PRELIMINARY REVIEW COPY

DEVELOPMENT OF A PORTABLE WEIGH-IN-MOTION SYSTEM

by

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Findings and Conclusions

The findings and conclusions resulting from the research are:

1) No inexpensive, easily handled transducer exists at present which would be suitable for a portable weigh-in-motion system.
2) A single hose filled with a non-compressible fluid does not provide pressure readings from which the passing wheel load can easily be determined.

Implementation

No implementation of the results can be recommended.

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Chapter 1

Introduction

One of the primary inputs into the structural design of pavements and pavement overlays is the volume and composition of the traffic stream. These data are also used in planning maintenance and reconstruction of highways. The acquisition of load and traffic data is usually performed by manually counting vehicles in each of several categories, measuring wheel or axle loads for typical vehicles and making assumptions of future traffic volume and composition. Since there are significant hourly, daily and seasonal variations in the traffic mix, a large volume of statistical data is required to determine the average daily traffic and the average annual daily traffic. If mechanical or electronic traffic counters are employed, the composition of the traffic must be assumed. Even if the composition is determined manually, assumptions regarding wheel or axle loads are likely to have significant error.

The determination of wheel loads on a random sampling basis usually entails the use of portable scales and stopping selected vehicles for weighing. This procedure presents some hazards to traffic and survey personnel, as well as general inconvenience to users, so that data collection is infrequently carried out. Yet there is a substantial need for wheel load information for design purposes.

Maintenance and reconstruction needs for Arkansas highways are increasing at a rate faster than the increase in available funds. Some of the causes of highway deterioration, such as weather, cannot be controlled, but excessive truck weight is one cause that can be controlled through an effective enforcement program.

The magnitude of the problem of overweight trucks is discussed in a recent General Accounting Office report. According to this report about one in four loaded heavy trucks exceeds the applicable state weight limits, as shown in Table I.

Table 1

Truck Category	Percent of Loaded Trucks Exceeding State Weight Limits
Light and Medium (two axles)	1
Heavy Single Units (three or more axles)	28
Tractor - trailers	22
Trucks with trailer	25

It is very difficult to establish permanent weight stations that cannot be bypassed, whereas portable scales generally are quickly spotted due to the congestion which accompanies their use. However, due to the highway damage presently occuring, which is aggravated by heavy trucks, every opportunity to reduce this damage must be examined carefully. One possibility addressed herein is that of quickly and easily detecting overweight vehicles while moving.

The objective of the project is to examine the feasibility for development of a portable weigh-in-motion system. If such a system were sufficiently accurate, it could be utilized for screening of overweight trucks. Its portability would allow it to be used at locations selected so that avoidance by an overweight vehicle would be very difficult. Hopefully, the cost of such a system would be low enough to allow the state to procure and utilize many units.

The work plan for the project began with a literature survey of various weigh-in-motion systems recently reported. This was followed by a data collection and analysis period which focused on selection of a suitable weight sensor for the portable system. Following the acquisition of an appropriate transducer, a prototype hardware system was to be assembled and tested. Subsequent chapters discuss the details and results of these efforts.

Chapter 2 Summary of Literature Survey

A number of projects have been described to date regarding a dynamic weighing process for either traffic classification or load enforcement (or both). Modern technology now allows a system with low power consumption, small size but with great signal processing power to be realized, so that the transducer becomes the major problem of concern. Thus, the literature was reviewed with a particular emphasis on a suitable sensor for portable applications.

Although several of the systems are reporting some success, the large majority are associated with some factor which makes them not compatible with the requirements for a portable weigh-in-motion system. For the most part, a permanent or near-permanent installation is required, usually because the transducer consists of strain gages mounted on a heavy plate (1,2,3,13,15,17,18,19), or instrumented bridge pilings(5,14,16). Several systems also required the vehicle velocity to be quite slow (6,10), although others claimed a reasonable highway speed.

A few systems were described which utilized sensors appropriate to a portable system (8,11,12). One such device was a commercial unit manufactured by the Tellurometer Division of Plessey Electronics Corp. This device is essentially a large capacitor with a rubber-air dielectric. Compression of the dielectric by the vehicle wheel alters the capacitance which can be externally recorded as a voltage change. The commercial literature indicates satisfactory results over a large range of speeds, and an installation time of less than one hour by two persons. This amount was of great interest at the beginning of the project due to its portability and claimed satisfactory results. However, a communication with the manufacturer in August 1980 stated that the Axle Weight Analyzer has been discontinued for some time and no subsequent re-engineering and production was forseen. Thus, it was not considered further.

After the beginning of this project, a new transducer was reported (12) which is also of interest. Of South African origin, the Traffic Axle Weight Classifier utilizes a large area transducer which, like the Plessey device, operates on a variable capacitance principle. Three sheet electrodes are separated by two thin layers of a soft dielectric, so that a load compresses the rubber and varies the capacitance between the center and outer electrodes. While the system characteristics are quite attractive, e.g. 10 minute setup time, transducer only .28 inches thick, and accuracy sufficient for classification of Axles into 10 weight groups, the commercial system is quite expensive, with the transducer alone priced at over $12,000 (1981), (Transport Technology, Inc., Washington, D. C.). Since at the time of the announcement of this system the present project was well under way, the work effort was not modified to include this device. Subsequent chapters describe these efforts.

Chapter 3 Data Acquisition and Analysis

As previously mentioned, the weight sensor for a portable system must be easily and quickly installed in order to preclude forewarning overweight traffic of its presence. In addition, it must be relatively inexpensive in order to make widespread usage by load enforcement officials possible. Since the signal processing portion of the system can be designed so that complex operations can be accomplished on-site, a decision was made to pursue an extremely simple type of transducer from which one could hopefully infer the weight of a passing axle through sufficient signal processing. Also, the presence of the Pavement Data Acquisition System (PDAS), described below, meant that prototype sensors could be examined without having to specially construct a high speed data collection system.

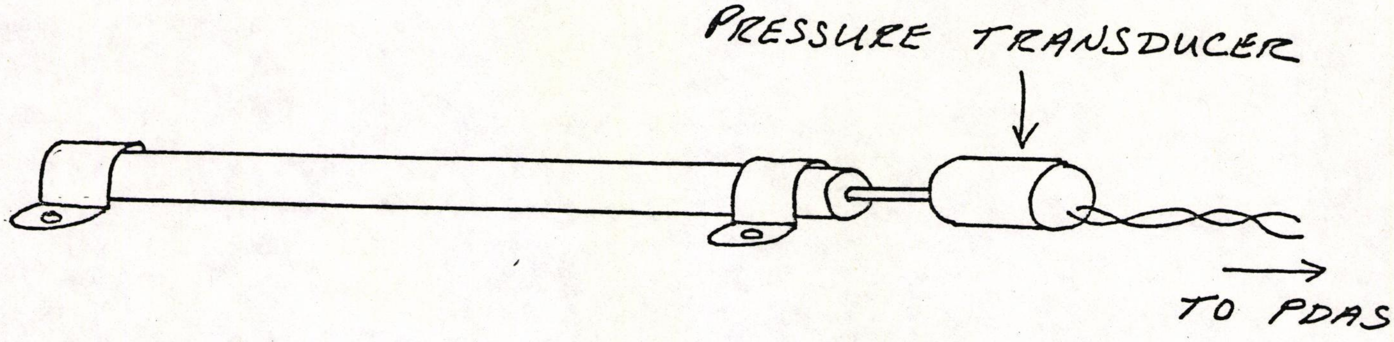
The weight transducer initially proposed was a fluid-filled hose stretched across the roadway. A pressure transducer is attached to one end of the hose, so that pressure variations within the fluid could be observed as a function of wheel load passage. Although the hose would never fully support the passing wheel at any instant of time, the intent was to determine if one could infer the axle load given the knowledge of internal fluid pressure and vehicle speed, both of which are easily measured. It was recognized that such factors as sidewall stiffness and tire pressure would have some influence on the hose pressure reading, as well as the stiffness of the vehicle suspension. In order to minimize the effect of compressing the suspension, the hose utilized should be as small as possible, while retaining sufficient strength to avoid bursting under heavy load. Considering the desirability of low cost also, the hose initially selected was ordinary ½ inch air pressure hose. This hose will withstand a minimum of 150-200 psi, is inexpensive and readily available, and has a durable, abrasion resistant covering.

