# Design and Reliability Assessment of Data Acquisition System for Louisiana Accelerated Loading Device

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The Louisiana Transportation Research Center has purchased an accelerated loading device that is capable of conducting full-scale simulated and accelerated load testing of pavements. A sophisticated data acquisition system was developed for monitoring various types of sensors installed in pavements that help in understanding pavement materials responses associated with simulated traffic loading and environmental factors. In addition, this system is capable of performing such tasks as data management, data reduction, and graphical presentation. Performance validation tests were conducted on an instrumented pavement site to evaluate the developed system. Two types of sensors (H-gauge, T-type thermocouple) and three types of loading systems (passenger vehicle, falling weight deflectometer, and Dynaflect) were used in this study. Test results demonstrated the excellent capabilities of the data acquisition system. Results were highly repeatable and proved that the system was capable of monitoring traffic loading. The influences of loading mechanisms such as vehicle loading, impulsive loading, and other forms of loading on the longitudinal strains developed in pavement layers were compared.

The accelerated loading device (ALD) testing system provides a new era in evaluating pavement materials, construction practices, and performance. Results of a full-scale pavement testing can be used to verify mathematical models, develop new mechanistic design procedures on the basis of full-scale pavement response, and evaluate in situ material properties under various loading and environmental factors. The ALD also provides researchers with the capability to study the effect of loading on the behavior of the pavement system. Several comparative research studies of various types of construction materials (*1*) are scheduled at the newly developed Pavement Research Facility of Louisiana Transportation Research Center (LTRC). These studies involve performance evaluation, which requires instrumentation of those test sections. The purpose of this study was to develop a data acquisition system and to validate the performance of its features as it is subjected to various types of loading using different types of gauges.

Pavement instrumentation and the data acquisition system play an integral part in the evaluation of material responses. Generally, a variety of measurements are used to characterize the structural performance of full-scale pavement sections. This includes measurement from deflection and strain data, load data, and temperature data. Because of the dynamic effects, load, deflection, and strain data require a higher sampling rate than temperature data. Thus, the data acquisition system developed has all the capabilities to acquire data from various types of sensors at various sampling rates. In addition, the system should be able to perform other tasks, such as data storage and management in a computer file format to be accessed either in real time or later for analysis, and graphical presentation using a graphical user interface (GUI) environment.

A menu-driven, user-friendly software, accelerated loading device instrumentation software (ALDIS), was developed in C-language under LabWindows environment. ALDIS offers attractive GUI features to acquire data from most common types of sensors at various sampling rates, data management, and real-time graphical presentation of data.

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## OBJECTIVE

The main objective of this paper is to provide details on the development of the state-of-art data acquisition system, ALDIS. A second objective of this study is to validate the performance of the features of ALDIS. Several H-gauges and T-type thermocouples were placed at various depths in a pavement test section. Loading on this pavement section was applied by using nondestructive devices [falling weight deflectometer (FWD), Dynaflect, etc.) and by a passenger vehicle. Material responses associated with loading and temperature profile were recorded. These test results were used to assess the reliability of the developed data acquisition system.

## BACKGROUND

The accelerated loading was used by AASHO in the late 1950s for conducting road tests. The results obtained in those tests were the basis for today's AASHTO pavement design procedures. The Accelerated Loading Facility (ALF) by the Australian Road Research Board has started a new innovative technique for evaluating pavement materials and construction practices. At present, there are two ALFs in the United States. FHWA owns the first one, which is located at Turner-Fairbank Highway Research Center in McLean, Virginia. LTRC owns the second one. This machine can test years of pavement wear in a few months and also provides real-time data on the performance of new and in-service pavement materials and designs. The results from the data col-

lected using ALDIS will help in the evaluation of materials, construction practices, and performances. In addition, these data will be used to verify mathematical models and evaluate in situ material properties. The details of the hardware and software features of the data acquisition system are described below.

## DATA ACQUISITION AND CONTROL SYSTEM

The main functions in a data acquisition and control system are sensor signal conditioning, isolation, analog-to-digital conversion, digital-to-analog conversion, data reduction and analysis, control algorithms, and permanent data storage. The first four of these features are primary functions of the signal conditioning and data acquisition hardware. The last three are the functions of the software. A detailed description of the above features was described previously (*2,3*).

## DESCRIPTION OF HARDWARE

Figure 1 shows a schematic diagram of the hardware architecture of the data acquisition system. In includes a 486 based personal computer (PC), plug-in distributed input/output board (I/O), interface circuit boards, and signal conditioning modules. The data acquisition board selected was a Microstar Laboratories model DAP 1200/4S. This 12-bit resolution board provides 16 single-ended analog input channels, or 8 differential-ended analog input channels with software selectable by channel and expansion to a maximum of 512 input channels through the use of a multiplexer scheme. The current configuration allows for 64 analog input channels. This board has 16 digital inputs that are synchronous and expandable to 64 inputs.

The material responses (i.e., load, deflection, strain, temperature) are fed into modulator signal conditioners (shown in Figure 1), which are used to translate a sensor's physical properties to either a digital value or a high-level analog output that can be digitized. In addition, these modules output a current loop in 0 to 20 mA/4 to 20 mA current standards. These current loop outputs are relatively immune to noise and can travel over several thousand feet without signal degradation.

The 0 to 20 mA loop current was carried to the DAP accessory board near the host computer for voltage conversion. A precision resistor was used to drop the current and the voltage across it. The voltage will be measured as analog input signal by the DAP. The PC was located in an instrumentation room about 70 ft (21.35 m) away from the test site.

