Developing and implementing traffic-speed network level structural condition pavement surveys

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ABSTRACT: Traffic-speed surveys of surface condition have been implemented on the English Strategic Road Network since 2000 but, at the same time, slow speed structural condition surveys using the Deflectograph were discontinued on a routine basis and only employed on a project-level basis. In the meantime, TRL have been developing a methodology for assessing the structural strength of the network based on regular surveys carried out at traffic speed under funding from the UK Highways Agency. This methodology was first applied to the network in 2010 and is now an established part of the Highways Agency's pavement assessment strategy. This paper will describe the various stages of the development of such a strategy from the initial worldwide review of available techniques, the acquisition of the most promising prototype equipment, the development into a robust tool and the creation of an interim quick-win method of interpreting the measurements. Operational issues associated with obtaining such survey data and the necessary quality assurance procedures needed to ensure robust and reliable data will be discussed. The acquisition of both surface and structural condition now enables the Agency to manage the network more efficiently with a minimum of disruption from condition surveys. With further development of the equipment and its interpretation there is potential for even more efficient and less disruptive data collection.

KEY WORDS: Pavement, condition, structure, surveys, traffic-speed.

1 INTRODUCTION

In recent years, the volume of traffic carried by the English Strategic Road Network (SRN) has increased significantly. The UK Highways Agency (HA) Business Plan for 2004-2005 listed headline objectives to reduce congestion and improve road safety for both road users and persons undertaking highway maintenance. In order for these aims to be successfully fulfilled, it was necessary that the work on active highways be kept to a minimum. Hence there existed a need to facilitate the collection of condition and structural data for the strategic network at traffic-speed wherever possible.

Deflection measurements currently remain the only reliable non-destructive method for determining the structural strength of flexible and flexible-composite pavements. Although the introduction of the long-life pavement (LLP) concept in the UK has changed the way in which deflection results are interpreted, deflection still plays a fundamental role in classifying pavements as long-life, determinate, or potentially upgradeable to long-life, as well as in determining any structural strengthening that is required.

In the UK, pavement deflection measurements are currently undertaken by either the Deflectograph or the Falling Weight Deflectometer (FWD). Both these devices provide a stationary frame of reference relative to which the pavement deflections are measured. To-date, this approach has been the only one capable of achieving the required resolution and accuracy. However, they employ slow-moving or static measurement techniques that are expensive to operate and can be hazardous for operators and disruptive for road users. These limitations resulted in suspension of the Deflectograph for routine network-level assessment in 2000. Nevertheless, due to the importance of deflection measurement on treatment design, the Deflectograph together with the FWD, continue to be used for scheme, or project-level, pavement assessment.

In 2000 the HA instructed TRL to examine available technology for measuring deflection at traffic speed. As a result, in 2005 TRL, on behalf of the HA, identified the High Speed Deflectograph originally developed in Denmark by Greenwood Engineering A/S (Greenwood, 2008) as being capable of performing deflection surveys at traffic speed. TRL was then commissioned to procure and develop the High Speed Deflectograph (subsequently renamed as the Traffic Speed Deflectometer (TSD)) into a survey tool capable of providing routine estimates of structural condition of the UK strategic road network. This paper briefly describes the equipment and its evaluation under a range of operating conditions. This assessment resulted in modifications being made to the equipment and its operation. Finally, this report details the development of the TSD into a fully functioning research tool, the investigation into its applicability for routine surveys of the strategic road network, and the implementation of network surveys at traffic speed on the English Strategic Road Network (SRN), including a robust quality assurance system and a practical method of interpreting the measurements.

2 DESCRIPTION OF TRAFFIC SPEED DEFLECTOMETER

The TSD contains a complex array of instruments and recording equipment within an insulated steel container which is mounted on a single rear axle trailer assembly having a rear axle load of approximately 10 tonnes. The layout of the primary instrumentation is shown schematically in Figure 1. The basic functionality is designed to measure the pavement response under the rear wheels, in the nearside wheel-path, by using four Polytec OFV 503 Doppler vibrometer heads positioned on a rigid steel beam. The instruments measure velocity along the axis of the laser by exploiting the Doppler effect. All four laser sensors are connected to their own Polytec LSV6200 Velocimeter Controller units that process the signal and extract the velocity measurement from the frequency content of the reflected laser signal.

