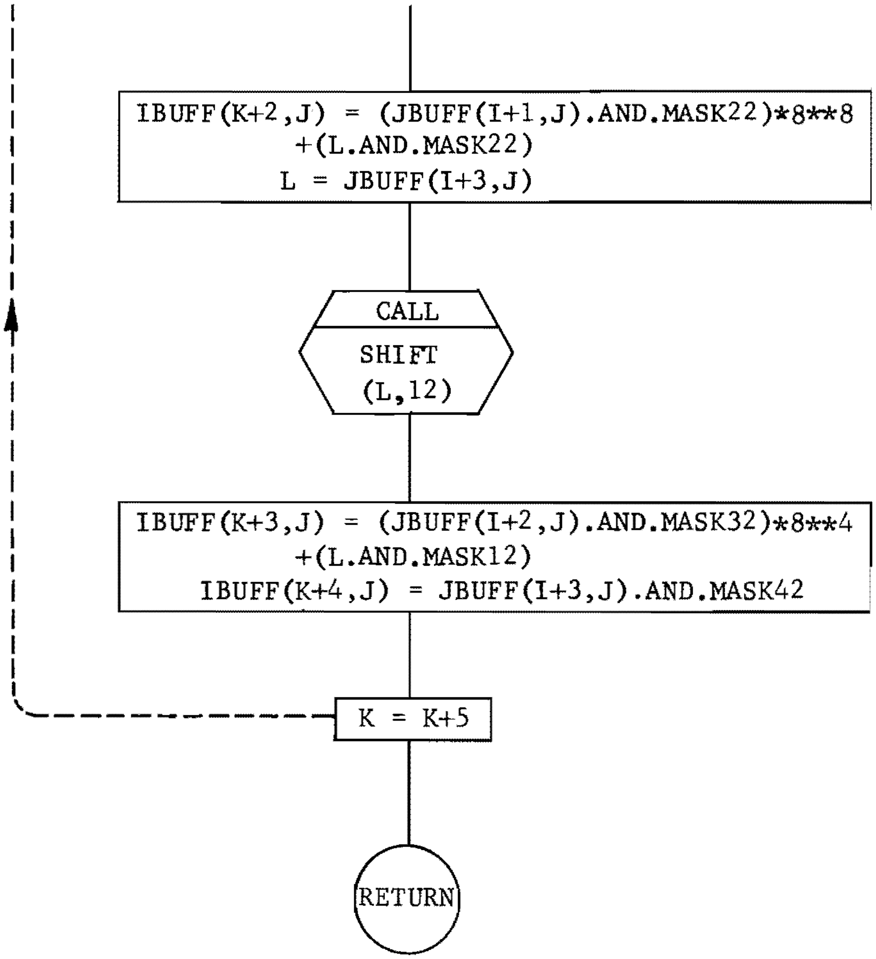

INDATA
JL1
= 2
= 1
JL1 = 2
KK = 2
J = 1
PARITCK = 0
REWIND 2
DO 1001
I=1,1600
1001
JBUFF(I,J) = 0
CALL
BUFF (5HTAPE 2,22B,JBUFF (I,J)
J BUFF (1600,J), ISTAT)
3
CALL
XRCL
0
ISTAT
0
= 0
13
LOADBUFF = LOADBUFF + I
JJ = J ; J=KK ; KK = JJ
13
DO 1002
I=1,1600
IBUFF(I,J)=0


CALL
BUFF(5HTAPE 2,22B,JBUFF(I,J), JBUFF(1600;J), ISTAT)
8
RETURN
20
ISTAT=-ISTAT
Yes
ISTAT.A.0010000000000000000B
No
ISTAT.A.2000000000000000000B
No
Yes
22
ISTAT=020
PARITCK= PARITCK+1
START NEW PAGE
Yes
PARITCK=1
No
21
LOADBUF & EOF message
LOADBUF, PARITCK & parity message
Yes
PARITCK<10
No
I TABLE(L), L=1,8

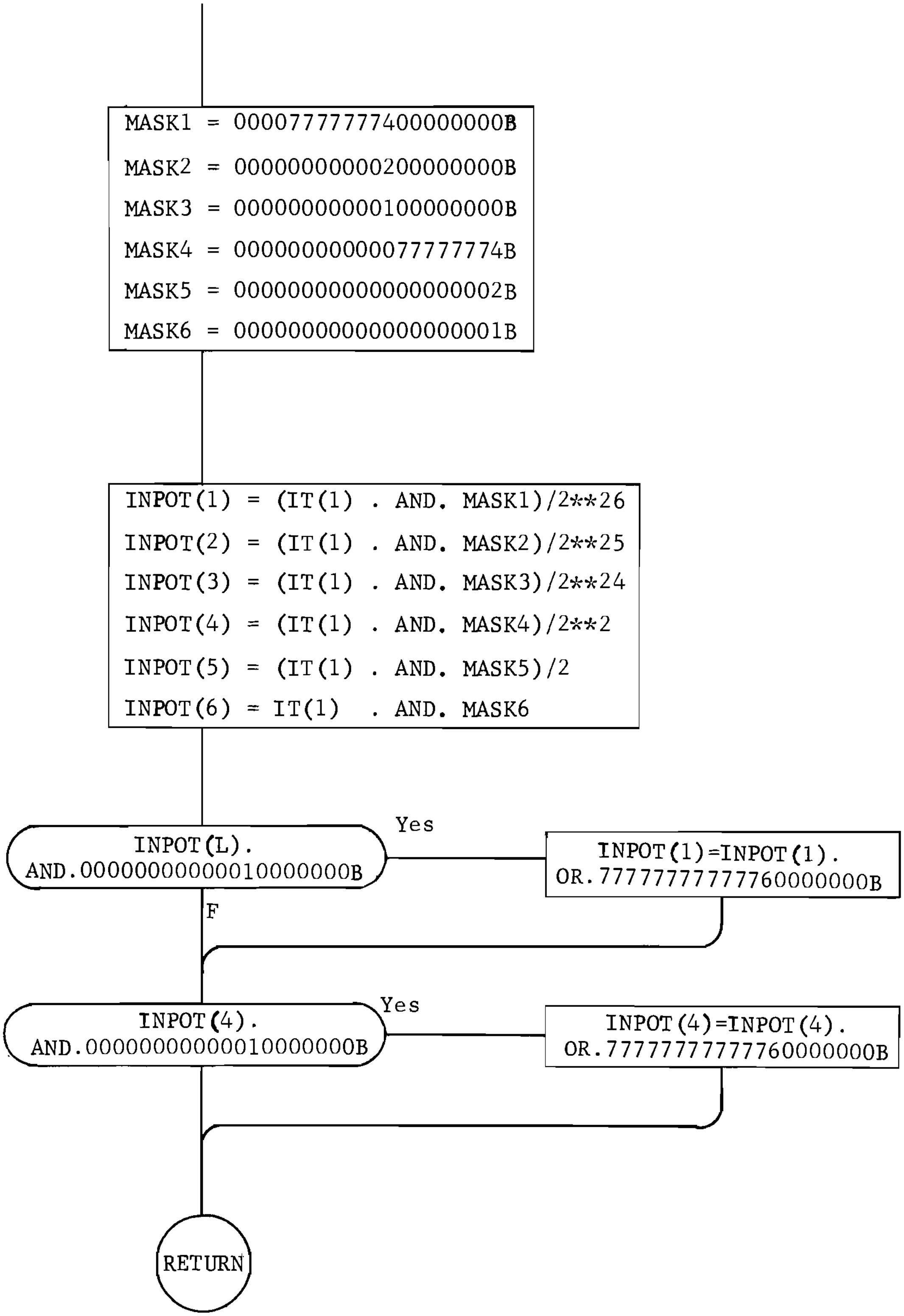

START NEW PAGE
Yes
ITABLE(1) = 10H1
No
ITABLE(1) 10HSTOP
Yes
STOP
No
TABLE (L), L = 1,8

SUBROUTINE CONVERT




IBUFF(K+2,J) = (JBUFF(I+1,J).AND.MASK22)*8**8
+(L.AND.MASK22)
L = JBUFF(I+3,J)
CALL
SHIFT
(L,12)
IBUFF(K+3,J) = (JBUFF(I+2,J).AND.MASK32)*8**4
+(L.AND.MASK12)
IBUFF(K+4,J) = JBUFF(I+3,J).AND.MASK42
K = K+5
RETURN

SUBROUTINE ADUNPAK



```
MASK1 = 00007777777400000000B
MASK2 = 00000000000200000000B
MASK3 = 00000000000100000000B
MASK4 = 00000000000077777774B
MASK5 = 00000000000000000002B
MASK6 = 00000000000000000001B
```

```
INPOT(1) = (IT(1) . AND. MASK1)/2**26
INPOT(2) = (IT(1) . AND. MASK2)/2**25
INPOT(3) = (IT(1) . AND. MASK3)/2**24
INPOT(4) = (IT(1) . AND. MASK4)/2**2
INPOT(5) = (IT(1) . AND. MASK5)/2
INPOT(6) = IT(1)  . AND. MASK6
```

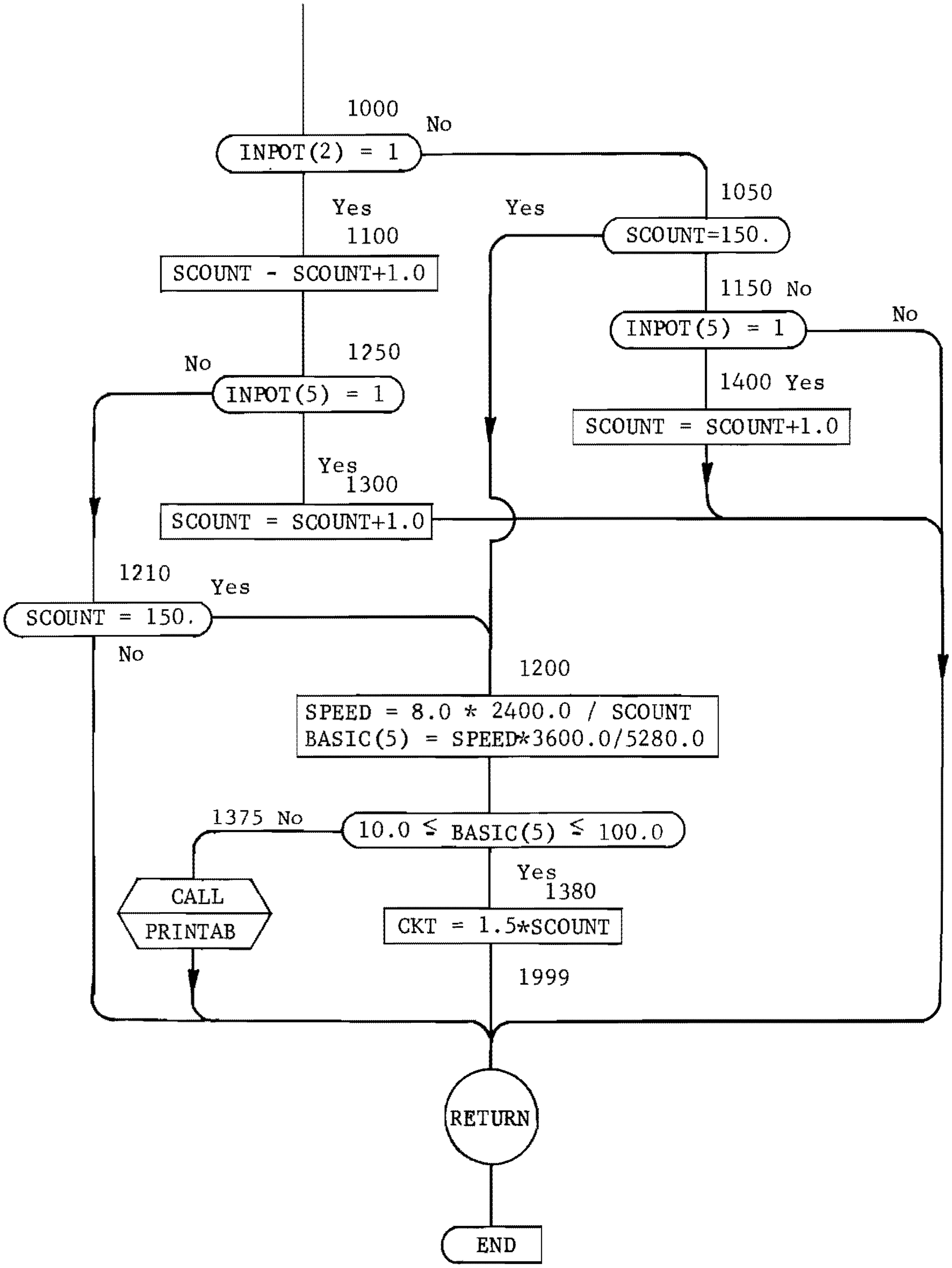
```
INPOT(L).
AND.00000000000010000000B
```

```
INPOT(1)=INPOT(1).
OR.77777777777760000000B
```

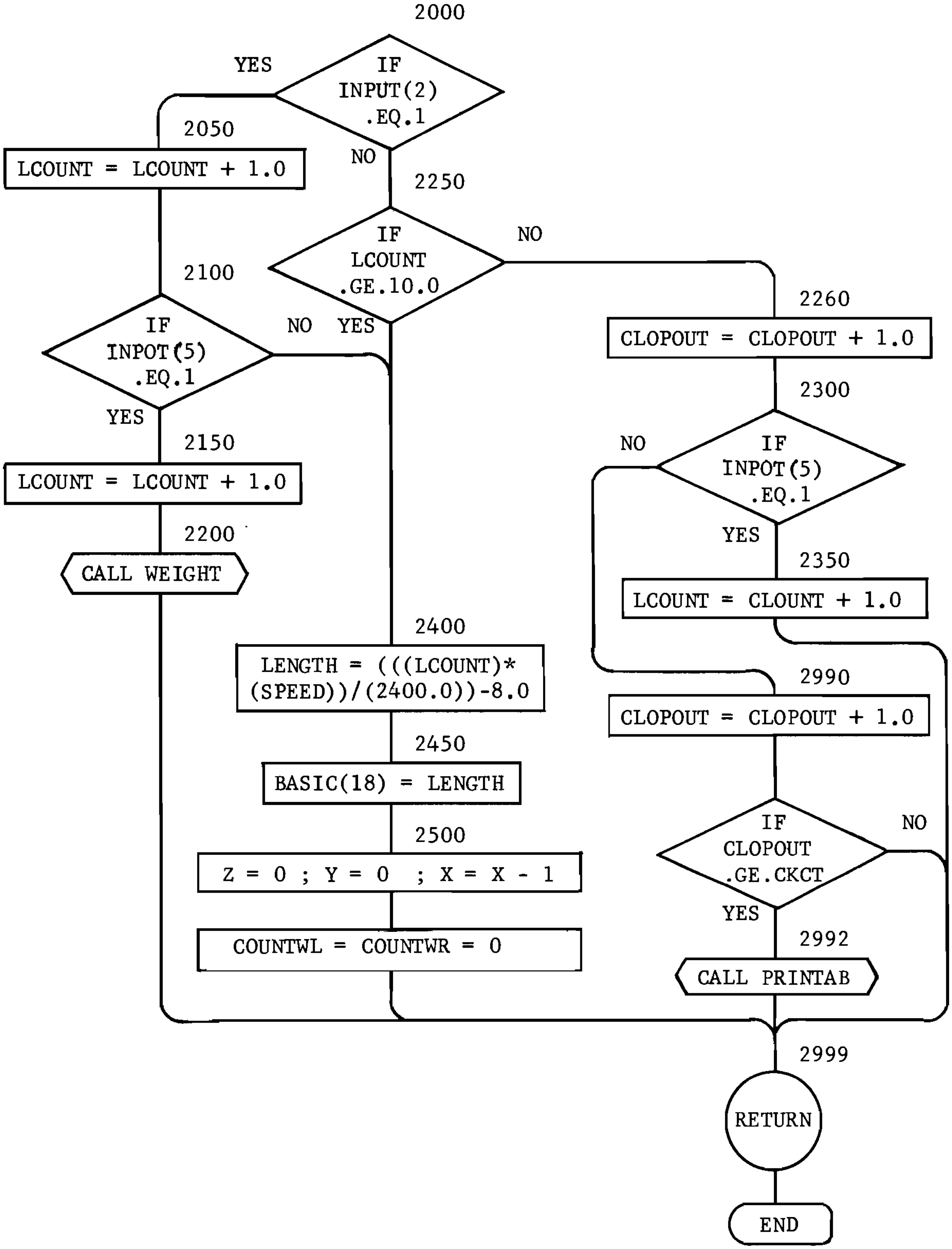
```
INPOT(4).
AND.00000000000010000000B
```

```
INPOT(4)=INPOT(4).
OR.77777777777760000000B
```

