**The following papers received awards at the Southern African Transport Conference**
that was held at the CSIR from 7 to 10 July 2014

**WINNER (PAVEMENT ENGINEERING)**
E van Aswegen and W J vd M Steyn
*Statistical modelling of the resilient behaviour of unbound granular material*

**COMMENDATIONS (PAVEMENT ENGINEERING)**
S Wilkinson, A Visser, T Henning, C Bennett, A Faiz
*Introducing Otta Seals for low volume roads in Tonga*

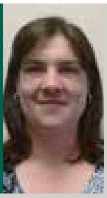
K Jenkins, M van de Ven, AH Greyling, B Constable, S Abrahams, A Stander, LR Lombard
*Binder adhesion testing using the bitumen bond strength test: State of the art*

**WINNER (TRAFFIC AND TRANSPORT ENGINEERING)**
C Venter and S Mohammed
*Estimating car ownership and transport energy consumption: A disaggregate study in Nelson Mandela Bay*

**COMMENDATIONS (TRAFFIC AND TRANSPORT ENGINEERING)**
C Venter
*The lurch towards formalisation: Lessons from the implementation of BRT in Johannesburg, South Africa*

C Venter and J Joubert
*Using multi-source GPS data to characterise multiday driving patterns and fuel use in a large city region*

# Statistical modelling of the resilient behaviour of unbound granular material



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This is a shortened version of the winning paper (pavement engineering) that was presented at the 2014 Southern African Transport Conference in July this year (see box above).

## OVERVIEW

The resilient behaviour of an unsaturated, unbound granular material is a primary input used in the mechanistic analysis of pavements incorporating such layers. Various models exist for the determination of the resilient behaviour, mainly based on the output of tri-axial laboratory testing. In a paper published in the *Slovak Journal of Civil Engineering* (Van Aswegen & Steyn 2013) an investigation is presented where basic engineering properties, such as grading, laboratory compaction characteristics and optimum moisture content, are incorporated into the resilient behaviour model to quantify the effect of basic material properties on the resilient response of unsaturated, unbound granular materials. Such a resilient behaviour model will enable practitioners to estimate the behaviour of specific material, which might enable the use of available quality material that was discarded in the past.

Data from tri-axial laboratory tests on materials originating from the Long-Term Pavement Performance test sections are combined with basic engineering parameters of typical unbound granular material through a statistical modelling process to develop a model for predicting resilient behaviour, which can be used as a practical predictor of the expected behaviour during a Level 2 and/or Level 3 Mechanistic Empirical Pavement Design analysis. The work illustrates the process and the potential to develop a general resilient behaviour model for unbound granular materials incorporating saturation effects.

## INTRODUCTION

The resilient modulus ($M_R$) is commonly used to characterise the behaviour of unsaturated, unbound granular material under repeatedly applied traffic loading. However, $M_R$ is not constant, and parameters such as stress level, density, moisture content and the number of load repetitions, to name a few, all influence the resilient behaviour of unbound granular material. Numerous models have been developed to approximate the behaviour of unsaturated, unbound granular material, mainly based on constitutive laws and correlations with other properties. The Mechanistic-Empirical Pavement Design Guide (MEPDG) recognises the influence of material and environmental factors on $M_R$ through the incorporation of the

Enhanced Integrated Climate Model (EICM) to model environmental effects on pavement layers. MEPDG adopted a hierarchical approach to designing the inputs, which aims to give the designer more flexibility in obtaining design inputs for a project based on the criticality of the project and available resources. The hierarchical approach is applied to traffic, materials and environmental inputs. In general, Level 1 inputs provide for the highest level of accuracy and thus would have the lowest level of uncertainty or error. Level 2 inputs provide an intermediate level of accuracy and typically would be user-selected, possibly from a database, could be derived from a limited testing programme, or could be estimated through correlations. Level 3 inputs provide the lowest level of accuracy.

For $M_R$ calculations at Level 1, MEPDG refers the designer to a constitutive equation that relates $M_R$ to bulk stress, octahedral shear stress, and atmospheric pressure at any given location within the pavement. Input Levels 2 and 3 do not consider stress sensitivity. At Level 2, the designer estimates $M_R$ at a reference moisture condition which is determined near at or near the optimum moisture content and maximum dry density. For input Level 3, an estimate of the $M_R$ is sufficient. To contextualise the MEPDG's hierarchical approach and the incorporation of environmental and material factors for South Africa, an initial investigation was done to develop Level 2 and/or Level 3 $M_R$ correlations through statistical distributions.