Two sensor configurations were initially fabricated. The simplest was a single 10 foot length of hose with one end capped and the other end connected to a shut off valve, static pressure gauge and a pressure transducer with a 150 psi, full scale capability. By means of the valve and cap, various fluids could be introduced into the hose. The entire sensor was held to the asphalt pavement by means of metal stays at each end nailed into the asphalt surface. (Figure 1a)

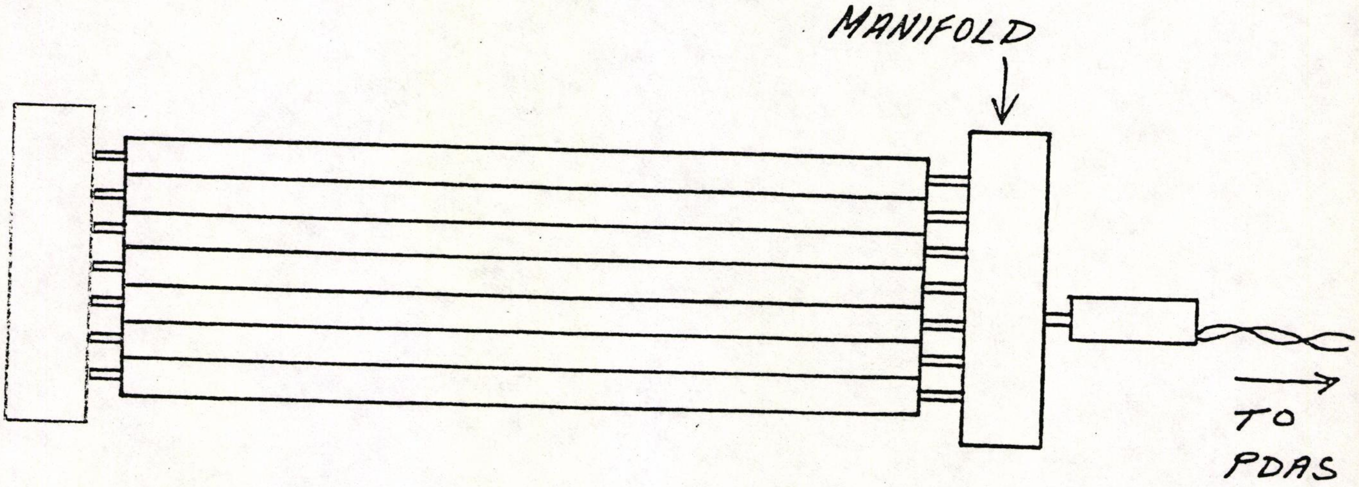
The second configuration consisted of a set of adjacent ½ inch hoses (touching) which were connected to a common manifold at each end. The intent was to more fully support the loaded wheel during its passage in the case that the single hose data were inconclusive. The pair of manifolds were designed to allow a variable number of hoses to be installed, ranging one to thirteen, the latter permitting a six and one half inch pressure sensitive area. Installation of the sensor was similar to that for the single hose device, with a shut off valve and pressure transducer connected to one of the manifolds. (Figure 1b)

The Pavement Data Acquisition System

The Pavement Data Acquisition System (PDAS) is a mobile, self contained multi-channel high speed data acquisition and recording system. Although originally designed for recording data from buried pairs of induction coils, the system can accept low amplitude voltage signals or monitor small impedance changes from a variety of sources.



SINGLE HOSE TRANSDUCER



MULTIHOSE TRANSDUCER

Figure 1. Initial configurations at fluid filled hose. Multihose manifolds are common to all hoses.

The original design goals for the PDAS were:

1. Acquisition and conditioning of at least 20 signals from induction coil pairs;
2. Digitization of each channel at a maximum sampling rate of 2000 Hz/channel (40 KHz sampling rate total) with a resolution of at least 8 bits;
3. Recording of this data on one-half inch magnetic tape in IBM-compatible format;
4. Capability for plotting out any selected channel from a previously recorded run for verification of run data; and
5. Straightforward system operation requiring minimal operator training.

1. THE PDAS HARDWARE - Physically, the PDAS instrumentation resides within a modified 1978 Ford long wheelbase van. The PDAS basically consists of three consoles, referred to below as left, right and center with an operator's chair facing the center console and looking out the left side of the vehicle. Provision for external AC power was also installed. The van itself is equipped with dual air conditioning blowers and the engine with heavy duty cooling capacity so that the interior of the van can be kept at near room temperatures even on very hot days.

The left console consists of the following items:

1. A bank of 20 Validyne CD90 Carrier Demodulators for powering each transmitting coil and decoding the signal from each receiving coil. These units reside in a case with a common power supply. Each transmitter output and each receiver input is

connected via a twisted wire pair to a BNC bulkhead connector located on the left rear quarter panel of the van. From outside the van, there appears two doors, approximately 8 in. square, each of which covers an array of 20 BNC connectors, with transmitting and receiving connectors grouped separately. In addition, there is also one BNC connector behind each door for attachment of tape switches for signaling the beginning and end of a run.

2. A variable frequency pulse generator for controlling the input signal sample rate.
3. The magnetic tape formatter which controls the tape drive and provides the appropriate characters necessary for producing an IBM-compatible tape.

The center console is a self-contained microcomputer with the following components:

1. Intel SBC 80/10 single board computer with 13K byte assembly language program.
2. Video controller board and 9-inch CRT.
3. Tape controller board.
4. ASCII keyboard.
5. Switching power supply.
6. 25 channel multiplexer with 8 bit A/D converter. Full scale input voltage ± 2.5 volts.

The right console consists of the following:

1. 45 ips magnetic tape drive (DigiData MAXIDECK), capable of reading and writing 2400 foot tape reels.
2. AXIOM 820 printer-plotter for reproducing run headers and data previously recorded on tape.

For conditioning the input AC power, a SOLA CVN voltage regulator was installed inside the left rear door of the van. A covered AC receptacle on the outside left rear quarter allows power to be provided by a stationary or portable source.

2. THE PDAS SIGNAL PROCESSING - The description which follows describes how buried coil pairs are interfaced with the PDAS. Connections are made between the van connector panels and the desired mix of buried transmitter and receiver coils. Each Validyne CD90 generates a 5 VRMS, 20 KHz signal for driving a transmitter (in phase for all 20 units). The output from a receiving coil is compared internally in the CD90 in magnitude and phase, resulting in a DC signal with a ±10 volt swing. Since this magnitude was found to generate considerable crosstalk in the downstream multiplexer, the CD90 outputs were modified with Zener diode clipping to restrict the output swing to ±4 volts. The CD90 has front panel controls for balancing (required for each change in initial coil spacing), zero offset and sensitivity (range 0.1 to 100 mv/v). The latter was set to the largest value which would not generate an output exceeding ±2.5 volts, generally on the order of .25mv/v.

The A/D converter produces an 8 bit digital equivalent of each signal on software selected channels. The sample rate can be varied by the pulse generator in the left console. The order in which input channels are sampled is controlled by software. The digitized signals are input to the tape controller, which writes the data to tape together with the IBM check characters. All data is written in 4K (4096) byte blocks. Recording format is ASCII for all text and 8 bit 2's complement for all data.