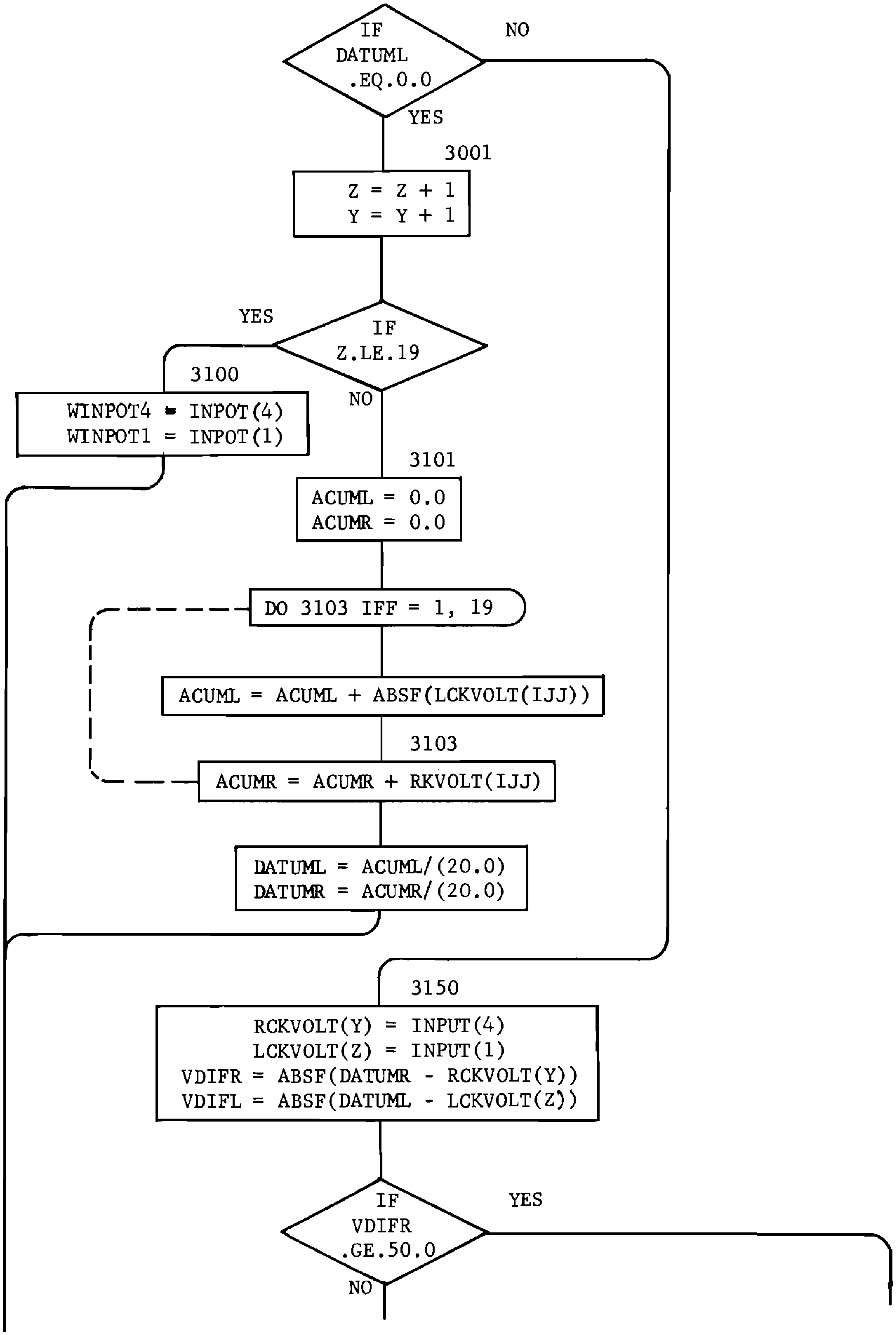
SUBROUTINE VLOCITY

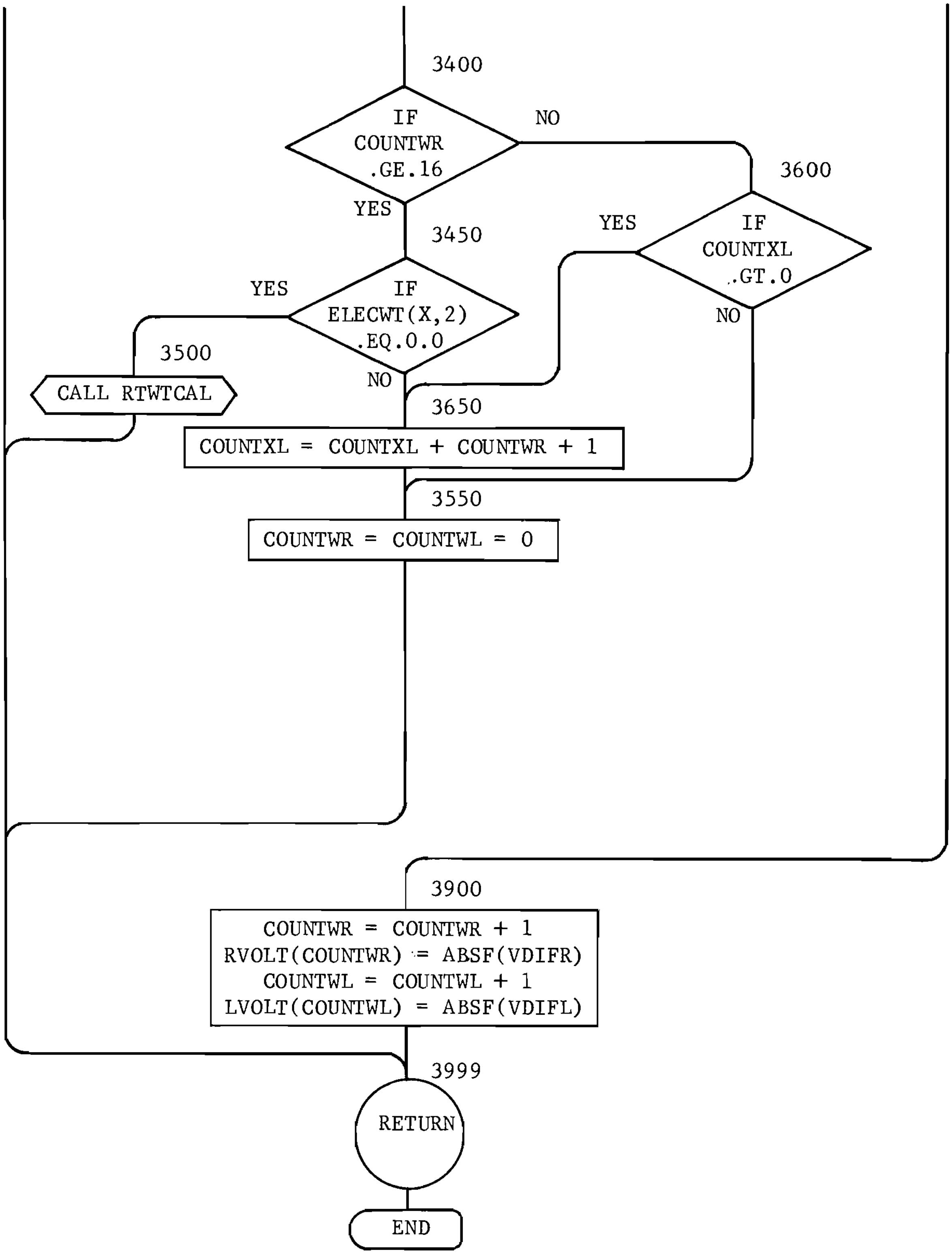


SUBROUTINE MEASURE

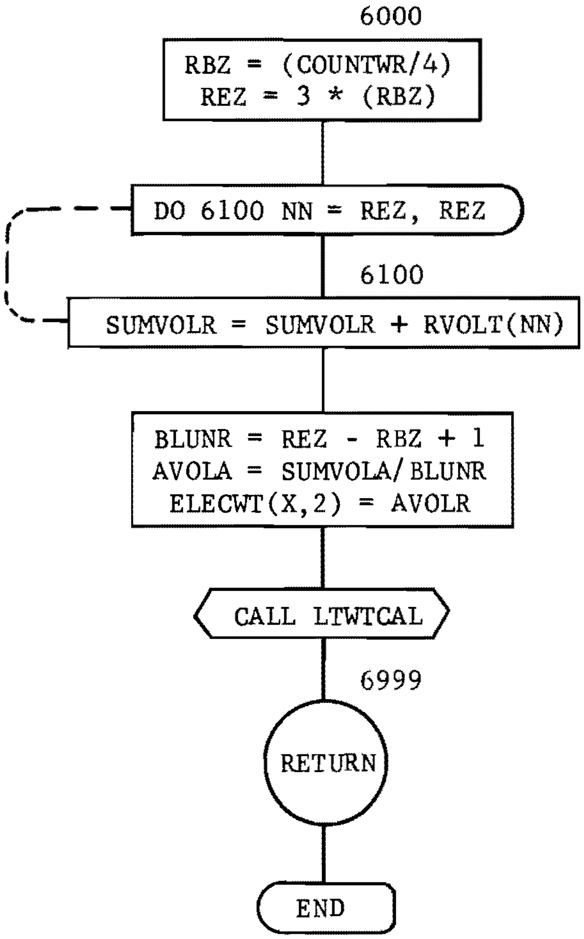


SUBROUTINE WEIGHT

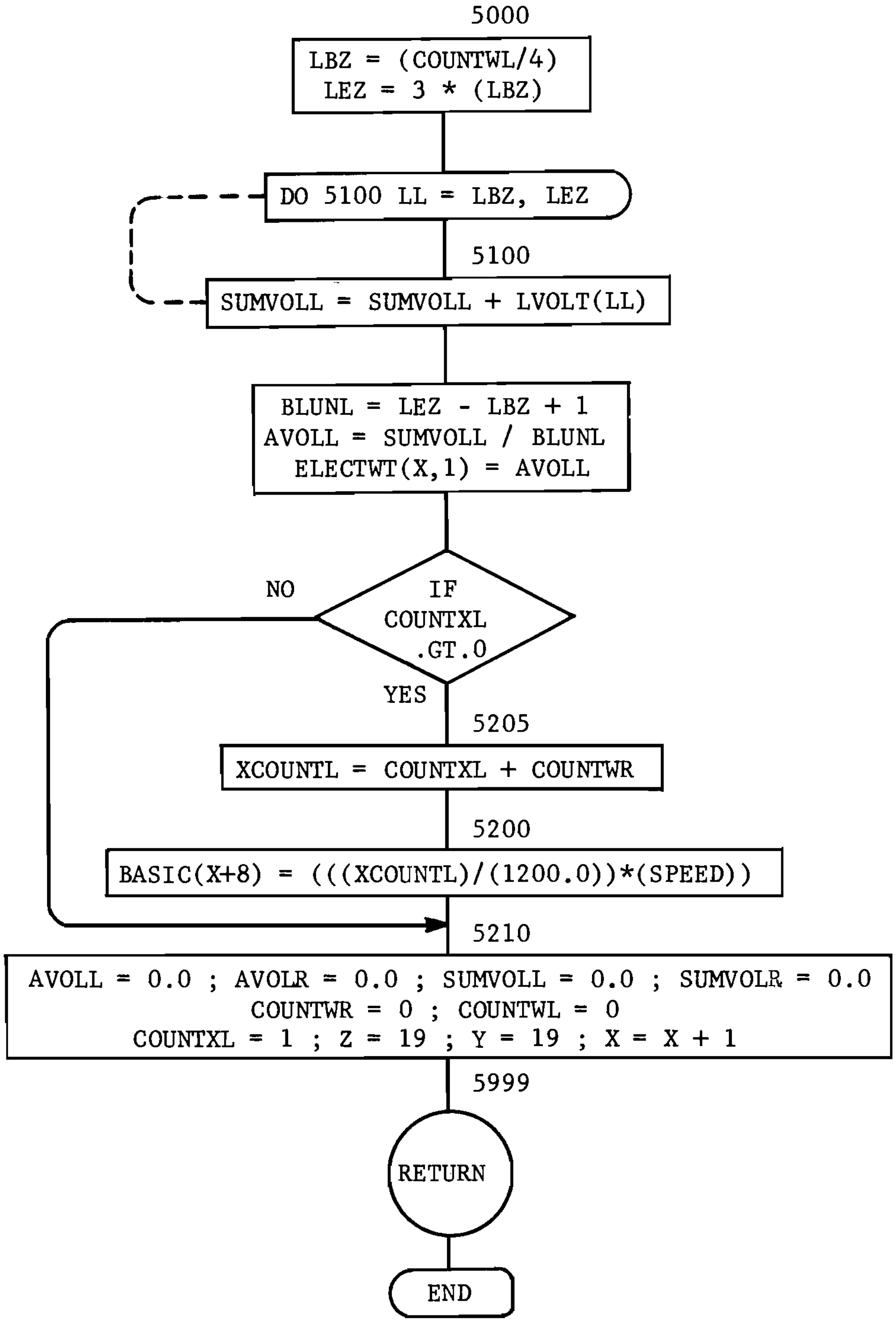



3400
IF COUNTWR .GE.16
NO
YES
3600
IF COUNTXL .GT.0
YES
NO
3450
IF ELECWT(X,2) .EQ.0.0
YES
NO
3500
CALL RTWTCAL
3650
COUNTXL = COUNTXL + COUNTWR + 1
3550
COUNTWR = COUNTWL = 0
3900
COUNTWR = COUNTWR + 1
RVOLT(COUNTWR) = ABSF(VDIFR)
COUNTWL = COUNTWL + 1
LVOLT(COUNTWL) = ABSF(VDIFL)
3999
RETURN
END