## SELECTION OF SOFTWARE DEVELOPMENT TOOL

Although the hardware used in data acquisition enables a computer to gather data from and control real-time events, it is the

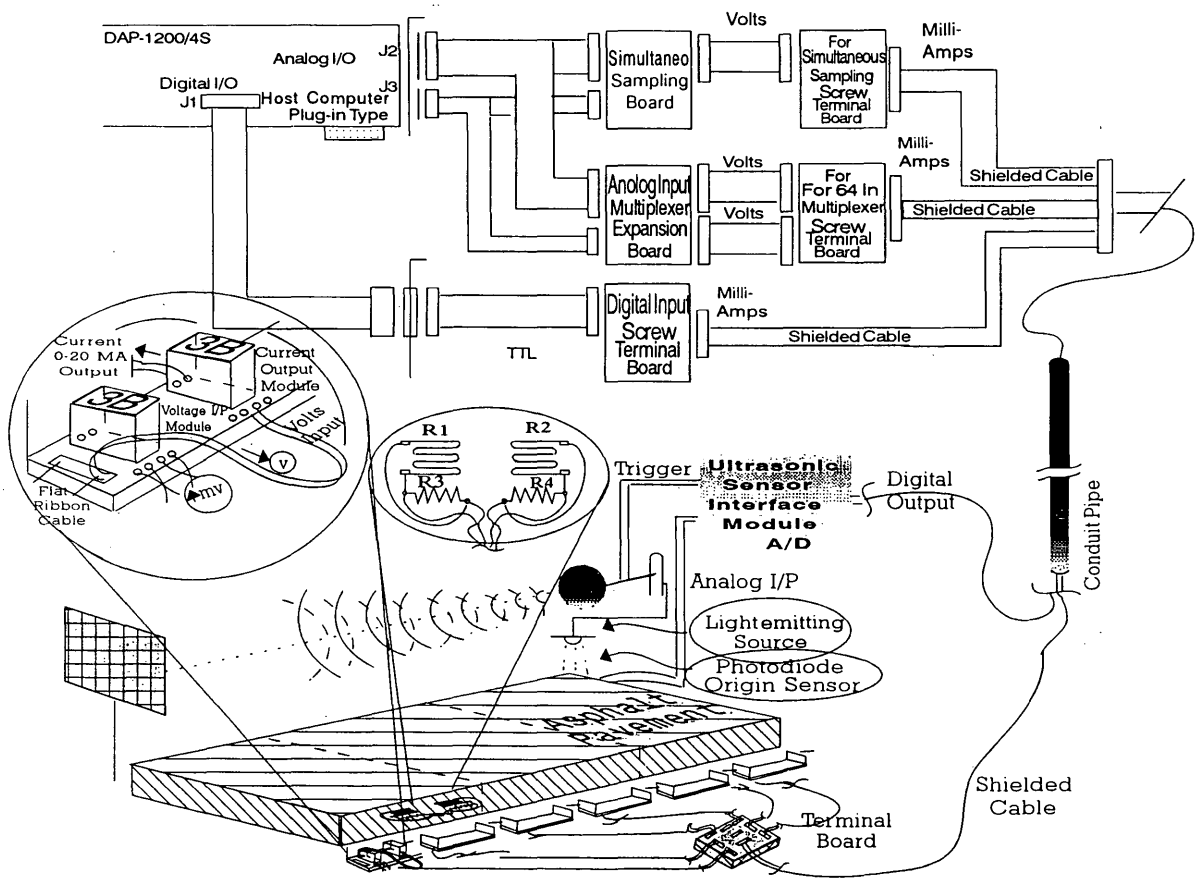



**FIGURE 1 Data acquisition system hardware architecture.**

software that provides the instructions. Software transforms the PC and data acquisition hardware into a complete data acquisition, analysis, and presentation system. The development of such software involves application of specific routines and interactive programs interfaced by system library functions.

The main criteria set for the selection of the development software was the ease of programming to take full advantage of the DAP board specifications in the GUI environment. Thus, National Instrument's LabWindows (*4*) development software was selected to meet this objective.

Included as part of the driver software were the instrument panel design routines. With usage of these routines one can develop and execute complex tasks with analog, digital, and counter/timer I/O monitoring routines under an attractive, user friendly, and menu-driven system. Instrumentation control panels can be integrated into data acquisition in designing multiple instrument panels. A detailed description of the hardware architecture and software features is described elsewhere (*3*).

## DESCRIPTION OF SOFTWARE

The data acquisition software developed in this study was named ALDIS version 1.0. ALDIS is a state-of-the-art integrated tool for data acquisition, storage, and presentation. The GUI associated with ALDIS includes an attractive display feature with instrument panels such as strip charts, *xy*-graphs, digital panel meters, ring switch control, binary switch control, and pushbottom controls, as shown in Figure 2.

ALDIS supports individual and group channel operations with user programmable features such as individual channel sampling rate, single/differential input signal, channel type (analog input or digital input), scale factors and offset, and time delay factor. It also offers programmable data storage formats such as file format in ASCII/Binary, converted data in United States/Système International variation and data storage file name.

ALDIS is developed in C-language and runs on a personal computer under LabWindows environment. The user-friendly GUI takes the user through the software set-up features in three different screens effortlessly with the context help providing useful notes. These three scenes, (a) channel setup, (b) data storage and file format, and (c) data presentation formats, are shown in Figure 3. Calibration and zeroing of the various sensors can be performed in the individual channel mode. The organizational chart of ALDIS is presented in Figure 4.

## RELIABILITY ASSESSMENT OF ALDIS

To access the performance of the features of ALDIS, a test strip was built and instrumented with two types of sensors (H-gauge and T-type thermocouple) (*3*). The test strip was then subjected to three types of loading (passenger vehicle, FWD, and Dynaflect). A detailed description of the test section, sensor selection, and sensor installation follows.

### Test Site

The test site was a pavement strip located adjacent to the LTRC building. It consisted of a 3-in. (75-mm) asphaltic concrete layer and a 6-in. (150-mm) sand-clay-gravel base material and clay sub-