Following a run, any selected channel can be plotted out on the AXIOM 820 plotter. Run header information and calibration data are also included. Since the data on tape represent digital samples, they must be converted before plotting. This is done by extracting the stored CD90 sensitivity settings and using the fact that for the A/D converter ±2.5 volts equals 256 counts. This results in the calculation of a demodulated voltage at the receiver coil. Then using the stored values of initial coil spacing and installation mode (e.g., coaxial, coplanar, etc.) and the nonlinear curve of displacement vs. voltage stored in ROM, the actual coil displacement from the initial spacing can be determined and plotted.

3. THE PDAS SOFTWARE - From the operator's viewpoint, PDAS control is very straightforward. A menu of operations is made available from which a mode is selected. Listed below is the menu; following the menu list is a desciption of each of the modes. The "MENU" key may be pressed any time during operation of the system. If an action is being performed, it will be halted. The system then displays a menu which describes each of the functions that may be performed. The operator selects a function, enters the corresponding funtion number, and presses the "ESC" key. The selected function will then be started.

The menu functions are:

1) reset date and time
2) initialize new tape
3) define channel
4) define channel order
5) display channel summary
6) start new run

7) rerun previous run
8) scratch last run on tape
9) plot run
10) tape diagnostic.

For the hose evaluation studies, the pressure transducer was connected to the PDAS in a manner similar to the above description. The transducer contained a bridge which was driven by the 20 KHz output of the CD90 unit. The pressure signal was obtained by demodulating the bridge output. The PDAS records digital counts on tape, so that any reference to initial spacings, gain, etc. is irrelevant. However, this did mean that any data plots contained some reference to displacement, but this was ignored.

The initial studies were intended to select a candidate hose configuration which would then be incorporated into the data collection portion of another project (TRC-61), since they both utilized vehicles with various axle loads and velocities. These studies consisted of driving a full size passenger car over the sensor at velocities of 5 mph and 30 mph while recording pressure data from various hose/transducer combinations. The plots generated within the van were then examined for indications of sensor applicability.

Two conclusions were drawn from these initial experiments:

1. As would be expected, a non-compressible fluid gave much higher pressure readings than air alone. Water was found to provide an excellent medium. Air, at static pressures up to 100 psi, did not appear to offer any advantages.

2. The single hose, water filled, appeared superior to the multi-hose arrangement. Not only is the pressure amplitude greater, but common manifold connecting multiple hoses permitted significant oscillation (ringing) of pressure wave following vehicle passage.

For these reasons the single water-filled hose was selected for the first large scale data collection activity as the most promising candidate for a simple transducer.

The concept of the single hose transducer was first tested in August 1981 at a test site near Benton, Arkansas, in conjunction with project TRC-61. The latter required vehicles of known axle loading to pass over a section of the roadway containing buried induction coil pairs extending across the roadway width. The PDAS van was parked adjacent to the site in order to record displacements of the buried coils and calculate vehicle speeds from two tape switches spanning the section. Two separate water-filled single hose transducers were placed adjacent to the downstream of the instrumented section for the weight-in-motion study. Vehicle speeds used were 5, 30, and 55 mph, while the axle loading varied from 1600 lbs (passenger car) to 33,000 lbs. (large truck).

Figures 2-11 depicts typical results from this test activity utilizing the fluid filled single hose. The traces are labeled in inch deflections only because the PDAS data processing program was designed for buried coil pair data. The actual graph is of fluid pressure versus time. By comparing traces, it is seen that there is no immediately apparent parameter which can be well correlated with axle loading. For example, while Figure 2 suggests that weight information might be present in the signal amplitude a repeat of the test (Figure 3) indicates the difficulty with that concept. Moreover, comparisons with Figure 9, a much larger truck, indicates that amplitude alone is not a suitable parameter. Area under the curve for each axle passenger also does not correlate with the known axle load, e.g. Figure 6. Thus it was tentatively concluded following analysis of the initial data that the single hose transducer did not provide sufficient information for reliable weight classification.

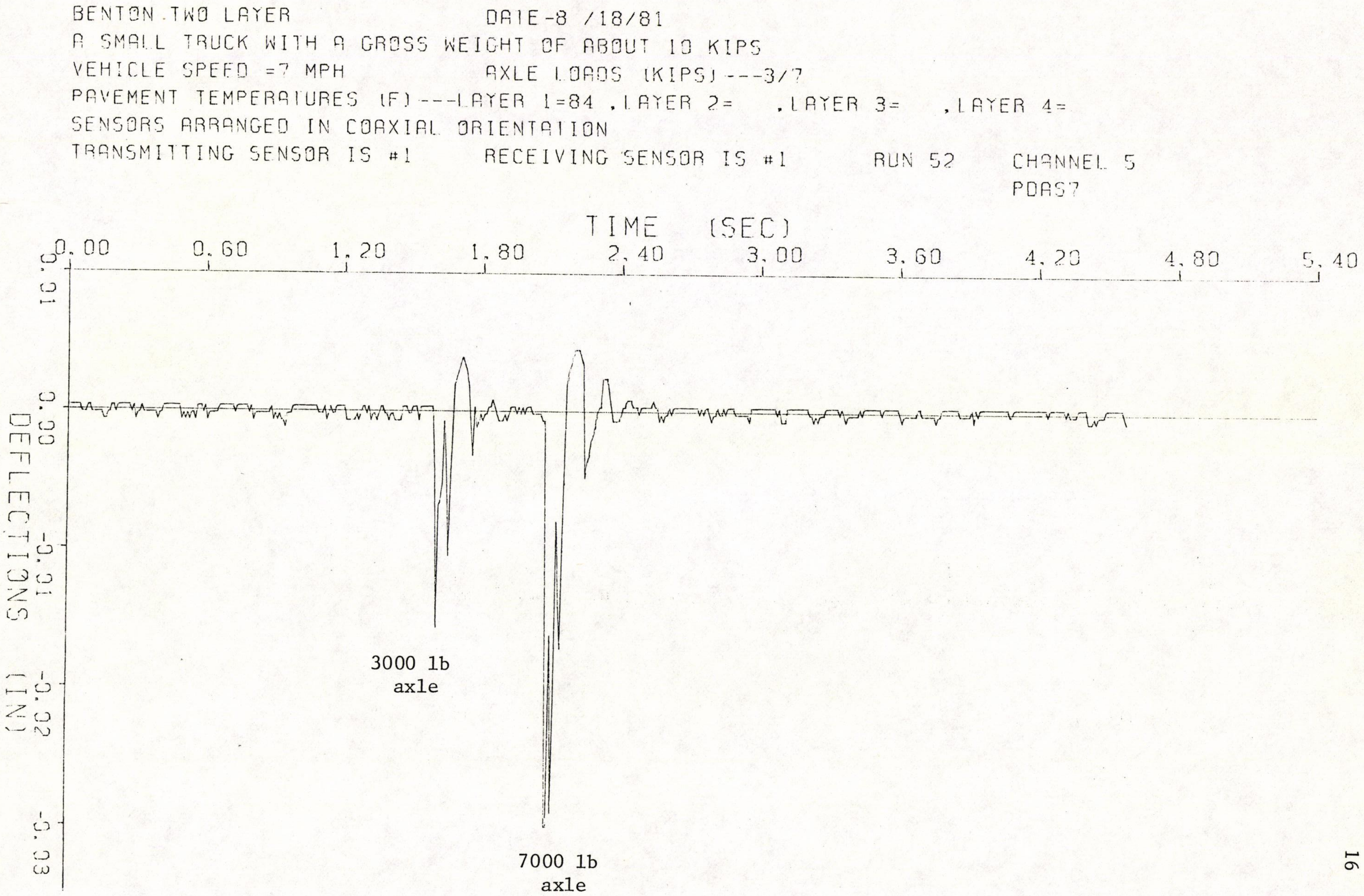


Figure 2. Single Hose Pressure Signal for Skid Truck at 7 mph.

