The use of LWD on granular bases and asphalt structures

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ABSTRACT: This paper covers the results of a study with the Light Weight Deflectometer (LWD) to determine a relationship between LWD deflection parameters and the degree of compaction of granular road foundations. The degree of compaction is the traditional quality control (QC) measure in the Netherlands for approval of these layers. The resulting relationship with the LWD as QC tool facilitates quicker assessment of the resistance to permanent deformation of unbound base courses. The paper also addresses the efforts made for finding relationships between the bearing capacity of a road foundation prior to overlaying by asphalt layers and the bearing capacity of the road foundation after one or more asphalt layers have been applied. The tool developed may be of use for verification whether the quality of work complies with the assumptions in the design phase.

KEY WORDS: Light Weight Deflectometer, degree of compaction, road foundation, performance based specifications, stress dependency.

1 INTRODUCTION

Traditionally, quality of road foundations in the Netherlands is verified by tests on gradation, density and degree of compaction. Assessment of stiffness does not form part of the quality approval (QA) procedure, although it is the most important parameter in mechanistic pavement design. Introduction of new aggregates and application of novel construction techniques, but most of all the changes in the relationship between commissioner and contractor, ask for a better fitting approach. Performance based specifications are a step in the direction to go.
Performance based specifications provide that long view, what goods and service are required, and not what materials are used and how they are produced. The goal is developing specifications that allow bidders to bring their individual expertise, creativity and resources to the bid process, without encumbering themselves with predetermined methods or detailed processes. Writing specifications from this point of view increases alternatives, attracting more potential bidders and fostering better competition. Performance based specification consists of several steps. Defining functional requirements in terms of availability or road safety is one of the first steps. This type of specifications however, can not be used for design and construction of a road. The requirements need to be expressed in technical terms, preferably at structure level and not at component level, such as bitumen content, gradation, etc. It is absolutely necessary, that the requirements are clearly specified, verifiable and measurable. The performance based specifications for road foundations in the Netherlands consist at measurable level the following specs [1]:

- layer thickness;
- roughness;
- resistance to fatigue (bound base courses only);
- stiffness;

- resistance to permanent deformation;
- resistance to cracking (bound base courses only);
- drainability.

Resistance to frost-thaw cycles and wet-dry cycles are assumed to be covered by the listed properties.

This paper focuses on resistance to permanent deformation and stiffness. Measurement of degree of compaction of granular road foundations is the most important QC/QA tool in the Netherlands. Several test methods are available to determine the degree of compaction, but all those tests partially require laboratory testing. This involves that results are not directly available. For a quick quality control, a faster method of assessment of the degree of compaction is urgently needed, preferably a method that can provide for answers in-situ. This paper presents the results of a study whether the LWD would be a feasible tool for this purpose.

Measurement of bearing capacity or stiffness modukus of a road foundation is no common procedure in the Netherlands. This might look a little awkward, since stiffness is the most important parameter in mechanistic pavement design procedures. The problem with assessment of stiffness of unbound granular aggregates is that the resilient behaviour is dependent on the applied stresses and the confinement of the overlying asphalt layers. This paper presents the findings of a study on how the LWD may be applied for verification to what extent the stiffness of the road foundation during construction phase complies with the design assumptions.

2 LIGHT WEIGHT DEFLECTOMETER

2.1 Device

The Light Weight Deflectometer (LWD) is a dynamic plate bearing test system for measuring the dynamic surface modulus of the subgrade/sub-base layers. It is highly portable and easily carried around a construction site. In this study the PRIMA100 produced by Grontmij|CarlBro was used. This device permits a variable drop height and drop weight, and incorporates both a load cell and a geophone (seismic velocity transducer) in immediate contact with the pavement construction layer through a centre hole in the loading plate. A foot plate of 300 mm was used. The load level was targeted to a contact stress level of 100 kPa by using the standard drop weight of 10 kg. The transient load pulse duration was aimed to vary between 16 and 20 ms.

2.2 Surface modulus

The foundation surface modulus used in this paper is the composite value of the stiffness value with contribution of all underlying layers [2]. The surface modulus is computed using the following formula:

$$E0 = \frac{S \cdot \left(1 - \nu^2\right) \cdot \sigma \cdot a}{d}$$

where	E0	=	surface modulus (MPa)
	S	=	plate rigidity factor (-)
	ν	=	Poisson's ratio (-)
	σ	=	contact stress (kPa)
	a	=	foot plate radius (m)
	d	=	peak value of centre deflection (mm)

In this case a plate rigidity factor of 2 was used (typical for a flexible plate) and a Poisson's ratio of 0.35.