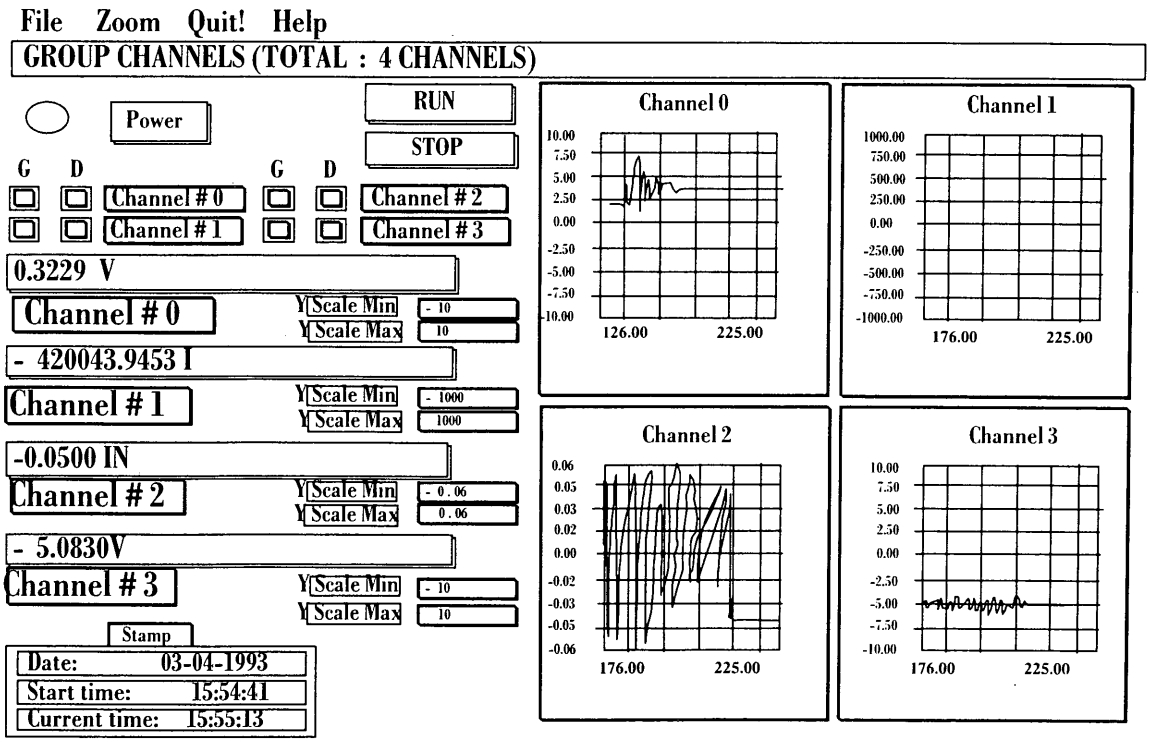
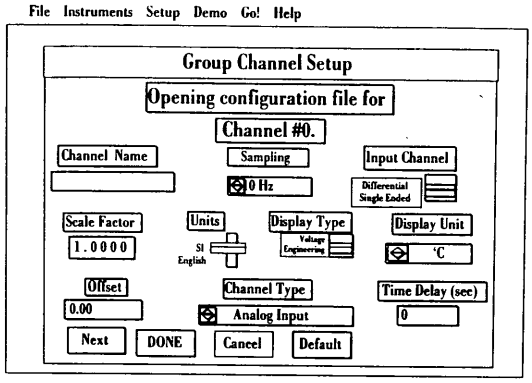
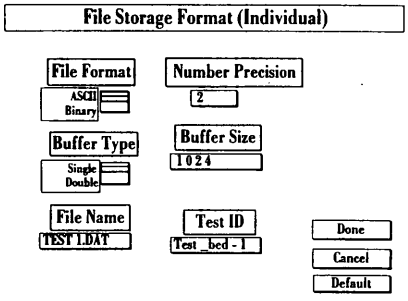


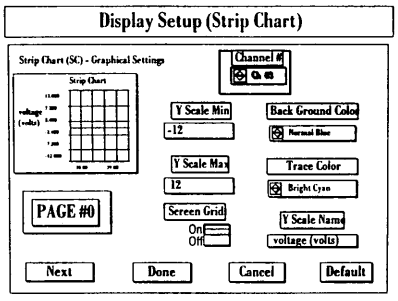

**FIGURE 2 Typical display screen from ALDIS.**




a) Channel Configuration




b) Data Storage and File Format




c) Data Presentation Attributes

**FIGURE 3 Setup screens.**

grade, as shown in Figure 5. In addition, a 2-in. concrete slab, on top of the surface layer, was used with FWD testing only.

## Sensor Selection

Strain measurement in flexible pavements is usually performed by electrical resistance strain gauges. Strain gauges are generally selected on the basis of their gauge length. For pavement applications, this criterion is based on the maximum aggregate size of the paving mixture. The length is usually three to five times the maximum aggregate size (*5*). From the earlier research work experience with different types of strain gauge sensors, it was decided that embedded strain gauges with anchor support using metal bars that form the shape of the letter H were the appropriate type of strain gauges for strain measurement in an asphalt layer. Various types of thermocouples are available. The selection of a specific type of gauge is based on the environmental conditions under which it will be used. T-type thermocouples made of copper and constantan are usually used in pavements because they can be used from subzero temperatures to about 700°F (370°C) with an accuracy of ±1.8°F.