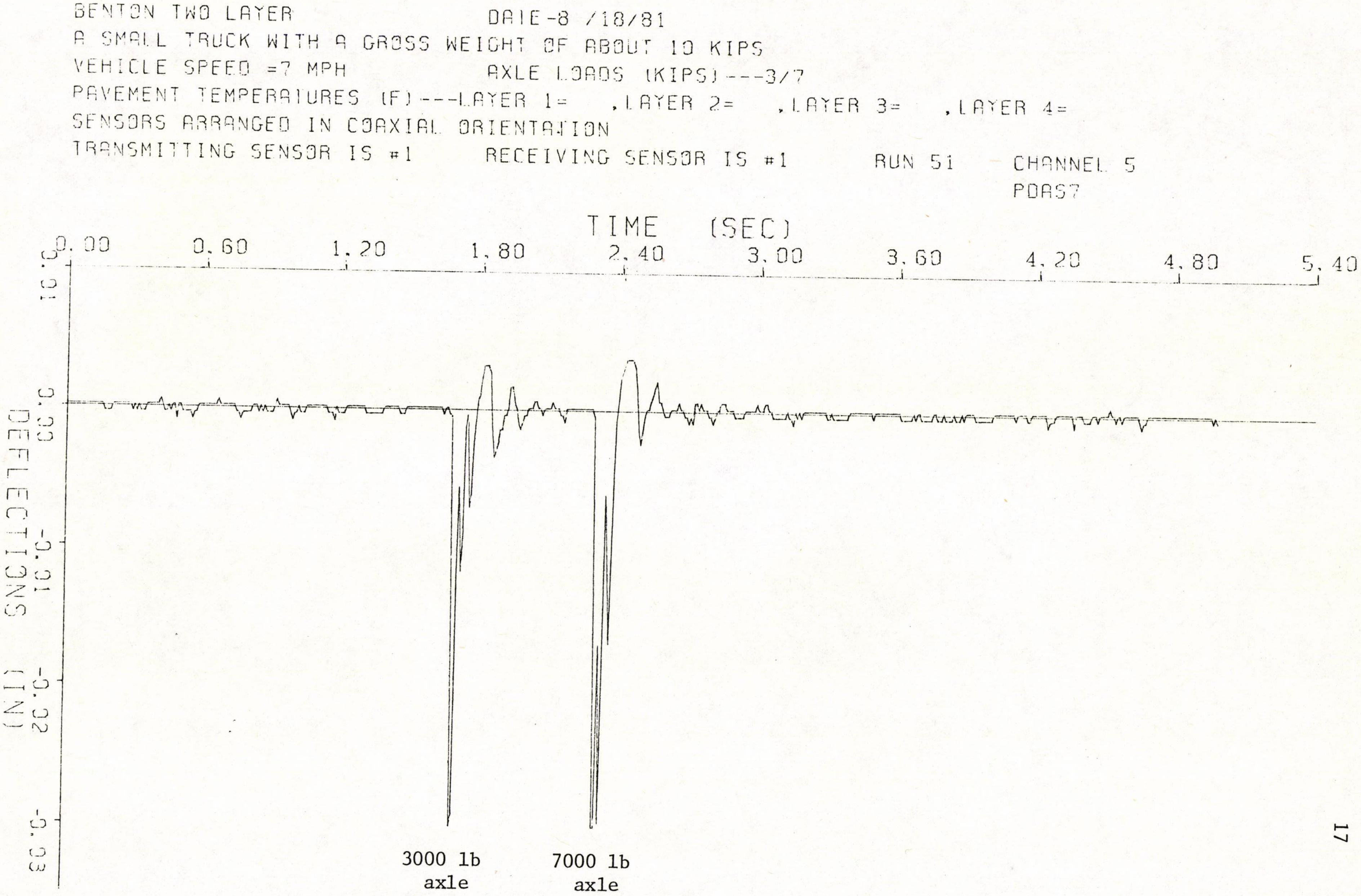
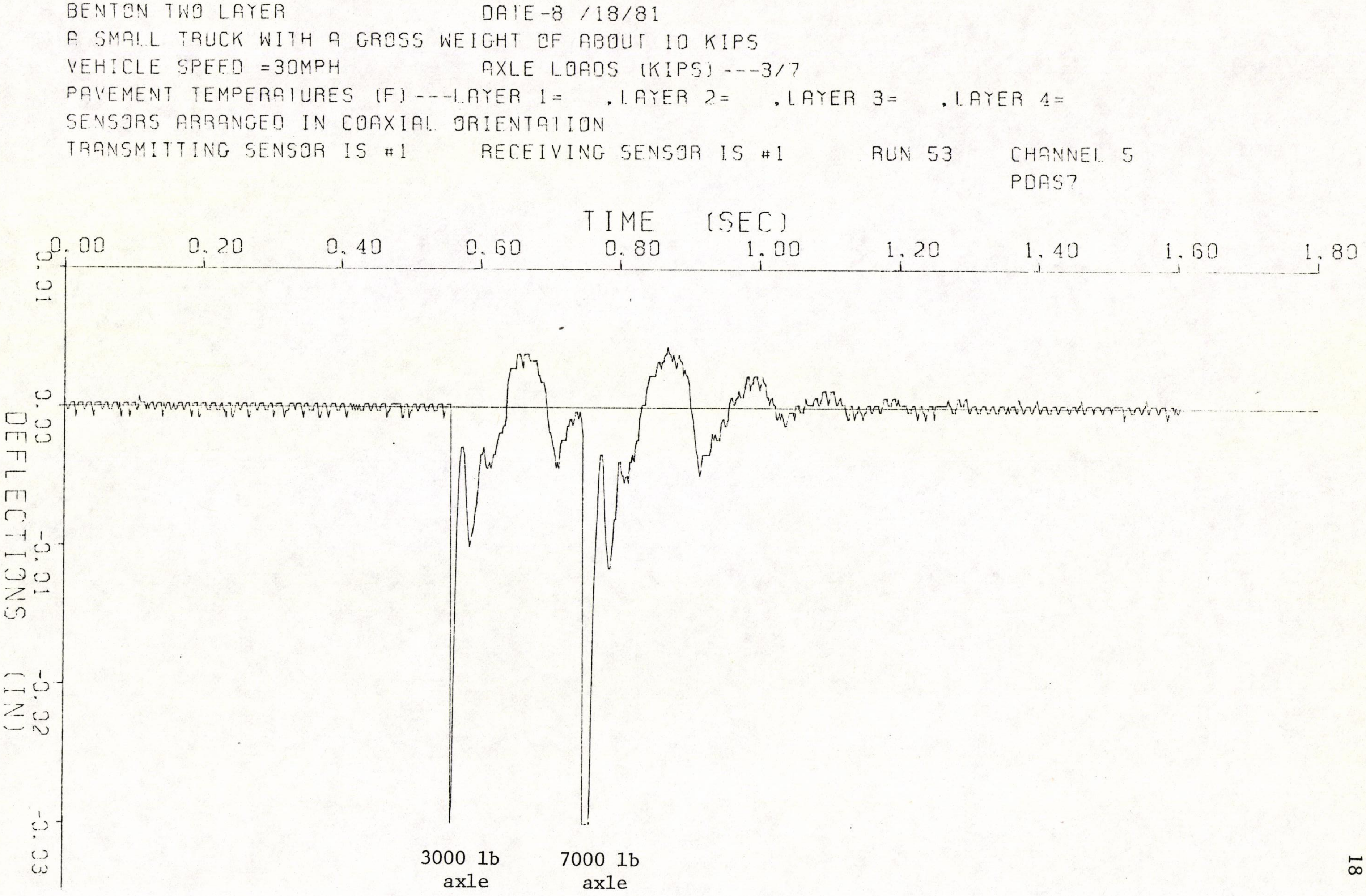


Figure 3. Single Hose Pressure Signal for Skid Truck at 7 mph.