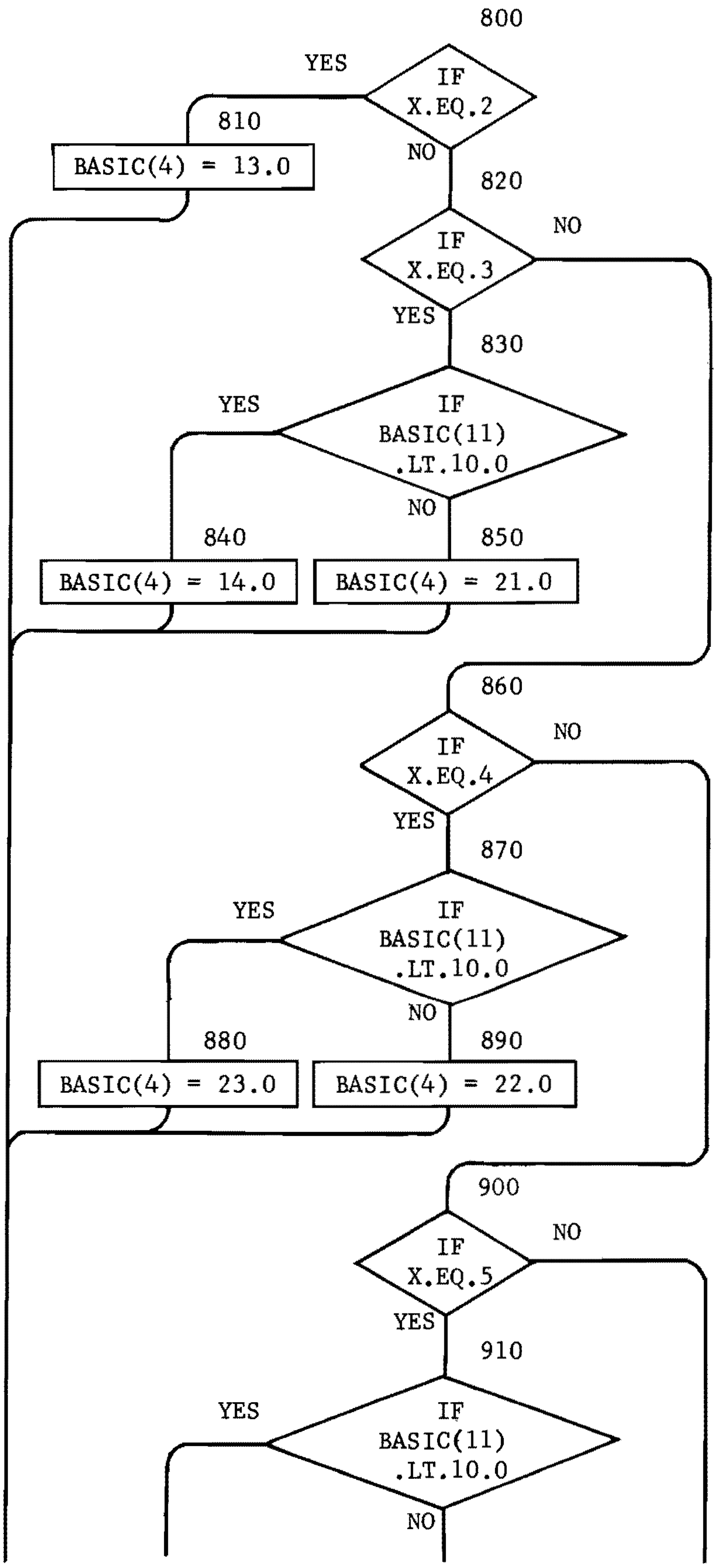
SUBROUTINE RTWTCAL

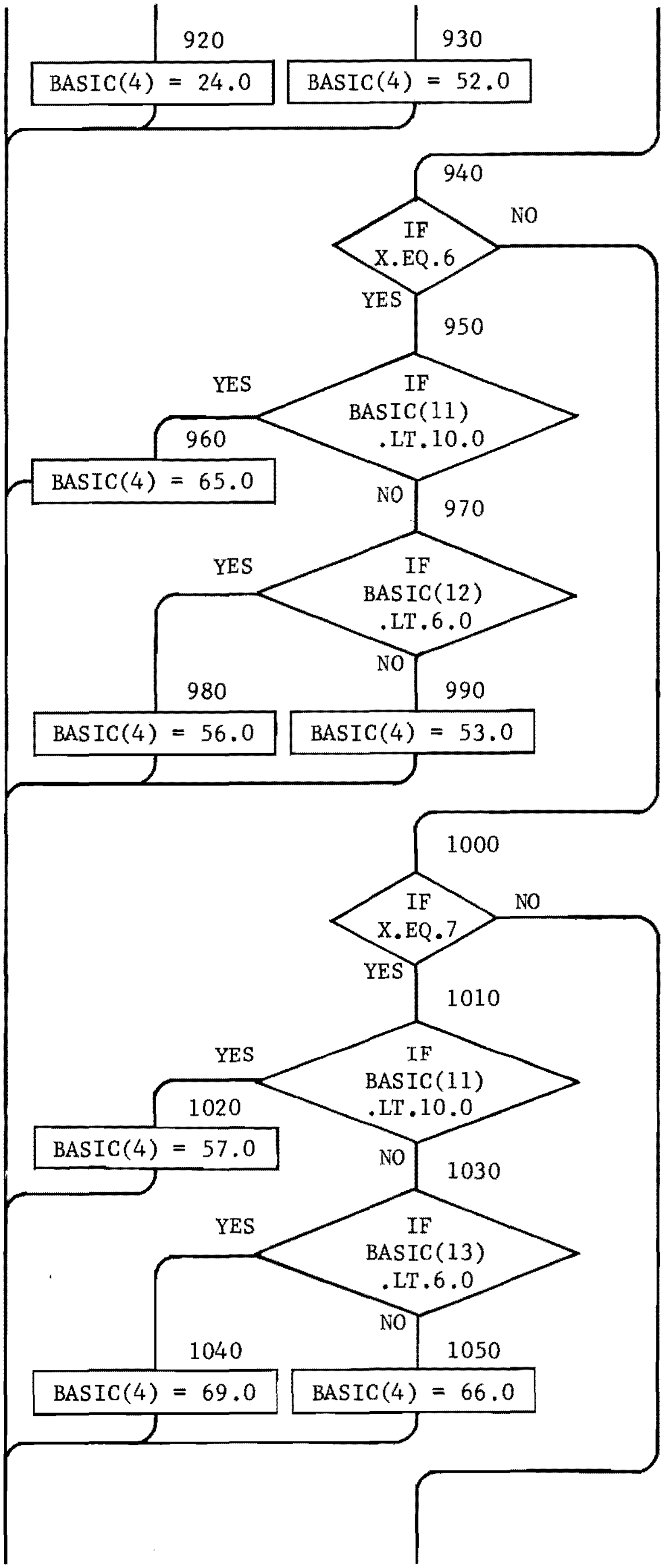


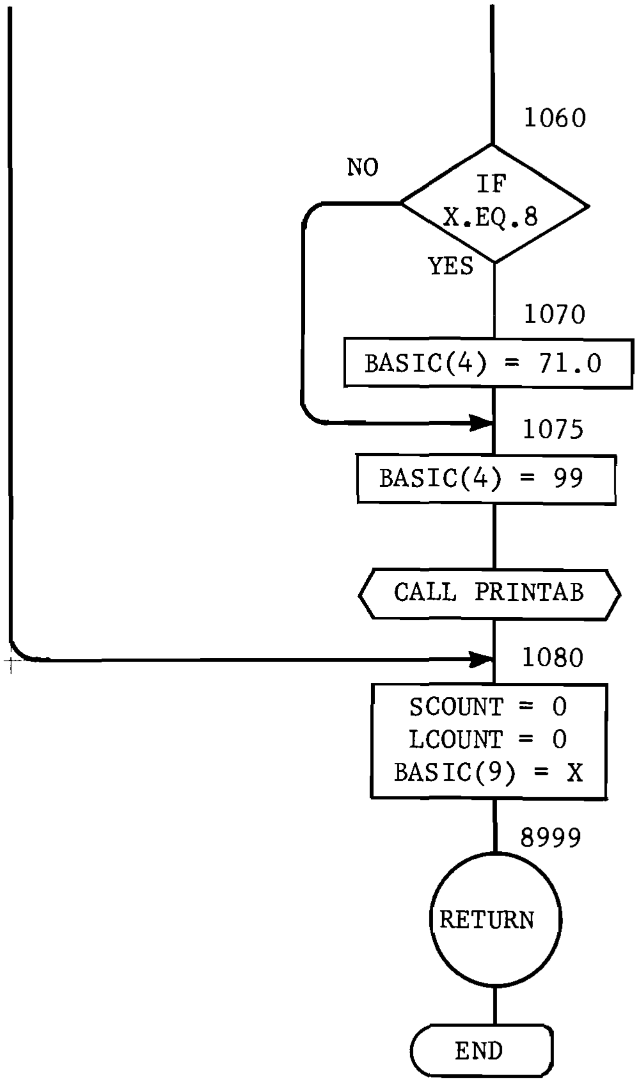
SUBROUTINE LTWTCAL



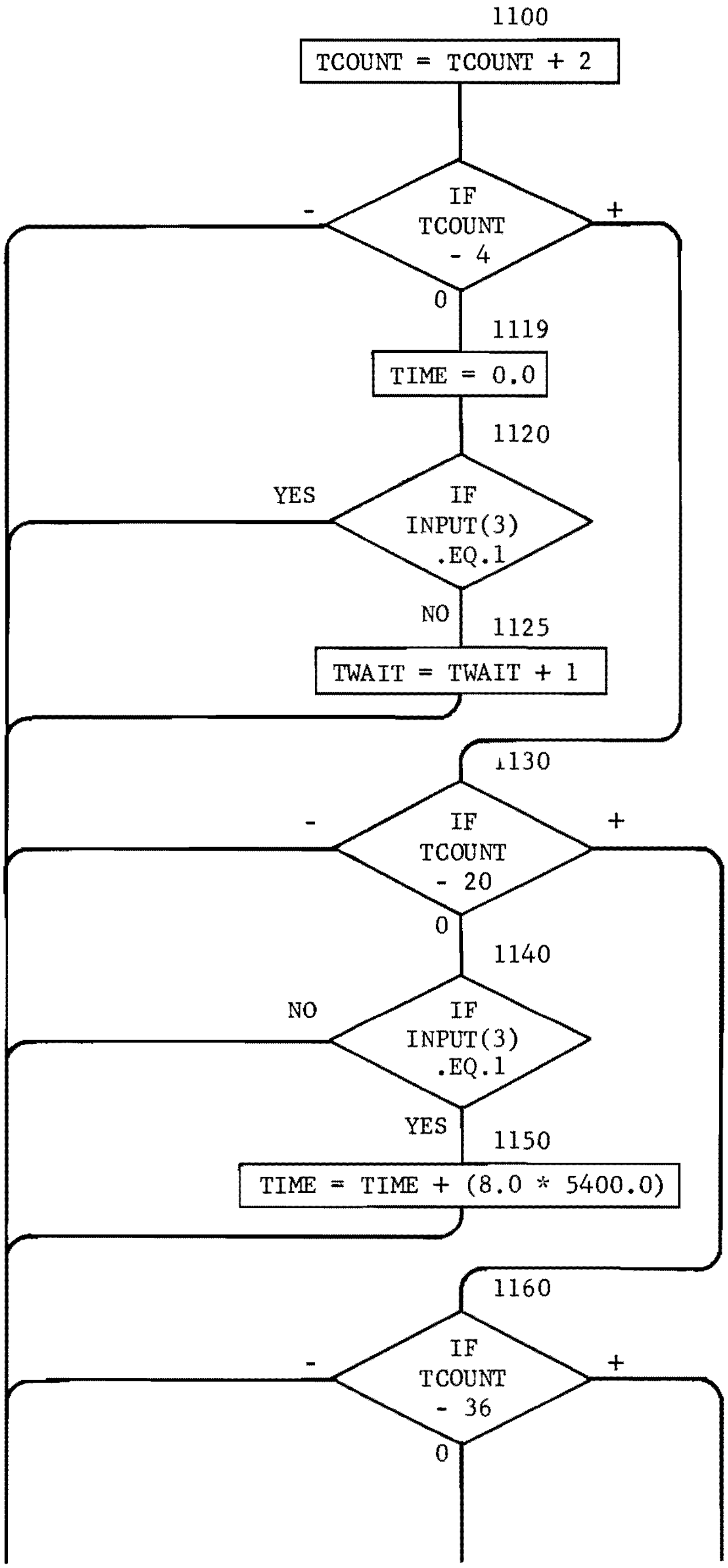
SUBROUTINE CLASIFY

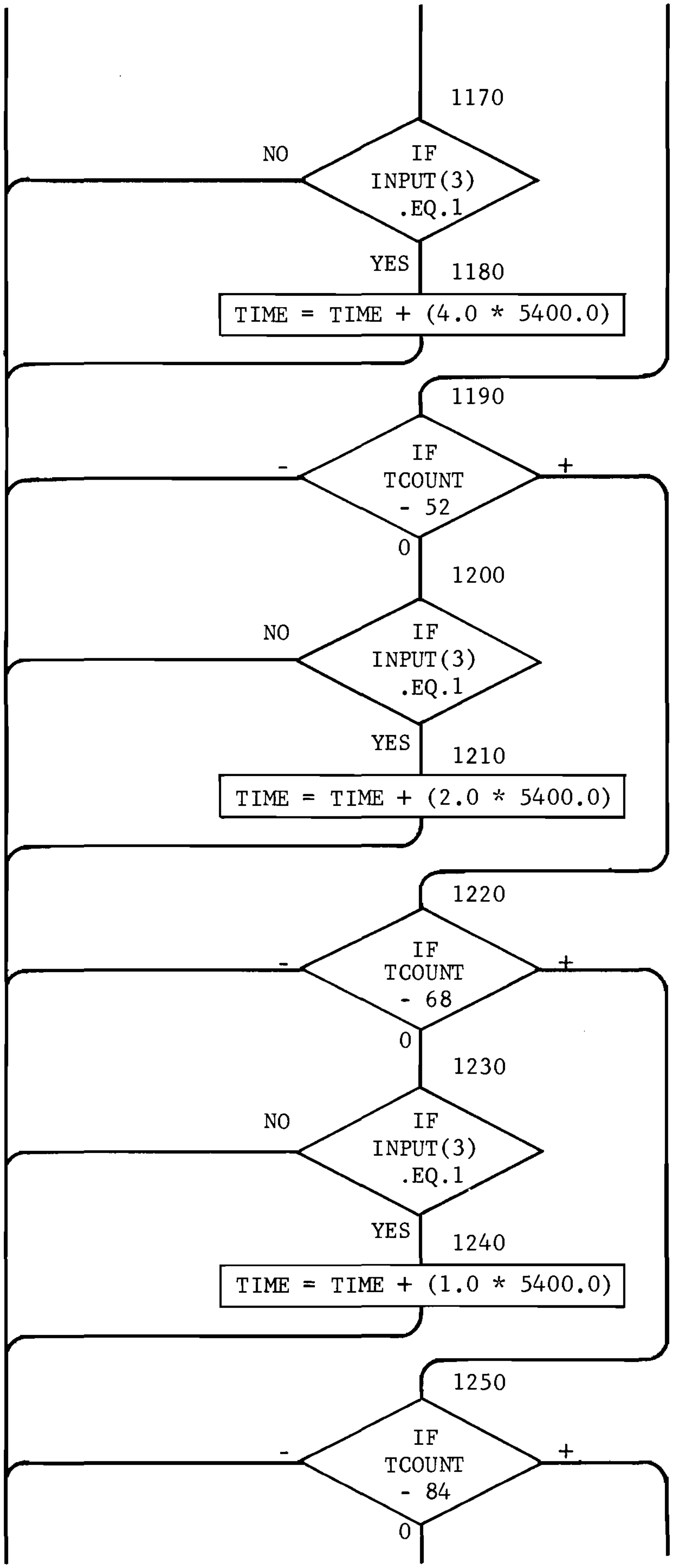


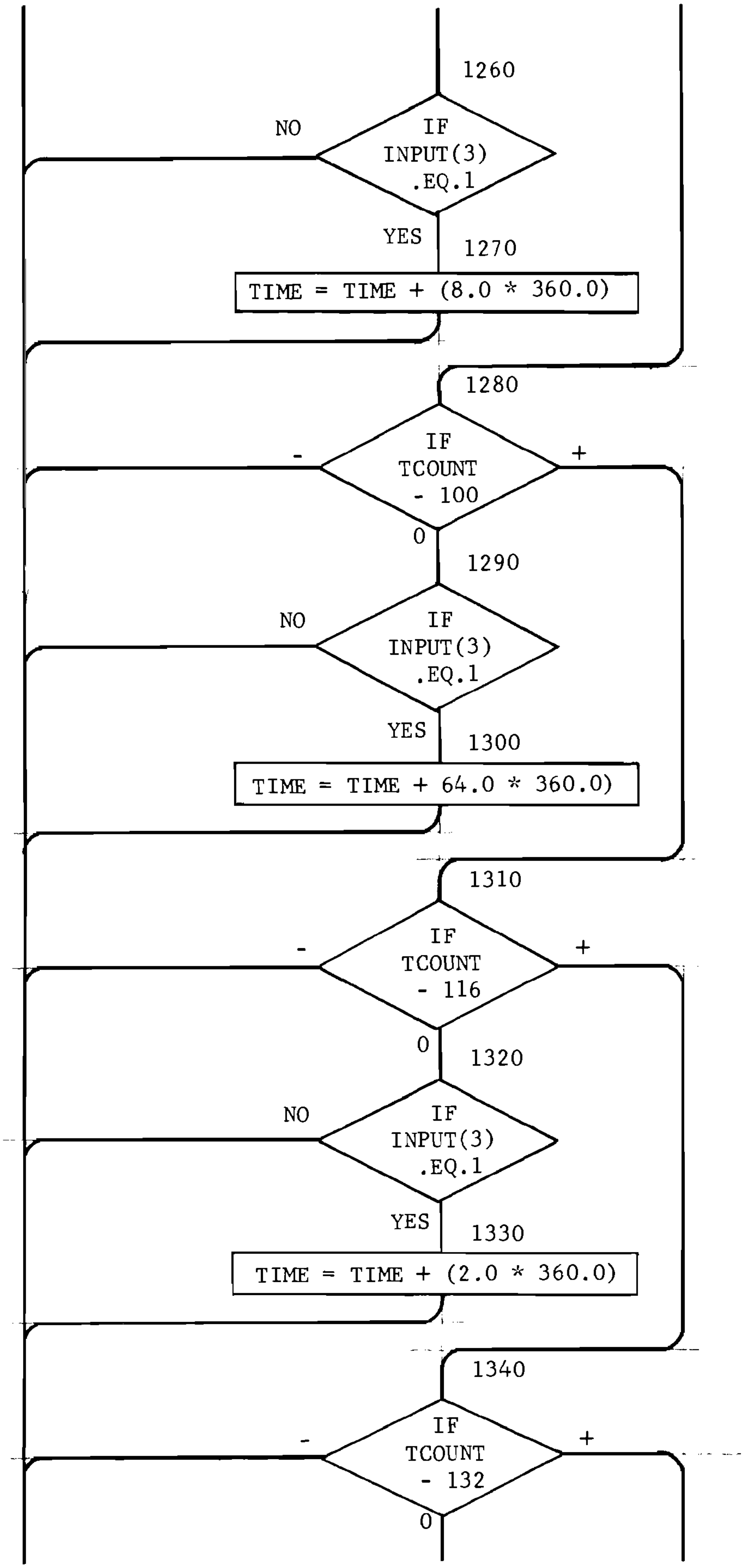

920
BASIC(4) = 24.0
930
BASIC(4) = 52.0
940
IF X.EQ.6
NO
YES
950
IF BASIC(11) .LT.10.0
YES
960
BASIC(4) = 65.0
NO
970
IF BASIC(12) .LT.6.0
YES
NO
980
BASIC(4) = 56.0
990
BASIC(4) = 53.0
1000
IF X.EQ.7
NO
YES
1010
IF BASIC(11) .LT.10.0
YES
1020
BASIC(4) = 57.0
NO
1030
IF BASIC(13) .LT.6.0
YES
NO
1040
BASIC(4) = 69.0
1050
BASIC(4) = 66.0

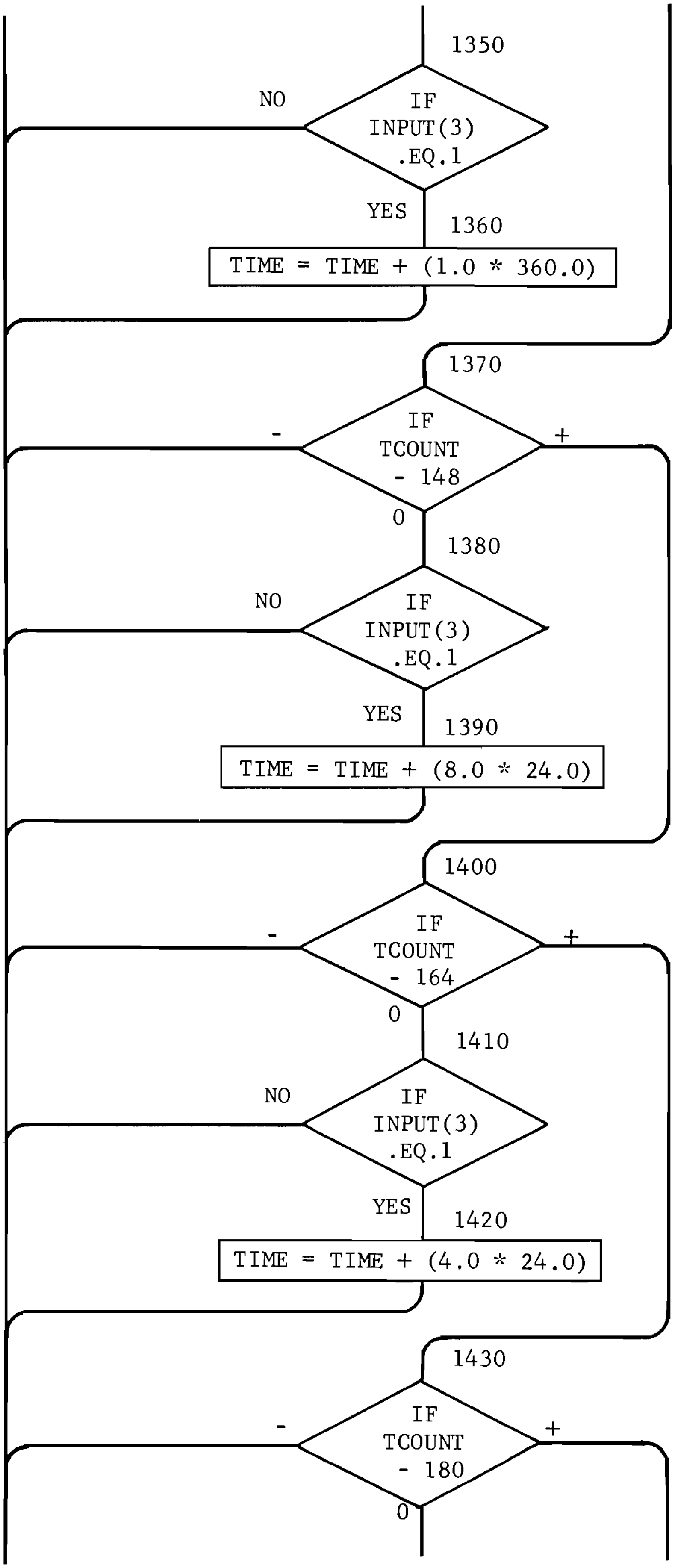

1060
NO
IF X.EQ.8
YES
1070
BASIC(4) = 71.0
1075
BASIC(4) = 99
CALL PRINTAB
1080
SCOUNT = 0
LCOUNT = 0
BASIC(9) = X
8999
RETURN
END

