# Full Scale Accelerated Testing of Bituminous Road Pavement Mixtures

M.D. Gilchrist[1] A.M. Hartman[1] P.M.O. Owende[2] S.M. Ward[2]

[1] Dept of Mechanical Engng, National University of Ireland – Dublin, IRELAND
[2] Dept. of Agriculture & Food Engng, National University of Ireland – Dublin, IRELAND

**Keywords:** Damage Assessment, Accelerated Test, Fatigue, Asphalt, Bituminous Mixture

## ABSTRACT

The in-service behaviour of a standard Irish Dense Base Coarse Macadam mixture (DBC) was evaluated by using the material to overlay a road section, which was based upon a weak pavement structure. The response of the layer under a fully laden dual axle truck was examined using a series of pressure cells and asphalt strain gauges that were embedded in the test section. The section was traversed repeatedly until a network of fatigue cracks was observed on the road surface. The transverse horizontal tensile strain was found to be the most critical parameter in initiating pavement damage.

## INTRODUCTION

Full scale test facilities offer particular advantages over simulated laboratory programmes: the effects of size, construction, substructure, boundary and loading conditions correspond more closely to the actual on-site conditions than can be simulated directly with model experiments. However, it is seldom possible to control temperature and moisture when using such facilities and consequently there are always inherent disparities when attempting to relate laboratory and in-situ test data.

Recent investigations have focussed on the mechanical performance of standard bituminous mixtures using uniaxial fatigue tests [1-3] and fatigue wheel tracking laboratory tests [4]. The present paper describes a full scale accelerated loading performance test on a 20mm Dense Base Coarse Macadam [6] which overlaid a peat based forest access roads [5]. Such forest roads generally have a weak pavement structure, which consists of a surface dressed granular base and a subbase (±0.5m deep) that overlay deep peat foundations. In general, peat (a soft biogenic deposit) provides a poor foundation for roads as it is frequently weak [7] and compressible, particularly after prolonged dry periods [8].

Various damage assessment procedures are used to evaluate the structural integrity of a pavement, for example the monitoring of crack initiation and propagation and permanent deformation on the pavement surface. In-situ material properties can be evaluated by measuring surface deflections with a Falling Weight Deflectometer (FWD), while internal stresses and strains can be monitored by use of appropriate transducers that are located at critical positions within a pavement structure. Environmental factors such as the moisture level in the subgrade and the pavement temperature can also be monitored. The present research has characterised and quantified the in-situ mechanical performance of a standard Irish Dense Base Course Macadam (DBC) by measuring surface strains, crack growth and subgrade stresses at incremental levels of fatigue cycles under controlled load conditions.

## LAYOUT AND CONSTRUCTION OF TEST SECTION

A suitable section of a forest access road was identified for the experiment. Figure 1 shows a schematic representation of the monitoring section, the dimensions of which are 3.3m (road width) by 35m (length of overlaid area). A central area in the outer wheel path was selected for instrumentation with pavement transducers, the detailed layout of which is shown in Figure 2. FWD points were marked over the test area to measure the global pavement response. Crack monitoring grids were randomly spaced in the outer wheel path over 15m along the section. A total of 19 grids were marked out to monitor cracking. Four permanent deformation cross section measurement positions were identified, two at both ends of the crack monitoring strip. The traffic counter was located at the end of the test section. The counter had to be placed as far away as possible from the crack monitoring and permanent deformation measurement positions since counter cables had to be machined into the overlay which could induce initial defects.