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BENTON TWO LAYER                DATE-8 /18/81
A SMALL TRUCK WITH A GROSS WEIGHT OF ABOUT 10 KIPS
VEHICLE SPEED =30MPH            AXLE LOADS (KIPS)---3/7
PAVEMENT TEMPERATURES (F)---LAYER 1=   ,LAYER 2=   ,LAYER 3=   ,LAYER 4=
SENSORS ARRANGED IN COAXIAL ORIENTATION
TRANSMITTING SENSOR IS #1       RECEIVING SENSOR IS #1       RUN 53     CHANNEL 5
                                                                        PDAS7
```

Figure 4. Single Hose Pressure Signal for Skid Truck at 30 mph.

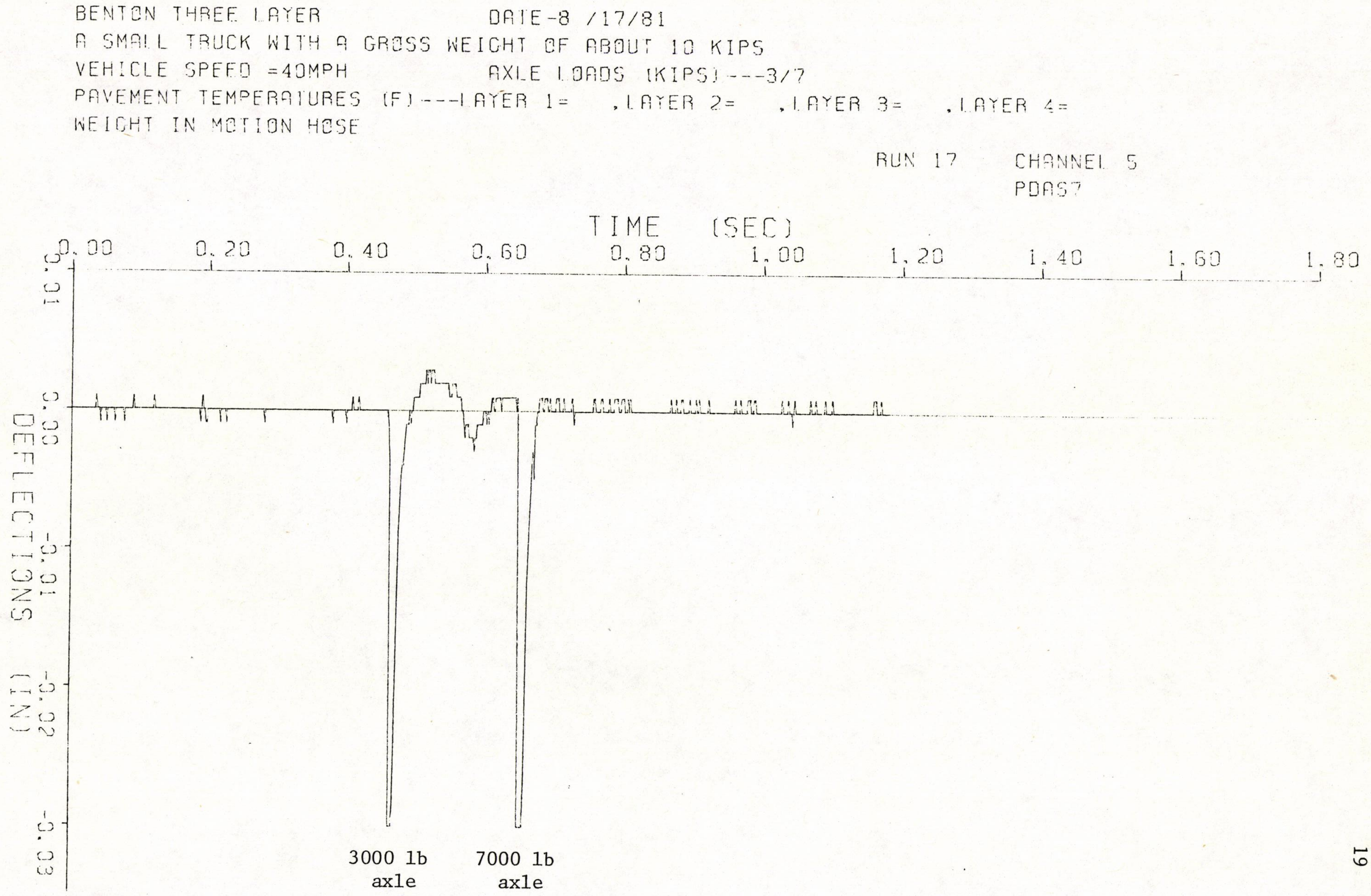

Figure 5. Single Hose Pressure Signal for Skid Truck at 40 mph.

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BENTON THREE LAYER                    DATE-8 /17/81
A SMALL TRUCK WITH A GROSS WEIGHT OF ABOUT 10 KIPS
VEHICLE SPEED =57MPH                  AXLE LOADS (KIPS)---3/7