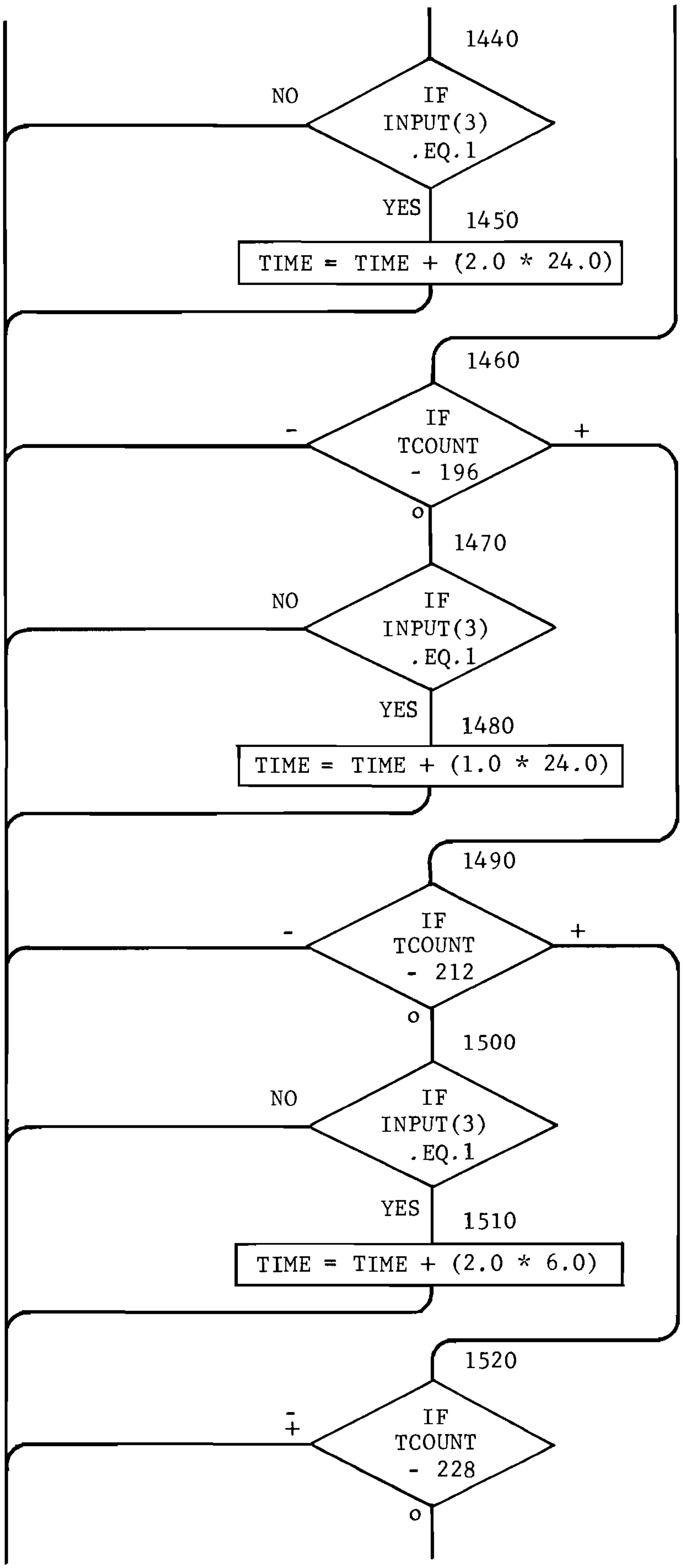
SUBROUTINE TOD

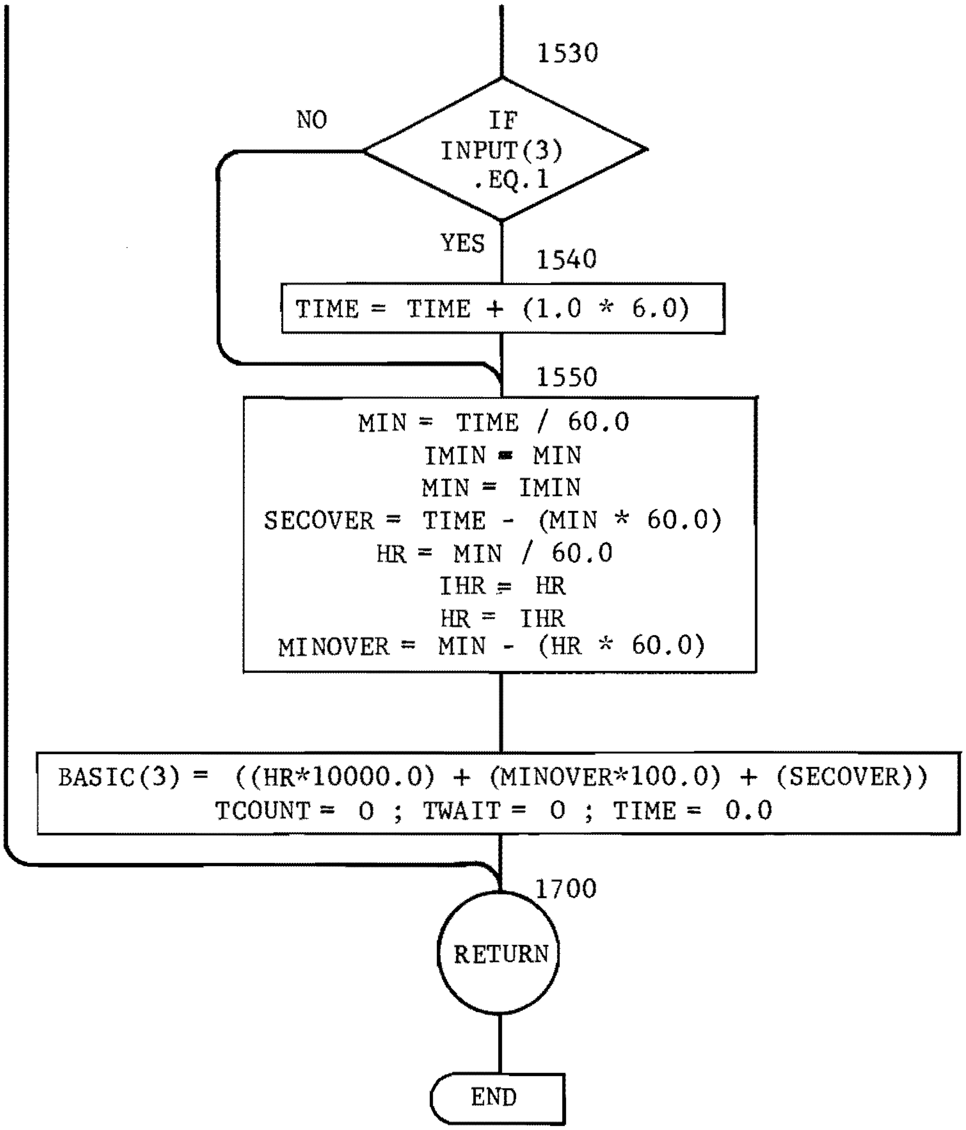



1170
NO
IF INPUT(3) .EQ.1
YES
1180
TIME = TIME + (4.0 * 5400.0)
1190
-
IF TCOUNT - 52
+
0
1200
NO
IF INPUT(3) .EQ.1
YES
1210
TIME = TIME + (2.0 * 5400.0)
1220
-
IF TCOUNT - 68
+
0
1230
NO
IF INPUT(3) .EQ.1
YES
1240
TIME = TIME + (1.0 * 5400.0)
1250
-
IF TCOUNT - 84
+
0

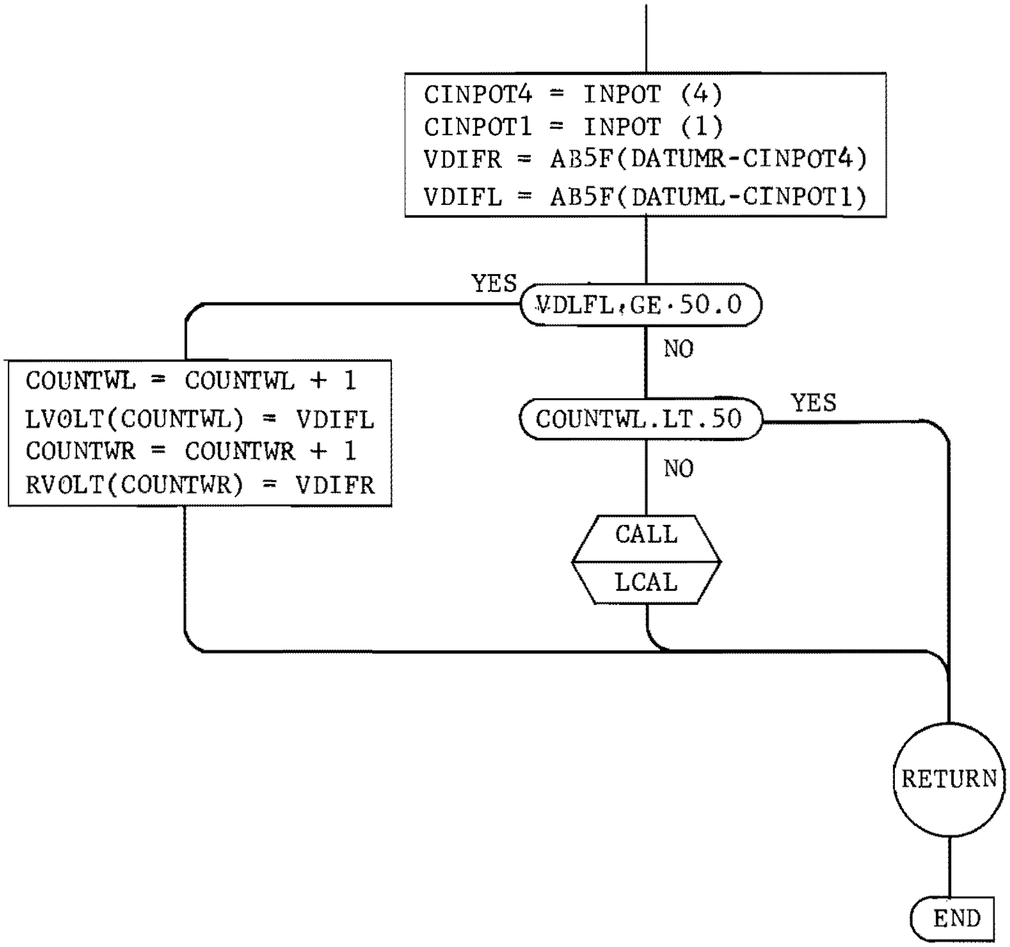

1260
NO
IF INPUT(3) .EQ.1
YES
1270
TIME = TIME + (8.0 * 360.0)
1280
-
IF TCOUNT - 100
+
0
1290
NO
IF INPUT(3) .EQ.1
YES
1300
TIME = TIME + 64.0 * 360.0)
1310
-
IF TCOUNT - 116
+
0
1320
NO
IF INPUT(3) .EQ.1
YES
1330
TIME = TIME + (2.0 * 360.0)
1340
-
IF TCOUNT - 132
+
0


1350
NO
IF INPUT(3) .EQ.1
YES
1360
TIME = TIME + (1.0 * 360.0)
1370
-
IF TCOUNT - 148
+
0
1380
NO
IF INPUT(3) .EQ.1
YES
1390
TIME = TIME + (8.0 * 24.0)
1400
-
IF TCOUNT - 164
+
0
1410
NO
IF INPUT(3) .EQ.1
YES
1420
TIME = TIME + (4.0 * 24.0)
1430
-
IF TCOUNT - 180
+
0

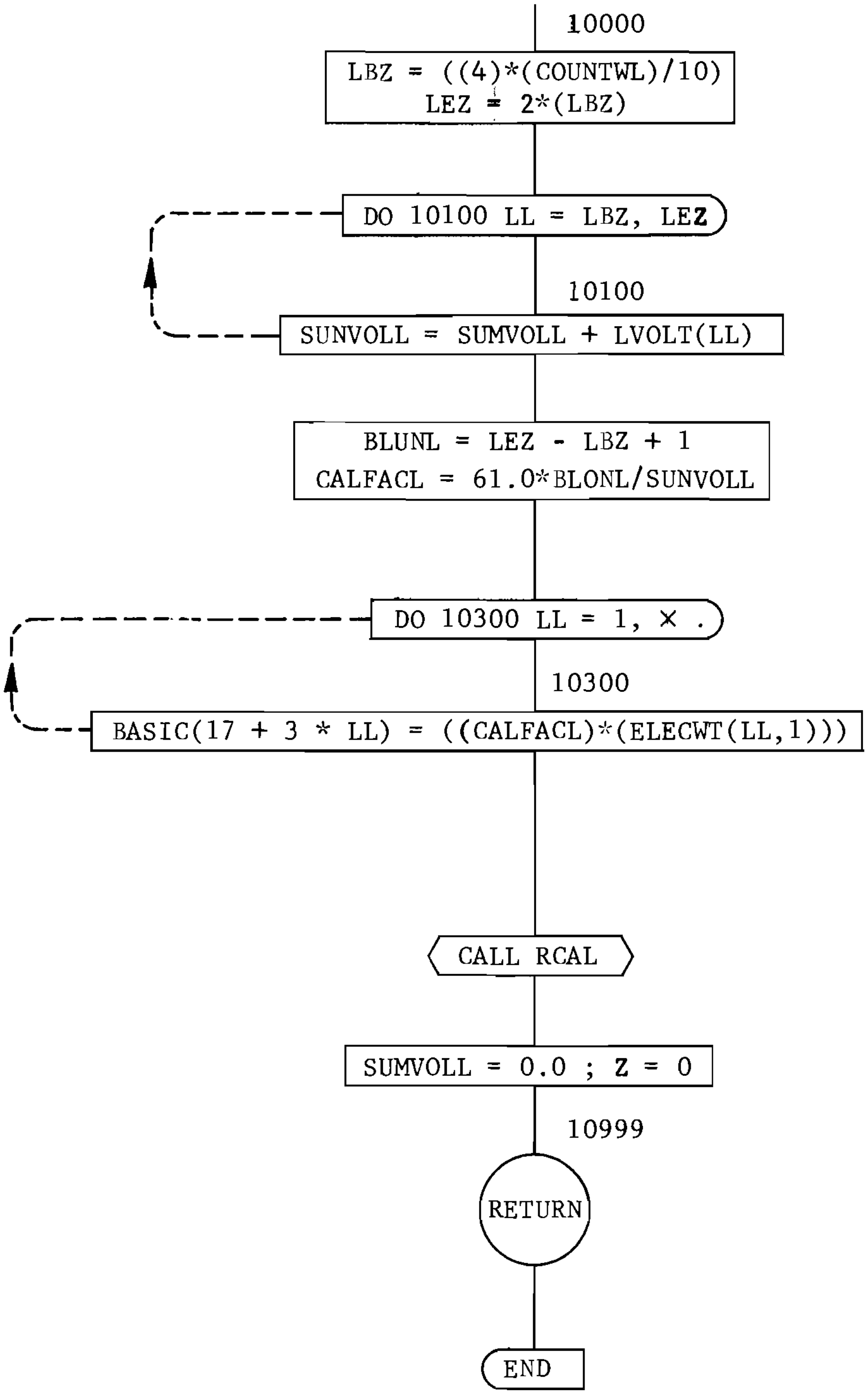

1440
NO
IF
INPUT(3)
.EQ.1
YES
1450
TIME = TIME + (2.0 * 24.0)
1460
-
IF
TCOUNT
- 196
+
0
1470
NO
IF
INPUT(3)
.EQ.1
YES
1480
TIME = TIME + (1.0 * 24.0)
1490
-
IF
TCOUNT
- 212
+
0
1500
NO
IF
INPUT(3)
.EQ.1
YES
1510
TIME = TIME + (2.0 * 6.0)
1520
-
+
IF
TCOUNT
- 228
0