When the TSD was procured the three measurement lasers were located at the rear of the beam and measured pavement surface velocity at 100mm, 200mm and 300mm in front of the rear wheel assembly. In early 2008 the laser mounted in the 200mm position was moved to a position 750mm in front of the rear axle in order to better investigate the structural contribution from the lower pavement layers. In this paper the outputs from the lasers, in their initial positions, are referred to as P100, P200 and P300, respectively, or generically as Px. The fourth Doppler laser is located 3m in front of the rear axle and measures the pavement response (Pref) at a point that is designed to be relatively unaffected by the load applied by the trailer or tractor unit. Further details of the equipment and calibration issues are provided by Ferne et al. (2009 a and b).

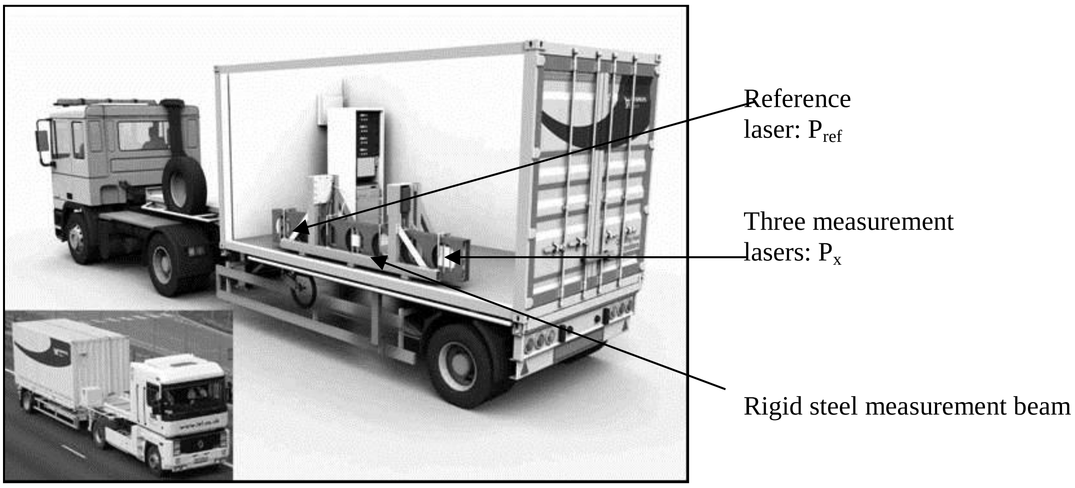

Figure 1: Cutaway of the HA TSD.

3 EVALUATION OF TSD PROTOTYPE AND DEVELOPMENT INTO ROBUST SURVEY TOOL

Following acceptance testing of the HA's TSD prototype in both Denmark and the UK the TRL carried out an extensive programme of evaluation of its capabilities and development into a tool suitable for routine surveys of the English Strategic Road network. The evaluation initially focused on the effect of operational conditions on the measurements. For example the effect of survey speed, temperature, road surface type, road geometry etc. On the basis of this assessment, modifications were made to the machine and acceptable operating conditions were defined to enable a programme of surveys to commence. In particular, repeatability testing of local routes suggested that the measurements were affected by not just the temperature of the road pavement but also the temperature of the equipment.

3.1 Effect of survey speed

Early surveys at nominal testing speeds of 60, 70 and 80km/h showed that although, in general, the TSD gave comparable results at these speeds the rate at which acceptable data was collected by the lasers, termed the data rate, significantly decreased at higher speeds contributing to excessive noise in the processed results. This decrease in data rate continued to give unsatisfactory results during the early months of 2007 and after discussions with Greenwood Engineering A/S, the manufacturers, they recommended that the TSD be returned to Denmark for modifications. These modifications included mounting the supports of the steel measurement beam, on which the lasers are fitted, immediately onto the chassis rather than onto the floor of the container.
The modifications made by Greenwood allowed the TSD to be operated satisfactorily at speeds up to 80 km/h. The relations between deflection slope and testing speed for three types of roadbase construction, recorded since these modifications, are shown in Figure 2.