3 DEGREE OF COMPACTION

3.1 Testing and parameters

Various construction sites were visited for collecting data on degree of compaction and deflection parameters by the LWD. The foundation of the sites varied form unbound granular aggregate, sand to recycled crushed asphalt with cement. Not all constituent layers were measured because not all sites were accessible at each stage.
Degree of density was measured by the core cutter method (in case of sand layer), gravel or sand replacement method or nuclear density gauge. Samples were taken and analysed in the laboratory for calculation of the moisture content and the dry density.

At each station of each site eight drops were used in LWD testing. The following parameters were used in the analysis of the data:

- foundation surface modulus at drop 3 ($E0_3$);
- foundation surface modulus at drop 8 ($E0_8$);
- difference between foundation surface moduli of drops 8 and 3 (ΔE0);
- proportional difference between foundation surface moduli of drops 8 and 3 (RE0);
- proportional difference between peak value of deflection and rebound deflection (Rd);
- area enclosed by load-deflection trace (A).

The parameters RE0 and Rd are calculated as follows:

$$RE0 = (E0_8 - E0_3)/E0_8$$

$$Rd = (d_{peak} - d_{rebound})/d_{peak}$$

The deflection parameters d_{peak}, $d_{rebound}$ and A are explained in Figure 1.

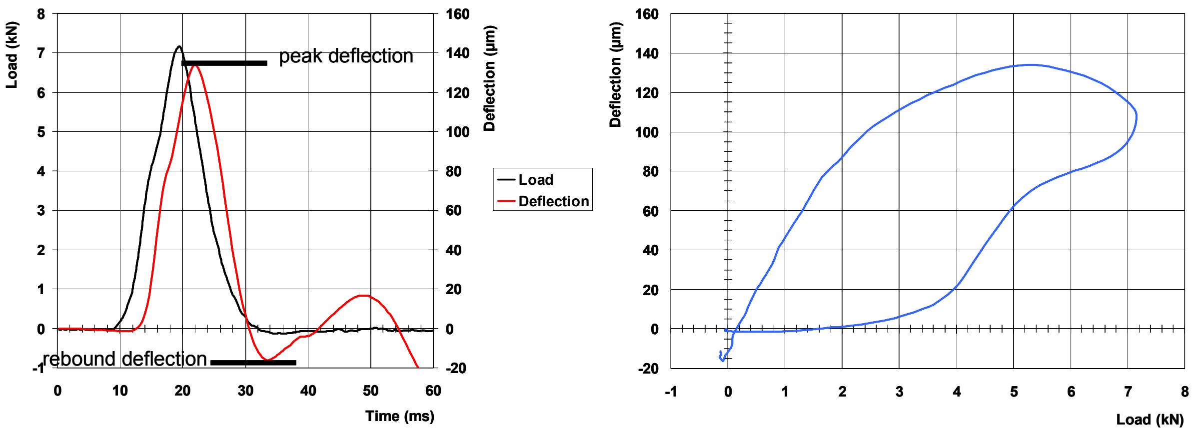

Figure 1 Definition deflection parameters

3.2 Hypothesis

The deflection parameters were selected because of the following hypotheses. Series of LWD drops generate post-compaction causing increasing foundation surface modulus with drop number. The higher the degree of compaction is, the smaller this increase will be. The area enclosed by the load deflection trace is a measure of permanent deformation. The more elastic the foundation responds to a LWD drop, the more the trace will follow a narrow band around the SW-NE diagonal. The more plastic or visco-elastic the foundation responds, the wider this band will be, the greater the surface area enclosed by the trace will be.
The shape of the deflection curve is a potential indicator of testing issues [3]. Moisture content but also the contact between the foot plate and the test structure are important when assessing the data quality. In normal situations the rebound deflection will be zero. A negative rebound deflection is

commonly seen when testing bound materials (when peak value of deflection is defined as positive). Positive rebound deflections may be an indicator of poor compaction.

Therefore, the following patterns were expected to be found with decreasing degree of compaction:
- increasing value of parameter RE0;
- decreasing value of parameter Rd;
- increasing value of parameter A.