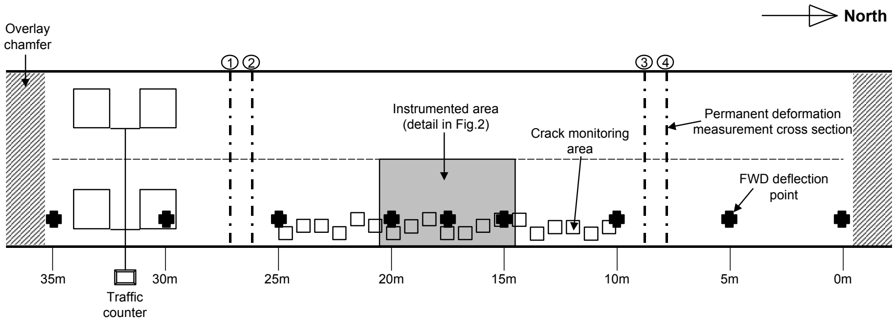



**Figure 1.** Layout of experimental road pavement section.

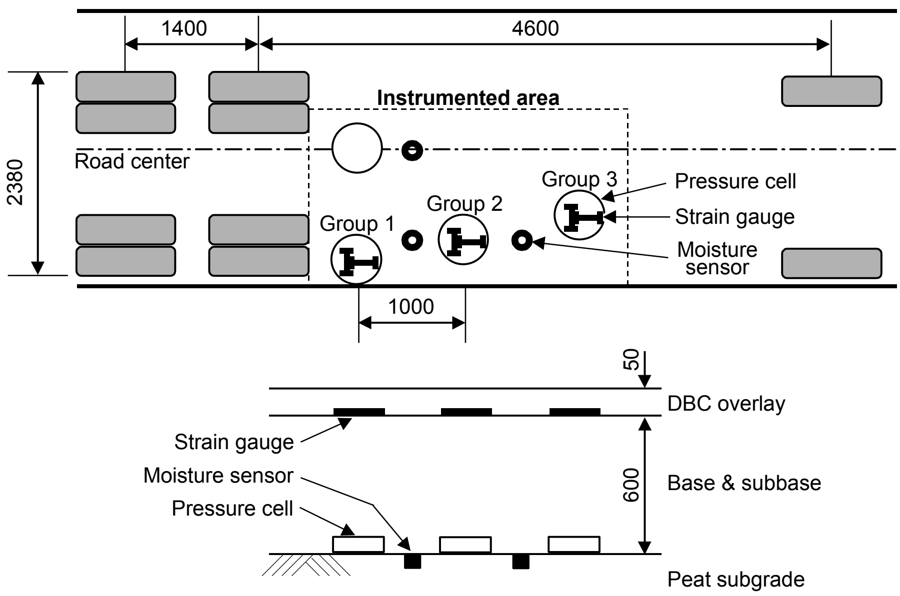



**Figure 2:** Layout of sensors and transducers within instrumented area; superimposed axle spacing and track width of experimental truck (dimensions in mm).

The asphalt strain gauges were installed at the time of the overlay construction. The strain gauge application points were smoothed to remove sharp and large aggregates from under the transducer and the gauges were positioned in the longitudinal and transverse directions. Grooves were cut through the existing surfacing and the lead wires from the strain gauges inserted into the grooves. The grooves were then filled with fine aggregates to protect the wire from damage during construction and loading. Mixture fines were sieved over the gauges and hand compacted to fix them into position. After the gauges were properly located construction of the full width layer was resumed; this involved the use of plant compaction equipment. All the sensor cables were soldered to individual sockets in a terminal box that was located at the roadside.

The total size of the overlaid area was approximately 120m$^2$; this required about 15 tonnes of mix to cover. Due to restrictive site access and subgrade conditions, the material had to be laid by hand. The area was sprayed with a tack coat after which the hot mixture was spread by wheelbarrow and rake. During the laying operation, loose mix was sampled to evaluate the mixture composition. The bitumen content (4.3% by wt.) was purposely chosen towards the lower end of the design spectrum to obtain a fatigue prone mixture. The compaction temperature was monitored with a hand held probe at around 110°C. The long hauling time from the Dublin materials plant (approximately 5h), the manual nature of the laying operation and the low air temperature (< 10°C) resulted in rapid cooling of the mixture and a low compaction temperature. This, combined with the light weight compaction plant (0.5 tonnes pedestrian roller) and the weak foundation support, resulted in poor densities being achieved (voids > 10%).