PAVEMENT TEMPERATURES (F)---LAYER 1=88 ,LAYER 2=   ,LAYER 3=   ,LAYER 4=
WEIGHT IN MOTION HOSE

                                                      RUN 18    CHANNEL 5
                                                                PDAS7
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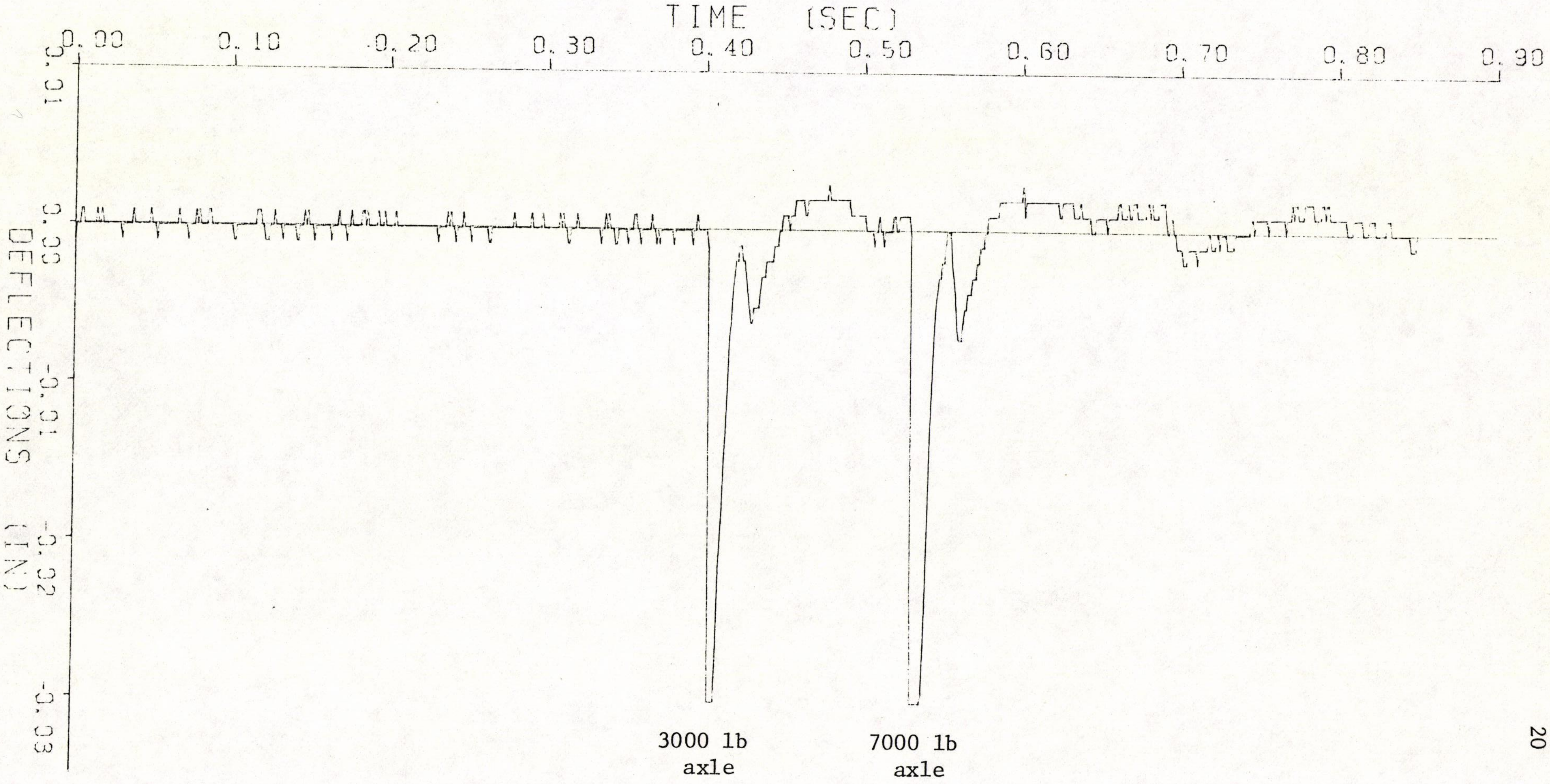
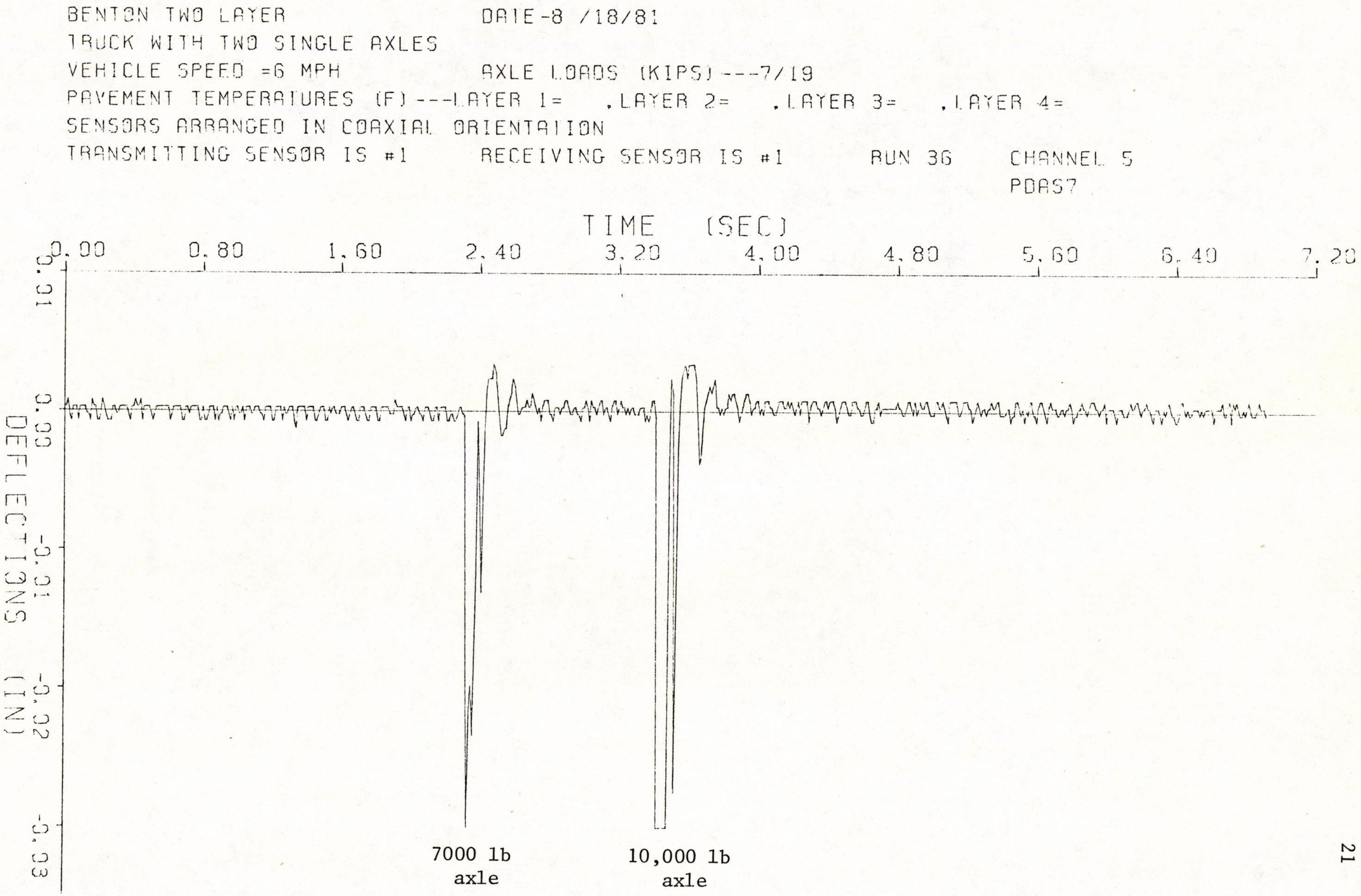


Figure 6. Single Hose Pressure Signal for Skid Truck at 57 mph.



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BENTON TWO LAYER                  DAIE-8 /18/81
TRUCK WITH TWO SINGLE AXLES
VEHICLE SPEED =6 MPH              AXLE LOADS (KIPS)---7/19
PAVEMENT TEMPERAIURES (F)---LAYER 1=   ,LAYER 2=   ,LAYER 3=   ,LAYER 4=
SENSORS ARRANGED IN COAXIAL ORIENTAIION
TRANSMITTING SENSOR IS #1      RECEIVING SENSOR IS #1       RUN 36    CHANNEL 5
                                                                      PDAS7
```