3.3 Influence of weather and moisture

Experience with LWD test results had revealed that weather conditions of the previous days might have their effect on the measured foundation surface modulus. Foundation surface moduli on well compacted road bases appeared to be lower when tested at a day after rainfall than at a day with dry periods prior to testing. More testing was performed whether this effect could be neglected or not. Figure 2 displays the LWD test results on an approximately one year old mixed granulate foundation. The differences in average foundation surface modulus are limited to a few percent, reason to ignore weather conditions in testing and analysis of the data.

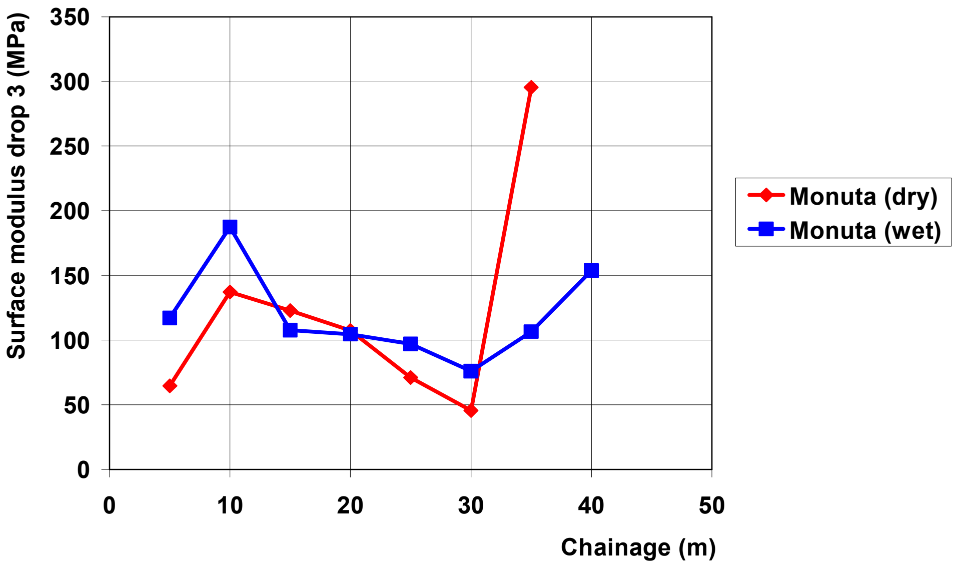

Figure 2 Influence of weather condition on foundation surface modulus

3.4 Test and analysis results

Figure 3 and Figure 4 present some results from the analysis of the data. The two graphs clearly show that the hypotheses may be accepted for the lower tail of the degree of compaction values. A less clear relationship may be observed in the range where degrees of compaction usually vary. It was expected that other variables and parameters might have a co-effect on the relationship.

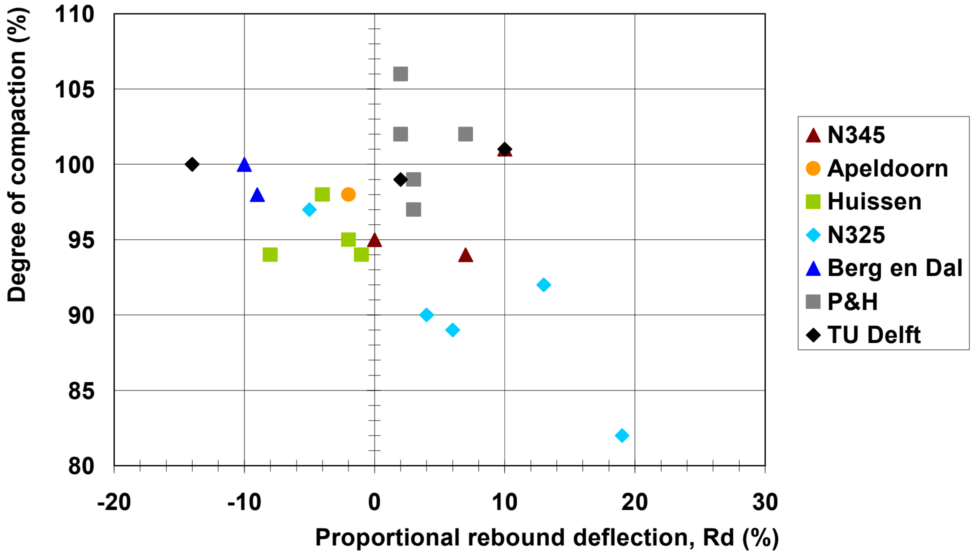

Figure 3 Relationship between proportional rebound deflection and degree of compaction

