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Development and Testing of a Portable Microprocessor-Based Capacitive Weigh-in-Motion System

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ABSTRACT

In this paper current techniques for the measurement of dynamic axle load are reviewed and the development and testing of a prototype portable weigh-in-motion (WIM) system at the University of Nottingham, England, are described. Current techniques for dynamic axle load detection tend to be characterized by a need for permanent sensors within the road pavement that can be both costly to install and maintain. A portable WIM system that uses a temporary capacitive weighmat has been developed at the National Institute for Transport and Road Research of South Africa, and extensive tests have revealed that the system can provide accurate results for accumulated axle loadings over large samples of vehicles, but that results for individual axle loads are subject to larger errors. In an attempt to improve the reliability of weight data from the capacitive sensor, a new microprocessor-based detector unit was developed at the University of Nottingham. Some current WIM systems developed in the United States and in the United Kingdom are evaluated, and the theory of operation of the capacitive sensor is described. Laboratory tests undertaken to determine the response of the sensor to controlled loading are discussed in detail, and the prototype detector unit is described along with the results of field trials conducted on a main U.K. highway. The results of these trials indicated that improvements over previous capacitive WIM systems had been achieved and that the combination of a commercially available capacitive sensor and a new microprocessor-based detector unit provided axle load data that was within ±15 percent of static weights. A commercially available capacitive WIM system, developed by the Golden River Corporation from this prototype system, is described along with a second-generation automatic weighing and classification system that was under development at the time of writing.

The geometric design of a highway is based on estimates of the expected total flow of traffic and the expected changes in the traffic flow over the design life of the road. Pavement design depends on other factors, and structural damage is caused almost exclusively by commercial vehicles (1). The normal practice in Europe and North America is to express the expected number of commercial vehicles as the cumulative total of equivalent standard axles. In the United Kingdom this is calculated by multiplying the expected number of commercial vehicles by two design factors, one characterizing the average number of axles per commercial vehicle and the other the number of standard axles per commercial axle.

The accuracy of the standard axle estimates is dependent on the reliability of data on past and present trends in axle loadings, which are in turn related to the size of the vehicle samples monitored. When manual classification and recording of axle loads are necessary, sample periods may be too short to allow accurate annual estimates of traffic loading to be deduced. In addition, axle load sta-

tistics tend to lag behind trends toward larger and heavier trucks.

The use of automatic vehicle classification systems (AVCSs) will enable data on axle numbers and vehicle types to be collected over extended periods. This could allow better estimates of heavy vehicle flows and of average numbers of axles per truck. Weigh-in-motion (WIM) facilities in conjunction with classification equipment could go further by improving the estimates of numbers of standard axles for particular vehicle classes or by direct measurements of standard axle loadings.

Investigations into the incorporation of WIM with automatic vehicle classification have been undertaken by the Transport and Road Research Laboratory (TRRL). Results presented by TRRL (2) have indicated that current axle weighing systems can provide the required data; however, these systems are unlikely to gain widespread acceptance because of their high cost. Only a minority of automatic traffic monitoring installations are likely to incorporate WIM using current, high-cost technology.

The unsuitability of current systems and the increasing demand for axle load data led to a research program at the University of Nottingham on dynamic axle load measurement, complementing ongoing work on automatic vehicle classification. Initial studies indicated that several possibilities existed for low-cost WIM sensors, and two of these were selected for further development. Vibracoax piezoelectric cable is being studied at Nottingham under contract to TRRL. Capacitive weighmats were the second technique to be studied, and these form the subject of this paper.

The capacitive weighmat concept was first developed and patented at TRRL. Basson (3) reviewed further development of the approach carried out at the National Institute for Transport and Road Research (NITRR) in South Africa. Field tests with this system, reported by Basson and Paterson (4), indicated that cumulative axle load measurements were accurate for large samples of vehicles, but that individual axle results were poor. The aims of the work at Nottingham were to note if accuracies could be improved by using digital processing techniques, and to develop a capacitive system that would be compatible with automatic vehicle classification equipment.

PREVIOUS SYSTEMS

Axle weighing systems fall into two main categories. The first can be used for static weighing or, in some cases, for weighing axles moving at low speeds (less than 8 km/h). The second is designed to record the axle loads of vehicles as they travel at normal speeds within the traffic flow.

Systems that are only able to measure axle loads of vehicles that are stationary or moving very slowly have little application for the automatic recording of axle weights because vehicles have to be separated from the normal traffic stream and directed over the weighing equipment. The cost of manual weighing is high, both for the public agency responsible and in terms of truckers' delays. Many systems fall into these static and slow-speed categories.

The most common static weighing devices use electrical resistance load cell units to support a steel deck onto which vehicles are driven. Alternatively, the plate can be fitted with strain gauges to measure its bending under load. The load cells and deck form a platform that may be sunk into the pavement or it may be surface mounted. Using this technique, wheel loads can be determined to a high degree of accuracy, especially if precautions are taken to eliminate the effects of vehicle tilt. Some of these systems are portable, but most are permanently fixed into pits in the pavement.

A few systems have been designed to measure the axle loads of vehicles moving at slow speeds in order to increase the efficiency of the weighing operation. They are generally large pieces of equipment consisting of a weighing platform wide enough to accommodate an entire axle or tandem. These slow-speed devices are similar to static weigh scales and accept a small loss of accuracy in exchange for an increased throughput of vehicles.

The first in-motion weighing systems were developed in the United States (5). Later work by Lee (6) led to the development of the Radian portable weigh scale, which consisted of steel platforms supported on eight load cells and mounted in a shallow pit. Wright (7) reported that the accuracy of the system is acceptable for most design purposes. However, running costs are high because constant manning is required during operation.

Several European systems use different techniques. The TRRL dynamic weighbridge consists of three or four units mounted side-by-side across one wheel track. Each unit contains an arrangement of load cells and springs, and each is mounted in a steel frame set in reinforced concrete. Bundesanstalt fur Strassenwesen (BAST) in West Germany developed its bending plate system for in-motion weighing (8) with three wider steel plates supported by a light steel frame in a shallow pit. Finally, the French Laboratoire Central des Ponts et Chausees (LCPC) developed a dynamic balance by using piezoelectric transducers located within alloy units sunk into the pavement (9).

