The effects of heavy vehicle loadings on pavement structures containing vertical discontinuities

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In the winter of 1991 and Spring of 1992, two full-scale pavement test sections were constructed along lightly and heavily trafficked roads in Northern Ireland. The two sections have been fully instrumented so that deformation, deflection, stress, strain, moisture and temperature at different levels in each pavement will be known at any time. Ultimately, the purpose of the project is to provide pavement engineers with important, field-verified information about the relationships between pavement response and performance criteria. Also, back-calculation of moduli and corresponding calculations of theoretical stresses and strains will be conducted using Falling Weight Deflectometer and Deflectograph load-deflection data.

1. INTRODUCTION

1. Pavement design and evaluation are developed from a blend of theory, laboratory testing, field testing and performance monitoring. This testing and performance monitoring is critical because it allows the theoretical concepts to be checked and modified to reflect actual conditions. Without this blend of theory, testing and performance monitoring, modern pavement design would not have developed to this present level.

2. The question still remains, however, whether the calculated stresses and strains using mechanistic approaches correspond to what actually occurs in the field under heavy traffic loads. If they do, then the mechanistic approaches currently used in design and evaluation would appear to be in question, although offsetting errors could very well result in more or less "correct" results in terms of expected pavement performance and resulting rehabilitation design.

3. The question also remains as to how pavements contain vertical discontinuities such as utility trenches perform under heavy traffic loadings and whether the same mechanistic relationships used for continuous pavements may be used in evaluating these road types subjected to essentially the same traffic loads.

2. EXPERIMENTAL DESIGN

1. Based on the needs arising from the new, mechanistic approaches to pavement evaluation, expected performance and rehabilitation design (as well as new pavement design), the Queen's University of Belfast has now initiated a full-scale project of investigate the response and performance of a variety of typical pavement types containing vertical discontinuities. In the experimental design of the project, it was deemed important to consider the wide variety of variables involved in a pavement behaviour. As a result of budget restrictions, we were obliged to select two sites instrumented with three sets of instruments.

2.1 Sites and typical sections

2. The first site selected is located at the Queen's University Halls of Residence and the second site is located at Hillsborough Bypass, on the A1 Belfast to Dublin highway. The first site would have a 0.5msa pavement design life and the second one would have 10msa pavement design life. The top layer in both sites is bituminous layer underlaid by unbound crushed rock materials. Each test section is approximately 30m.

2.2 Instrumentation

3. In each site trench was excavated in three sections of width 300mm, 450mm and 600mm. This was designed to compare the behaviour of different trench sizes under the same traffic loads. The depth of excavation was 1.2m from the road surface. It was decided to install the following instrumentation at three different cross sections:

- one subgrade pressure cell
- one subgrade vertical deformation transducer
- five subgrade moisture content cells
- two subgrade thermocouples
- two base layer pressure cells (vertical and horizontal)
- one base layer vertical deformation transducer
- five base layer moisture content cells
- two base layer thermocouples
- one bituminous layer pressure cell
- four bituminous layer strain gauges
- six bituminous layer thermocouples

4. A typical schematic of the placement of the instrumentation is shown in Figure 1.

3. SPECIFICATIONS AND INSTALLATION

1. All the sensors described above were installed during the reinstatement of the excavated trenches. The installation of the sensors at the interface between two layers is relatively easy matter. Precautions need to be taken however to ensure that the sensor is in

the right position and that it is properly protected in connection with the application of road construction plant on the site.

3.1 Gauge types and specifications

2. 3.1.1 Stress Gauges. We decided to employ two different types of sensors for the measurement of both the vertical and horizontal stresses in order to guard against the general failure of one particular type and so as to be able to compare the results of two different sets of measurements. These types of stress gauges were manufactured by the Dynatest Pavement Consultants in Denmark and in the University of Nottingham in the UK. Their design is based on over 20 years of research at the Technical University of Denmark and the University of Nottingham in gauge design installation and direct experience with a variety of commercial types. The Dynatest Gauges were chosen primarily because they are believed to be very reliable, durable and accurate even under conditions of varying temperature and modulus of the material in which the gauge is embedded.