Figure 7. Single Hose Pressure Signal for Small Truck at 6 mph.

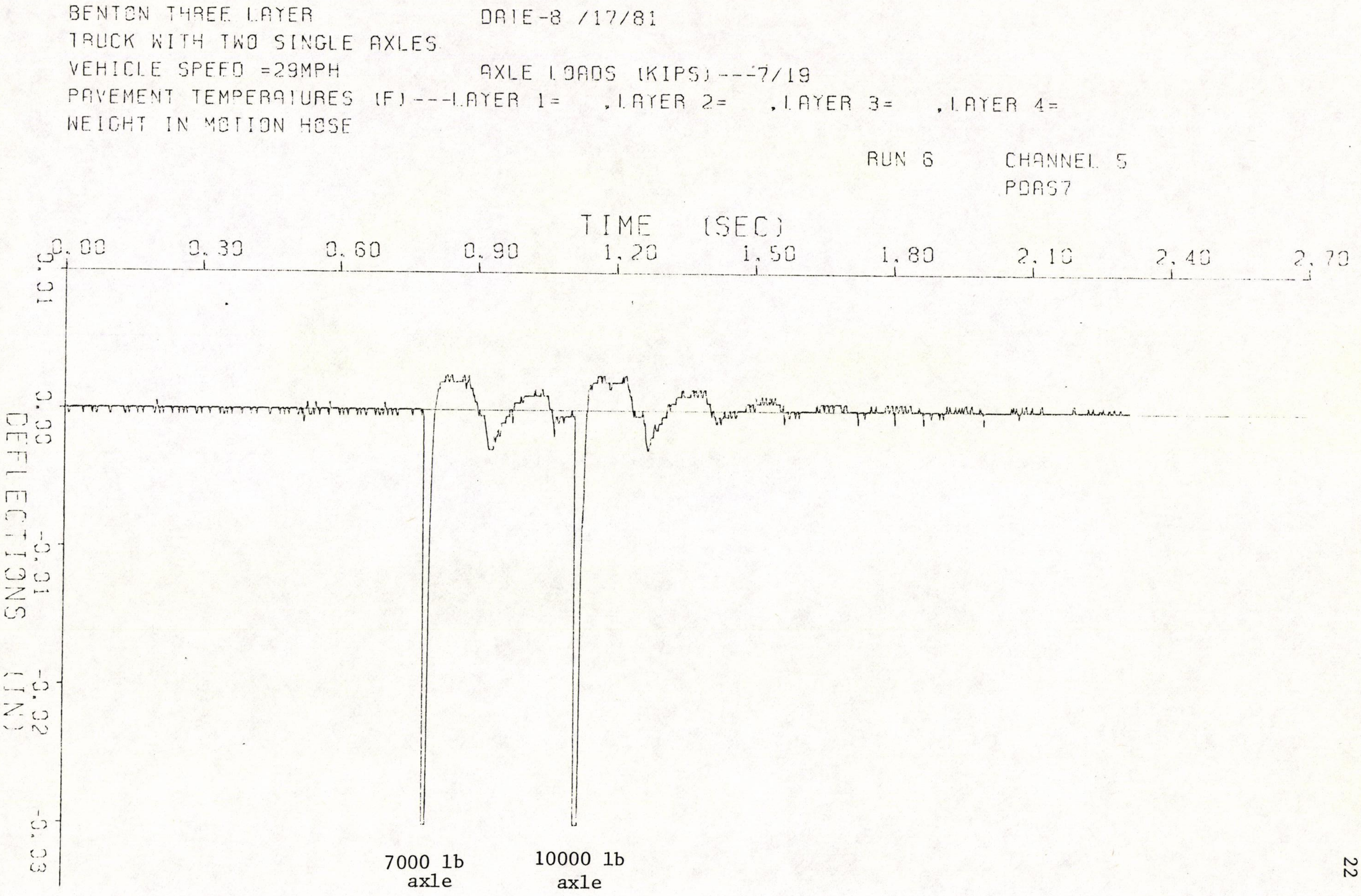

Figure 8. Single Hose Pressure Signal for Small Truck at 29 mph.

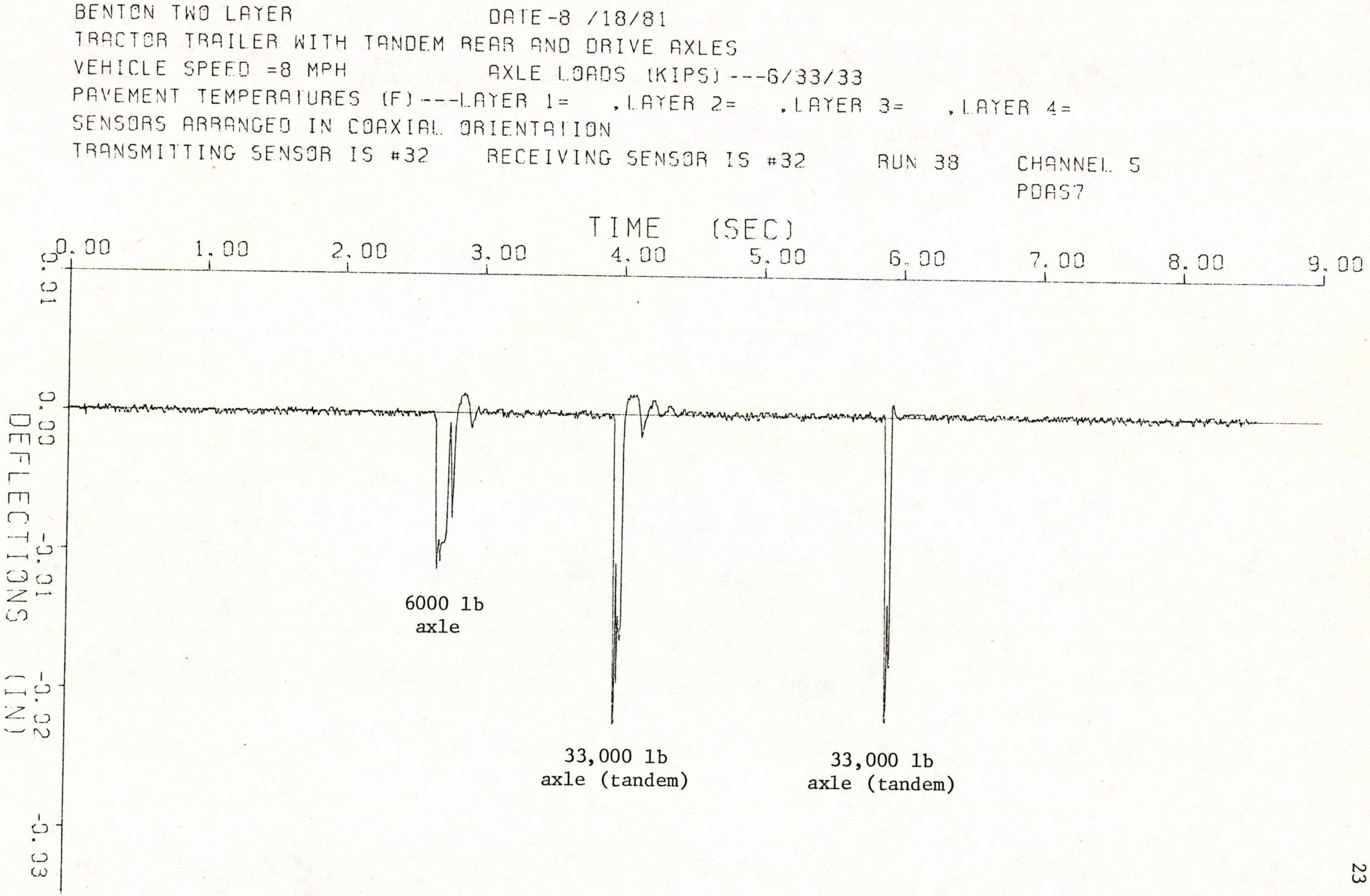

Figure 9. Single Hose Pressure Signal for Large Truck at 8 mph.