1530
NO
IF
INPUT(3)
.EQ.1
YES
1540
TIME = TIME + (1.0 * 6.0)
1550
MIN = TIME / 60.0
IMIN = MIN
MIN = IMIN
SECOVER = TIME - (MIN * 60.0)
HR = MIN / 60.0
IHR = HR
HR = IHR
MINOVER = MIN - (HR * 60.0)
BASIC(3) = ((HR*10000.0) + (MINOVER*100.0) + (SECOVER))
TCOUNT = 0 ; TWAIT = 0 ; TIME = 0.0
1700
RETURN
END

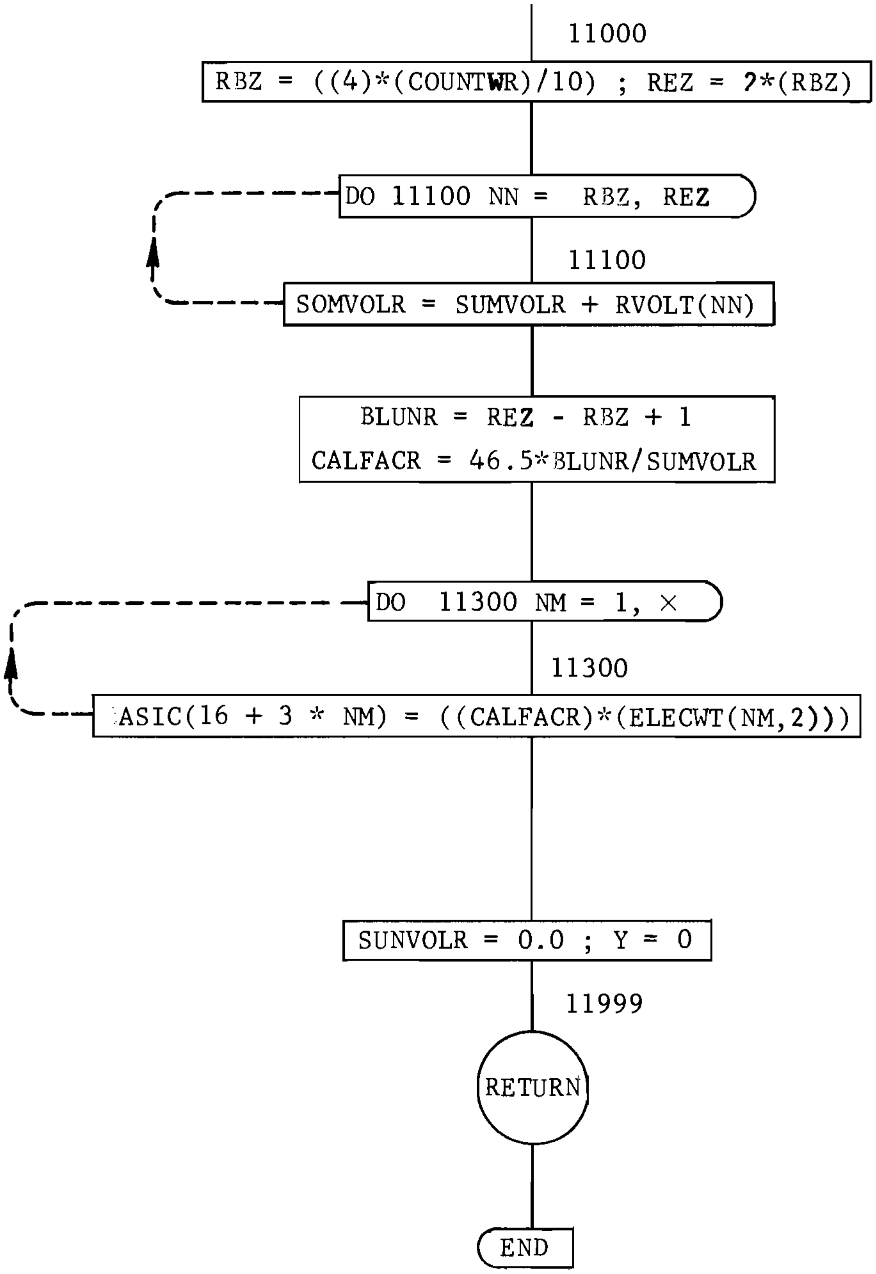
SUBROUTINE CALIB



SUBROUTINE LCAL

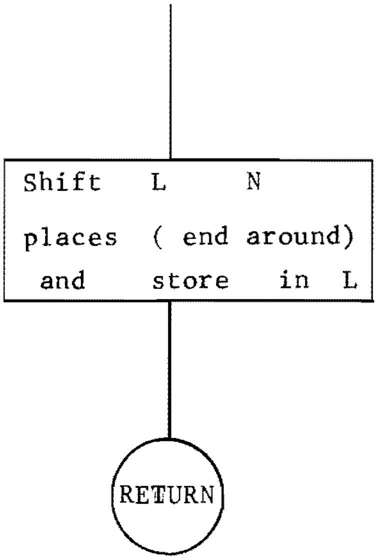


SUBROUTINE RCAL

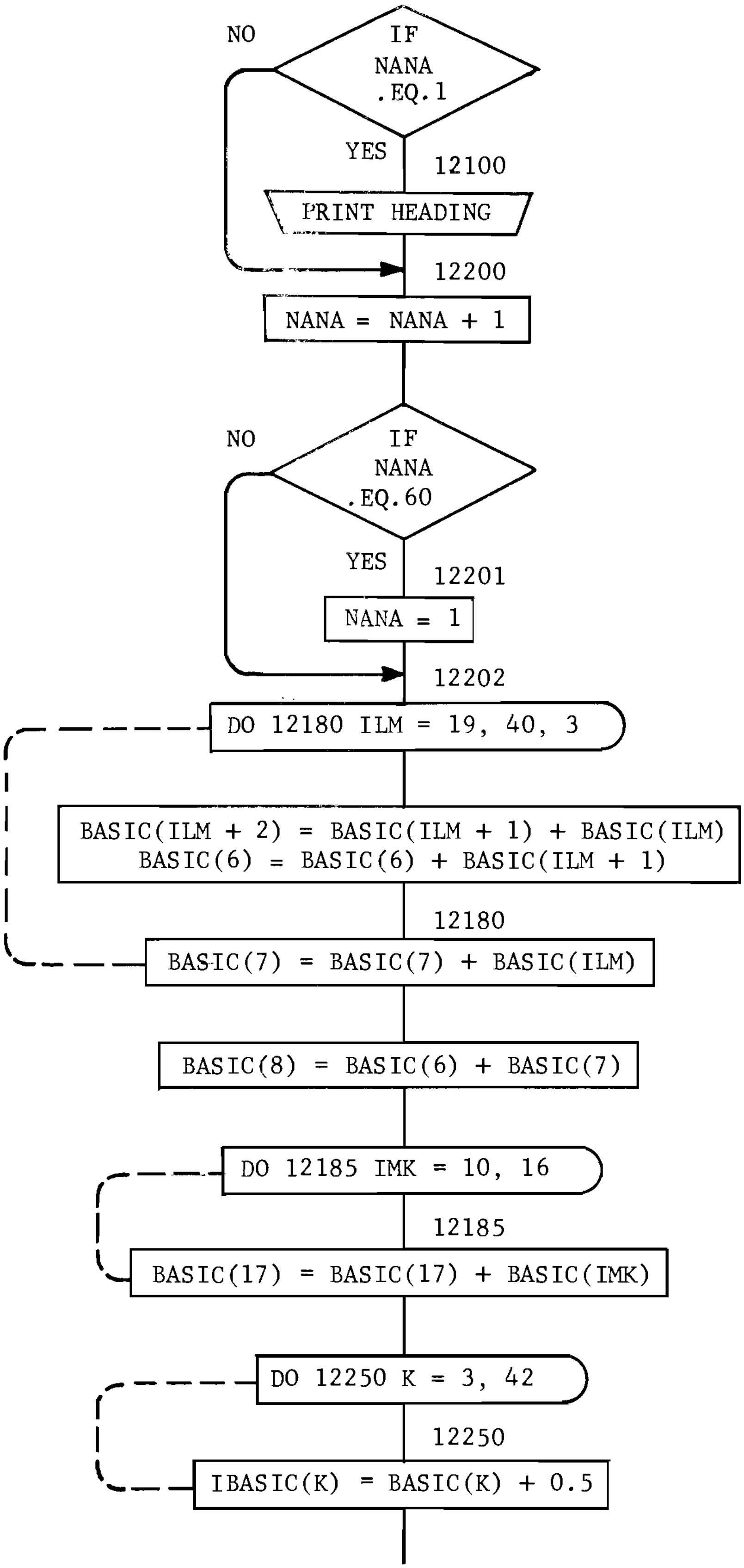


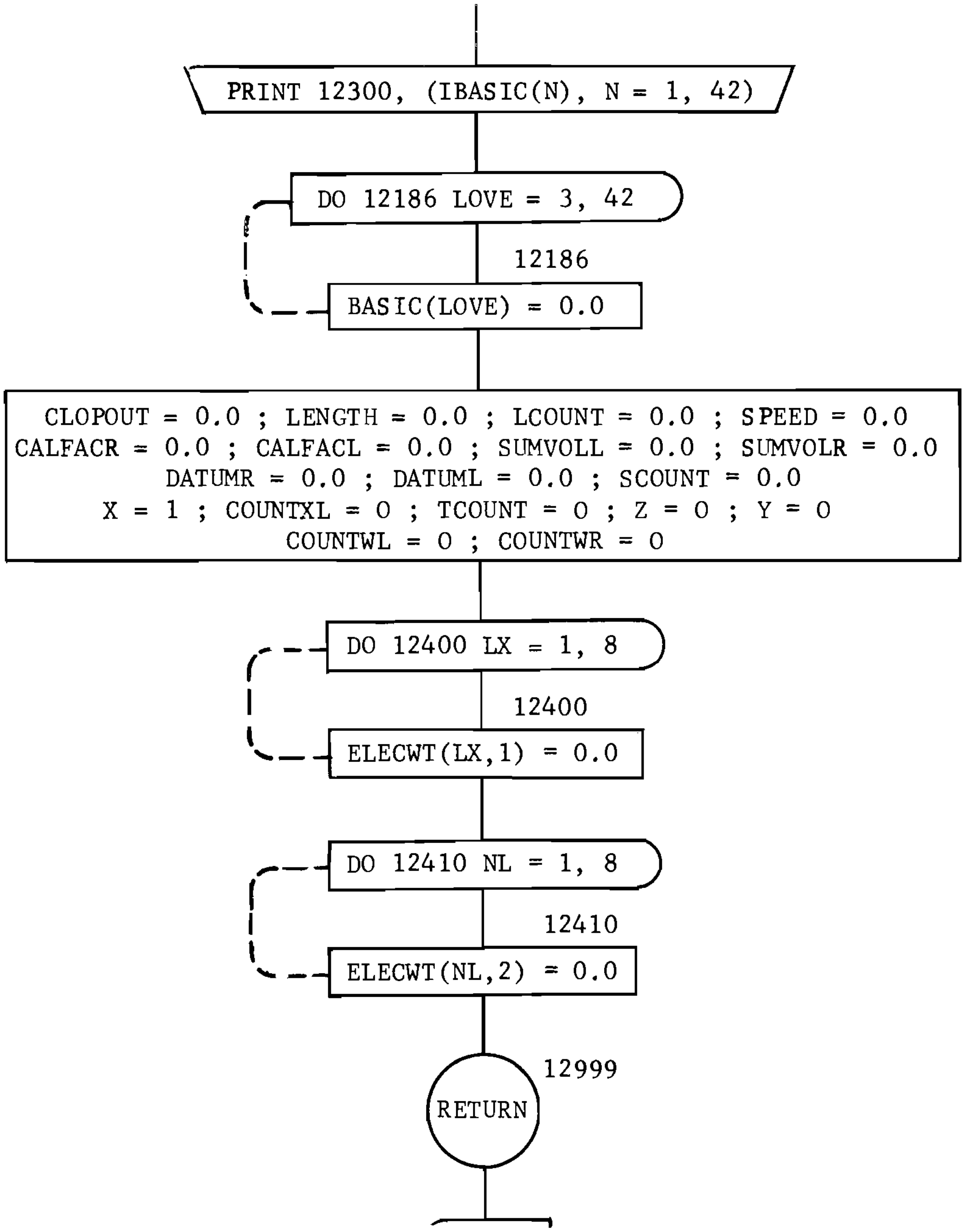
SUBROUTINE SHFT

L , N



SUBROUTINE PRINTAB




PRINT 12300, (IBASIC(N), N = 1, 42)
DO 12186 LOVE = 3, 42
12186
BASIC(LOVE) = 0.0
CLOPOUT = 0.0 ; LENGTH = 0.0 ; LCOUNT = 0.0 ; SPEED = 0.0
CALFACR = 0.0 ; CALFACL = 0.0 ; SUMVOLL = 0.0 ; SUMVOLR = 0.0
DATUMR = 0.0 ; DATUML = 0.0 ; SCOUNT = 0.0
X = 1 ; COUNTXL = 0 ; TCOUNT = 0 ; Z = 0 ; Y = 0
COUNTWL = 0 ; COUNTWR = 0
DO 12400 LX = 1, 8
12400
ELECWT(LX,1) = 0.0
DO 12410 NL = 1, 8
12410
ELECWT(NL,2) = 0.0
12999
RETURN

```
LEE,1,400,200000.CE514276,THABIT.
RUN(S).
REQUEST TAPE2.432X321,THD 231,556BPI,THABIT.
LGO.
'
      PROGRAM WIM(INPUT,OUTPUT,TAPE2)
      COMMON/SCOTT/JBUFF(1600,2),JJ,LOADBUF,JL1,PARITCK
      COMMON/ARROY/IT(1),INPOT(6)
      COMMON/THABIT/IBUFF(2000,2)
      COMMON/NASSER/X,LENGTH,SPEED,SCOUNT,BASIC(42),ITITLE(16),Z,Y,LCKVO
     1LT(5000),RCKVOLT(5000),VDIFL,VDIFR,COUNTWL,ELECWT(8,2),COUNTXL,LVO
     2LT(5000),RVOLT(5000),CKT,CLOPOUT,DATUMR,DATUML,COUNTWR,TCOUNT,NANA
     3,SUMVOLL,SUMVOLR,LCOUNT
      TYPE INTEGER    TWAIT,X,Y,Z,COUNTWL,COUNTWR,TCOUNT,COUNTXL,ERROR,A
     1REA,REZ,RBZ,LEZ,LBZ,PARITCK
      TYPE REAL LCOUNT,LCKVOLT,MIN,MINOVER,LVOLT,LENGTH
      JL1=JL2=1
C
C      INITIALIZATION OF VARIABLES AND PARAMETERS AND ARRAYS
C   BASIC    -OUTPUT ARRAY(FORTY TWO VALUES,FLOATING POINTS)
C   CALFACL -CALIBRATION FACTOR FOR LEFT SIDE
C   CALFACR -CALIBRATION FACTOR FOR RIGHT SIDE
C   CKCT     -SPECIFIED MAXIMUM NUMBER OF SAMPLES BETWEEN SPEED LOOP
C             OUT AND LENGTH LOOP ON
C   CLOPOUT -NUMBER OF SAMPLES BETWEEN SPEED AND LENGTH LOOP
C   COUNTWL -NUMBER OF SAMPLES IN A LEFT WEIGHT PULSE
C   COUNTWR -NUMBER OF SAMPLES IN A RIGHT WEIGHT PULSE
C   COUNTXL -NUMBER OF SAMPLES BETWEEN TWO CONSECUTIVE AXLES
C   DATUML   -AVERAAE OF VOLTAAE LEVEL FOR THE FIRST TWENTY SAMPLES AFTER
C             LOOP START AND USED AS A REFERENCE FOR NO PULSE LEVEL(LEFT)
C   DATUMR   -SAME AS DATUML EXCEPT THAT IT IS FOR RIGHT SIDE
C   ELECWT   -ARRAY FOR STORING WEIGHTS IN TERMS OF VOLTS.
C   IBASIC   -OUTPUT ARRAY AFTER CHANGING TO FIXED POINTS
C   LBZ      -BEGINNING OF AVERAGING ZONE WITHIN A LEFT WEIGHT PULSE
C   LCKVOLT -SAMPLE VOLTAGE-LEFT SIDE
C   LCOUNT   -NUMBER OF SAMPLES IN A LENGTH LOOP
C   LENGTH   -LENGTH OF VEHICLE (FEET)
C   LEZ      -END OF AVERAGING ZONE WITHIN A LEFT PULSE
C   LOADBUF -A COUNTER FOR NUMBER OF DATA BLOCKS
C   LVOLT    -SAMPLE VOLTAGE WITHIN LEFT WEIGHT PULSE
C   NANA     -A COUNTER USED TO CONTROL OUTPUT
C   RBZ      -BEGINNING OF AVERAGING ZONE WITHIN A RIGHT PULSE
C   RCKVOLT -SAMPLE VOLTAGE - RIGHT SIDE
C   REZ      -END OF AVERAGING WITHIN A RIGHT PULSE
C   RVOLT    -SAMPLE VOLTAGE   WITHIN A RIGHT PULSE
C   SCOUNT   -NUMBER OF SAMPLES IN A SPEED LOOP
C   SPEED    -SPEED OF THE VEHICLE IN FT/SEC
C   TCOUNT   -NUMBER OF SAMPLES WITHIN TIME PULSES ZONE
C   VDIFL    -DIFFERENCE BETWEEN REFERENCE VOLTAGE(DATUM) AND SUBSEQUENT
C             SAMPLE VOLTAGES TO DETECT WEIGHT OR CALIBRATION PULSES(LEFT)
C   VDIFR    -SAME AS VDIFL EXCEPT FOR  RIGHT SIDE
C   X        -NUMBER OF AXES
C   Y,Z      -COUNTERS USED TO CONTROL NUMBER OF SAMPLES USED TO ESTABLISH
C             DATUMR AND DATUML RESPECTIVELY
      CLOPOUT=0.0    $    LENGTH=0.0    $    LCOUNT=0.0    $    SPEED=0.0
```

```
      CALFACR=0.0   $   CALFACL=0.0   $   SUMVOLL=0.0   $   SUMVOLR=0.0
      DATUMR=0.0   $   DATUML=0.0    $    SCOUNT=0.0
      LOADBUF=0   $   COUNTXL=0   $   TCOUNT=0   $   Z=0   $   Y=0
      COUNTWL=0   $   COUNTWR=0  $   X=1   $   NANA=1
          DO 10 JL = 1,42
   10     BASIC(JL) = 0.0
          DO 20 IK = 1,8
          DO 20 IL = 1,2
   20     ELECWT(IK,IL) = 0.0
      READ 21,(ITITLE(I),I=1,16)
   21 FORMAT(8A10)
  100 CALL INDATA
      CALL CONVERT
   90 J = JJ
      GO TO(101,102),JL2
  101 JL2=2        $     II=3    $    GO TO 110
  102 II = 1
  110 DO 999 I = II,2000
      IT(1)=IBUFF(I,J)
      CALL ADUNPAK
C
C     BEGIN DRIVER PROGRAM
C
      IF(SPEED.EQ.0.0)150,200
  150 CALL VLOCITY     $     GO TO 999
  200 IF(LENGTH.EQ.0.0)250,300
  250     CALL MEASURE         $    GO TO 999
  300 IF(BASIC(4).EQ.0.0)350,400
  350 CALL CLASIFY
      GO TO 999
  400 IF(BASIC(3).EQ.0.0)450,500
  450     CALL TOD
      IF(TCOUNT.GE.106)500,999
  500 IF(BASIC(20).EQ.0.0)550,600
  550 CALL CALIB         $    GO TO 999
  600 IF(BASIC(3).EQ.0.0)999,700
  700 CALL PRINTAB
      PARITCK=0
  999 CONTINUE
      GO TO 100
      END
```

```
      SUBROUTINE INDATA
      DIMENSION ITABLE(8)
      COMMON/SCOTT/JBUFF(1600,2),JJ,LOADBUF,JL1,PARITCK
      TYPE INTEGER PARITCK
      GO TO (1,2),JL1
    1 JL1=KK=2   $   J=1   $   PARITCK=0
      REWIND 2
  4   DO 1001 I=1,1600
 1001 JBUFF(I,J)=0
      CALL BUFF(5HTAPE2,22B,JBUFF(1,J),JBUFF(1600,J),ISTAT)
    3 CALL XRCL
    2 IF(ISTAT)20,3,13
   13 LOADBUF  = LOADBUF  + 1
    9 JJ = J  $  J = KK  $  KK = JJ
    7 DO 1002 I=1,1600
 1002 JBUFF(I,J)=0
      CALL BUFF(5HTAPE2,22B,JBUFF(1,J),JBUFF(1600,J),ISTAT)
    8 RETURN
   20 ISTAT=-ISTAT
      IF(ISTAT.A.0010000000000      B)GO TO 21
      IF(ISTAT.A.20000000000        B)GO TO 22
      PRINT 27,ISTAT
   27 FORMAT(* ISTAT = *O20)
      GO TO 13
   21 PRINT 12,LOADBUF
   12 FORMAT(*1LOGICAL END OF PROGRAM - JOB COMPLETED*/I4* DATA BLOCKS H
     *AVE BEEN PROCESSED*)
      GO TO 24
   22 PARITCK  = PARITCK  + 1
      IF(PARITCK.LT.10)GO TO 13
      PRINT 113,LOADBUF
  113 FORMAT (*110 SUCCESSIVE PARITY ERRORS OCCURRED IMMEDIATELY FOLLOWI
     *NG RECORD NO. *I3 *BEFORE REACHING THE END OF FILE MARK*
   24 READ 31,(ITABLE(L),L=1,8)
   31 FORMAT(8A10)
      IF(ITABLE(1).EQ.10H1         )32,33
   32 PRINT 25
   25 FORMAT(1H1)
      GO TO 24
   33 IF(ITABLE(1).EQ.10HSTOP      )STOP
      PRINT 34,(ITABLE(L),L=1,8)
   34 FORMAT(10X,8A10)
      GO TO 24
      END
      END
```

```
      SUBROUTINE CONVERT
      COMMON/SCOTT/JBUFF(1600,2),JJ,LOADBUF,JL1
      COMMON/THABIT/IBUFF(2000,2)
      MASK12=00000000000000007777B
      MASK22=00000000000077777777B
      MASK32=00000000777777777777B
      MASK42=00007777777777777777B
      J=JJ
      K=1
      DO 1 I=1,1597,4
      L=JBUFF(I,J)
      CALL SHIFT(L,48)
      IBUFF(K,J)=L.AND.MASK42
      L=JBUFF(I+1,J)
      CALL SHIFT(L,36)
      IBUFF(K+1,J)=(JBUFF(I,J).AND.MASK12)*(8**12)+(L.AND.MASK32)
      L=JBUFF(I+2,J)
      CALL SHIFT(L,24)
      IBUFF(K+2,J)=(JBUFF(I+1,J).AND.MASK22)*(8**8)+(L.AND.MASK22)
      L=JBUFF(I+3,J)
      CALL SHIFT(L,12)
      IBUFF(K+3,J)=(JBUFF(I+2,J).AND.MASK32)*(8**4)+(L.AND.MASK12)
      IBUFF(K+4,J)=JBUFF(I+3,J).AND.MASK42
    1 K=K+5
      RETURN
      END
```

```
      SUBROUTINE ADUNPAK
      COMMON/ARROY/IT(1),INPOT(6)
      MASK1=00007777777400000000B
      MASK2=00000000000200000000B
      MASK3=00000000000100000000B
      MASK4=00000000000077777774B
      MASK5=000000000000       2B
      MASK6=000000000000       1B
      INPOT(1)=(IT(1).AND.MASK1)/(2**26)
      INPOT(2)=(IT(1).AND.MASK2)/(2**25)
      INPOT(3)=(IT(1).AND.MASK3)/(2**24)
      INPOT(4)=(IT(1).AND.MASK4)/(2**2)
      INPOT(5)=(IT(1).AND.MASK5)/(2)
      INPOT(6)=IT(1).AND.MASK6
      IF(INPOT(1).AND.00000000000010000000B)INPOT(1)=INPOT(1).OR.7777777
     17777760000000B
      IF(INPOT(4).AND.00000000000010000000B)INPOT(4)=INPOT(4).OR.7777777
     17777760000000B
      RETURN
      END
```

```
      SUBROUTINE VLOCITY
      COMMON/ARROY/IT(1),INPOT(6)
      COMMON/NASSER/X,LENGTH,SPEED,SCOUNT,BASIC(42),ITITLE(16),Z,Y,LCKVO
     1LT(5000),RCKVOLT(5000),VDIFL,VDIFR,COUNTWL,ELECWT(8,2),COUNTXL,LVO
     2LT(5000),RVOLT(5000),CKT,CLOPOUT,DATUMR,DATUML,COUNTWR,TCOUNT,NANA
     3,SUMVOLL,SUMVOLR,LCOUNT
      TYPE INTEGER    TWAIT,X,Y,Z,COUNTWL,COUNTWR,TCOUNT,COUNTXL,ERROR,A
     1REA,REZ,RBZ,LEZ,LBZ
      TYPE REAL LCOUNT,LCKVOLT,MIN,MINOVER,LVOLT,LENGTH
C
C   THIS SUBROUTINE IS USED TO CALCULATE THE SPEED OF THE VEHICLE. THE TIME
C   THAT THE VEHICLE TAKES TO TRAVEL A SPECIFIED DISTANCE IS DETERMINED BY
C   DIVIDING THE NUMBER OF SAMPLES BY THE SAMPLING FREQUENCY. THE SPEED IS
C   THEN CALCULATED. THE SPECIFIED DISTANCE IS THAT BETWEEN PRESSURE TUBES.
C
 1000 IF(INPOT(2).EQ.1)1100,1050
 1100     SCOUNT = SCOUNT + 1.0
 1250 IF(INPOT(5).EQ.1)1300,1210
 1300     SCOUNT = SCOUNT + 1.0          $      GO TO 1999
C
 1050 IF(SCOUNT.GE.150.0)1200,1150
 1150     IF(INPOT(5).EQ.1)1400,1999
 1400          SCOUNT = SCOUNT + 1.0          $      GO TO 1999
C
 1210 IF(SCOUNT.GE.150.)1200,1999
 1200 SPEED =(((8.0)*(2400.0)) / SCOUNT)
 1350 BASIC(5) = ((SPEED)*((3600.0)/(5280.0)))
      IF(BASIC(5).LE.10.0.OR.BASIC(5).GE.100.0)1375,1380
 1375 CALL PRINTAB   $   GO TO 1999
 1380 CKT=1.5*SCOUNT
 1999 RETURN
      END
```

```
      SUBROUTINE MEASURE
      COMMON/ARROY/IT(1),INPOT(6)
      COMMON/NASSER/X,LENGTH,SPEED,SCOUNT,BASIC(42),ITITLE(16),Z,Y,LCKVO
     1LT(5000),RCKVOLT(5000),VDIFL,VDIFR,COUNTWL,ELECWT(8,2),COUNTXL,LVO
     2LT(5000),RVOLT(5000),CKT,CLOPOUT,DATUMR,DATUML,COUNTWR,TCOUNT,NANA
     3,SUMVOLL,SUMVOLR,LCOUNT
      TYPE INTEGER    TWAIT,X,Y,Z,COUNTWL,COUNTWR,TCOUNT,COUNTXL,ERROR,A
     1REA,REZ,RBZ,LEZ,LBZ
      TYPE REAL LCOUNT,LCKVOLT,MIN,MINOVER,LVOLT,LENGTH