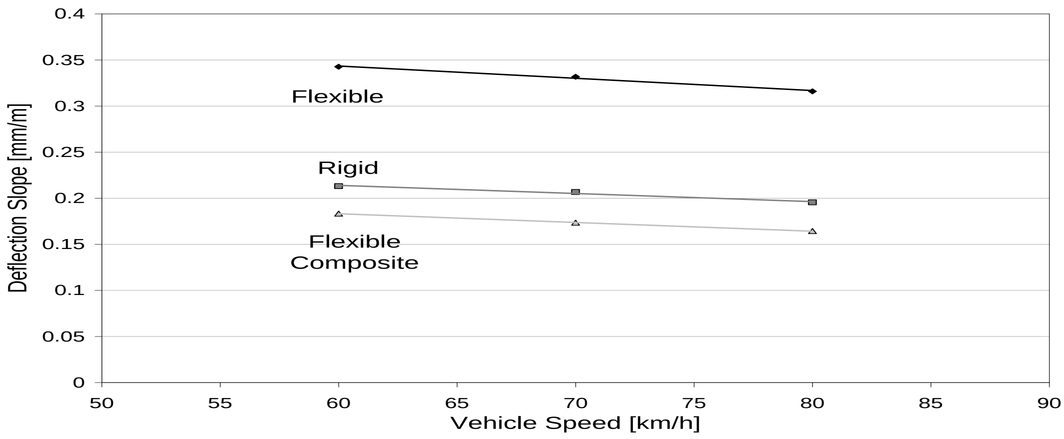

Figure 2: Effect of testing speed on deflection slope

Further repeat runs have been carried out with the HA TSD at different speeds. A small change with increasing speed has been shown but insufficient data has been so far collected to enable the development of a correction procedure to a reference speed. Figure 3 illustrates this by presenting the TSD P100 slope profiles as 10 m means for a 1.5 km section of flexible pavement at 60, 70 and 80 km/h.

An analysis of network TSD measurements, collected in the UK during 2010 and the early part of 2011 over a wide range of speeds, some outside the current recommended limits, is shown in

Figure 4 in the form of a distribution plot. This suggests a reduction in response with increasing speed but there are many other confounding effects present in this data so it can only be taken as an indication of the likely effect of survey speed. The figure shows a two dimensional version of a three-dimensional plot, in which the lines are contour lines containing given proportions of the total dataset. For example, 20% of the data was collected at speeds of around 61 km/h with slopes from 0.18 to 0.37 mm/m. The other concentration of data is just below 70 km/h. These were the two target speeds in the surveys but other speeds were covered for various practical reasons.

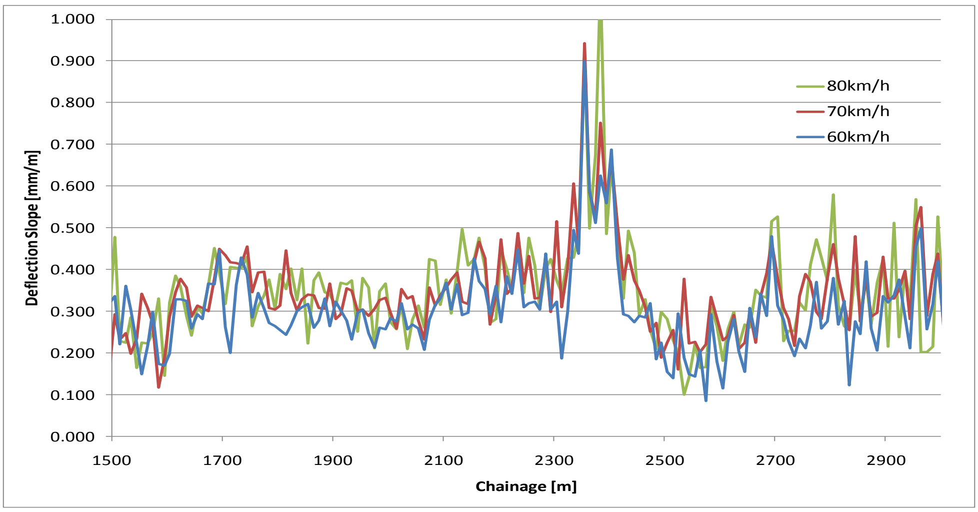

Figure 3: TSD slope profiles for 10 m means on a section of a UK road at various survey speeds