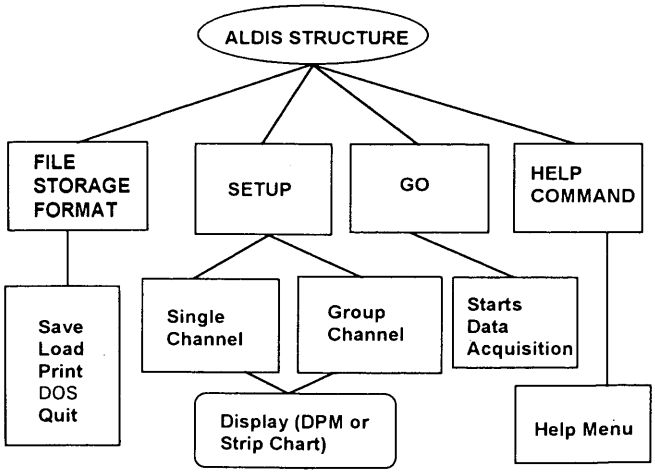



**FIGURE 4 Organization of the ALDIS software.**

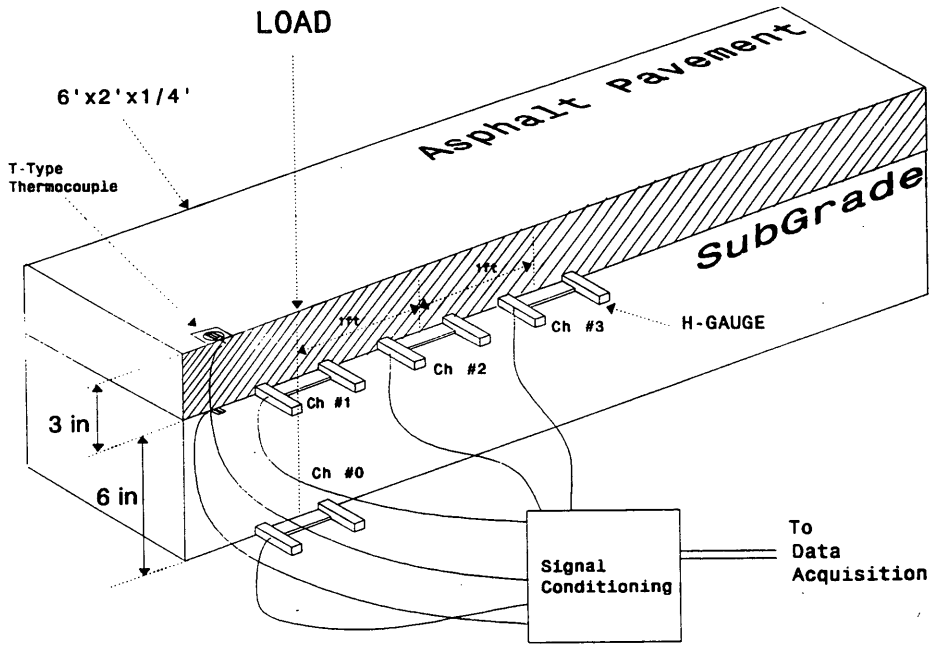



**FIGURE 5 Instrumented pavement test section.**

### H-Gauge Construction and Specification

Figure 6 presents a typical H-gauge. It consists of two strips of aluminum/brass material that anchors the strain gauge firmly in pavement layers. The strain gauge type used was a KM-120-120-H2-11W1M3 from Kyowa Engineering, Inc. The dimensions were 4.68 × 0.58 × 0.17 in. (120 × 15 × 4.5 mm) (length × width × thickness) in matrix dimension with 120 Ω-gauge resistance, 2.0-gauge factor. Two aluminum bars, 2.92 × 0.46 × 0.39 in. (75 × 12 × 10 mm) anchor the embedment-type strain gauge to form the shape of the letter H. The strain gauge was flushed to the bottom of the anchor bars to give a good surface contact underneath it.

### Sensor Installation Procedure

The location of the strain gauges and thermocouples in the test section is shown in Figure 5. The proper installation procedure is very important for precise data acquisition that otherwise would have resulted in either loss of data or improper data. Therefore, proper care should be taken while placing the sensors in the pave-

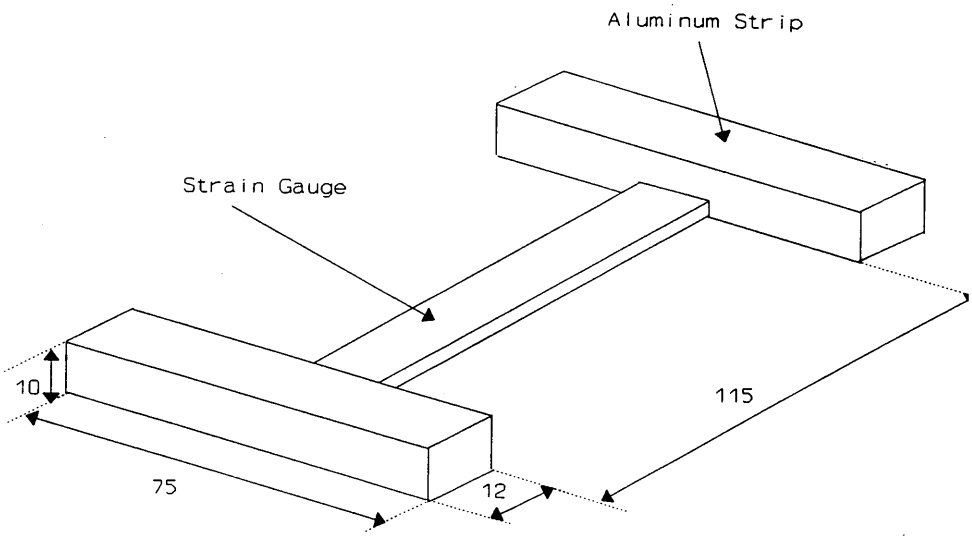



**FIGURE 6 Schematic diagram of the H-gauge (embedded strain gauge); all dimensions are in millimeters.**

ment. First, the existing pavement surface was removed up to a depth of the base layer, 3 in. (75 mm). Another 6 in. (150 mm) of the base layer was excavated and removed. The removed granular base material was used again as a replacement material. Six H-type strain gauges were placed in the test section. The first and the second gauges were on the same vertical axis, 9 and 3 in. below the surface, respectively, whereas the remaining four gauges were placed at the bottom of the asphalt layer 1 ft apart as shown in Figure 5. Two T-type thermocouples were used to measure the temperature at the surface and at the bottom of the asphalt layer. One was placed at the bottom of the asphalt layer, and the second one was on the surface. The sensors were carefully placed on top of the subgrade and base layers. Then, the replacement material was placed on the first sensor and cold mix was placed on top of the other sensors. Compaction was achieved by tamping with a 10-lb (44.4-N) hammer and subsequently passing a vehicle on top of it. Care was taken during compaction so that sensor wires were not disturbed and damaged.

### Testing Procedure

The sampling rate plays an important role in the precision of test data results. Generally, higher sampling rates provide a better profile. However, storage of the data can be a problem because the data occupy a large space on a hard disk; thus, an optimum rate needs to be established. Three sampling rates of 10, 40, and 100 Hz were evaluated to examine changes in the precision of the response from the H-gauges.

Loading of the pavement section was performed in three phases. In the first phase, a passenger vehicle was passed. The second involved the loading of the pavement section by using an FWD. Tests were conducted by dropping the hammer of FWD directly on top of the pavement as well as on a concrete slab 2 in. (50 mm) thick placed on top of the test section. The third phase used a Dynaflect testing, which is of sinusoidal shape. The data acquisition system was used to monitor the sensors during all three phases of testing. Three types of sampling rates—10, 40, and 100 Hz—were used for storing the data.