Bergan and Dyck (10) describe the development of a dynamic weighing platform at the University of Sascatchewan in Canada. The unit consists of two rectangular plates resting on a common foundation. One platform is located in each wheel track. Loads on the platforms produce a vertical movement in a centrally located oil-filled piston, which acts as a load cell. Additional vehicle parameters are measured by using inductive loops.

These dynamic axle-weighing systems are all characterized by a need to excavate the road pavement for installation. Installation costs are generally high, and the work disrupts traffic flow for substantial periods of time. The objective of the work described in this paper was to investigate fully portable systems that do not require any permanent fixtures in the highway for their operation.

CAPACITIVE SYSTEMS

A design for a flexible weighpad consisting of two or more parallel sheets acting as the plates of a capacitor was patented in 1968 by J.J. Trott and J.W. Grainger (Improvements in Capacitors, U.K. Patent No. 1234083, filed April 2, 1968). This device consisted of three perforated plates separated by and enclosed in layers of natural rubber. Subsequent inventions by R.P. Miller (Electrical Weighing Apparatus Using a Capacitive Flexible Mat, U.S. Patent No. 3565195, filed April 16, 1969) and by S.H. Kuhn, C.R. Freeme, R. Beulink, and J.E.B. Basson (Measuring Transient Loads, U.S. Patent No. 3782486, filed May 12, 1971) were devices of slightly different construction, but which operated on the same principle.

The theoretical performance of the capacitive weighpad is described by Basson (3) by considering the deflection of a mechanical model of the weighpad sensor under load. Empirical data on the deflection of the actual sensor and on the relationships be-

tween tire contact area and wheel load were applied to this model to produce a theoretical relationship between axle load and percentage change in capacitance. An outline of this evaluation is presented here.

Consider the mechanical model shown in Figure 1. A wheel load (P) acts over a tire contact area (Aa) on a senor of total area (A). The sensor has an unloaded capacitance of Cu and a loaded capacitance of Cw. The sensor comprises three plates, each separated by a material of thickness X. The deflection of the sensor under load is dX.

The sensor capacitance in the unloaded state is given by

$$Cu = K \cdot 2 \cdot A/X \tag{1}$$

where K is a constant, depending on the dielectric properties of the material between the capacitor plates.

The sensor capacitance in the loaded mode is given by

$$Cw = [K \cdot 2 \cdot (A - Aa)/X] + \{K \cdot 2 \cdot Aa/[1 - (dX/2)]\} \tag{2}$$

Therefore the change in capacitance is given by

$$\begin{aligned} dC &= Cu - Cw \\ &= (K \cdot 2 \cdot A/X) - \{K \cdot 2\ [(A - Aa)/X]\} - \{K \cdot 2 \cdot Aa/[1 - (dX/2)]\} \\ &= K\ \big((2 \cdot Aa/X) - \{2 \cdot Aa/[X-(dX/2)]\}\big) \end{aligned} \tag{3}$$

Hence the change in capacitance relative to the initial sensor capacitance is given by

$$dC/Cw = \big((2 \cdot Aa/X) - \{2 \cdot Aa/[X-(dX/2)]\}\big)/(2 \cdot A/X) \tag{4}$$

or

$$dC/Cw = (Aa/A)\ \{1 - X[X-(dX/2)]\} \tag{5}$$

In order to evaluate the theoretical performance of the sensor, the relationships between wheel load, inflation pressure, and tire contact area were established by empirical tests on a variety of tire types. Similarly, the deflection of a weighmat sensor for varying loads and tire contact pressures was also measured in a laboratory testing rig. For a given wheel load and inflation pressure, it was therefore possible to calculate the tire contact area, the average contact pressure, and hence the sensor deflection. These could then be substituted into Equation 5 to give the theoretical change in capacitance for a particular wheel load and inflation pressure.

The results of the exercise indicated that the relationship between wheel load and percentage change in sensor capacitance was linear and passed through the origin. There was also no apparent difference in the relationship for the range of wheel loads and inflation pressures found on single or dual-wheeled axles.

Construction of the three-plate capacitive sensor developed at NITRR is described by Basson (3). Initial designs comprised steel mesh conductors separated by a polyurethane dielectric. Problems with the mechanical strength of the mesh and dielectric and the sensitivity of the polyurethane to changing loads led to a final design comprising steel plates separated by natural rubber. The plates are encased in a tough synthetic rubber compound. The sensor unit, which is 1.8 m x 0.4 m x 7 mm in thickness, is secured to the road in one wheel track by means of perforated plates pop-riveted to its sides. The perforated plates are fixed to the road with strips of bituminous tape and road nails, as shown in Figure 2.

The equipment has had extensive testing in South Africa and has also been appraised in other countries. Results from South Africa, reported by Basson and Paterson (4), indicate that with correct calibration the system gave accurate results for accumulated axle loadings over large samples of vehicles. However, individual vehicle results were subject to large errors, as indicated for a 500-vehicle sample given in Table 1. Graphical results from a 13-site evaluation program in South Africa are also shown in Figure 3, where dynamic load from the Axle Weight Analyser is plotted against actual static axle load.

The apparent conclusion that might be drawn from the NITRR weighmat studies is that practical capacitive WIM systems have not entirely lived up to their theoretical performance. On the other hand, the systems demonstrate considerable promise as relatively low-cost, portable approaches that might be refined to produce results of higher accuracy. With these tentative conclusions in mind, a program of laboratory and development studies was commenced at the University of Nottingham during 1982.