The total thickness of the overlay, as measured from the cores, was slightly less than 50mm. Permanent deformation wheeltracking tests [9] were conducted on four 200mm diameter cores to determine the rut susceptibility of the mixture. An average rut rate of 1.5mm/h was measured; this is substantially less than the 5mm/h limit set in the specification. It can thus be anticipated that any rutting measured would mainly be due to deformation in the underlying layers. At 20°C the mixture had a relative low Indirect Tensile Stiffness Modulus (ITSM ≈ 1500MPa) with a large coefficient of variation (28%), which is most likely due to the variations in void content (29%) [1].

## EXPERIMENTAL TRUCK SPECIFICATIONS

The test section was loaded using a three-axle (single front and dual in tandem rear) fixed-bed timber transportation truck. The vehicle had a 10-spring flat-leaf suspension and was fitted with 10R20 tyres. This truck configuration is representative of the heavier carriage used by the timber industry in Ireland. The truck was loaded with timber that gave maximum axle loads of 63kN (front) and 89 and 88kN for the rear tandem axles respectively. The load sharing coefficient (ratio of the load on the heaviest axle to the average load) of the tandem axle was approximately unity, which indicates that a near perfect load distribution was achieved with this configuration.

## DAMAGE ASSESSMENT METHODS

### *Crack Monitoring*

A procedure similar to Miradi et al [10] was adopted for monitoring the crack growth in the present experimental investigation. Cracks were monitored by tracing any visible cracks in the predetermined monitoring areas on to Perspex sheets (300x300x2mm). The monitoring areas were staggered randomly across the wheelpath and their positions were located with white road marking paint. The pavement surface was investigated prior to testing and all construction defects were marked accordingly on the Perspex sheets. Subsequent damage was marked in different colours on the same Perspex sheets.

The crack patterns on the sheets were digitised in the laboratory using an Olympus C-840L digital camera under controlled lighting conditions. Selection of the monitoring area, filtering of the background and storage of the image data in a compressed, greyscale format (.JPG) were done with the Ulead PhotoImpact image processing package [11]. The greyscale images were imported into UTHSCSA Image Tool [12] for image processing and analysis. The dimensions of the monitoring area (300x300mm) were calibrated against the pixel size so that direct dimensional measurements could be established for the digital images. The grey scale images were converted into binary format (consisting of only pure white and pure black pixels) by applying a threshold value. The selection of this threshold value was achieved by applying a range of thresholds and manually selecting the particular value that best represented the crack damage. This same threshold was then applied to all subsequent images.

To calculate the total length of cracks, an algorithm that counts the number of black pixels was applied to the images that were captured with the digital camera. No distinction was made between narrow and wide cracks and all visible defects were recorded with a marker of standard width. Thus, by normalising the area against the width of the tracing marker, the actual total crack length was determined. The spatial calibration of this data allowed the area to be given in $m^2$.

Measurements of crack direction were also made on the traced crack network patterns. An image analysis subroutine was used to identify cracks as objects. The major axis angle, i.e., the angle of the longest line drawn through the object to the horizontal, was determined for each object. The major axis angle, normalised to the length of each crack, represents the effective growth direction of each crack.

***Permanent Deformation Monitoring***

Permanent deformation was monitored with an optical level at four cross section positions. At each cross section position 14 measurements were taken at 230mm intervals. The exact positions were marked with road marking paint on the pavement surface. A specially constructed attachment was fixed to the end of the levelling staff to ensure that measurements were taken consistently at the same position.

## RESULTS OF PAVEMENT MONITORING

***Measurements from In-situ Transducers***

Figure 3 illustrates the pavement response outputs as recorded by the different groups of transducers during dynamic loading. The position of the transducers relative to the loading wheel influenced the recorded levels of strain although the measured stress on the subgrade remained relatively constant, displaying similar peak values corresponding to the passage of individual wheels.

The Group 1 gauges were situated directly under the front and outer middle and rear wheels and consequently they identified the peak levels of strain as each wheel passed overhead. For Group 2 gauges, the front wheel passed adjacent to the edge of the group resulting in lower strain readings. The gap between the dual wheels (of the middle and rear axle) passed over the Group 2 gauges, resulting in a compressive transverse strain. For Group 3 gauges the front wheel passed to the right of the gauges, which consequently recorded lower longitudinal strains than Group 1 and Group 2 gauges and compressive strain in the transverse direction.