## DISCUSSION OF RESULTS

### Phase 1

In Phase 1, a passenger vehicle traveling at a speed of 14 mph with a front axle load of 1,940 lb (8.62 kN) and a rear axle load of 1,160 lb (5.15 kN) was used. The measured data were recorded in volts and then converted to microstrain using the following formula:

$$\text{Strain} = \frac{\text{unstrained volt}}{\dfrac{\text{ch. gain} \times \text{excitation volt}}{\text{gauge factor}}} - \frac{\text{strained volt}}{\dfrac{\text{ch. gain} \times \text{excitation volt}}{\text{gauge factor}}} \times 10^6$$

The first set of strain readings was measured when the front wheel was on top of the pavement section, Figure 7 (top). The second set of peak strain readings was recorded when the rear wheel was on top of this section. Higher strains were measured under front wheel loading (shown as A in the figure) than those under rear wheel loading (shown as B). This difference is because the higher loading occurred under the front wheel that includes the engine load. The second set of strain readings, taken when the car was driven in reverse direction, was lower than the first set of peak readings. This difference can be the result of partial recovery of the viscoelastic component of the strains in the material during the reverse movement of the car. As expected, the strain varied from tension to compression as the loading approached and left the sensor, respectively.

#### *Repeatability*

Repeatability of the test results is an important aspect of this kind of testing. The repeatability was evaluated by passing the passenger vehicle on the pavement section several times and recording the strains in the gauge under each wheel. Five sets of readings were recorded in a span of 2 min by passing and reversing the vehicle over this section (B, Figure 7). The test results were examined in terms of the coefficient of variation (CV), and these results are presented in Table 1. The CV ranged between 1.7 and 4.7 for front wheel loadings and 3.7 and 8.1 for rear wheel loadings. The peak microstrains ranged from 64 to 74, and a standard deviation value of 3.5 was recorded under the front wheel. The peak microstrains under the rear wheel ranged from 62 to 66 with a standard deviation of 2.5, indicating the excellent repeatability of the responses measured with the data acquisition system.

#### *Thermal Variations*

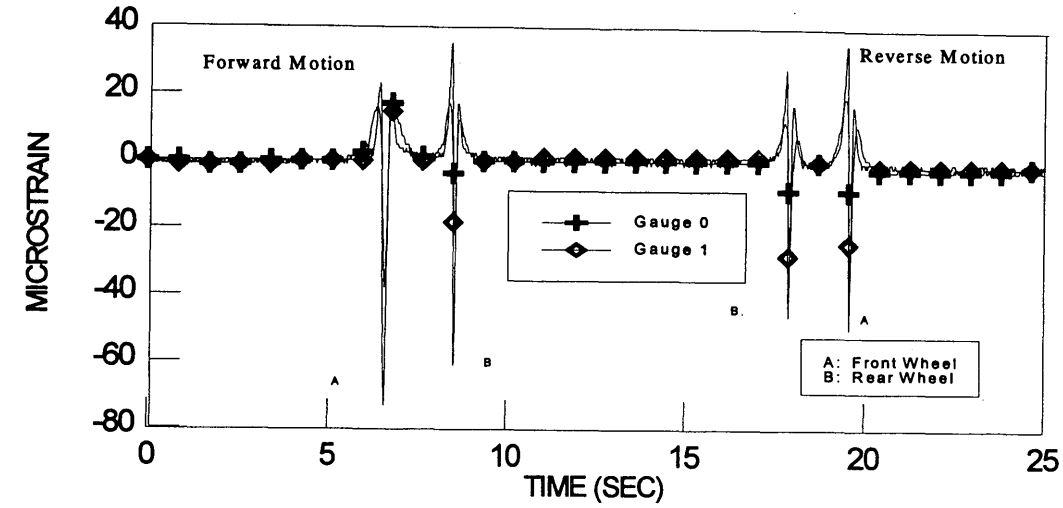
Figure 8 presents a typical temperature measurement from the test site at the surface and at the bottom of the asphalt layer using a T-type thermocouple. The noon temperature measurements for the surface and the bottom of the asphalt layer were 115°F and 108°F, respectively. The surface temperature was validated with a digital temperature meter. Figure 8 demonstrates the capability of the data acquisition to measure the temperature profile.

#### *Comparisons of H-Gauge Results*

Figure 9 presents a comparison of the results between Gauges 0 through 2 as a result of the movement of the passenger vehicle. Gauge 0, which is located on the top of the subgrade, measured lower strains than Gauge 1, which is on top of the base layer. The magnitude of stress distribution, which decreases with the depth, produces lesser strains. Also, the confining stresses at these depths reduced the strains developed. These results were in agreement with those of theoretical models that show this strain trend with depth associated with stiffness variations of asphalt and soils. This is also the basis behind flexible pavement design, which provides lesser strain in the soil layers.

#### *Numerical Simulations*

A comparison of the measured longitudinal strains to the computed values was made. The numerical strains were obtained using