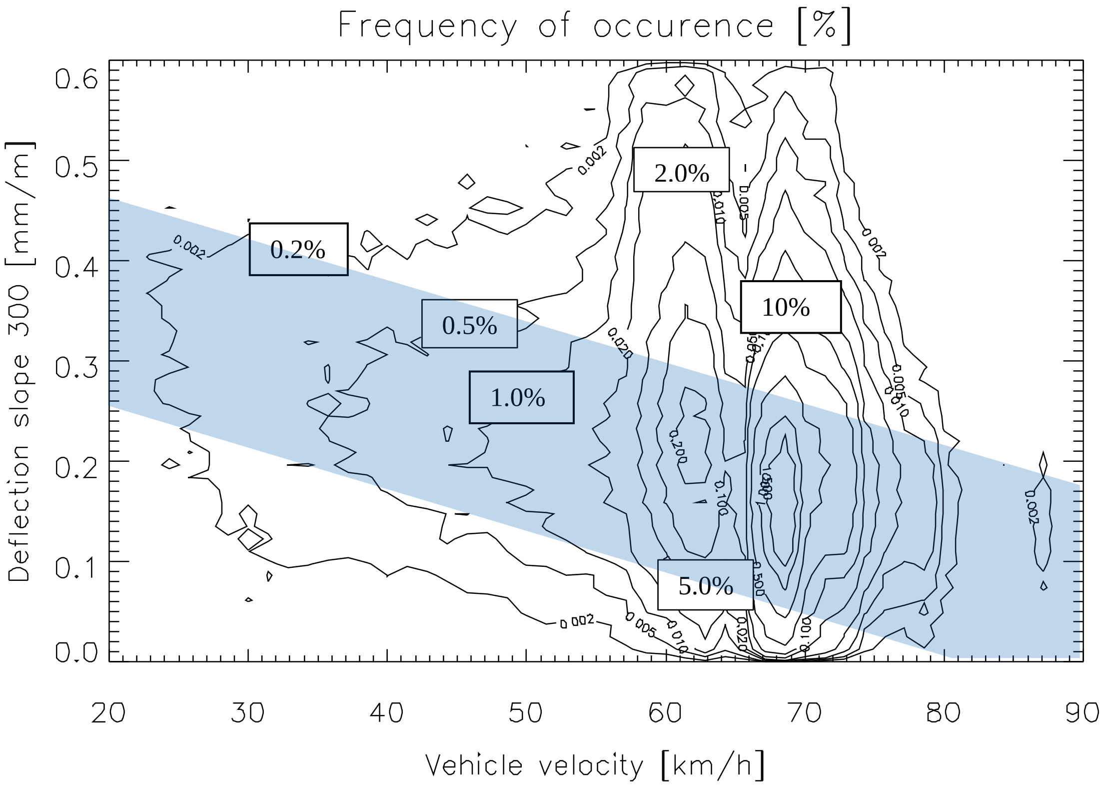

Figure 4: Effect of survey speed on TSD deflection slope

3.2 Effect of temperature

Since repeatability testing began in October 2006 it became apparent that temperature has an effect on the value of deflection slope recorded by the TSD, as might be expected for many pavement types. However, it was not entirely clear whether the temperature was affecting the response of the equipment or the road or both.

The testing first identified that at very low temperatures of the measurement beam, the data rate of the lasers decreased significantly, resulting in a commensurate drop in the value of deflection slope. It is believed that this effect was caused by the measurement beam acting as a ‘heat sink’ which was preventing the lasers reaching their correct operating temperature. Subsequent to this, repeatability testing was restricted to data collected when the temperature of the measurement beam was greater than 15^{o}C.

Despite this, the longer term variation in repeat testing, was still greater than had been anticipated. A more thorough investigation showed that as the lasers heated up they were causing temperature gradients, of over 4^{o}C, within the measurement beam itself, Figure 5a, as illustrated by infrared images of the measurement beam in Figure 5b. These temperature gradients were sufficient to cause the recorded differences in deflection slope by distorting the measurement beam.

In March 2008 the TSD was fitted with two fans which virtually eliminated the development of temperature gradients within the measurement beam, as illustrated by Figure 6b. At the same time the laser, originally mounted in the 200mm position, was moved to 750mm in front of the rear axle. More recently a full air conditioning system has been fitted as illustrated in Figure 6a.

Figure 5a: Measurement beam before fans fitted.