3. The soil pressure cells, called the SOPT (Soil Pressure Transducers) series, are designed for use in both cohesive and granular materials. This transducer type is based on a new design which yields important advantages over the normal membrane-type pressure cells (Nottingham pressure cells). The latter type is generally non-linear with respect to the modulus of the soil medium as well as its moisture content and gradation etc. The sensitivity and linearity problems previously encountered with soil pressure gauges have been virtually eliminated with the SOPT hydraulic pressure design, which utilises a thin membrane over the entire cell area allowing the measurement of liquid pressure. These cells are temperature compensated for use in the range of -30°C to 150°C. They are 68mm in diameter and should perform for at least 36 months or 3,000,000 cycles, whichever comes first.

4. 3.1.2 Strain gauges. The Dynatest asphalt strain gauges, TRRL soil transducers and the BISON coils were employed for the measurement of both the vertical and horizontal strains in the bituminous layers and in the unbound base and subgrade layers. Strains in the unbound base layer and in the subgrade were determined by the BISON coils or the TRRL soil strain transducer, which mainly measure the differential displacement between two points. The TRRL soil strain transducer measures the differential deflection by an LVDT. The BISON coils measure the deflection by measuring the changes in the mutual induction of two coils. An important advantage of the latter system is that the coils are not mechanically connected as in the TRRL transducer. A disadvantage is that moving metallic masses also induce a signal in the coils. Both types may be used to measure resilient as well as permanent deformations. The Dynatest asphalt strain gauges, called the PAST (Pavement Strain Transducer) series, are designed to measure horizontal strains at the bottom of bituminous layers. A PAST unit is an "H" type precision strain gauge, some 102mm in length and constructed using materials with a relatively low stiffness, while at the same time exhibiting very high flexibility and strength. The gauges are protected against mechanical and chemical deterioration by means of a multi-layer coating, allowing them to perform in fatigue up to 100,000,000 loading cycles or 36 months. The temperature range of the PAST series of gauges is some -30°C to 150°C.

5. 3.1.3 Moisture cells. Two methods are used to measure in-situ soil moisture content, WATERMARK electrical resistance block and time-domain reflectometry (TDR). The WATERMARK block is composed of a perforated plastic tube. Two electrodes are embedded into a porous matrix that provides adequate sensitivity even when the soil is near saturation. In addition, the block contains a chemical buffer to offset the influence of soil salinity on resistance. These sensors are sensitive to changes in the amount of water contained in the porous matrix due to the ions dissolved in the water. Time-domain reflectometry (TDR) is a relatively new and promising method for measuring soil water content. The change in the apparent dielectric permittivity of the soil is the measured property that is related to volumetric water content. Principal advantages of TDR are that it is insensitive to the effects of temperature, salinity and bulk density, which distinguishes it from most of the instruments for measuring soil water content based on changes in soil electrical properties. The TDR unit contains a pulse generator, a sampler that produces a low frequency facsimile of the high frequency output and an oscilloscope that displays the sampler output. Electromagnetic pulses containing a spectrum of frequencies in the 1 MHz to 1 GHz range are sent down a transmission line that terminates in a parallel pair of steel waveguides embedded in the soil. Any change in the impedance along the waveguides causes a partial reflection which is visible on the oscilloscope trace. Thus there is a partial reflection where the waveguides enter the soil and the remainder is reflected at the end of the waveguides. The travel time of the pulse between these points can be measured on the oscilloscope trace and it is a function of the relative permittivity of the soil surrounding the waveguides. Relative permittivity is in turn a strong function of the water content since the relative permittivity of air, dry soil and water are approximately 1, 4 and 80 respectively.

6. 3.1.4 Thermocouples. Accurate and regular measurement of the temperature is essential. About a dozen of thermocouple wires of the standard type "K" were fitted at different levels in each of instrumented sections. A complete set of temperature readings are taken for each phase of measurements and during the loading phases a set of such readings are taken.

7. 3.1.5 Installation of sensors. All the sensors described above were installed as construction progressed layer by layer. The installation of the sensors within the granular layers and subgrade is more difficult matter than at the bottom of bituminous layer. Having laid the unbound material or soil, it is necessary to excavate a cavity and to place the sensor in the correct position within the cavity

on making sure that its "zero setting" has been respected. The excavated material has then to be replaced on respecting the initial conditions as well as possible.

8. As far as it is known at the present time, all gauges installed are performing properly except the TRRL soil strain gauges which until now we could not obtain the correct signal out of them. The final "verdict" though will not be known until the subgrade reaches its equilibrium condition and the top layers reach a stable state of compaction from the daily traffic.