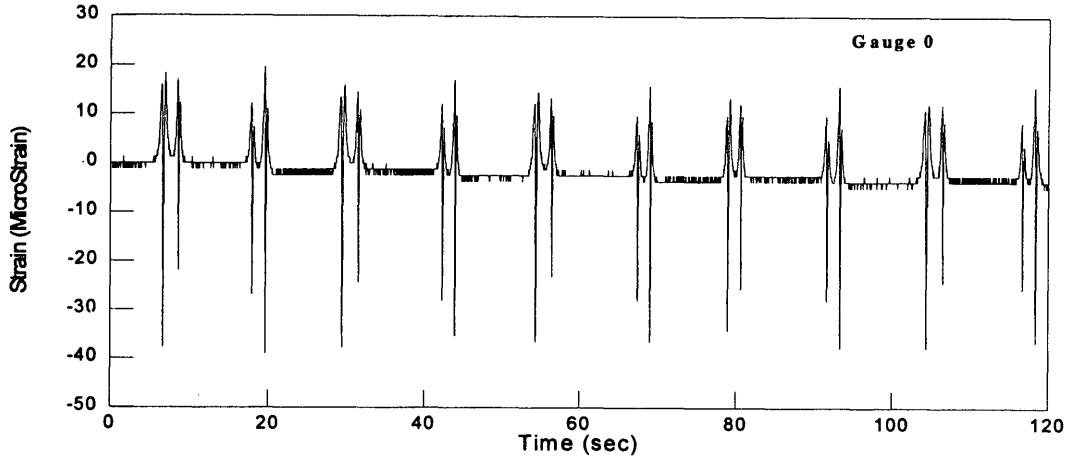




**FIGURE 7** Typical response curve for longitudinal strain associated with passenger vehicle loading.

**TABLE 1** Typical Peak Microstrains Under Passenger Vehicle Loading

| No. of | Front Wheel | | | | Rear Wheel | | | |
|---|---|---|---|---|---|---|---|---|
| Passes | Gauge 0 | Gauge 1 | Gauge 2 | Gauge 3 | Gauge 0 | Gauge 1 | Gauge 2 | Gauge 3 |
| 1 | -37.8 | -73.2 | -34.2 | -37.8 | -22.0 | -58.6 | -35.4 | -31.7 |
| 2 | -34.8 | -68.4 | -35.4 | -36.6 | -20.8 | -63.5 | -31.7 | -30.5 |
| 3 | -34.2 | -64.7 | -35.4 | -36.6 | -23.2 | -64.7 | -31.7 | -31.7 |
| 4 | -34.1 | -64.7 | -34.2 | -35.4 | -25.6 | -61.0 | -30.2 | -28.1 |
| 5 | -37.8 | -63.5 | -34.2 | -34.2 | -24.4 | -64.7 | -27.6 | -30.5 |
| Mean | -35.8 | -66.9 | -34.7 | -36.1 | -23.2 | -62.5 | -31.3 | -30.5 |
| S.D. | -1.7 | -3.6 | -0.6 | -1.2 | -1.7 | -2.4 | -2.5 | -1.3 |
| %C.V. | 4.8 | 5.3 | 1.7 | 3.4 | 7.4 | 3.8 | 8.1 | 4.4 |

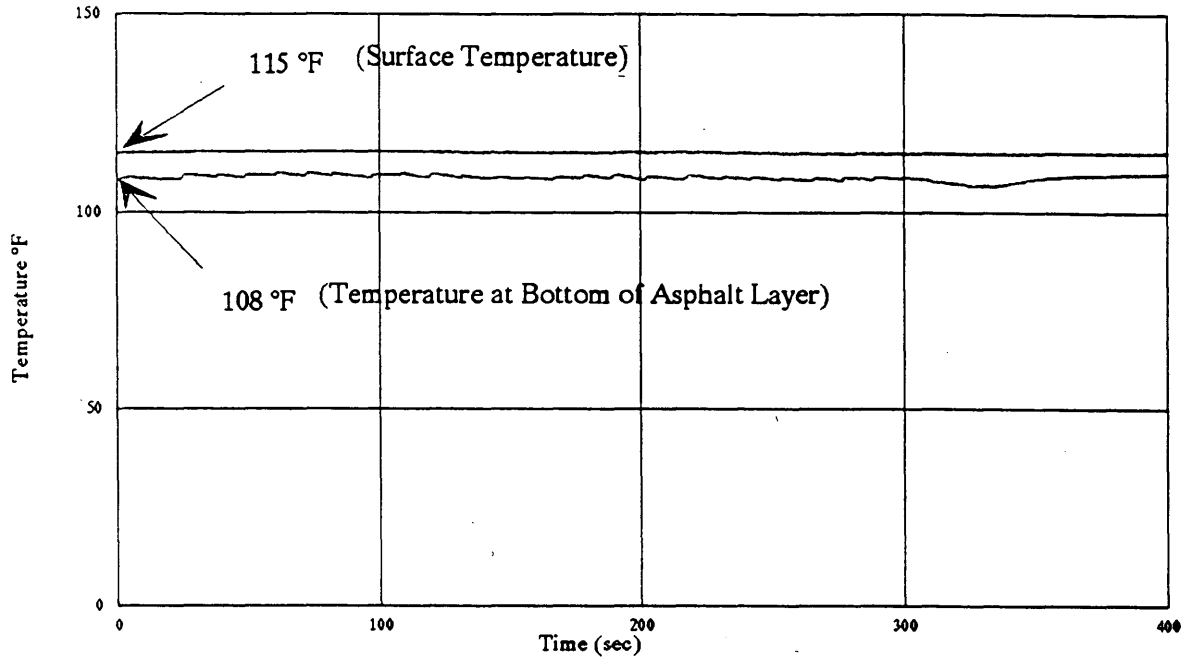



**FIGURE 8 Typical temperature response from the test site.**

a three-dimensional ideal elastic layered pavement system computer program, ELSYM5. Figure 10 presents the computed and measured longitudinal strains. The moduli and Poisson's ratio were estimated for each layer and a good agreement between the theoretical and measured values, as recorded and stored with ALDIS, was observed.

## Phase 2

Loading in this phase was applied using the FWD. Loading is performed first on the original test section, then on the concrete slab 2 in. (50.08 mm) thick placed on top of the asphaltic concrete surface. This loading, which is an impulse type of loading, consists of dropping a known mass from a predetermined height. The falling weight strikes a plate placed on the pavement and thereby transmits a force to the pavement. Four sets of loads [3,431 lb (15.23 kN), 5,791 lb (25.71 kN), 8,934 lb (39.66 kN), and 13,176 lb (58.5 kN)] were applied. Figure 11 presents the strains of three different gauges developed because of these loads. H-gauges at Locations 0 and 1 show similar pattern of strains because they were located along the same vertical loading axis. However, Gauge 1, at the top of the base layer, produced lower strains than Gauge 0, located at the top of the subgrade. This difference is attributed to the dissipation of energy developed as a result of the impulse loading, which needs a longer time to dissipate than the energy from a typical traffic loading. Gauge 2, which was located away from the loading axis, as expected, yielded tensile strains as shown in Figure 11.