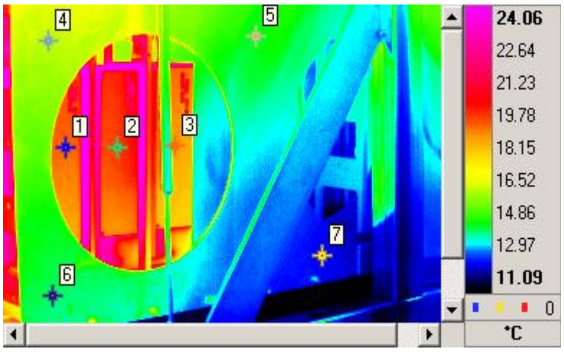

Figure 5b: Surface temperature of beam before fans fitted.

Figure 6a: Measurement beam after air conditioning fitted

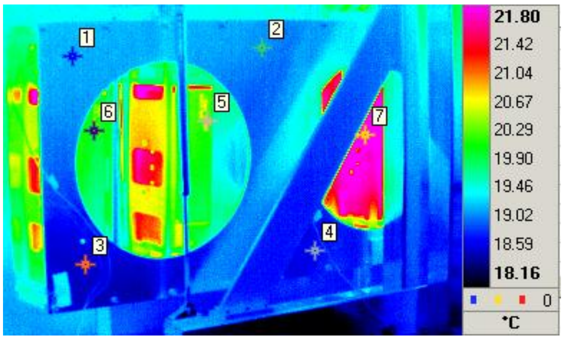

Fig 6b: Surface temperature of beam after fans fitted.

3.3 Other operating issues

The effect of other operating conditions, e.g. surface condition, surface type, road geometry, were investigated but found to have secondary effects. In order to implement routine network surveys as soon as possible it was agreed that standard operating procedures would be developed that enabled robust results to be obtained without the need for correction to standard operating conditions. In the longer term it is hoped that the accuracy and repeatability of the measurements can be improved by developing such correction procedures. Part of the standard operating procedures developed for the HA TSD included a robust quality assurance methodology. This included the definition of required primary (fortnightly) checks, secondary (weekly) checks and daily checks. Much of these checks involved the repeat surveys of established reference sites distributed around the English Strategic Road Network as shown in Figure 7.