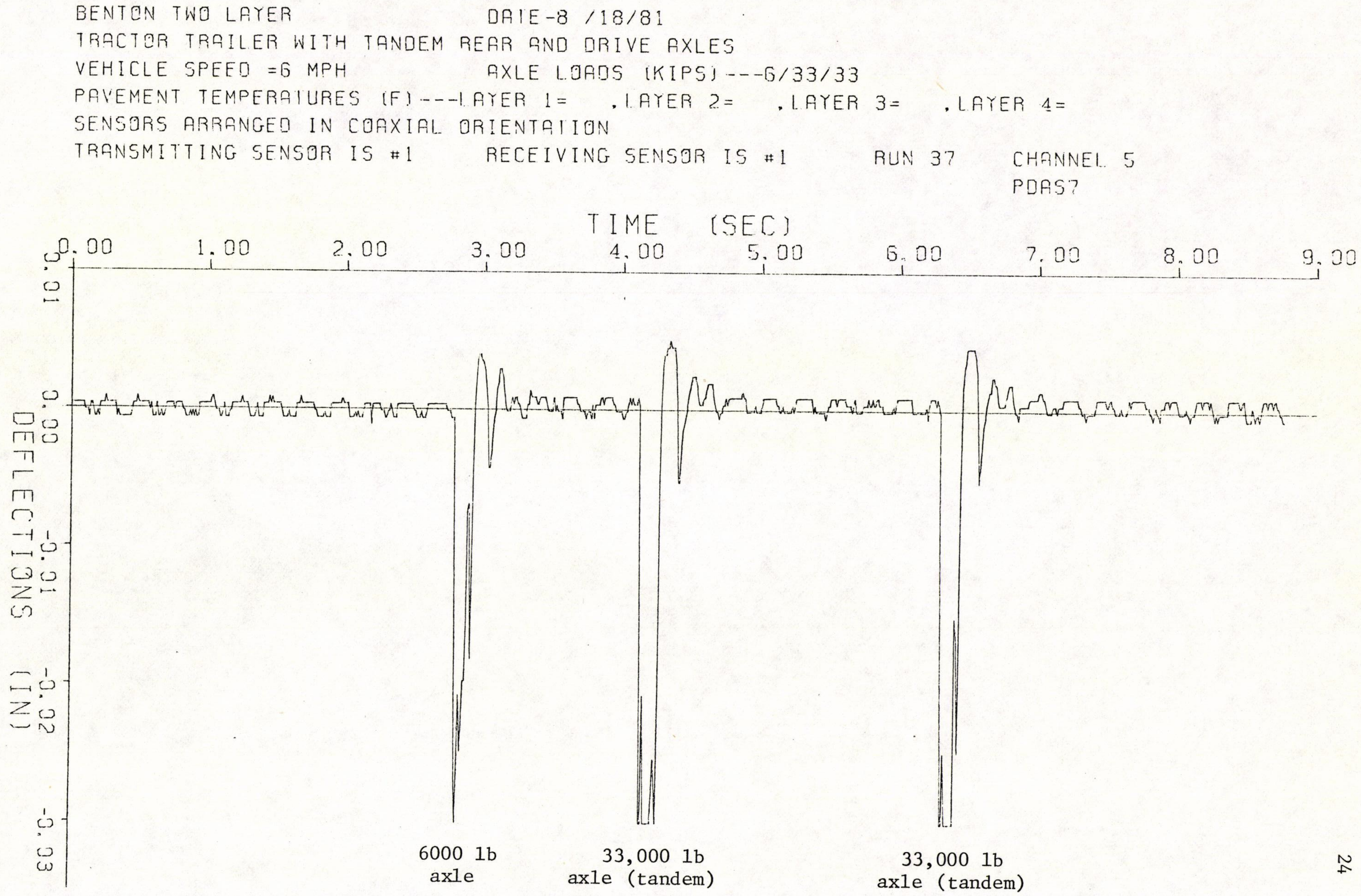

Figure 10. Single Hose Pressure for Large Truck at 6 mph.

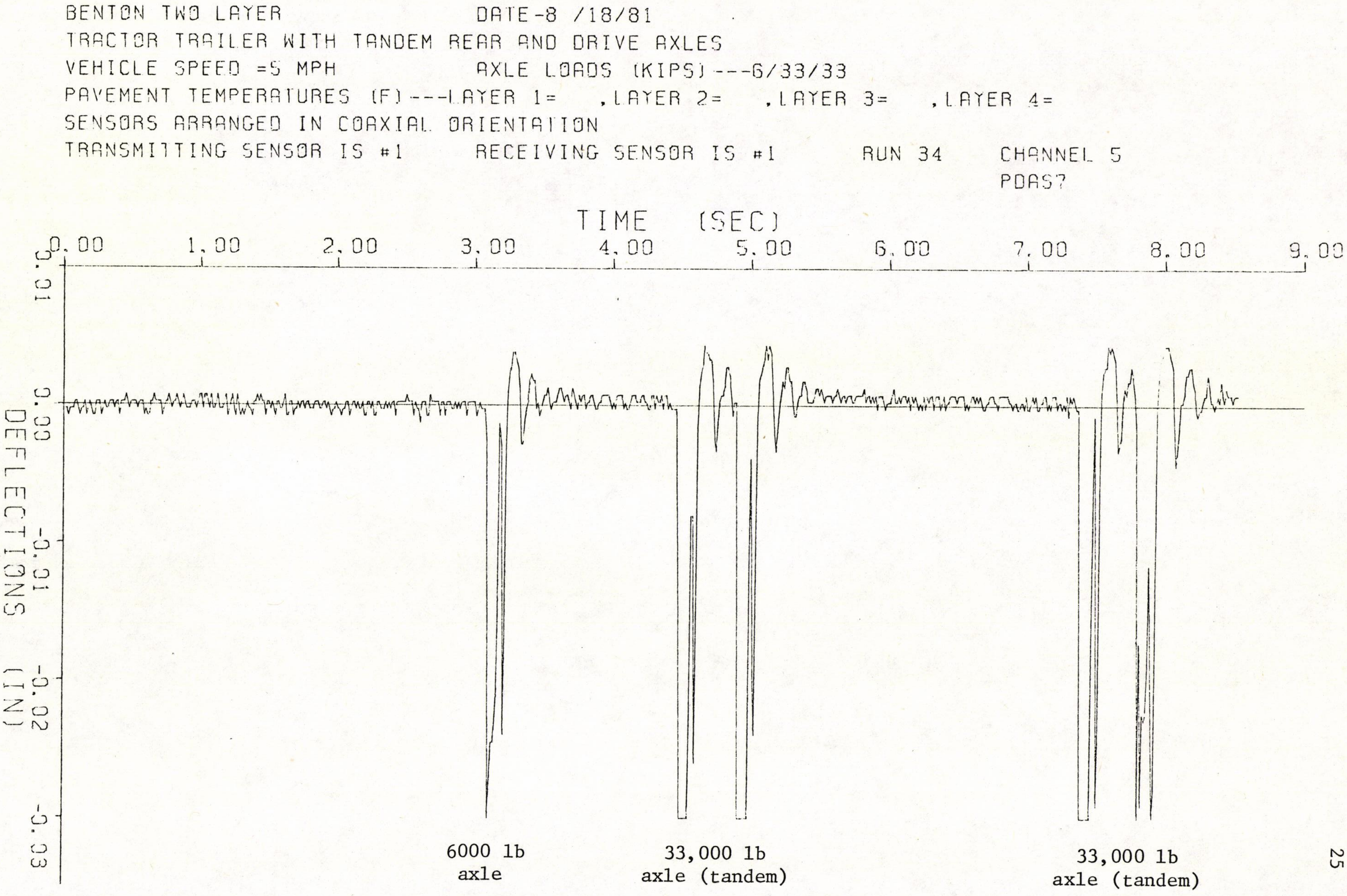

Figure 11. Single Hose Pressure Signal for Large Truck at 5 mph.

Chapter 4 Conclusions and Recommendation

Shortly after the analysis described in Chapter 3 was completed, the results were presented to the 34th Transportation Research Committee meeting at Pine Bluff, Arkansas, (April 1982). Since these results regarding the single hose transducer were not encouraging, it was proposed that the multiple hose configuration next be examined. This would presumably improve the results by supporting most, if not all of the wheel load at some point during its passage. The general concensus was that since the single hose supported little of the total wheel load at any point in time, the pressure values recorded were too dependent on uncontrollable factors such as tire sidewall stiffness and tire pressure. The pressure ringing recorded previously in the multihose configuration could be largely reduced by capping the outer hose ends rather than connecting them to a common manifold.

Following the above presentation, the Transportation Research Committee decided to terminate the project prior to its scheduled completion date since the single hose data did not support further effort in the area. It was felt that a multihose setup, while perhaps feasible from a technical viewpoint, was diverging from the goal of a small, inobtrusive portable weight sensor. Thus all work on the weigh-in-motion transducer investigations was halted at this point.

Future effort in the area might be fruitful provided a new technology is developed which would present a thin, easily handled transducer which would totally support the passing wheel load. As mentioned previously, current technology is quite capable of extracting a small signal from a large amount of noise. The weigh-in-motion concept relies primarily on the emergence of a suitable sensor.

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