LABORATORY TESTS

At the start of the laboratory tests an existing capacitive weighmat system was tested under laboratory conditions to determine its response characteristics to loading. This was followed by the development of a microprocessor-based monitoring

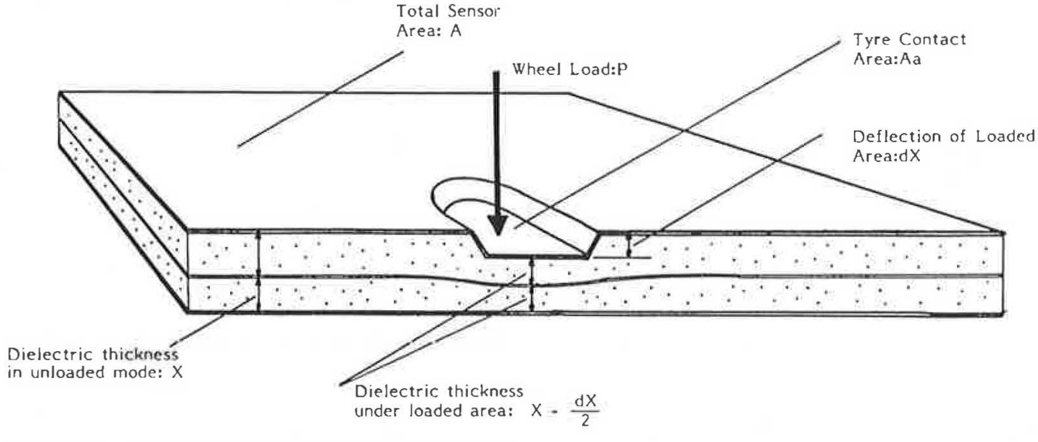

FIGURE 1 Model of the capacitive sensor under load.

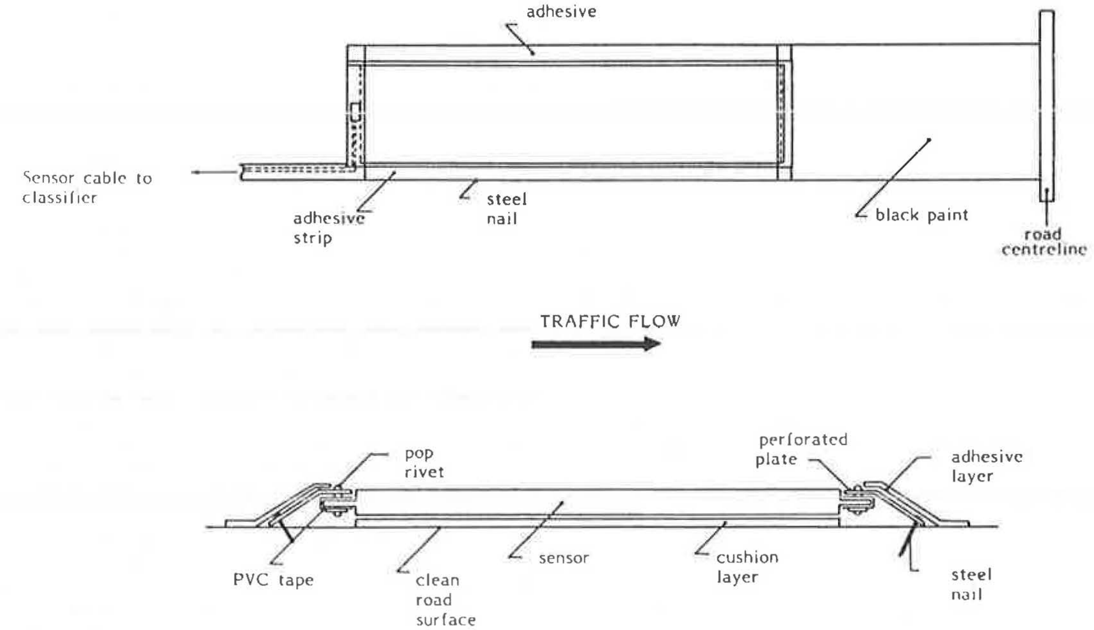

FIGURE 2 Sensor layout for the NITRR dynamic weighbridge.

TABLE 1 Accuracy of Static and Dynamic Load Comparisons with NITRR Equipment

	Percentage Errors			
Confidence Level (%)	Total Mass		Single-Axle Mass	
	Lower	Upper	Lower	Upper
80	-4	+11	-42	+67
90	-6	+14	-58	+83
95	-9	+16	-71	+96
99	-14	+21	-97	+122