9. 3.1.6 Data logging equipment. Contrary to our expectations, considerable difficulties were experienced in the acquisition of the data logging equipment. The difficulty appeared to be in obtaining the required scanning rate, the number of gauges to be read at one time, the time of reading and the desired accuracy of the readings. Finally, a data acquisition unit was designed and assembled which would read 10 gauges at 70 readings per second per gauge to an accuracy of one microvolt under an excitation voltage of 10V. The entire operation is being controlled by a Toshiba microcomputer equipped with LabWindows software.

4. FIELD TESTS

1. Two types of field tests are conducted before and after construction of the instrumented sections:-

(a) Falling Weight Deflectometer (FWD) Tests
(b) Heavy Moving Wheel Load (Deflectograph) Tests

2. The FWD and Deflectograph tests are employed on three monthly and monthly basis respectively. Testing of the instrumented pavements started one year before installing the instruments. The data gathered from these tests before and after constructing the reinstatement sites are used to back-calculate the elastic moduli of the pavement layers. These back-calculated moduli can be used as an input to mechanistic finite element model (ABAQUS) to determine the theoretical stresses and strains in the pavement. Figure 2 presents the result of such back-calculation data obtained from the FWD deflections before and after the instrumented trench reinstatement. From Figure 2, it can be seen that the modulus of bituminous layer (E1) is higher than that of the original pavement. The base modulus (E2) is slightly lower than that of the original pavement which can be explained by the compaction state of the new road base. The subgrade modulus (E3) is generally lower than the original modulus of the same subgrade. This can be due to seepage of surface water into the trench during construction causing this reduction in stiffness. Similar trends were obtained from the Deflectograph deflection tests.

3. Deflectograph moving heavy wheel load tests are being conducted to examine the response of the instruments. The tests are conducted at various vehicle velocities. These tests will be repeated every month to take into account the seasonal effect on the stress and strain levels into a pavement from the same load.

5. IN-PAVEMENT INSTRUMENT RESPONSE TO HEAVY VEHICLE LOADINGS

While a wide variety of tests were done at the instrumented sites, not all results are relevant to the present paper. Therefore, only a limited amount of data is presented here with a view to show the depth of heavy wheel load effect. Figure 4 shows a typical response from the stress gauges due to the Deflectograph. Both front and rear wheel stress bowls are plotted. The location of the four stress gauges within the pavement structure is also illustrated in Figure 4. It is interesting to note the similarity between the front and rear axle bound layer interface stress bowls despite both, the difference in load, 2.8t and 6.3t approximately, and the dual wheel arrangement on the rear axle. It can also be seen that the loading cycle spreads as the stress levels are dissipated into the lower layers of the pavement and the subgrade. Indeed, the stress bowl within the subgrade layer shows that the stress levels are not so easily dissipated by the dual wheel rear axle of the deflectograph. In contrast, tests with the impact loaded FWD have shown no widening of the load cycle with depth of sensor. The project will now compare these pavement instrument responses with those recorded by the data logger to check accuracy of instrumentation and NDT devices. A further comparison between the site data and the finite element model being developed is also envisaged. The effects of temperature and moisture levels will also be input into the theoretical model at a later stage.

6. CONCLUSIONS

1. With a steadily increasing amount of traffic on our existing roadways and the constant need for reconstruction, structural monitoring has become increasingly important in all aspects of the pavement evaluation process.

2. The purpose of most road structural monitoring is to:-

a) evaluate the system without destroying it;
b) reduce testing time and minimise interference with traffic operations;
c) improve the quality of the test so that it can reproduce as nearly as possible the loading conditions during actual field operation;
d) simulate the effect of moving wheel loads.

3. Current research work is aimed at improving the validity of such road structural monitoring by both theoretical and in-service modelling.