The inner middle and rear wheels passed straight over the Group 3 gauges resulting in similar strain levels being sensed as by the Group 1 gauges.

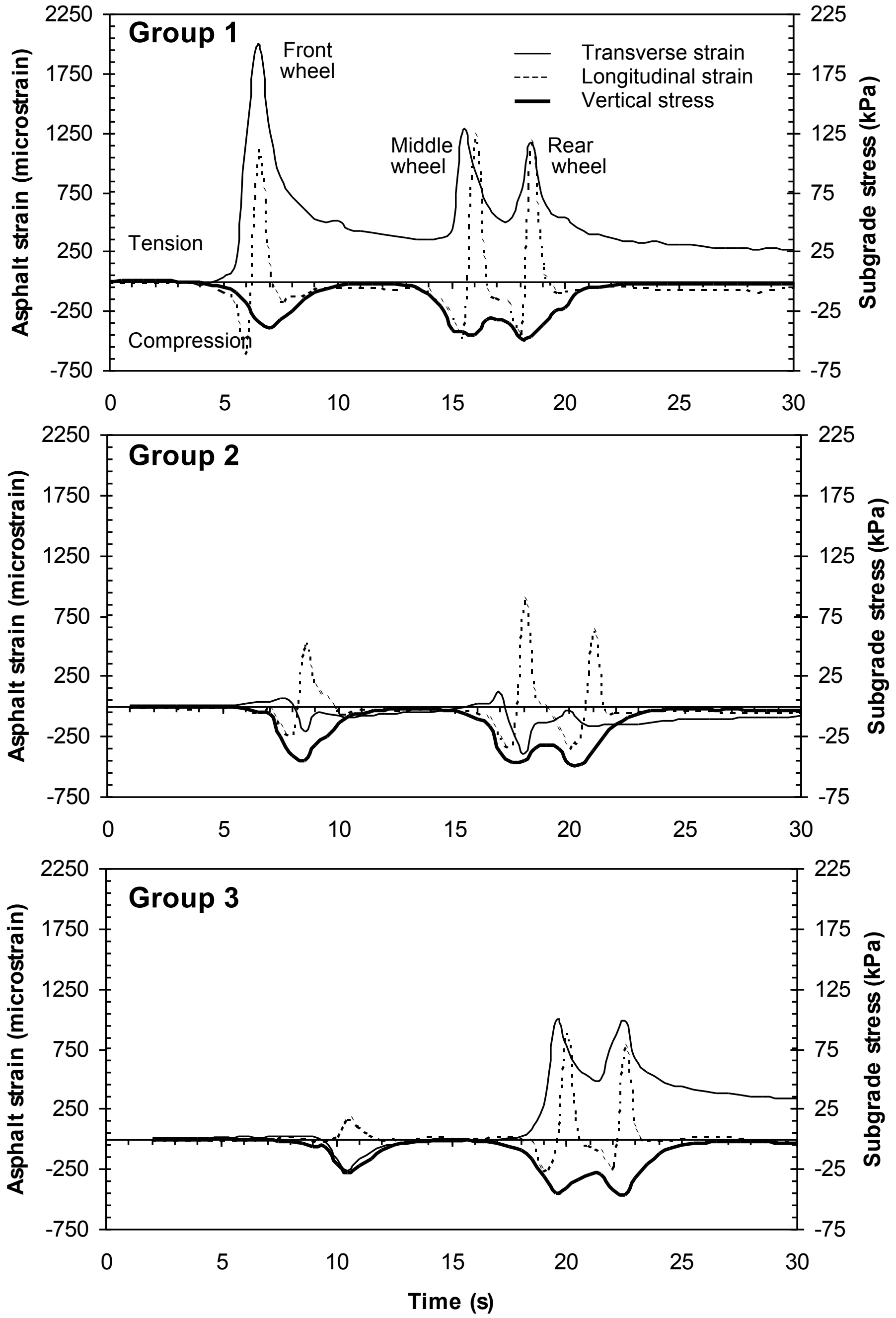



**Figure 3.** Typical response sensed from embedded gauges at different positions with reference to loading wheels (vehicle speed = 2km/h). Groups 1, 2 and 3 refer to strain gauge locations identified in Figure 2.