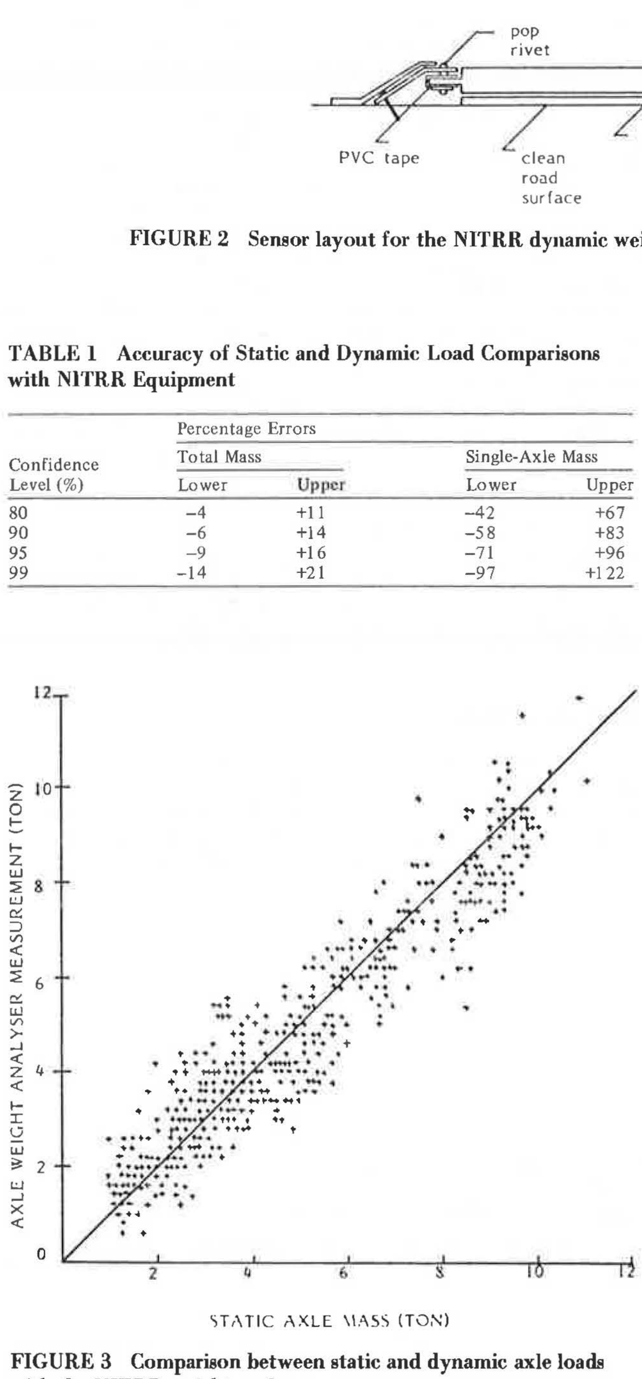

FIGURE 3 Comparison between static and dynamic axle loads with the NITRR weight analyzer.

system that was capable of automatically recording the weight of axles passing over the weighmat. The new system was then tested under field conditions to assess its accuracy and reliability.

The existing system tested at the start of the program consisted of a capacitive weighmat sensor and a dedicated electronic detector unit. The sensor was constructed from perforated steel sheets encased in rubber, which formed the parallel plates of a capacitor. The dedicated electronics comprised a frequency-to-voltage convertor that translated changes in sensor capacitance to a proportional analogue voltage output. For this purpose, the sensor formed part of a tuned circuit driven by a sinusoidal oscillator. Increases in sensor capacitance produced a reduction in the frequency of oscillation that was converted to a change in the voltage output. The analogue voltage was then used as the input to an electro-mechanical counter unit.

The laboratory tests carried out on the system involved the application of static and dynamic loads applied in an electronic servo-controlled hydraulic load testing machine, similar to those developed at the University of Nottingham for the testing of subgrades, pavements, and piezoelectric axle load sensors. A fairly large capacity machine was required to simulate actual tire contact pressures over the loading plates, which were approximately the same size in contact area as a vehicle tire. The loading rig was capable of producing at least 10 tonnes at a frequency of 10 Hz. For load applications, the mat was divided into 150-mm sections numbered 1 to 12, and loading tests were conducted at each position.

The weighmat was subjected to four basic loading tests to determine its response to static and dynamic loading. Initially, the capacitance change of the weighmat under various static loads was measured directly with a Wayne Kerr capacitance bridge unit. Figure 4 shows the capacitance change of the weighmat over the load range of 0 to 10 tonnes. The relationship is not linear, but capacitance increases throughout with load.

To verify that the signal-conditioning elec-

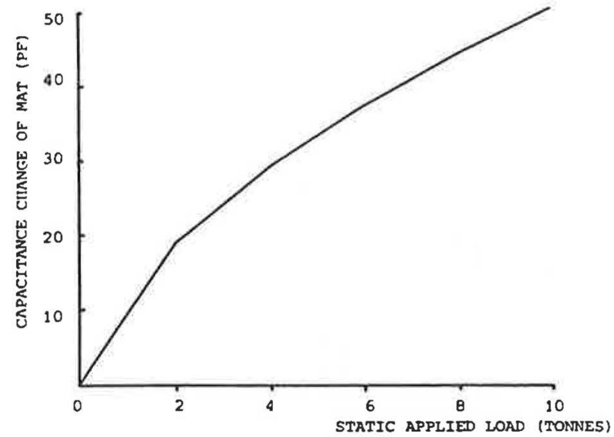

FIGURE 4 Change in weighmat capacitance with applied load.

tronics of the weighmat system were not distorting this relationship, the same loadings were applied at the same position on the mat and the corresponding output from the detector unit was recorded. The two sets of results were then constrained to coincide for loads of 0 and 10 tonnes on a composite graphical plot. Figure 5 shows that for observations at a constant temperature, the voltage output from the detector unit follows close to the capacitance change of the mat.

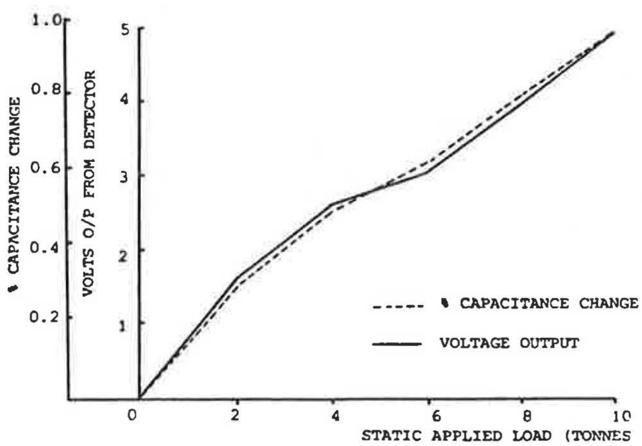

FIGURE 5 Voltage output from detector compared with mat capacitance change under varying load.

The weighmat was then loaded through four different footprint areas to determine the effect of changing tire size and configurations. The results, shown in Figure 6, indicate that the output from the weighmat is not wholly independent of tire contact area as would be suggested by the theory of operation.