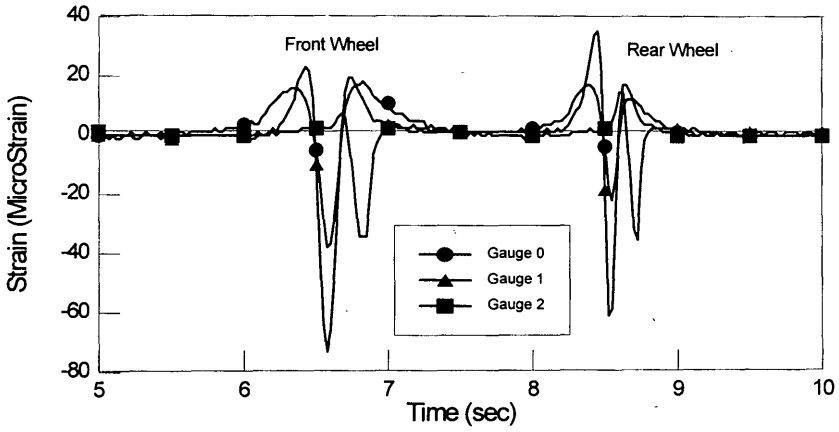



**FIGURE 9 Comparison of longitudinal strain responses of gauges at different depths under passenger vehicle loading.**

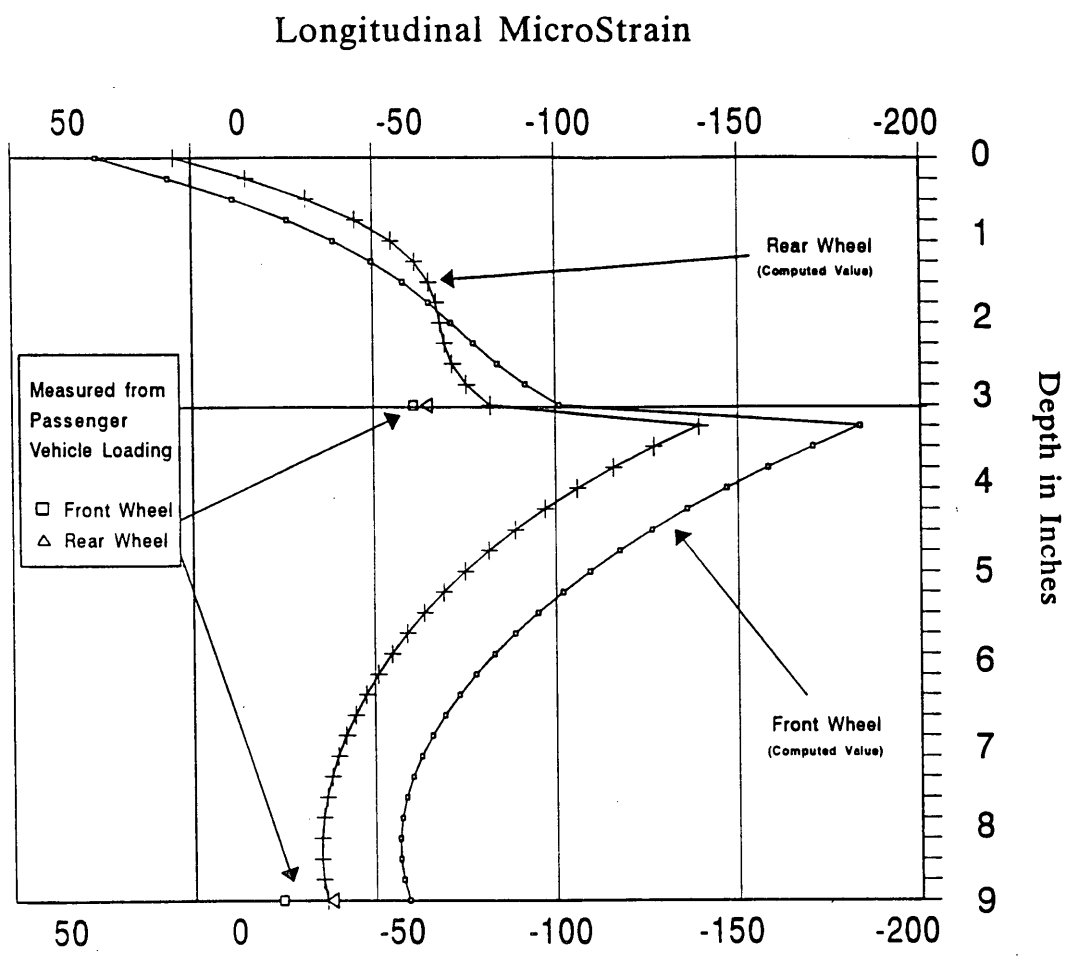



**FIGURE 10** Comparison of the measured and computed longitudinal microstrain.

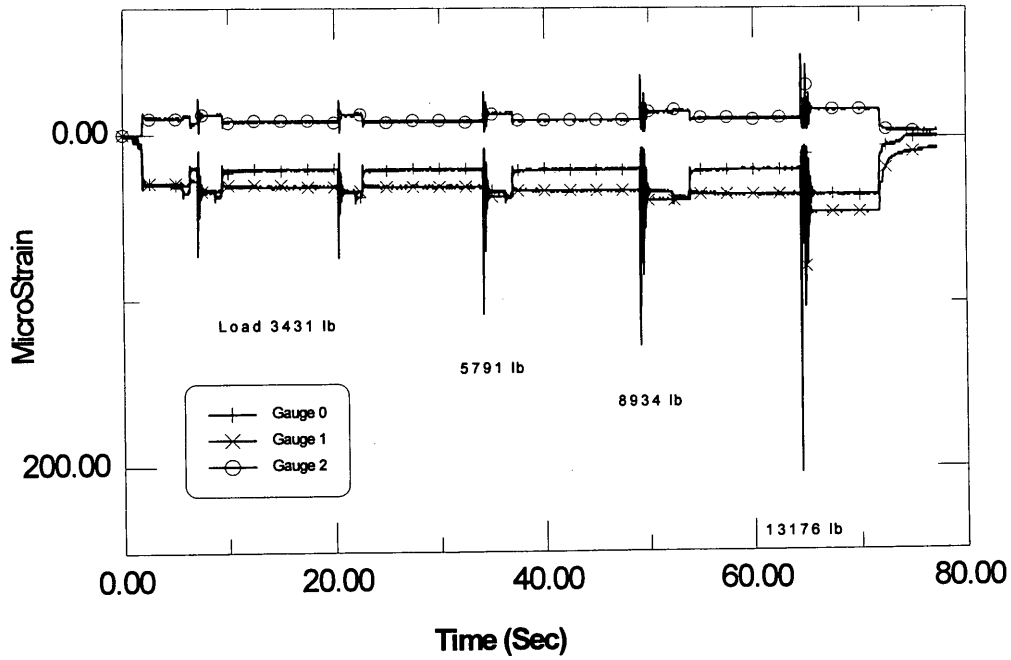



**FIGURE 11** Typical response curve under FWD loading.

*Sampling Rate*

All the above results were obtained with a frequency of 40 Hz. To study the influence of sampling rate, a test with a frequency of 100 Hz was conducted. Figure 12 presents the comparisons between the test results of 10, 40, and 100 Hz. The trends of these deflection profiles appear to be similar except at certain peaks. The 40-Hz sampling rate appears to be sufficient from this type of loading.