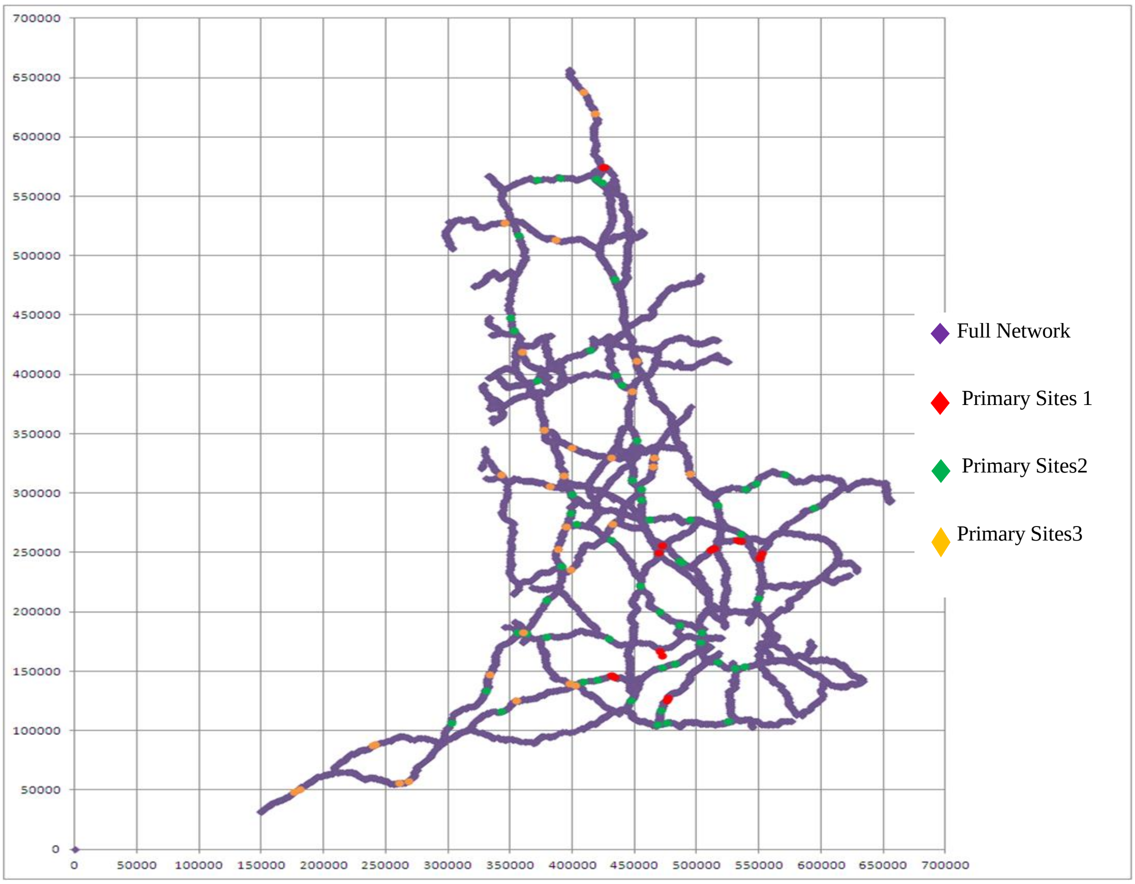

Fig 7: Location of primary reference sites on English SRN

4 INTERPRETATION OF TSD MEASUREMENTS

In order that the TSD can be used as an effective network survey assessment tool it is important that the data it provides is not only repeatable but also that it can be shown to relate to the structural performance of the pavement at a prescribed level of confidence. In the long term this will be done by directly relating TSD data to the performance of the UK strategic road network, however, in the short term this can be achieved by developing a simple relation between deflection slope, as measured by the TSD, and deflection, as measured by the UK Deflectograph. This has enabled the existing UK relation between Deflectograph deflection and residual life (UK Highways Agency, 2001 and 2008) to be used to estimate the structural condition of the road pavement.

There are a number of possible problems with this approach as it assumes that there is a single relation between Deflectograph deflection and the TSD slope for flexible pavements. This is obviously unlikely to be entirely true when the different types, thickness and condition of a range of flexible pavements are considered. However, the potential variability in the results can be reduced by determining a relationship for each construction type. The level of sub-classification will depend on the desired level of consistency for network level use.

In order to determine these relationships it is desirable to carry out the TSD and Deflectograph surveys at approximately the same time and hence limit any substantial real change in the structural strength of the pavement due to environmental conditions. Figure 8

illustrates the relationship for a 107 100m sites between characteristic peak Deflectograph deflections with deflection slopes measured 100mm in front of the rear axle of the TSD.
In order to make an early implementation of the results within the UK Highways Agency pavement management system (HAPMS) the results from any TSD surveys have been processed as follows. The analysis procedure uses an algorithm to convert each of the 1m TSD slopes to an estimated peak Deflectograph value. The procedure also uses the construction data held in HAPMS to determine the characteristic base type for each 100m length. The analysis procedure uses the estimated peak Deflectograph values together with the construction and traffic information to provide a measure of structural condition for each 100m length. These measures are then used to assign one of four levels of Network Structural Condition (NSC) category to each 100m reporting length using criteria that depend on the characteristic base type. The definition of each of the NSC categories is provided in Table 1.