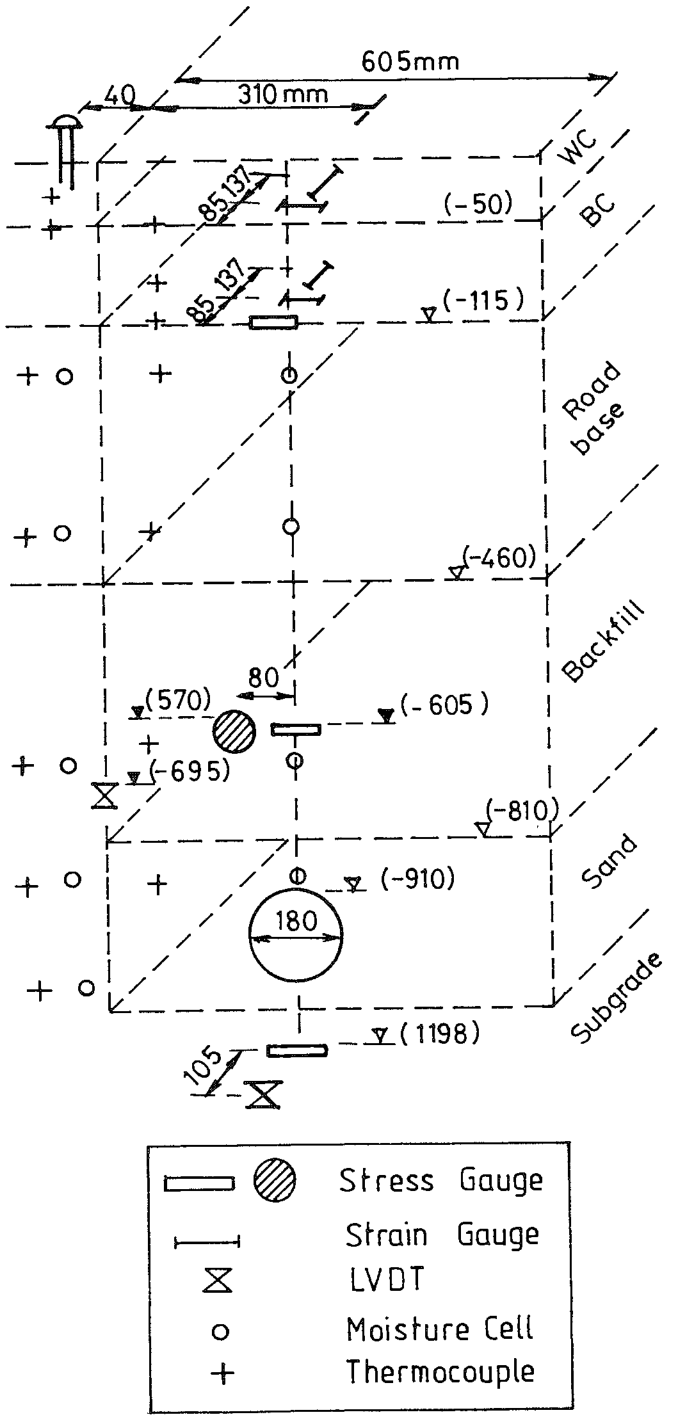

Fig. 1 Cross-section of the Test Road at QUB site showing instrumentation.