Using the dynamic capability of the loading rig, a series of tests was undertaken to determine the sensitivity of the weighmat to variations in the frequency of the applied load. Loads of 0 to 10 tonnes were applied at a variety of positions along the mat and at a range of frequencies. Figure 7 shows the peak output from the detector for various dynamic loads applied at frequencies of 2, 5, and 10 Hz. These results are typical of the plots obtained

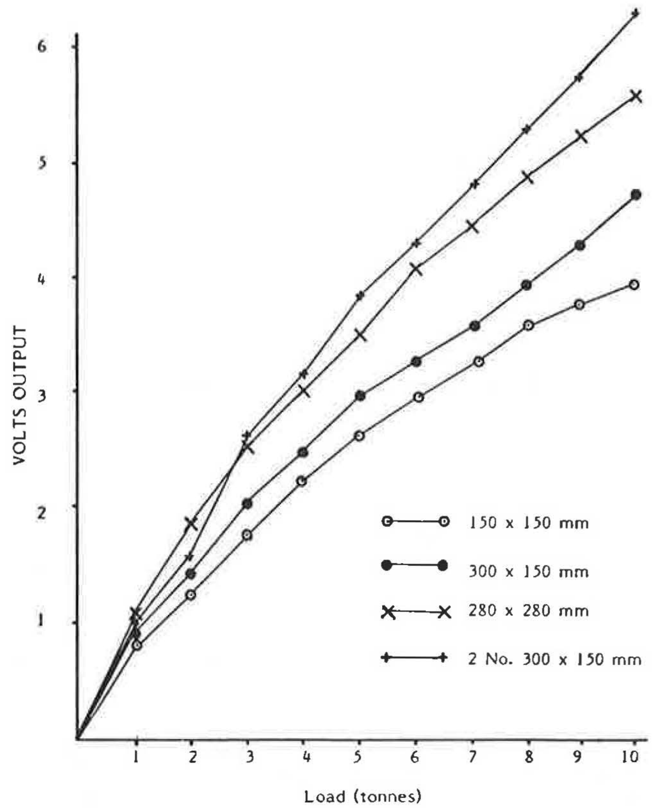

FIGURE 6 Weighmat output with varying load and tire footprint area.

at other positions on the mat and indicate that the detector output is independent of the frequency of the applied load.

Figure 8 shows the variation in positional sensitivity of the weighmat for a range of dynamic loads, all applied at a frequency of 5 Hz. The results indicate that the sensitivity of the weighmat is not constant over its length. Variations of approximately ±10 percent are evident over the width of the sensor.

PROTOTYPE HARDWARE DEVELOPMENT

Following the tests on this first design of the weighmat, a second weighmat was tested to the current NITRR specification. The two main differences from the earlier weighmat design were (a) the parallel plates of the capacitor were fabricated from three solid-steel sheets rather than from perforated plates, and (b) the sine-wave oscillator that drives the tuned circuit was incorporated in the cable connector fixed to the weighmat on the road. This latter development has the effect of eliminating any effects of capacitance changes in the connecting cable between the mat and the detector unit.

A prototype microprocessor detector unit was developed to work with the modified design of the weighmat, based on digital loop detector technology. Digital loop detectors use the loop as the inductive element in a tuned circuit, where changes in loop inductance produce a change in the resonant frequency of that circuit. By using two crystal oscillators, the number of oscillations of the tuned circuit in a given time period can be counted. This count is used by the unit as a digital measure of loop inductance.

The digital measurement of capacitance was ap-

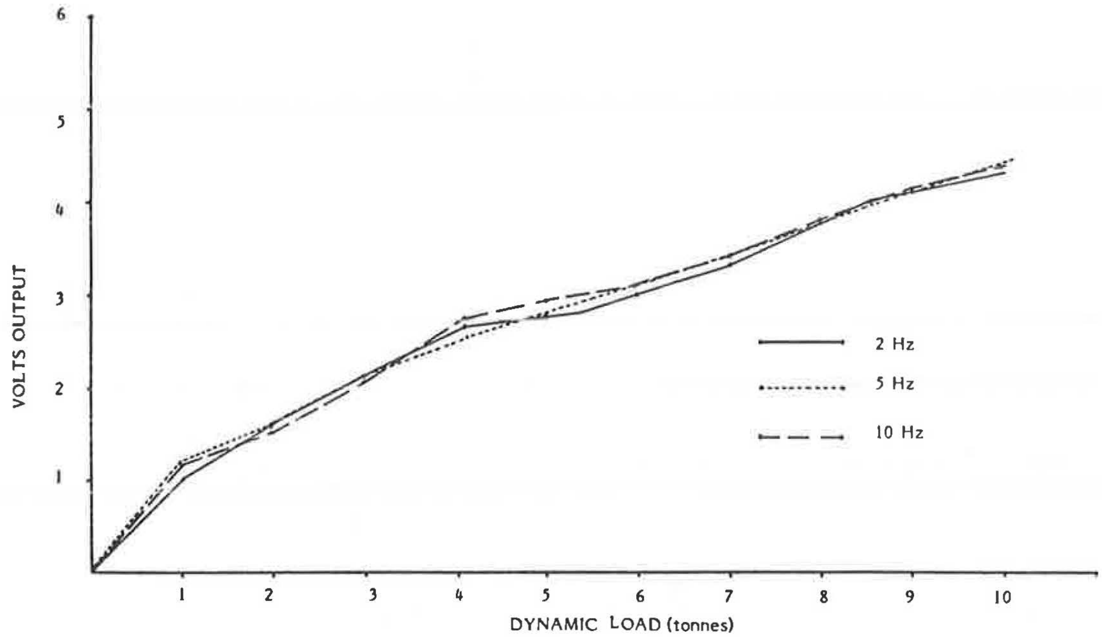

FIGURE 7 Weighmat output for three different loading frequencies.

proached in the same way. The capacitive weighmat replaced the inductive loop as the variable element in a current digital loop detector unit. This modified loop board was mounted in a Golden River portable roadside Environmental Computer at the University of Nottingham. Machine code routines were written for the manipulation of this digital weigh board output, initially for its display on a video display unit (VDU). A further series of laboratory tests was undertaken by using this new detector unit to establish its compatibility with the capacitive sensor for axle load detection.

Initially, further laboratory tests were undertaken to determine the response of the new sensor and detector units to controlled loading. The weighmat was loaded in the hydraulic testing rig at a variety of positions by using three standard static loads. Figure 9 shows the digital output from the detector for loads of 2, 4, and 6 tonnes. The results indicated that the combination of the capacitive sensor and new detection hardware produced linear outputs with load, and that variations in sensitivity along the length of the mat were on the order of ±10 percent.