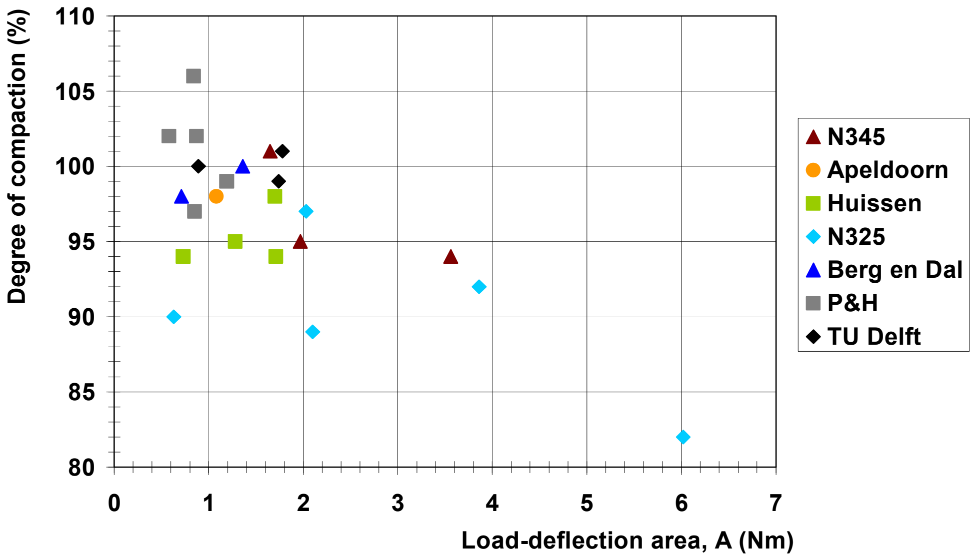

Figure 4 Relationship between load-deflection area and degree of compaction

The previously mentioned deflection parameters were used as input variables in a linear regression analysis for developing an LWD-based equation for prediction of the degree of compaction of granular road bases and sand sub-bases. The outlying low value of degree of compaction was omitted from analysis. Figure 5 shows the accuracy of the predictive equation.

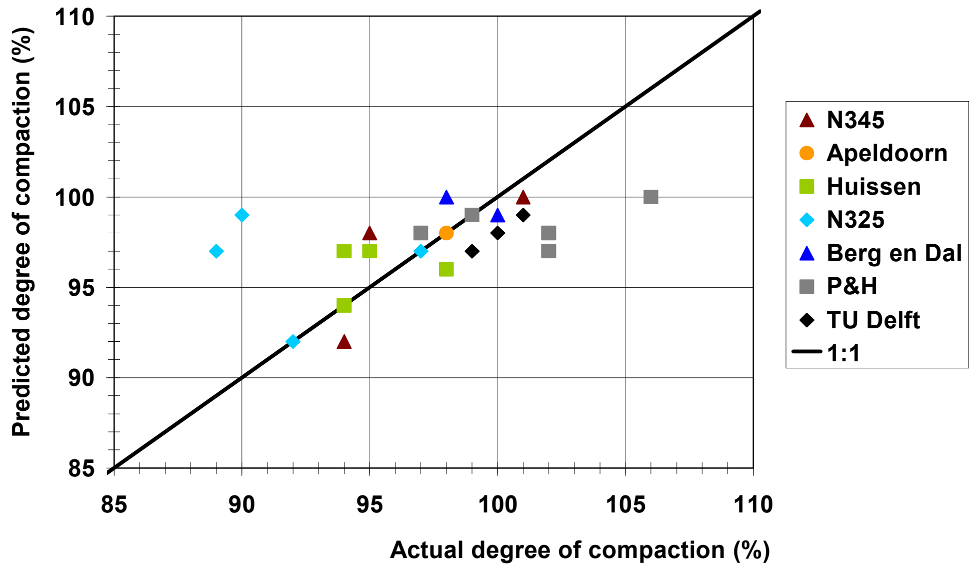

Figure 5 Accuracy of LWD prediction of degree of compaction

The graph clearly shows that the variables used in the equation and/or the model are not discriminative enough for an accurate prediction of the degree of compaction. Presumably more information from the tail of the deflection pulse might provide improvement.