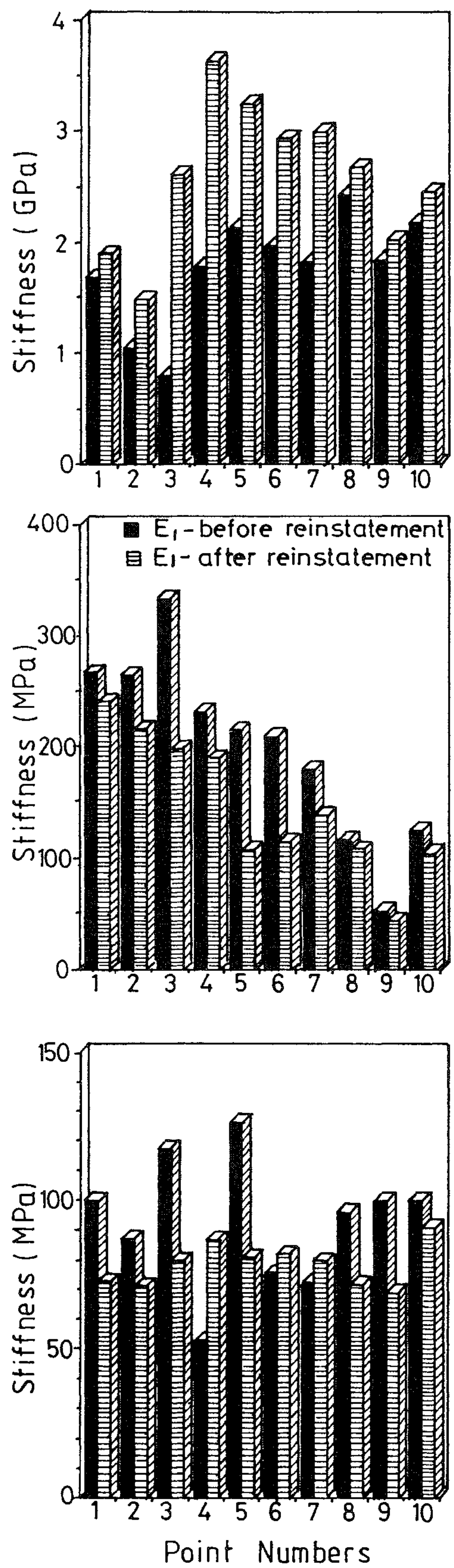

Fig. 2 Changes in Pavement Moduli due to Reinstatement

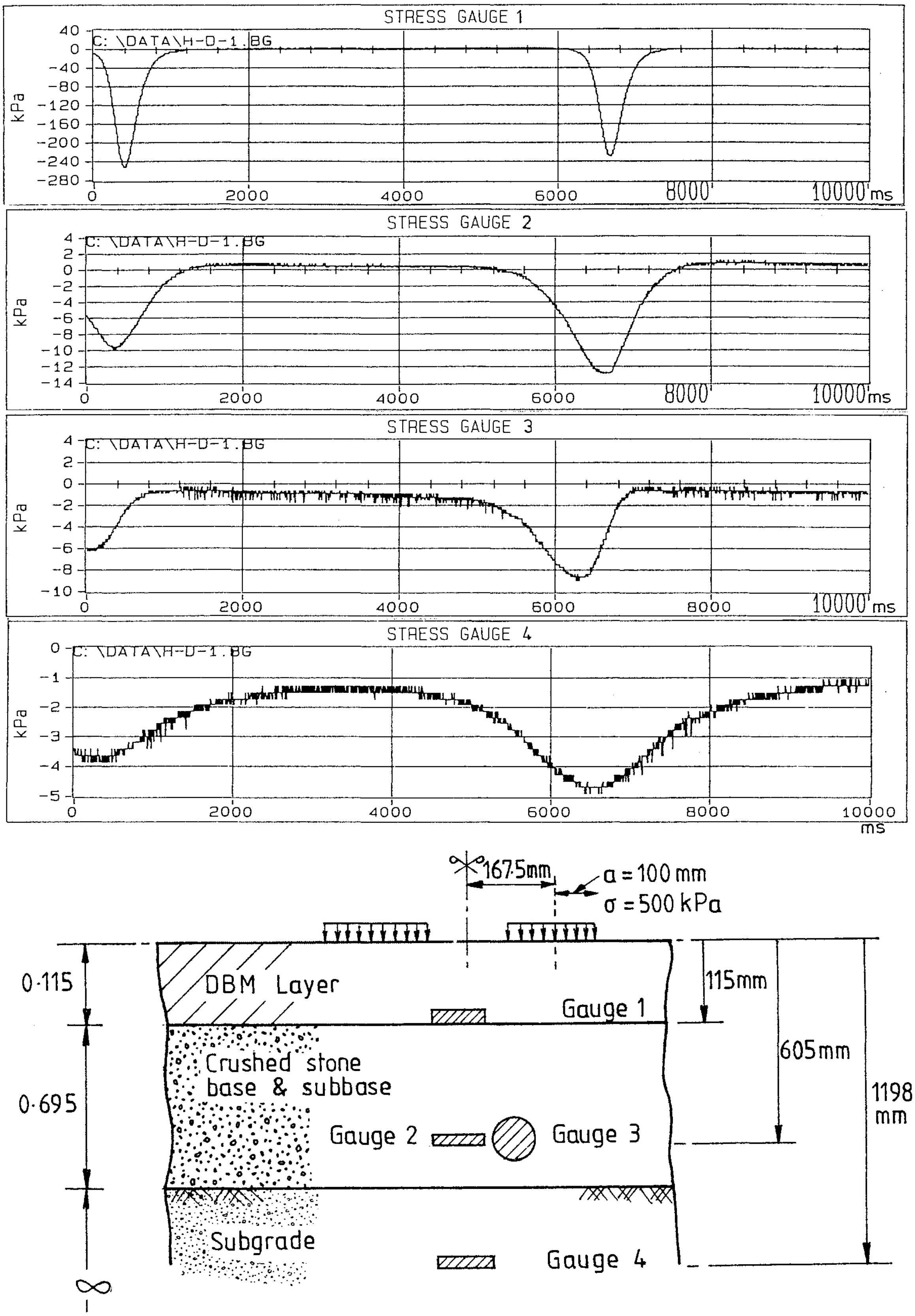

Fig. 3 Stress measurements under Heavy Vehicle