To examine the sensitivity of the mat to changing environmental conditions, a series of temperature tests was undertaken. The sensor unit was heated with infrared lamps, and the temperature of the top and bottom surfaces of the mat, in the vicinity of the load position, was recorded with

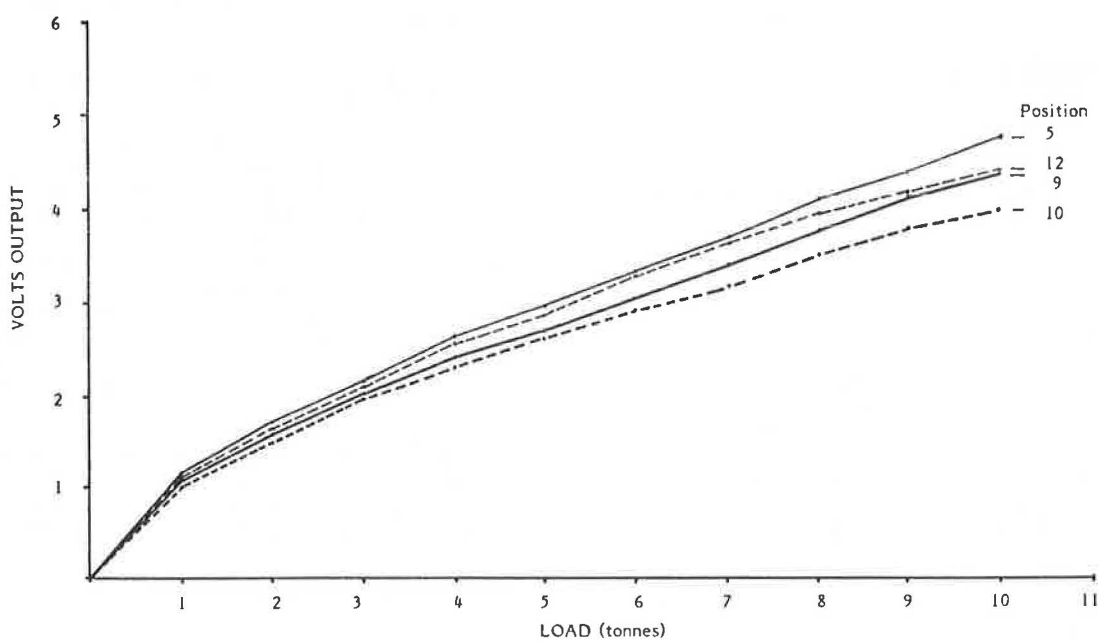

FIGURE 8 Positional sensitivity of the weighmat with dynamic loading.

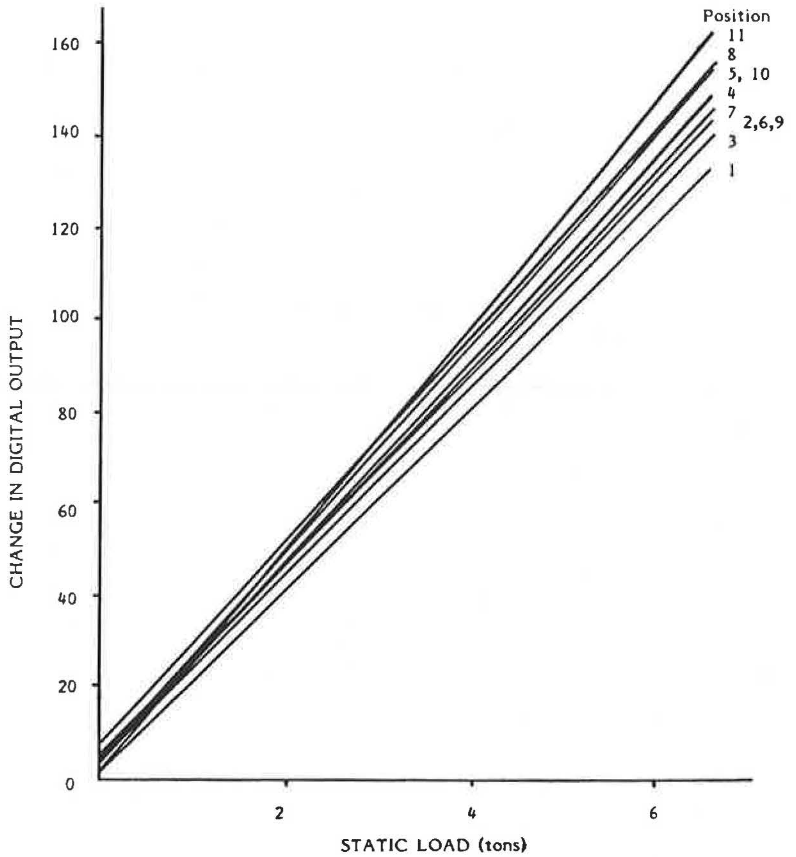

FIGURE 9 Weighmat sensitivity with varying load and lateral position.

thermocouples. When stable temperatures were reached, static loads were applied and the detector output noted. Figure 10 shows the variations in the output for four mat temperatures.

Both the absolute output from the mat and the changes in output with load vary with temperature. The absolute output variations could be caused by oscillator characteristics as well as by expansion of the rubber dielectric of the capacitor because of heating. The changing sensitivity with load was attributed to variations in the elastic properties of the rubber dielectric between the capacitor plates with temperature. However, the effect is only marked at relatively high temperatures and wheel loads.

For the laboratory tests, the software used for

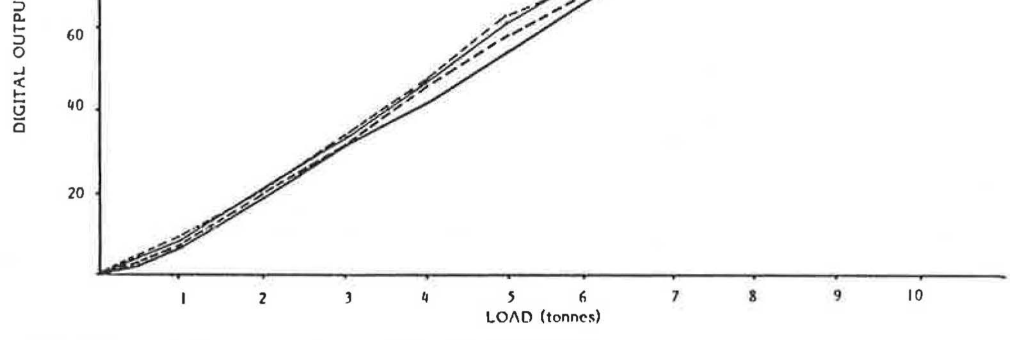

FIGURE 10 Variations in weighmat output with temperature.

the digital readout from the new detector system had been limited to simply reading and displaying the raw digital value from the modified loop board. Before the system could be used for continuous monitoring of vehicle loads, software had to be developed to determine when an axle was on the mat, to smooth the signal, and to read and store the maximum digital value produced by that axle.