The transverse strain pulse remains tensile for the Group 1 gauges as the wheel load passes over the pavement, while the longitudinal strain changes from compression to tension and back to compression. As reported by Huhtala et al [13], the transverse strain under the steering wheel was higher than the corresponding strain for the dual wheels in the rear tandem axles. However, the longitudinal strain under the steering wheel was similar to the longitudinal strains excited by the rear duals. The Group 1 gauges also indicate that a degree of permanent deformation is experienced in the transverse direction as evidenced by the nonzero levels of strain after loading. No stress reversal takes place and the gradual dissipation of strain can be ascribed to the viscoelastic behaviour of the bituminous layer. The higher transverse strains would indicate that initial fracture would be due to these strains and that damage would be apparent in the form of longitudinal cracking in the wheel path.

Examination of the longitudinal strains indicates that the magnitude of the compression pulse preceding the tension pulse was much greater than the compression pulse following the tension pulse. It was observed that the longitudinal strain dissipated after each wheel load; this would indicate that the pavement responded to the three axles as a series of separate and independent loads in the longitudinal direction. A summary of the measured maximum strains and stresses is given in Table 1.

| Axle | * Axle load (kN) | Strain at bottom of asphalt layer (µstrain) | | Stress on top of peat subgrade (kPa) |
|---|---|---|---|---|
| | | Longitudinal | Transverse | |
| Front | 63 | 1097 | 2000 | 36.3 |
| Middle | 89 | 1244 | 1287 | 39.2 |
| Rear | 88 | 1177 | 1165 | 41.1 |
| * Note: Tyre pressure at 770kPa | | | | |

**Table 1.** Summary of maximum strain and stress measurements.

***Measurement of Permanent Deformation***
Incremental change in the cross section profile over the length of the monitoring section was insignificant which suggests that failure was mainly a fatigue phenomenon. Towards the end of the test a small amount of permanent deformation (< 10mm) was observed in the outer wheel track.

***Crack Monitoring***
The first cracks were visible after approximately 2000 experimental truck loadings. The cracks appeared close to the Group 1 gauges and were aligned in the longitudinal direction. This confirmed the assumption that transverse strains were responsible for crack initiation.

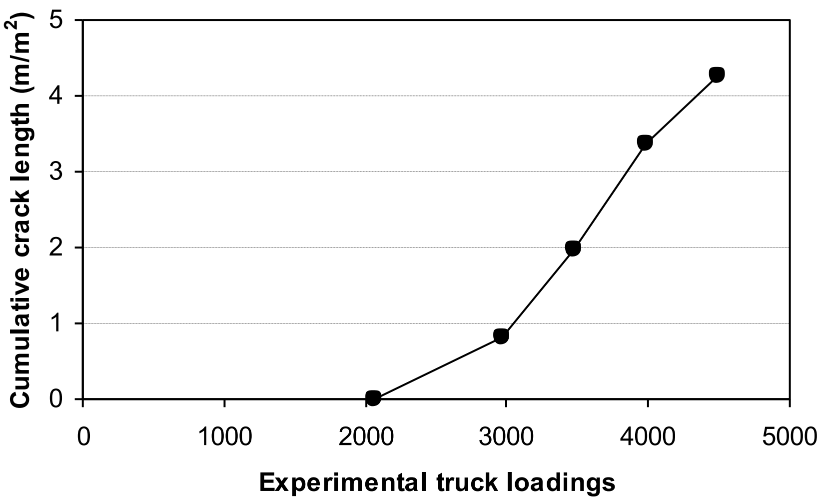
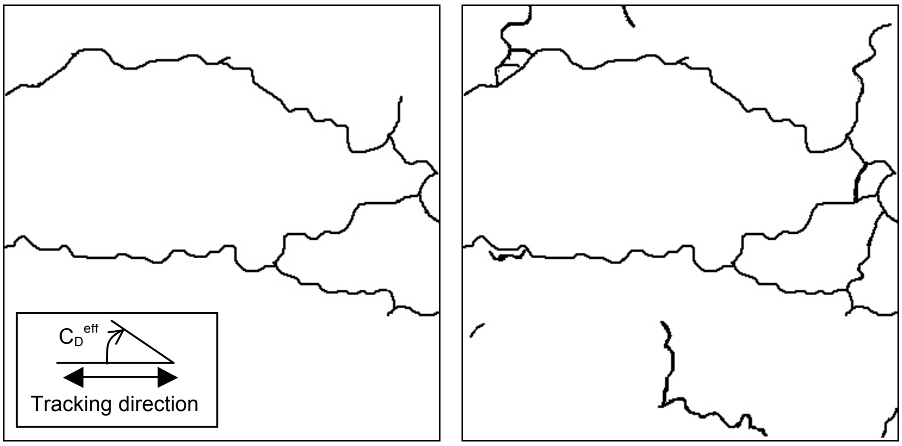