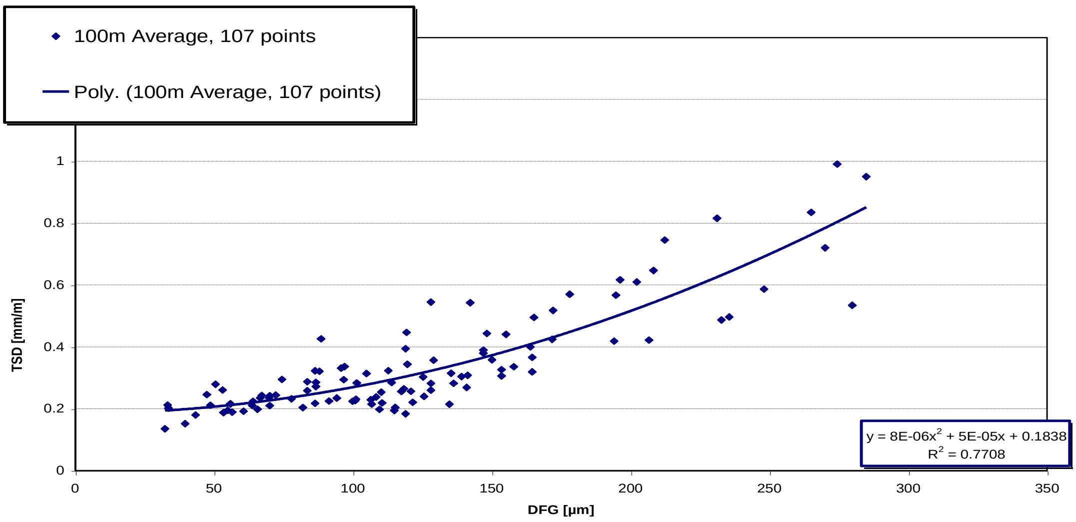

Figure 8: Relationship between Deflectograph peak deflections and TSD deflection slopes 100mm in front of the rear axle.

Table 1: UK Network Structural Condition categories

Category	Description
1	Flexible pavements without any need for structural maintenance
2	Flexible pavements unlikely to need structural maintenance
3	Flexible pavements likely to need structural maintenance
4	Flexible pavements very likely to need structural maintenance

5 IMPLEMENTATION ON ENGLISH STRATEGIC ROAD NETWORK

As a first stage, HA commissioned an implementation strategy study to explore the procurement options for future structural condition surveys of the English Strategic Road Network (SRN). The recommendations were for a phased approach to increase industry knowledge of the techniques enabling maximum use of the research vehicle for both routine and research surveys, in parallel, with a view to fully commercial surveys sometime in the future. The ultimate aim was to enable the phasing out of slow speed Deflectograph surveys by 2016 or soon after. At this stage the intention was that the TSD results should be used at network level to guide the level of additional investigations required at scheme or project level, not as a substitute for Deflectograph surveys which are currently only carried out for scheme level purposes on the SRN. As a consequence TRL was commissioned by HA to carry out and manage the first phase of TRAffic-speed Structural condition Surveys (TRASS) of the strategic road network, termed TRASS1. Prior to the start of the TRASS1 project, TRL was asked to carry out surveys of around 1000km of the hard shoulder on some of the English motorway network to inform strengthening requirements in anticipation of possible more frequent trafficking of these parts of the network. This work was carried out successfully during April to June of 2009 and provided valuable experience which influenced the vehicle modifications and the future operational procedures.

TRASS1 was carried out in three stages. Stage 1 comprised the preparation of TSD into a suitably robust form to carry out intensive routine surveys by commercial survey operators. It also required the development of software for routine survey processing and fitting to the road network, establishing standard operating procedures and providing a survey database and reporting capability. Stage 2 required a minimum of 5,000 lane km of surveys by TRL including the establishment of a quality assurance regime and suitable calibration sites. Finally Stage 3 involved the training and commissioning of two commercial survey contractors to each carry out up to 6000 lane km of surveys in two four month survey periods under a strict QA regime managed by TRL. In the event, between June 2010 and March 2011 a total length of 15,000 lane km was surveyed of which around 12,000 km were successfully validated. TRL carried out a further 3,500 lane km in the Autumn of 2011 and supervised a further 5500 lane km carried out by a third commercial survey contractor in early 2012. A summary of the survey coverage by the HA's TSD on the SRN is summarised in Table 2.

Table 2: Summary of TSD surveys on UK HA SRN

Year	Length of validated data (lane km.)	Length of unvalidated data (lane km)
2009	1,000	-
2010	11,000	-
2011	9,500	-
2012	5,500	-
Total	27,000	36,000

The results of the surveys have now been loaded into the Highways Agency's Pavement Management System and are available to the contractors managing the network, on the HA's behalf, in the form of one of four structural condition categories for each 100m length of the surveyed network, as described earlier in Section 5.

6 SUMMARY AND CONCLUSIONS

Following ten years of cooperative development routine network level traffic speed surveys of the structural condition of the flexible road pavements of a national road network are now being carried out and the results made available in a national database in the form of one of four different structural condition classifications for each 100m length. This is enabling more efficient management of the network, minimizing traffic disruption and improving road safety. Further development of the equipment should provide even more benefits when applied to all types of pavement at both network and project level

7 ACKNOWLEDGEMENTS

 This paper has been produced by TRL Limited as part of a contract placed by the Highways Agency. Any views expressed in it are not necessarily those of the Agency.

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