SOFTWARE DEVELOPMENT

An assembly language program was written at the University of Nottingham to perform the tasks of signal processing and data storage for axle load measurement. The Golden River Environmental Computer's Forth Assembler was used to produce a machine code routine capable of scanning the weighmat at high speed in real time.

The software for the detection, manipulation, and storage of digital signals from the weighmat had to be capable of performing six principal functions:

1. To determine, by smoothing and processing signals from the mat, when an axle is present on the sensor;
2. To read the digital output from the modified loop board at a fast enough scanning rate to ensure that the peak of the signal is detected;
3. To determine, in the period between signal scans, the amplitude of the signal and assess whether it is the peak value;
4. To determine when the axle has left the mat and store the difference between the peak and the base value;
5. To track any gradual changes in mat capacitance resulting from environmental drift; and
6. To allow user control over the running of the program and the reading of the stored data.

A typical vehicle wheel traveling at 40 mph will pass over the mat in approximately 30 to 40 milliseconds. The duration of the peak value was not known at first, but it was thought likely to be only a few milliseconds. To achieve the fast scanning rate required to detect this peak, functions 1-6 were performed in the machine code portion of the routine. The user control program was written in Forth, which is a higher-level language fast enough for between-vehicle processing.

The main steps of the code routine are as follows:

1. The routine tells the weighmat processor board that a digital value of mat capacitance is required. A special function of the capacitance value is taken to speed processing at a later stage.
2. The value read on this scan of the mat is smoothed exponentially with a previously weighted value to reduce the effect of noise.
3. The smoothed value is then compared with a threshold. If the current value exceeds this threshold, a wheel is assumed to be on the mat.
4. The maximum value of the signal from the weighmat is accumulated as the wheel passes over the sensor.
5. If the mat has been active for a relatively long period, it is assumed to be locked on. This might be as a result of sudden heavy rainfall, or could be caused by a vehicle parking on the sensor. In this event the routine is automatically reset.
6. If the mat has just changed from being active to inactive, the maximum value it has accumulated is stored in memory.
7. Automatic tracking and compensation take place when the sensor is inactive to allow for factors such as temperature changes.
8. The user keyboard, located on the front panel of the computer, is checked to determine whether the user wishes to suspend program operation.

The Forth program that permits user control allows the user to operate the computer in one of four modes: (a) run the assembler program, (b) successively display the last N peak values stored in memory on the eight-digit LCD display on the computer's front panel, (c) display the number of memory bytes already used for data storage, and (d) display capacitance scans (signatures) of vehicles. The Environmental Computer operates off its own internal battery supply and therefore, by using this software, it was possible to test the weighmat in the field and to assess its performance for dynamic axle load detection.

FIELD TRIALS

To assess the performance of the system for automatically recording axle loads, a series of correlation exercises was undertaken. The sensor unit was fixed to a highway that had a good ride quality. Vehicles that had previously been weighed at nearby static scales were recorded as they passed over the weighmat. Weights were subsequently compared by matching license plate numbers, which is easy in Europe because of the large size of the plates.

In addition to the recording of these random vehicles, two test vehicles were driven over the sensor at a range of speeds. Single-axle loads of up to 10 tonnes were recorded. Tandem axles were weighed together on static scales but were recorded separately on the weighmat. These dynamic recordings were combined to allow them to be plotted on the calibration graph given in Figure 11. Recordings were taken on three separate days, and the weighmat was removed at the end of each of the recording periods.

The results of this correlation exercise indicated that the capacitive sensor, coupled with a prototype microprocessor-based detector unit, was capable of recording dynamic axle loads in the range 0 to 10 tonnes to within approximately ±15 percent of their static value at a confidence level of 95 percent. For the heaviest loads, where the individual axles of tandems were recorded separately and combined to correlate with weighbridge data, the accuracy of the comparisons improved to approximately ±10 percent for 95 percent confidence. These figures correspond to statistical accuracies (standard errors) of about 7.5 and 5 percent, respectively.

PRODUCTION SYSTEMS

Production capacitive WIM systems have been developed by Golden River Corporation from the research prototype development system previously described. These systems have involved complete hardware and software redesigns to take account of a number of development program findings and to ensure compatibility with other Golden River Marksman and Retriever equipment.

The Marksman Axle Weight Classifier uses a capacitive weighmat sensor with a portable roadside Marksman microprocessor traffic counter and classifier. Axle counts in 12 user-defined weight bins are stored in solid-state memory at preset intervals of between 1 min and 24 hr on the internal clock and calendar. Individual axle weights can also be displayed in any appropriate unit for checking of calibration.