**Figure 4.** Variation of cumulative crack length with truck loading cycles.

Figure 4 shows the increase of crack length within the wheel path with the number of experimental truck passes. The increase of crack length follows an almost sigmoidal pattern with an initial rapid increase being followed by a slower increase.

Figure 5 describes a typical example of traced cracks after the first and final tracings. On average, the crack angle changed from 31° to 41°, from the plane parallel to the direction of travel. Therefore, the majority of cracks formed in the longitudinal direction ($C_D^{eff} < 45°$). This observation suggests that cracks mainly initiate in the longitudinal direction with subsequent lateral networking. This implies that while the transverse strain governs the initiation of fatigue cracks, the subsequent networking of the cracks is influenced by longitudinal strains. The final crack pattern on the surface was typical of crocodile cracks as shown in Figure 6.




Cycle count: 3000
$C_D^{eff} = 31°$

Cycle count : 4500
$C_D^{eff} = 41°$

**Figure 5.** Change in crack direction over fatigue life.

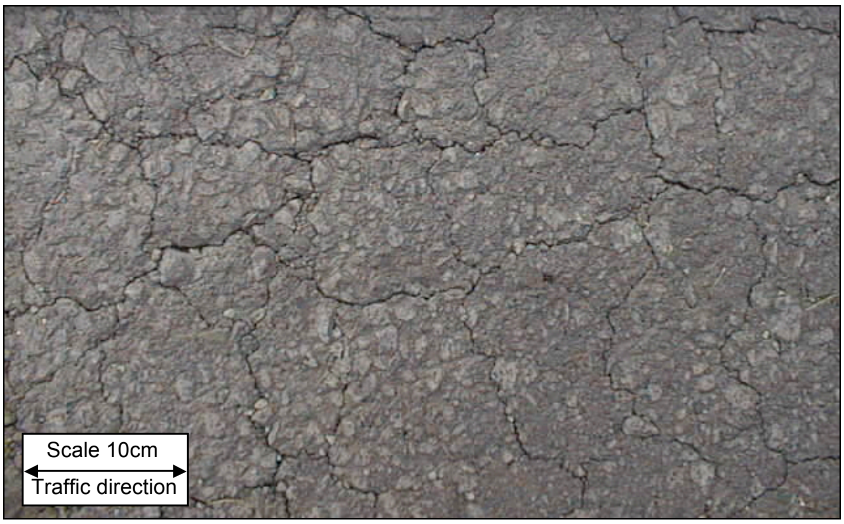



**Figure 6.** Final crocodile crack pattern observed at 'failure' of road section.

### *Observed Fatigue Damage*

The total number of experimental truck passes required to cause visual evidence of crack initiation was approximately 2000 cycles. The pavement temperature during the tracking experiment was not constant but varied about an average of 6°C (±4°C). As discussed earlier, the transverse tensile strain at the bottom of the asphalt layer was responsible for causing the first longitudinal cracks to appear.