4 VERIFICATION OF DESIGN VALUE OF FOUNDATION STIFFNESS

4.1 Pavement design

For pavement design purposes, estimated values of the stiffness moduli of the constituent layers are needed. These values can be estimated from laboratory of field experiments. Table 1 presents an example of a pavement design of a not too heavily trafficked road.

Table 1 Example of pavement design

Material	Layer thickness (mm)	Stiffness modulus (MPa)
Asphalt	140	7500
Unbound granular base	300	400
Subgrade	infinite	100

A commonly used procedure of verification of the design is Falling Weight Deflection testing after constructions works on the road have been completed. A problem will arise when the backcalculated stiffness moduli will not comply with the design values, certainly when the design life will not be met. It would have been much nicer when verification during construction would have been performed and pointed at layers to be improved or to be redesigned.
This issue sounds easier, than it is. If pavement materials would exhibit a linear elastic behaviour, testing of the stiffness modulus might be performed in any construction stage. Unfortunately, most granular layers and cohesive soils are stress dependent, involving that stiffness modulus will change with vertical pressure and level of confinement. In the linear elastic case, the foundation surface modulus of the example presented in Table 1 would have been 150 MPa, when using the centre deflection as equivalency criterion. this means that the example pavement structure and a structure with a 140 mm thick asphalt layer with stiffness modulus of 7500 MPa, resting on a composite foundation with stiffness modulus 150 MPa, both have the same centre deflection. In reality, the overburden of the asphalt layer will hamper this easy way of conversion and verification.

4.2 Model development

A few projects with asphalt pavements under construction and a site with various thicknesses of asphalt layers were used for development of a model that would facilitate adjustment of the foundation surface modulus for thickness of the overlying asphalt. The asphalt thicknesses varied between 140 mm and 300 mm. Both LWD and FWD were used for this purpose. The FWD was used to enable backcalculation of the stiffness moduli.

In a first step surface moduli derived from LWD and FWD data were compared pairwise to see whether and how conversion from one device to another device should be arranged. Figure 6 shows that the LWD produces the same surface moduli as the FWD. Most of the testing was performed at the top of the asphalt layer. When comparing LWD and FWD foundation surface moduli, the data points are sometimes not positioned on the line of equality.

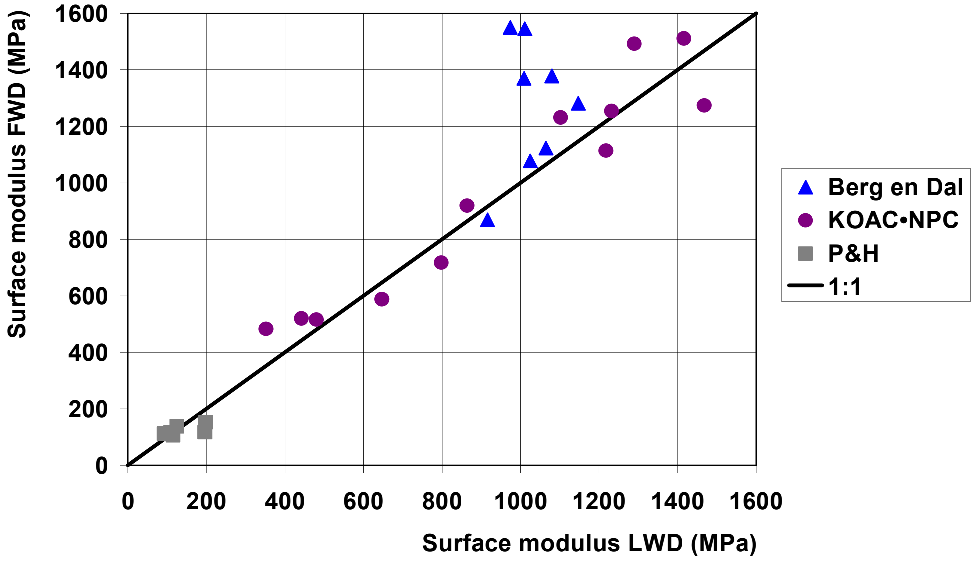

Figure 6 Relationship versus LWD and FWD generated surface moduli

In the analysis the layer moduli were backcalculated using the FWD deflections as input. In a next step the foundation surface modulus was computed while keeping the asphalt stiffness modulus at the backcalculated value and the centre deflection at the measured value. The LWD was used to determine the foundation surface modulus directly on the foundation. Per site and per asphalt layer thickness the difference was calculated between the foundation surface modulus with an overlying asphalt layer and the foundation surface modulus without any overburden. This difference is displayed in Figure 7 as a function of the asphalt layer thickness. The graph evidently shows that the increase of foundation surface modulus can be predicted from the thickness of the asphalt layer.