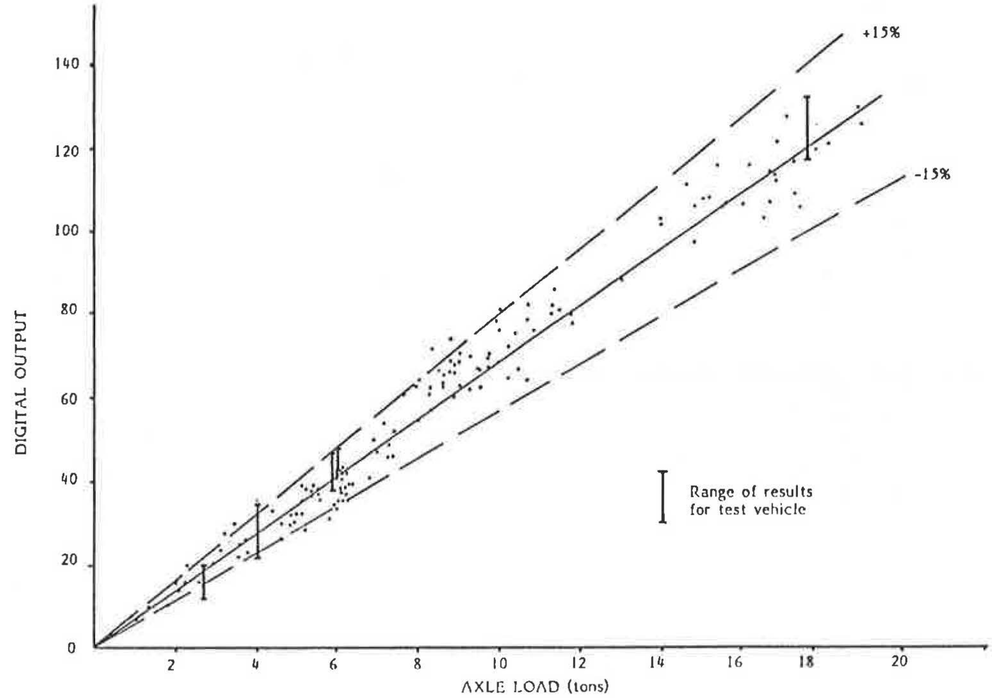

FIGURE 11 Results from the weighmat calibration exercise.

Data retrieval is by a separate microprocessor-based Retriever, which is compatible with other Marksman counters and classifiers, or by direct telephone modem. Internal rechargeable batteries will support the Retriever for several days and the Marksman for about 5 weeks. The Marksman weight classification equipment has been tested in the United Kingdom and in the United States in Arizona.

The second production capacitive weighing system is the Golden River Advanced Vehicle Classification and Weighing System (AVCWS), which will be available shortly. This equipment will count, weigh, and classify vehicles by type, as required by the user. Operation is fully automatic and takes place in real time. Vehicles are classified into 1 of 14 categories recommended by FHWA; for each class, leading axles, other axles, tandems, and gross vehicle weights are recorded in 12 user-defined weight bins, thereby giving a large number of possible categories. Alternatively, data can be grouped into fewer weight or type categories, or individual vehicle dimensions, weights, speeds, and class can be stored in memory for subsequent analysis.

Recording intervals can again be preset by the user, although necessarily with short intervals and using maximum numbers of categories, because memory storage capacity limits the interval between data retrieval. Compliance with the Bridge Formula is also tested for each vehicle in real time, and the proportion of vehicles violating the formula is stored in each time period. Fully automatic adjustment of axle weights is included in the microprocessor algorithms according to vehicle speeds and ambient temperature.

Road sensors for classification and weighing consist of two inductive loops and one capacitive weighmat per lane. If classification is required without weighing, the weighmat can be replaced by a pneumatic tube. Fully portable operation can be achieved by the use of bituthene or similar temporary loops, or permanent speed measuring loops can be used instead. The equipment is housed in a standard Marksman box with internal rechargeable battery power, and is again serviced by a Retriever for initialization and data retrieval. System accuracies have yet to be established, but are likely to be similar to the prototype for individual axle weights, rather better for gross vehicle weight, and around 90 to 95 percent accurate for 14 vehicle type classifications.

SUMMARY

Capacitive weighmat systems have been tested under laboratory conditions to determine their response characteristics to load. Investigations revealed that the sensor unit had a reasonably linear response to load, but that the output was also related to the tire contact area and to the position at which the sensor was loaded.

A new microprocessor-based detector unit has been developed for the capacitive weighpad, and initial field trials have indicated that the statistical accuracy of dynamic axle load determination using this portable system is in the region of ±7.5 percent. On the basis of this work a Marksman Axle Weight Classifier has been developed and further tests on the system are currently in progress. The combination of axle weighing and automatic classification facilities is now a practical proposition, and the first AVCWSs are expected to be available shortly.

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Development of a Data Base for Nondestructive Deflection Testing of Pavements

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ABSTRACT

Currently the U.S. Army is using a pavement management system called PAVER that was developed by the U.S. Army Construction Engineering Research Laboratory (CERL). Along with the Army, the American Public Works Association, the U.S. Navy, and the U.S. Air Force have implemented the management system at several sites. The present system has been developed over several years. The system is centered around a hierarchical data base used to store pertinent information [System 2000 is the data base management system (note that System 2000 is a registered trademark of Intel Corporation)]. Using the data base and interface analysis programs, the user is provided with rapid report generation and analysis of critical information, which allows objective input to the decision-making process. A recent addition to the data base structure is the ability to store nondestructive deflection testing data. The development of the data structure used to store this information and its planned use are described.

Nondestructive testing (NDT) deflection data are an important addition to the PAVER pavement management system for the purpose of pavement design and evaluation and condition prediction. The PAVER system is designed to be a comprehensive management tool (1,2). Therefore, it is imperative that all relevant pavement information for management at both the project and network levels be included. The concept of storing all data in a comprehensive data base structure, where it can be manipulated and processed, is also appealing to the user from an organizational viewpoint.

At the project level NDT data are used for the purposes of pavement evaluation and subsequent restoration, rehabilitation, and resurfacing design. There are several deflection-approach pavement design schemes that require deflection information as input. NDT can also be used to determine in situ material properties of individual layers such as modulus of elasticity (E). This is usually done based on deflection values, layer thicknesses, and using analysis techniques such as elastic layer or finite-element methods. The in situ material properties are used for computing stresses and strains for the selected design vehicle(s), which are in turn used to compute remaining pavement structural life based on past and future traffic.

At the network level NDT data can be used for planning and forecasting. The deflection values, normalized for temperature and time of year, can be assumed to be constant until very near failure. Thus a pavement's deflection, or a derivative function of deflection, can be used as an indicator of pavement strength. This indicator then becomes an independent