C
C   THIS SUBROUTINE IS USED TO CALCULATE THE LENGTH OF THE VEHICLE. THE
C   DURATION OF THE LENGTH LOOP IS DETERMINED BY DIVIDING THE NUMBER OF
C   SAMPLES IN THE LOOP BY THE SAMPLING FREQUENCY. THEN USING THE SPEED,
C   THE CORRESPONDING DISTANCE IN FEET IS DETERMINED. THIS DISTANCE
C   CORRESPONDS TO THE LENGTH OF THE VEHICLE PLUS DISTANCE BETWEEN PRESSURE
C   TUBES. THIS SUBROUTINE ALSO REJECT THE VEHICLE IF THE NUMBER OF SAMPLES
C   BETWEEN SPEED AND LENGTH LOOPS EXCEEDS A MAXIMUM VALUE.
C
 2000 IF(INPOT(2).EQ.1)2050,2250
 2050     LCOUNT = LCOUNT + 1.0
 2100        IF(INPOT(5).EQ.1)2150,2400
 2150     LCOUNT = LCOUNT + 1.0
 2200 CALL WEIGHT      $      GO TO 2999
C
 2250 IF(LCOUNT.GE.380.0)2400,2260
 2260 CLOPOUT=CLOPOUT+1.0
 2300     IF(INPOT(5).EQ.1)2350,2990
 2350        LCOUNT = LCOUNT + 1.0       $    GO TO 2999
C
 2400 LENGTH = (((LCOUNT)*(SPEED))/(2400.0)) - 8.0
 2450 BASIC(18) = LENGTH
 2500 Z=0      $     Y=0      $     X=X-1
      COUNTWL=COUNTWR=0
       GO TO 2999
 2990 CLOPOUT=CLOPOUT+1.0
      IF(CLOPOUT.GE.CKT )2992,2999
 2992 CALL PRINTAB
 2999 RETURN
      END
```

```
       SUBROUTINE WEIGHT
      COMMON/ARROY/IT(1),INPOT(6)
      COMMON/NASSER/X,LENGTH,SPEED,SCOUNT,BASIC(42),ITITLE(16),Z,Y,LCKVO
     1LT(5000),RCKVOLT(5000),VDIFL,VDIFR,COUNTWL,ELECWT(8,2),COUNTXL,LVO
     2LT(5000),RVOLT(5000),CKT,CLOPOUT,DATUMR,DATUML,COUNTWR,TCOUNT,NANA
     3,SUMVOLL,SUMVOLR,LCOUNT
      TYPE INTEGER    TWAIT,X,Y,Z,COUNTWL,COUNTWR,TCOUNT,COUNTXL,ERROR,A
     1REA,REZ,RBZ,LEZ,LBZ
      TYPE REAL LCOUNT,LCKVOLT,MIN,MINOVER,LVOLT,LENGTH
C
C   THIS SUBROUTINE IS USED TO ESTABLISH A REFERENCE NO-PULSE-VOLTAGE LEVEL
C   (DATUML AND DATUMR).THEN IT DETECT THE PRESENCE OF A WEIGHT PULSE,COUNT
C   NUMBER OF SAMPLES BETWEEN PULSES TO CALCULATE AXLE SPACING,AND STORE
C   THE SAMPLE VOLTAGES WITHIN A WEIGHT PULSE (RVOLT AND LVOLT).
C
       IF(DATUML.EQ.0.0)3001,3150
 3001 Z=Z+1     $     Y=Y+1
      IF(Z.LE.20)3100,3101
 3100 RCKVOLT(Y) = INPOT(4)      $      LCKVOLT(Z) = INPOT(1)
        GO TO 3999
 3101 ACUML=0.0      $      ACUMR=0.0
      DO  3103 IJJ=1,20
      ACUML=ACUML+ABSF(LCKVOLT(IJJ))
 3103 ACUMR=ACUMR+RCKVOLT(IJJ)
      DATUML=ACUML/(20.0)      $      DATUMR=ACUMR/(20.0)
      GO TO 3999
 3150 WINPOT4=INPOT(4)    $    WINPOT1=INPOT(1)
      VDIFR=ABSF(DATUMR-WINPOT4)    $    VDIFL=ABSF(DATUML-WINPOT1)
      IF(VDIFR.GE.50.0)GO TO 3900
 3400 IF(COUNTWR.GE.16)3450,3600
 3450 IF(ELECWT(X,2).EQ.0.0)3500,3650
 3500 CALL RTWTCAL       $       GO TO 3999
 3600 IF(COUNTXL.GT.0)3650,3550
 3650 COUNTXL=COUNTXL+COUNTWR+1
 3550 COUNTWR=COUNTWL=0
        GO TO 3999
 3900 COUNTWR=COUNTWR+1     $     RVOLT(COUNTWR)=VDIFR
       COUNTWL=COUNTWL+1     $     LVOLT(COUNTWL)=VDIFL
 3999 RETURN
      END
```

```
      SUBROUTINE RTWTCAL
      COMMON/NASSER/X,LENGTH,SPEED,SCOUNT,BASIC(42),ITITLE(16),Z,Y,LCKVO
     1LT(5000),RCKVOLT(5000),VDIFL,VDIFR,COUNTWL,ELECWT(8,2),COUNTXL,LVO
     2LT(5000),RVOLT(5000),CKT,CLOPOUT,DATUMR,DATUML,COUNTWR,TCOUNT,NANA
     3,SUMVOLL,SUMVOLR,LCOUNT
      TYPE INTEGER    TWAIT,X,Y,Z,COUNTWL,COUNTWR,TCOUNT,COUNTXL,ERROR,A
     1REA,REZ,RBZ,LEZ,LBZ
      TYPE REAL LCOUNT,LCKVOLT,MIN,MINOVER,LVOLT,LENGTH
C
C   THIS SUBROUTINE ESTABLISHES THE AVERAGING ZONE WITHIN A PULSE, FIND
C   THE ARITHMETIC MEAN,AND STORES IT IN ELECWT ARRAY (RIGHT SIDE).
C
 6000 RBZ = (COUNTWR/4)        $      REZ = 3*(RBZ)
      DO 6100 NN=RBZ,REZ
 6100 SUMVOLR = SUMVOLR + RVOLT(NN)
C
      BLUNR=REZ-RBZ+1
      ELECWT(X,2)=SUMVOLR/BLUNR
      CALL LTWTCAL
 6999 RETURN
      END
```

```
      SUBROUTINE LTWTCAL
      COMMON/NASSER/X,LENGTH,SPEED,SCOUNT,BASIC(42),ITITLE(16),Z,Y,LCKVO
     1LT(5000),RCKVOLT(5000),VDIFL,VDIFR,COUNTWL,ELECWT(8,2),COUNTXL,LVO
     2LT(5000),RVOLT(5000),CKT,CLOPOUT,DATUMR,DATUML,COUNTWR,TCOUNT,NANA
     3,SUMVOLL,SUMVOLR,LCOUNT
      TYPE INTEGER    TWAIT,X,Y,Z,COUNTWL,COUNTWR,TCOUNT,COUNTXL,ERROR,A
     1REA,REZ,RBZ,LEZ,LBZ
      TYPE REAL LCOUNT,LCKVOLT,MIN,MINOVER,LVOLT,LENGTH
C
C   THIS SUBROUTINE ESTABLISHES THE AVERAGING ZONE WITHIN A PULSE, FIND
C   THE ARITHMETIC MEAN,AND STORES IT IN ELECWT ARRAY (LEFT SIDE).THEN
C   IT CALCULATES THE AXLE SPACING AND STORES IT IN BASIC ARRAY.
C
 5000 LBZ = (COUNTWL/4)        $     LEZ = 3*(LBZ)
      DO 5100 LL=LBZ,LEZ
 5100 SUMVOLL = SUMVOLL + LVOLT(LL)
C
      BLUNL=LEZ-LBZ+1
      ELECWT(X,1)=SUMVOLL/BLUNL
      IF(COUNTXL.GT.0)5205,5210
 5205 XCOUNTL=COUNTXL+COUNTWR
 5200 BASIC(X+8) = (((XCOUNTL)/(1200.0))*(SPEED))
 5210 AVOLL=0.0    $    AVOLR=0.0    $    SUMVOLL=0.0    $    SUMVOLR=0.0
      COUNTWR=0      $      COUNTWL=0
       COUNTXL=1      $      X=X+1
 5999 RETURN
      END
```

```
      SUBROUTINE CLASIFY
      COMMON/NASSER/X,LENGTH,SPEED,SCOUNT,BASIC(42),ITITLE(16),Z,Y,LCKVO
     1LT(5000),RCKVOLT(5000),VDIFL,VDIFR,COUNTWL,ELECWT(8,2),COUNTXL,LVO
     2LT(5000),RVOLT(5000),CKT,CLOPOUT,DATUMR,DATUML,COUNTWR,TCOUNT,NANA
     3,SUMVOLL,SUMVOLR,LCOUNT
      TYPE INTEGER    TWAIT,X,Y,Z,COUNTWL,COUNTWR,TCOUNT,COUNTXL,ERROR,A
     1REA,REZ,RBZ,LEZ,LBZ
      TYPE REAL LCOUNT,LCKVOLT,MIN,MINOVER,LVOLT,LENGTH
C     VEHICLE CLASSIFICATION ROUTINE
C
C   THIS SUBROUTINE  USES THE STORED AXLE SPACINGS TO ESTABLISH THE CLASSI-
C   FICATION OF THE VEHICLE. A CLASSIFICATION OF 99 INDICATES A BAD RECORD
C   AND MUST BE DISREGARDED.
C
      IF(X.LT.2.OR.X.GT.8)GO TO 1075
  800 IF(X.EQ.2)810,820
  810     BASIC(  4) = 13.0   $    GO TO 1080
  820 IF(X.EQ.3)830,860
  830 IF(BASIC(   11).LT.10.0)840,850
  840     BASIC(  4) = 14.0   $    GO TO 1080
  850     BASIC(  4) = 21.0   $    GO TO 1080
  860 IF(X.EQ.4)870,900
  870 IF(BASIC(   11).LT.10.0)880,890
  880     BASIC(  4) = 23.0   $    GO TO 1080
  890     BASIC(  4) = 22.0   $    GO TO 1080
  900 IF(X.EQ.5)910,940
  910 IF(BASIC(   11).LT.10.0)920,930
  920     BASIC(  4) = 24.0   $    GO TO 1080
  930     BASIC(  4) = 52.0   $    GO TO 1080
  940 IF(X.EQ.6) 950,1000
  950 IF(BASIC(   11).LT.10.0)960,970
  960     BASIC(  4) = 65.0              $ GO TO 1080
  970 IF(BASIC(   12).LT.6.0)980,990
  980     BASIC(  4) = 56.0   $    GO TO 1080
  990     BASIC(  4) = 53.0   $    GO TO 1080
 1000 IF(X.EQ.7)1010,1060
 1010 IF(BASIC(   11).LT.10.0)1020,1030
 1020     BASIC(  4) = 57.0   $    GO TO 1080
 1030 IF(BASIC(   13).LT.6.0)1040,1050
 1040     BASIC(  4) = 69.0   $    GO TO 1080
 1050     BASIC(  4) = 66.0    $   GO TO 1080
 1060 IF(X.EQ.8)1070,1075
 1070     BASIC(  4) = 71.0              $  GO TO 1080
 1075   BASIC(4)=99
      CALL PRINTAB           $    GO TO 8999
 1080 SCOUNT = 0   $   LCOUNT = 0
      BASIC(9) = X
 8999 RETURN
      END
```

```
      SUBROUTINE TOD
      COMMON/ARROY/IT(1),INPOT(6)
      COMMON/NASSER/X,LENGTH,SPEED,SCOUNT,BASIC(42),ITITLE(16),Z,Y,LCKVO
     1LT(5000),RCKVOLT(5000),VDIFL,VDIFR,COUNTWL,ELECWT(8,2),COUNTXL,LVO
     2LT(5000),RVOLT(5000),CKT,CLOPOUT,DATUMR,DATUML,COUNTWR,TCOUNT,NANA
     3,SUMVOLL,SUMVOLR,LCOUNT
      TYPE INTEGER    TWAIT,X,Y,Z,COUNTWL,COUNTWR,TCOUNT,COUNTXL,ERROR,A
     1REA,REZ,RBZ,LEZ,LBZ
      TYPE REAL LCOUNT,LCKVOLT,MIN,MINOVER,LVOLT,LENGTH
C     TIME OF DAY COMPUTATION
C
C   THIS SUBROUTINE CALCULATES THE TIME THE VEHICLE PASSED OVER THE SCALE.
C   THE CALCULATION PROCEEDS BY DETECTING THE PRESENCE OF ELECTRONIC PULSES
C   GENERATED BY THE ELECTRONIC LOGIC CIRCUIT HAVING A CERTAIN MAGNITUDE
C   AND DURATION. DETECTION OF THESE PULSES START AT THE INSTANT THE LOOP
C   DETECTOR GOES OUT (END OF LENGTH LOOP).
C
 1100     TCOUNT = TCOUNT + 2
      IF(TCOUNT - 4)1700,1119,1130
 1119 TIME = 0.0
 1120 IF(INPOT(3).EQ.1)1700,1125
 1125 TWAIT=TWAIT+1
      GO TO 1700
 1130 IF(TCOUNT - 20)1700,1140,1160
 1140   IF(INPOT(3).EQ.1  )1150,1700
 1150     TIME = TIME + (8.0*5400.0)  $  GO TO 1700
 1160 IF(TCOUNT - 36)1700,1170,1190
 1170   IF(INPOT(3).EQ.1  )1180,1700
 1180     TIME = TIME + (4.0*5400.0)  $  GO TO 1700
 1190 IF(TCOUNT - 52)1700,1200,1220
 1200   IF(INPOT(3).EQ.1)1210,1700
 1210     TIME = TIME + (2.0*5400.0)  $  GO TO 1700
 1220 IF(TCOUNT - 68)1700,1230,1250
 1230   IF(INPOT(3).EQ.1  )1240,1700
 1240     TIME = TIME + (1.0*5400.0)  $  GO TO 1700
 1250 IF(TCOUNT - 84)1700,1260,1280
 1260   IF(INPOT(3).EQ.1  )1270,1700
 1270     TIME = TIME + (8.0*360.0)  $    GO TO 1700
 1280 IF(TCOUNT - 100)1700,1290,1310
 1290   IF(INPOT(3).EQ.1  )1300,1700
 1300     TIME = TIME + (4.0*360.0)  $    GO TO 1700
 1310 IF(TCOUNT - 116)1700,1320,1340
 1320   IF(INPOT(3).EQ.1  )1330,1700
 1330     TIME = TIME + (2.0*360.0)  $    GO TO 1700
 1340 IF(TCOUNT - 132)1700,1350,1370
 1350   IF(INPOT(3).EQ.1  )1360,1700
 1360     TIME = TIME + (1.0*360.0)  $    GO TO 1700
 1370 IF(TCOUNT - 148)1700,1380,1400
 1380   IF(INPOT(3).EQ.1  )1390,1700
 1390     TIME = TIME + (8.0*24.0)   $    GO TO 1700
 1400 IF(TCOUNT - 164)1700,1410,1430
 1410   IF(INPOT(3).EQ.1  )1420,1700
 1420     TIME = TIME + (4.0*24.0)  $    GO TO 1700
 1430 IF(TCOUNT - 180)1700,1440,1460
 1440   IF(INPOT(3).EQ.1  )1450,1700
```

```
 1450     TIME = TIME + (2.0*24.0)   $    GO TO 1700
 1460 IF(TCOUNT - 196)1700,1470,1490
 1470   IF(INPOT(3).EQ.1  )1480,1700
 1480     TIME = TIME + (1.0*24.0)  $    GO TO 1700
 1490 IF(TCOUNT - 212)1700,1500,1520
 1500   IF(INPOT(3).EQ.1  )1510,1700
 1510     TIME = TIME + (2.0*6.0)  $    GO TO 1700
 1520 IF(TCOUNT - 228)1700,1530,1700
 1530   IF(INPOT(3).EQ.1  )1540,1550
 1540     TIME = TIME + (1.0*6.0)   $    GO TO 1550
C     ARITHMETIC CALCULATION OF TIME
 1550     MIN = TIME/60.0
      IMIN=MIN       $     MIN=IMIN
          SECOVER = TIME - (MIN*60.0)
          HR = MIN/60.0
          IHR = HR
          HR = IHR