*Influence of Concrete Block*

The loading of FWD was performed on a concrete slab that was placed above the pavement surface. Figure 13 compares the results with loading on a concrete block and without it. Lower strains were observed in the case of a loading with a concrete block. This is because the energy applied in loading is mostly taken by the block; therefore, the stresses applied to the pavement layers are substantially lower than those applied in a loading without a block. Also, the stiffness variations between the concrete and pavement layers can contribute to the above variation.

## Phase 3

Phase 3 involves using a loading by using a Dynaflect. The loading system consists of two counter-rotating eccentric masses. A load of 4.45 kN at a frequency of 8 cps was applied through two steel wheels that are 0.51 m apart. Figure 14 shows the measured strains versus the time in seconds. It is interesting to note that eight deflection cycles are measured in each second, which is the Dynaflect frequency. This phase also proves the capability of the developed data acquisition system.

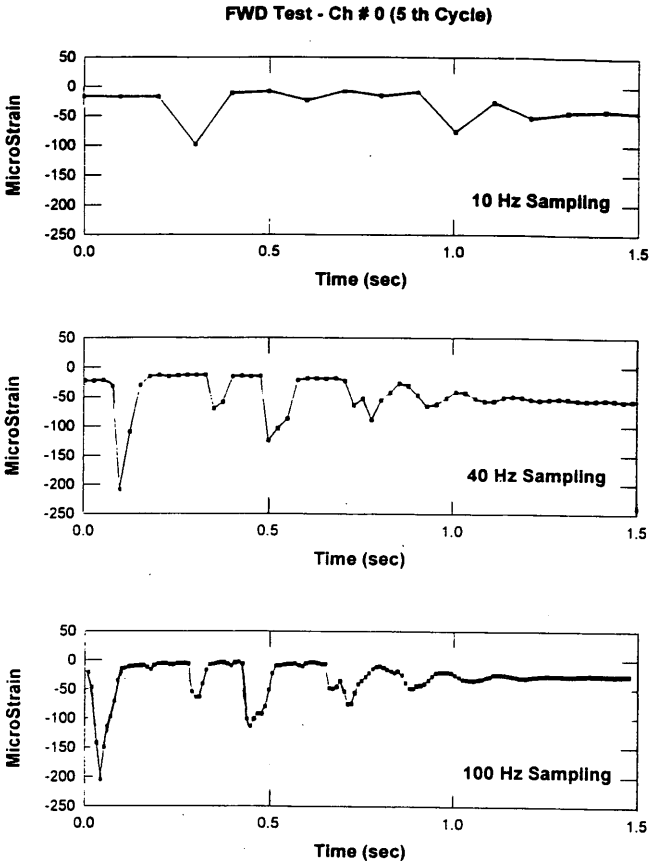



**FIGURE 12 Influence of sampling rate on measured strain profile.**

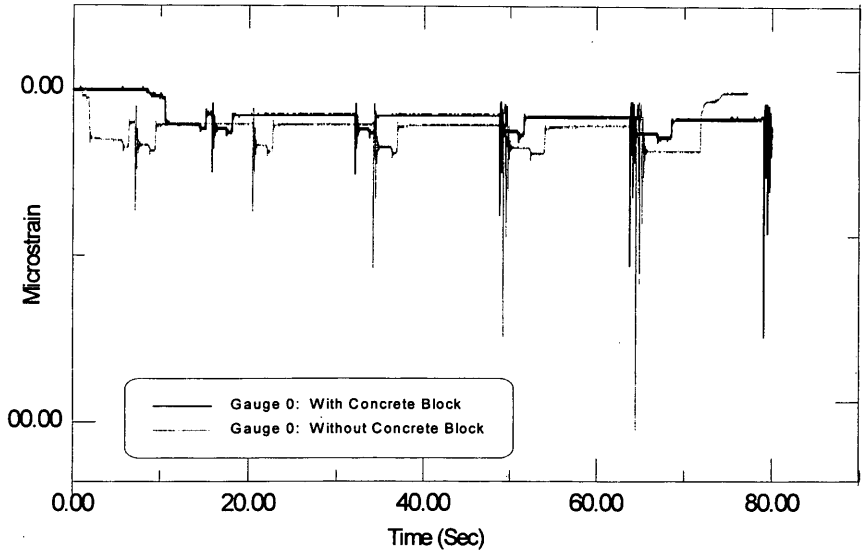



**FIGURE 13 Influence of loading via concrete block on strains.**

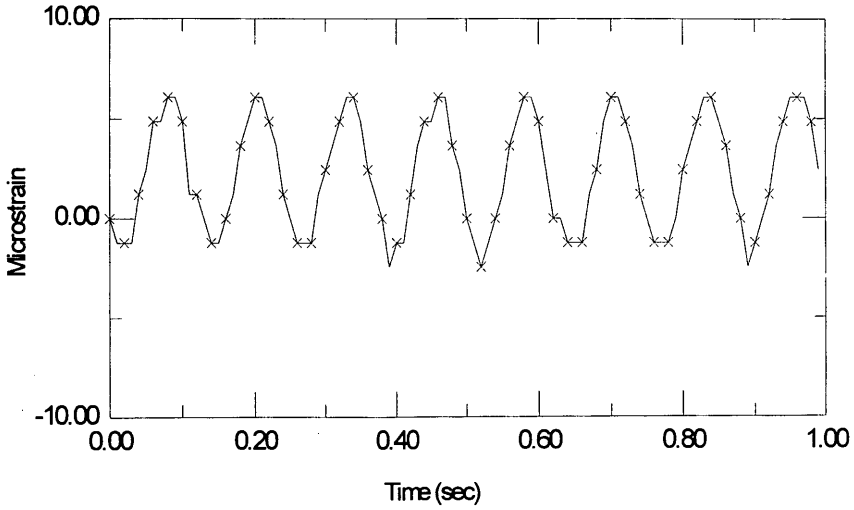



**FIGURE 14 Typical strain response curve from Dynaflect loading.**

## SUMMARY AND CONCLUSIONS

A sophisticated data acquisition system was developed for use in monitoring various sensors under an ALD. Capabilities and reliability of this system are assessed by monitoring different sensors under various loadings. The results showed that this system is capable of capturing all types of responses under all types of loading at various frequencies. Also, H-gauges have demonstrated excellent capabilities in measuring the strains of different layers.

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