No sufficient data was available to investigate whether the increase of foundation surface modulus is controlled by the thickness of the asphalt layer only or that other factors such as asphalt stiffness and characteristics of the subgrade and road base might have their influence as well.

Since only a few days passed per site between the test rounds on the various asphalt pavement structures, self hardening of the mixed granulate road bases was expected to be of minor importance. This phenomenon will have more effect when several months elapse since the first round of deflection testing.

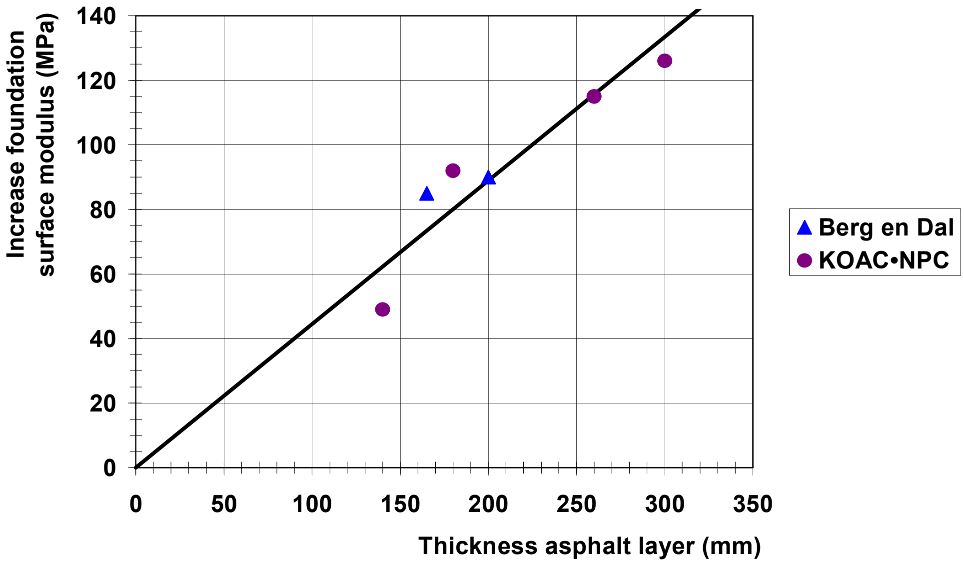

Figure 7 Increase of foundation surface modulus with asphalt layer thickness

The slope of the graph depicted in Figure 7 is 0.44 MPa per millimetre asphalt thickness. This means that the foundation surface modulus measured at the top of the foundation will increase by 0.44 MPa for each millimetre of asphalt. In the example of Table 1, the foundation surface modulus of the designed pavement structure was calculated to be 150 MPa. Since the asphalt layer thickness was 140 mm, the foundation surface modulus without the overlying asphalt should be 150 - 0.44 x 140 = 88.4 MPa. This value should be complied with when verification or quality control activities were performed during construction. The approach may also be used between various asphalt shifts.

5 CONCLUSIONS AND RECOMMENDATIONS

The Light Weight Deflectometer appears to be a practicable tool for structural assessment of a pavement structure during construction.

Using multiple drops in a LWD test procedure provides data for estimation of the degree of compaction of a road foundation. More research is needed for improvement of the predictive accuracy. Especially detailed analysis of the tail of the deflection pulse is recommended.

Stiffness modulus of granular road bases is dependent on the imparted vertical stress due to transient loading and the overburden of overlying layers but also on the level of confinement. From LWD and FWD testing can be concluded, that the increase in road foundation surface modulus, i.e. the composite value of the stiffness moduli of all underlying layers, can be estimated from the thickness of the overlying asphalt layer. This relationship may be used to verify whether the work under construction complies with the stiffness moduli used in the design phase.

6 REFERENCES

1 Guidelines Performance based Specifications Road Bases (Richtlijn functionele eisen wegfunderingen). Publication 205. CROW. Ede, October 2004.
2 Design Guidance for Road Pavement Foundations (Draft HD25). Interim Advice Note 73/06 Revision 1. February 2009.
3 Lambert, J.P., Novel Assessment Test for Granular Road Foundation Materials. PhD thesis. Loughborough University. Loughborough, United Kingdom, March 2007.