          MINOVER = MIN - (HR*60.0)
      BASIC(3) = ((HR*10000.0) + (MINOVER*100.0) + (SECOVER))
      TWAIT=TIME=TCOUNT=0
 1700 RETURN
      END
```

```
      SUBROUTINE CALIB
      COMMON/ARROY/IT(1),INPOT(6)
      COMMON/NASSER/X,LENGTH,SPEED,SCOUNT,BASIC(42),ITITLE(16),Z,Y,LCKVO
     1LT(5000),RCKVOLT(5000),VDIFL,VDIFR,COUNTWL,ELECWT(8,2),COUNTXL,LVO
     2LT(5000),RVOLT(5000),CKT,CLOPOUT,DATUMR,DATUML,COUNTWR,TCOUNT,NANA
     3,SUMVOLL,SUMVOLR,LCOUNT
      TYPE INTEGER    TWAIT,X,Y,Z,COUNTWL,COUNTWR,TCOUNT,COUNTXL,ERROR,A
     1REA,REZ,RBZ,LEZ,LBZ
      TYPE REAL LCOUNT,LCKVOLT,MIN,MINOVER,LVOLT,LENGTH
C
C   THIS SUBROUTINE DETECT THE PRESENCE OF THE CALIBRATION PULSE,STORES
C   THE SAMPLES VOLTAGES WITHIN THE LEFT AND RIGHT CALIBRATION PULSES.
C
 8150 CINPOT4=INPOT(4)    $    CINPOT1=INPOT(1)
      VDIFR=ABSF(DATUMR-CINPOT4)    $    VDIFL=ABSF(DATUML-CINPOT1)
      IF(VDIFR.GE.50.0)GO TO 8550
 8300 IF(COUNTWL.LT.50)8999,8450
 8450 CALL LCAL       $       GO TO 8999
 8550 COUNTWL=COUNTWL+1
 8770 LVOLT(COUNTWL)=VDIFL
      COUNTWR=COUNTWR+1
      RVOLT(COUNTWR)=VDIFR
 8999 RETURN
      END
```

```
      SUBROUTINE LCAL
      COMMON/NASSER/X,LENGTH,SPEED,SCOUNT,BASIC(42),ITITLE(16),Z,Y,LCKVO
     1LT(5000),RCKVOLT(5000),VDIFL,VDIFR,COUNTWL,ELECWT(8,2),COUNTXL,LVO
     2LT(5000),RVOLT(5000),CKT,CLOPOUT,DATUMR,DATUML,COUNTWR,TCOUNT,NANA
     3,SUMVOLL,SUMVOLR,LCOUNT
      TYPE INTEGER    TWAIT,X,Y,Z,COUNTWL,COUNTWR,TCOUNT,COUNTXL,ERROR,A
     1REA,REZ,RBZ,LEZ,LBZ
      TYPE REAL LCOUNT,LCKVOLT,MIN,MINOVER,LVOLT,LENGTH
C
C   THIS SUBROUTINE ESTABLISHES THE AVERAGING ZONE WITHIN THE LEFT
C   CALIBRATION PULSE,DETERMINS THE ARITHMETIC AVERAGE,DETERMINS THE LEFT
C   CALIBRATION FACTOR ,   CALCULATES THE WEIGHTS IN HUNDREDS OF POUNDS,
C   AND STORE THESE WEIGHTS IN BASIC ARRAY.
C
10000 LBZ = ((4)*(COUNTWL)/10)     $      LEZ =2*(LBZ)
      DO 10100 LL=LBZ,LEZ
10100     SUMVOLL = SUMVOLL + LVOLT(LL)
      BLUNL=LEZ-LBZ+1
C
      CALFACL=61.0*BLUNL/SUMVOLL
C
      DO 10300 LL=1,X
10300     BASIC(17+3*LL) = ((CALFACL)*(ELECWT(LL,1)))
C
      CALL RCAL
      SUMVOLL=0.0    $     Z=0
10999 RETURN
      END
```

```
      SUBROUTINE RCAL
      COMMON/NASSER/X,LENGTH,SPEED,SCOUNT,BASIC(42),ITITLE(16),Z,Y,LCKVO
     1LT(5000),RCKVOLT(5000),VDIFL,VDIFR,COUNTWL,ELECWT(8,2),COUNTXL,LVO
     2LT(5000),RVOLT(5000),CKT,CLOPOUT,DATUMR,DATUML,COUNTWR,TCOUNT,NANA
     3,SUMVOLL,SUMVOLR,LCOUNT
      TYPE INTEGER    TWAIT,X,Y,Z,COUNTWL,COUNTWR,TCOUNT,COUNTXL,ERROR,A
     1REA,REZ,RBZ,LEZ,LBZ
      TYPE REAL LCOUNT,LCKVOLT,MIN,MINOVER,LVOLT,LENGTH
C
C   THIS SUBROUTINE IS THE SAME AS THE LCAL EXCEPT THAT IT IS FOR THE RIGHT
C   SIDE.
C
11000 RBZ = ((4)*(COUNTWR)/10)    $      REZ = 2*(RBZ)
      DO 11100 NN=RBZ,REZ
11100     SUMVOLR = SUMVOLR + RVOLT(NN)
C
      BLUNR=REZ-RBZ+1
      CALFACR=46.5*BLUNR/SUMVOLR
C
      DO 11300 NM=1,X
11300     BASIC(16+3*NM)= ((CALFACR)*(ELECWT(NM,2)))
C
C
      SUMVOLR=0.0      $      Y=0
11999 RETURN
      END
```

```
      SUBROUTINE PRINTAB
      COMMON/NASSER/X,LENGTH,SPEED,SCOUNT,BASIC(42),ITITLE(16),Z,Y,LCKVO
     1LT(5000),RCKVOLT(5000),VDIFL,VDIFR,COUNTWL,ELECWT(8,2),COUNTXL,LVO
     2LT(5000),RVOLT(5000),CKT,CLOPOUT,DATUMR,DATUML,COUNTWR,TCOUNT,NANA
     3,SUMVOLL,SUMVOLR,LCOUNT
      DIMENSION IBASIC(42)
      TYPE INTEGER    TWAIT,X,Y,Z,COUNTWL,COUNTWR,TCOUNT,COUNTXL,ERROR,A
     1REA,REZ,RBZ,LEZ,LBZ
      TYPE REAL LCOUNT,LCKVOLT,MIN,MINOVER,LVOLT,LENGTH
C
C   THIS SUBROUTINE IS CALLED WHEN THE WHOLE VEHICLE IS PROCESSED,IN
C   ORDER TO PRINT THE OUTPUT TABLE.    REINITIALIZATION OF VARIABLES
C   IS DONE AT THE END OF THIS SUBROUTINE.
C
      IF(NANA.EQ.1)12100,12200
12100 PRINT 12150,(ITITLE(I),I=1,16)
12150 FORMAT(1H1/2(1X,8A10/)//*   TIME  VT  VS  LTOT  RTOT  GROS  N  AB
     *BC CD DE EF FG GH WB VL AR AL  A BR BL  B CR CL  C DR DL  D ER EL
     * E FR FL  F GR GL  G HR HL  H*/)
12200 NANA = NANA + 1
      IF(NANA. EQ.52)12201,12202
12201 NANA = 1
12202 DO 12180 ILM=19,40,3
      BASIC(ILM+2) = BASIC(ILM+1) + BASIC(ILM)
      BASIC(6) = BASIC(6)+ BASIC(ILM+1)
12180 BASIC(7) = BASIC(7) + BASIC(ILM)
      BASIC(8) = BASIC(6) + BASIC(7)
      DO 12185 IMK=10,16
12185 BASIC(17) = BASIC(17) + BASIC(IMK)
      DO 12250 K=3,42
12250     IBASIC(K) = BASIC(K) + 0.5
C
      PRINT 12300,(IBASIC(N),N=3,42)
12300 FORMAT(I7,2I4,3I6,I3,I4,32I3)
C
      DO 12186 LOVE=3,42
12186 BASIC(LOVE) = 0.0
      CLOPOUT=0.0    $     LENGTH=0.0    $     LCOUNT=0.0    $    SPEED=0.0
      CALFACR=0.0    $   CALFACL=0.0    $    SUMVOLL=0.0    $    SUMVOLR=0.0
      DATUMR=0.0    $    DATUML=0.0     $     SCOUNT=0.0
      X=1           $   COUNTXL=0    $    TCOUNT=0    $    Z=0    $    Y=0
      COUNTWL=0    $    COUNTWR=0
      DO 12410 NL=1,8
      ELECWT(NL,1)=0.0
12410 ELECWT(NL,2)=0.0
      RETURN
      END
```

```
          ASCENT
          ENTRY   SHIFT
          VFD     D30/SHIFT,N30/2
SHIFT     CON     0
SHR       SA2     B2+B0    .
          SA1     B1+B0    .
          SB3     X2+B0    .
          LX6     B3,X1    .
          SA6     B1
          EQ      SHIFT
          END
```

```
          IDENT        ATOD
          ENTRY        ATOD
ATOD      SLJ          **
          LDA          FIVE
          STA          5
          EXF      5   CELL
LP        LDA          5
          SUB          FIVE
+         SLJ      5   *-3
          AJP      1   LP
          LDA          FIVEQ
          LDQ          FIVE
          STA          5
          STA          FIVE
          LDA          FWA
          SAU          5
          ALS          24
          STA          FWA
          STQ          FIVEQ
          SAU          LP1
          SAL          ARRAY
          SAU          STA
          ENI      1   9999
LP1       LDA      1   **
          ENI      2   11
          ENQ          0
          ALS          36
LP2       QLS          2
          LLS          1
          IJP      2   LP2
STA       STQ      1   *
          IJP      1   LP1
          ENA          01
          ENQ          FORM
+         CALL         Q8QINGOT
+         CALL         Q8QGOTTY
          0            NXT
ARRAY     60           10000
          01           **
 NXT      CALL         Q8QENGOT
+         SLJ          LP
FORM      BCD          1(10013)
FIVE      ZRO          CELL+10000
          ZRO          CELL+10001
FIVEQ     ZRO          CELL+20000
          ZRO          CELL+20001
FWA       ZRO          CELL
          ZRO          CELL+10000
CELL      BSS          20000
          END
          END          ATOD
          FINIS
'EXECUTE.
'EXECUTE,,56.
'EXECUTE,,56.
```

```
         IDENT        ATOD
         ENTRY        ATOD
ATOD     SLJ          **
         EXF     0    42031B
         EXF          42005B
         EXF     7    42000B
         LDA          FIVE
         STA          5
         EXF     5    CELL
LP       LDA          5
         SUB          FIVE
+        SLJ     5    *-3
         AJP     1    LP
         LDA          FIVEQ
         LDQ          FIVE
         STA          5
         STA          FIVE
         LDA          FWA
         SAU          5
         ALS          24
         STA          FWA
         STQ          FIVEQ
         SAU          LP1
         SAU          LP3
         INA          1
         SAU          LP2
         ENI     1    0
         ENI     3    0
LP2      LDQ     1    **
         LLS          46
         ALS          1
         LLS          2
         ALS          11
LP1      LDQ     1    **
         QLS          36
         LLS          10
         ALS          1
         LLS          13
         ARS          11
         ALS          35
         ARS          11
LP3      STA     3    **
         INI     1    2
+        ISK     3    1999
         SLJ          LP2
         LIU     1    LP1
         SIU     1    OUT
         INI     1    2000
+        EXF     7    00041B
         SLS          *+1
         SIL     1    4
OUT      EXF     4    **
+        SLJ          LP
FIVE     ZRO          CELL+4000
         ZRO          CELL+4001
```

```
FIVEQ    ZRO        CELL+8000
         ZRO        CELL+8001
FWA      ZRO        CELL
         ZRO        CELL+4000
CELL     BSS        20000
         END
         END        ATOD
         FINIS
```

```
      PROGRAM ADLIST
      DIMENSION INP(2000)
      COMMON/ARRAY/IT(7)
      PRINT 100  $  WRITE(10,100)  $  PAUSE  $  REWIND 12
      DO 5 I = 1,4
      PRINT 10, I
      BUFFER IN(12,1)(INP(1),INP(2000))
    1 IF(UNIT,12) 1,2,3,4
    2 DO 15 J = 1,2000
      IT(1) = INP(J)
      CALL ADUNPACK
      PRINT 20,(IT(K),K = 1,7)
   15 CONTINUE
    5 CONTINUE
      GO TO 9999
    4 PRINT 40   $   GO TO 2
    3 PRINT 30  $  GO TO 9999
   10 FORMAT(1H1,50X,15HDATA BLOCK NO. ,I1/)
   20 FORMAT(1X,7O18)
   30 FORMAT(///,1X,5HEOF   )
   40 FORMAT(27H PARITY ERROR ON INPUT DATA)
  100 FORMAT(32H MOUNT TAPE NO.654 ON LOGICAL 12)
 9999 STOP
      END
```

```
      PROGRAM ADLST1B
      DIMENSION ARRAY(1000)
      DIMENSION IAA(18),IA(120),JB(30)
    1 FORMAT (10(1X,12I1))
      CALL PLOTS (ARRAY,1000,34)
      CALL PLOT (0,15.,-3)
      X=0
   10 BUFFER IN (1,0) (IAA(1),IAA(18))
    7 IF (UNIT,1) 7,8,8,8
    8 DECODE (130,1,IAA) IA
      K=1 $ DO 5 I=1,109,12
      JK=I+1 $ II=0 $ JJ=I+9
      IF (IA(I)) 34,44
   34 DO 3 J=JK,JJ
    3 II=II*2+IA(J)-1
      GO TO 33
   44 DO 4 J=JK,JJ
    4 II=II*2+IA(J)
   33 JB(K)=II
      Y=II $ Y=Y/20.
      IF(ABSF(Y) .GT. 14.) 18,17
   17 CONTINUE
   18 CONTINUE
      X=X+.01
      JB(K+1)=IA(I+10)
      JB(K+2)=IA(I+11)
    5 K=K+3
      PRINT 20,JB
   20 FORMAT (1X,10(I8,2I2))
      GO TO 10
      END
```