## CONCLUSION

An accelerated loading test was performed on a 50mm DBC macadam layer overlaying a 600mm deep granular base and subbase on a weak peat subgrade. The test road was continuously tracked until crack initiation with a fully laden three axle timber haulage truck. The response of the layer was monitored using in-situ gauges, FWD deflections and visual inspections of crack and rut formation. Pavement healing and limited traffic wander occurred during the test sequence.

It was found that the transverse horizontal tensile strain is the most critical parameter with respect to crack initiation. This was confirmed by the predominant appearance of longitudinal cracks in the wheelpath. The single front steering wheel induced higher transverse strains than the tandem duals, indicating that this axle configuration is critical in initiating asphalt fatigue damage. Transverse strain pulses showed a level of residual strain, the magnitude of which varied with lateral position on the wheel track.


### Acknowledgements

Funding and support for this research has been provided by Enterprise Ireland (Applied Research Grants HE/1996/148 and HE/1998/288), the Irish Forestry Board, the National Council for Forest Research and Development (COFORD), the National Roads Authority, Roadstone Dublin and Wicklow County Council.


### References


1. HARTMAN, A.M., ‘An experimental investigation into the mechanical performance and structural integrity of bituminous pavement mixtures under the action of fatigue load conditions.’ PhD Thesis, University College Dublin, Ireland, 2000.
2. HARTMAN, A.M., GILCHRIST, M.D., WALSH, G., ‘Effects of bituminous mix compaction on indirect tensile stiffness and fatigue.’ Submitted for publication in ASCE Journal of Transportation Engineering September 2000.
3. HARTMAN, A.M., GILCHRIST, M.D., ‘Evaluation of the static and dynamic four-point bending properties of two Irish bituminous mixtures.’ Submitted for publication in ASCE Journal of Materials in Engineering September 2000.
4. HARTMAN, A.M., GILCHRIST, M.D., NOLAN, D, ‘Wheeltracking fatigue simulation bituminous mixtures.’ Submitted for publication in the Journal of Road Materials and Pavement Design September 2000.
5. BS 4987: PART 1, ‘Coated Macadams for roads and other paved areas.’ British Standards Institution, London, England, 1993.
6. OWENDE, P.; HARTMAN, A.M., WARD, S.M.; GILCHRIST, M.D.; O’MAHONY, M.J., ‘Minimising distress on flexible pavements using variable tire pressure.’ Accepted for publication in ASCE Journal of Transportation Engineering August 2000.

7. O'MAHONY, M.J.; VEBERSCHAER, A.; OWENDE, P.; WARD, S.M., 'Bearing capacity of forest access roads built on peat soils.' Journal of Terramechanics, Vol. 37 no. 3, pp. 127-138, 2000.
8. DAVITT, S.; KILLEEN, R.C., 'Maintenance techniques for bog roads.' NRA Report RC.375, National Roads Authority, Ireland, 1996.
9. BS 598: PART 110, 'Sampling and examination of bituminous mixtures for roads and other paved areas: Part 110. Method of test for the determination of the wheel-tracking rate.' British Standards Institution, London, England, 1996.
10. MIRADI, A.; GROENENDIJK, J.; DOHMEN, L.J.M., 'Crack development in linear tracking test pavements from visual survey to pixel analysis.' Transportation Research Record 1570, Transportation Research Board, Washington, USA, pp. 48-54, 1997.
11. ULEAD SYSTEMS, 'Ulead PhotoImpact Version 3.0SE.' Ulead Systems International Inc., Taipei, Taiwan, 1996.
12. UTHSCSA IMAGE TOOL, 'Image Tool Version 2.0.' University of Texas Heath Science Centre Department of Dental Diagnostic Science, San Antonio, Texas, USA, 1996.
13. HUHTALA, M.; ALKIO, R.; PIHIJAMAKI, J.; PIENIMAKI, M.; HALONEN, P., 'Behaviour of bituminous materials under moving wheel loads.' Proceedings of the Association of Asphalt Paving Technologists, Vol. 59, pp. 422-442, 1990.