APPENDIX B

FIELD INSTALLATION

APPENDIX B. FIELD INSTALLATION

The field installation of the road transducers and loop detectors consists of four main operations. First, laying the positions for saw cuts; second, saw cutting; third, removal of pavement; and fourth, installation of wiring and the transducer. (See illustrations, Figs B.1 through B.6.)

The equipment and materials needed for carrying out these operations are: measuring tape, nails, hammer, chalk line, chalk, strings, power-driven saw, crow bar, wheel barrow, trowel, shovels, chassis grease, sand-cement grout, 0.001-inch dial indicator on surface plate mount, and 1-inch masking tape.

The laying out of the positions for saw cuts consists of the following steps and by using nails to mark the corresponding points:

(1) Establish the origin "0" of the layout coordinate system (Fig B.7) on the lane line.

(2) Mark points A , B , and C according to their corresponding coordinates.

(3) Mark an arc of a circle with a 15-foot radius with A as a center and intersecting another 12-foot arc with center 0 at point D .

(4) Extend line OD using a chalk line and mark points D and E . Then mark points F using a 14-foot arc and an 18-foot arc with centers E and C , respectively.

(5) Mark point G by the same procedure outlined in Step 4 and using appropriate arc lengths.

(6) Extend lines GD′ and FE and mark points H and J , respectively.

(7) Mark the guide points shown on lines BJ , CF , D'G , and EF using the dimensions shown. These guide points establish the boundaries of the saw cuts.

(8) Mark with chalk the positions of the saw cut by using a string joining two corresponding guide points as a guide line.

After laying out the boundaries of the saw cut, the saw-cutting operation can be started at the specified positions with proper alignment with the corresponding guide line which is offset 6 inches from the saw-cut position.

At the conclusion of the saw-cutting operation, the following steps must be carried out:

(1) Remove the top 2-1/2 inches of the pavement and clean loose material from the exposed surface of the underlying layer.

(2) Place the wire for the loop detector in the saw cut specified for that purpose and grout with thin cement.

(3) Using a double saw cut to curb from end of transducer location, lay 3/4-inch conduit with sufficient "fall" to provide water drainage.

(4) Bolt the eight bearing plates to the bottom of the transducer frame and leveling bars to the upper frame surface.

(5) Mix sufficient "Speed Crete" (or other rapid setting cement) to embed the bearing plates. Place a minimum of 1/2 inch of cement under each plate to provide sufficient base.

(6) Set frame and bearing plates, working into cement until leveling bars are in contact with the road. Use excess cement to form a drain and grout 3/4-inch conduit at the drain end of the transducer.

(7) Fill and finish the saw cut over the drain to the curb and fill around the frame to within 1 inch of the road surface. Care must be taken in filling around the frame to work the cement so that no voids are left between the frame and the road material.

(8) After the cement has dried sufficiently under the bearing plates, remove the bolts holding the plates to the frame. Insert the measuring circuit assembly and feed 3/8-inch copper tubing through the 3/4-inch conduit to the measuring-circuit junction box. Make mechanical connections to the junction box fitting.

(9) Feed the signal cable through the copper tubing and make electrical connections at the junction box to the bridge circuit. Check the bridge resistance between any corner of the bridge and the measuring-circuit frame should be 1000 megohms or more and will be completely unsatisfactory if less than 100 megohms.

(10) Install the load transfer plates beginning with the center plate. Adjust the leveling screws to align the upper surface of the frame (using dial indicator) with all four leveling screws in contact with the load cell under each. (There should be no "rocking" when proper adjustment is reached.)

Each end plate is placed using the same procedure as above by adjusting the two leveling screws provided. Any rocking of the load-transfer plates will cause noise on the output signal of the transducer due to vibration.

Horizontal alignment and lateral alignment is maintained by the adjustable contact screws in the edges of the plates, thus maintaining alignment of hardened leveling screws with the load-cell boss. The contact screws should not fit the frame so tight that the load will be transferred to the frame since this would decrease the electrical output of the transducer.

(11) With all plates properly aligned the cover should be installed. Three layers of masking tape around the edges of the cover before installation will provide clearance between the cover and grout if the cover is ever removed and replaced for service. Bolt the cover securely with the "nylock" screws provided and finish grouting to complete the installation.

(12) A junction box for protection of the signal cable should be provided by covering it with a small barrel fastened to bolts set into the curb with cement.

Fig B.1. Saw cutting operation.

Fig B.2. Removal of pavement.

Fig B.3. Saw cuts cleaning.

Fig B.4. Frame and pads in place.

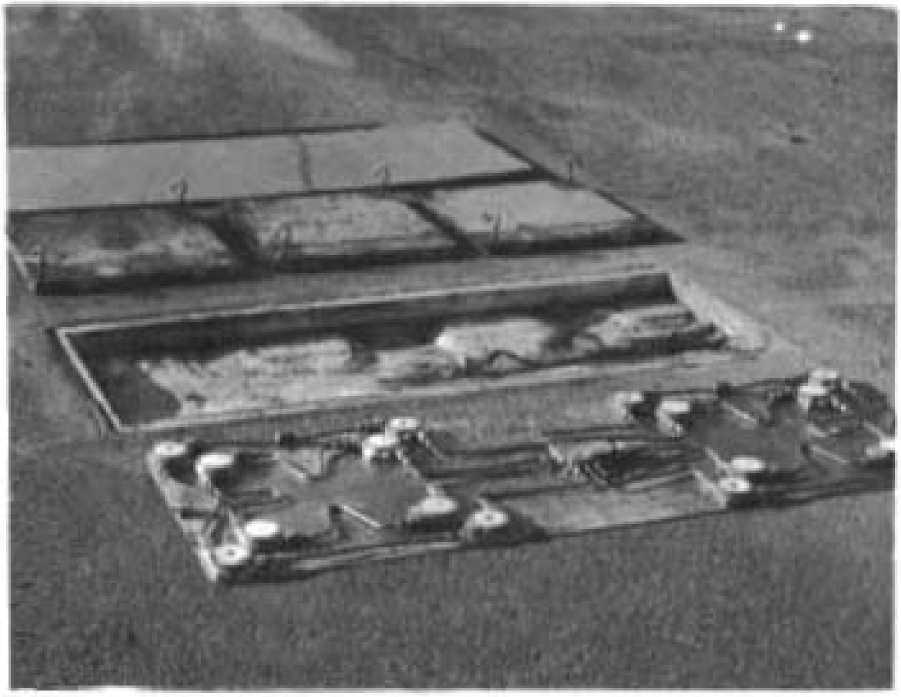


Fig B.5. Model 880 Chassis.

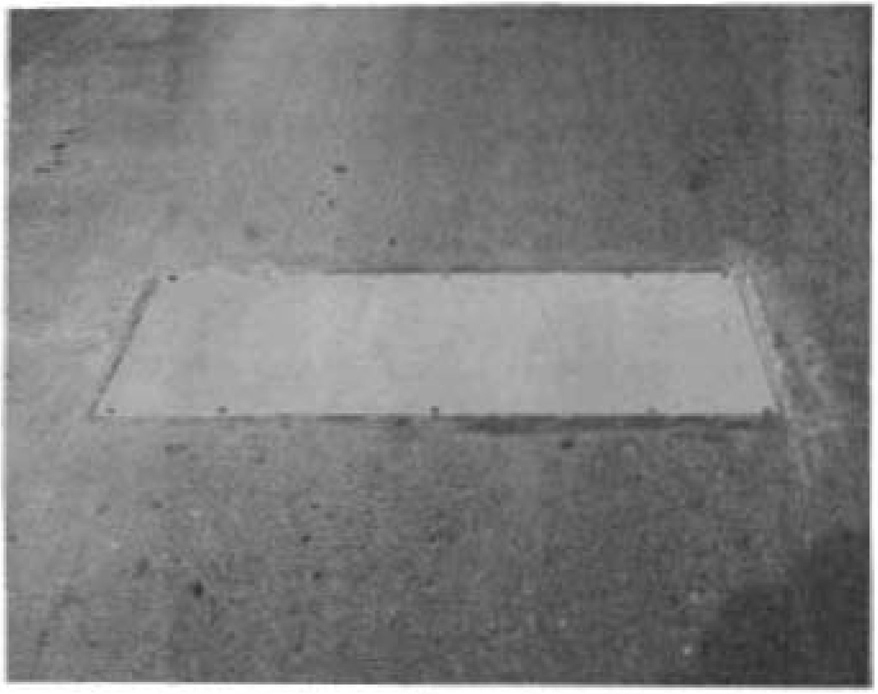


Fig B.6. Installed transducer.

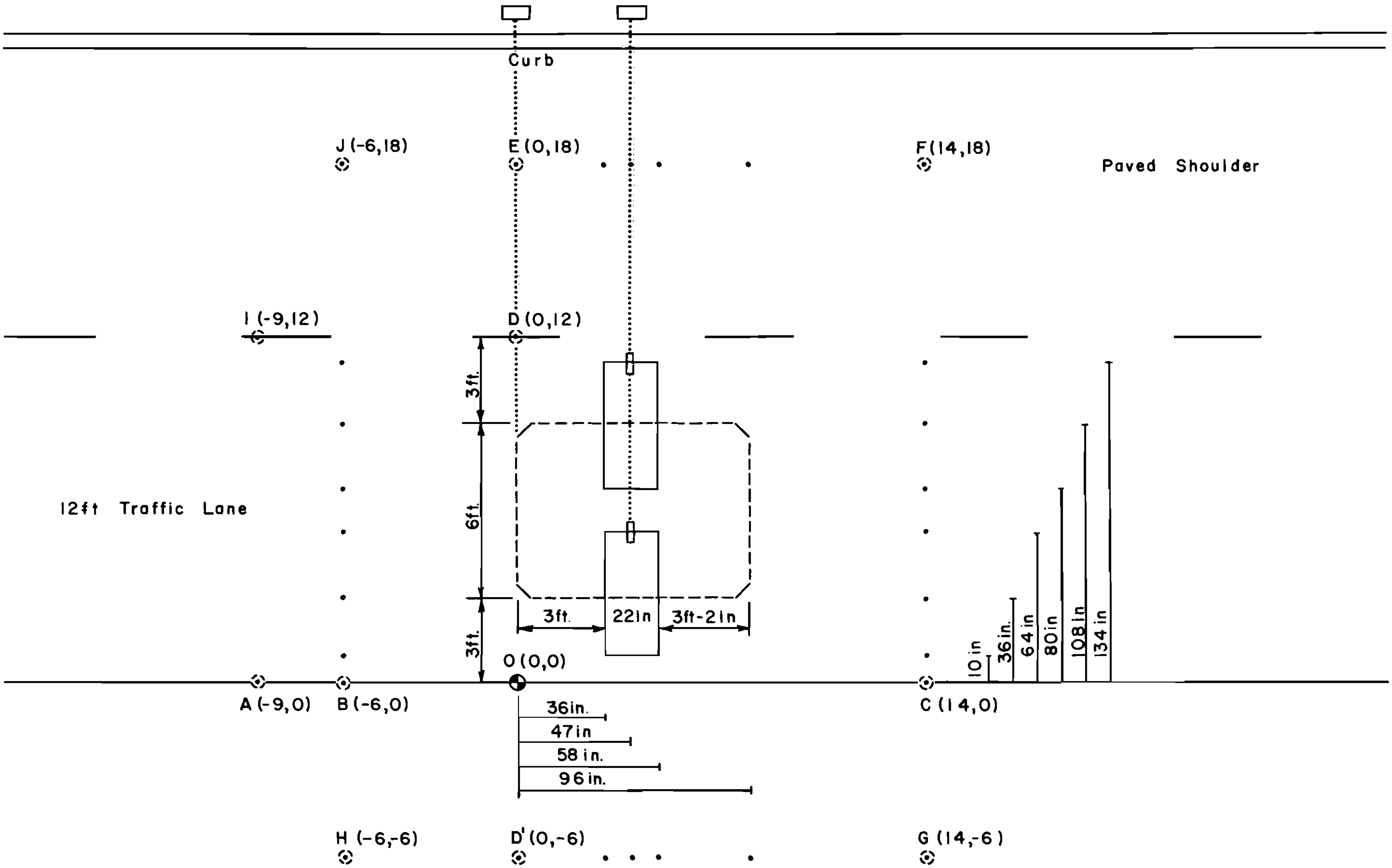


Fig B.7. Field installation: dimensions for saw cuts (coordinates in feet).