## INITIAL STUDY INTO STATISTICAL DISTRIBUTIONS

An initial study, which was a precursor to a more in-depth investigation, was conducted to predict the resilient behaviour based on the basic engineering properties of the material. The process is based on a statistical evaluation of the measured resilient behaviour and measured basic engineering properties of a range of materials. The measured $M_R$ tri-axial test data and basic engineering properties from the Long-Term Pavement Performance (LTPP) project database were evaluated. Only unbound granular material data was included in the data set. Two data sets of the $M_R$ tri-axial test data and basic engineering properties of the South African (SA) material were included. These samples were tested over a wider range of

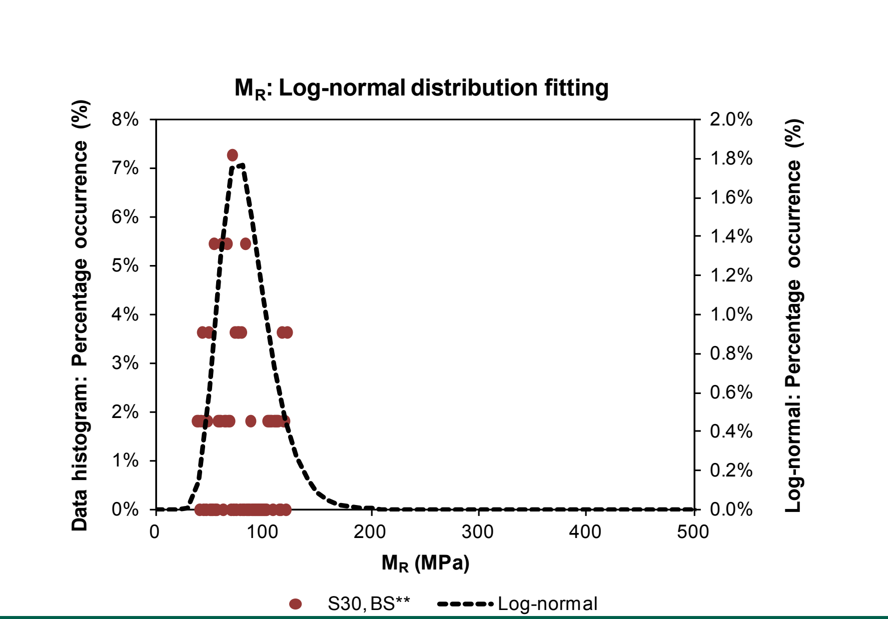



Figure 1: Log-normal distributions obtained from the statistical parameter equations

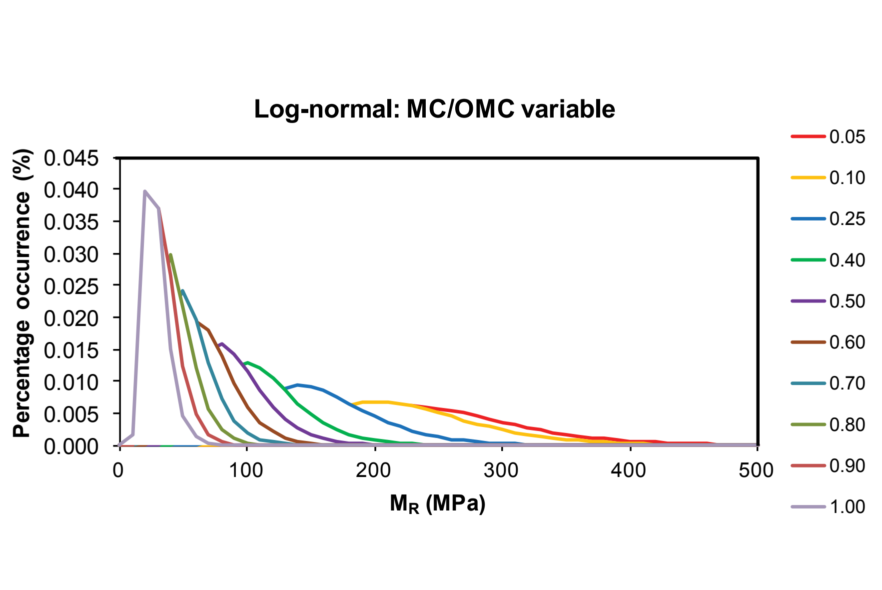
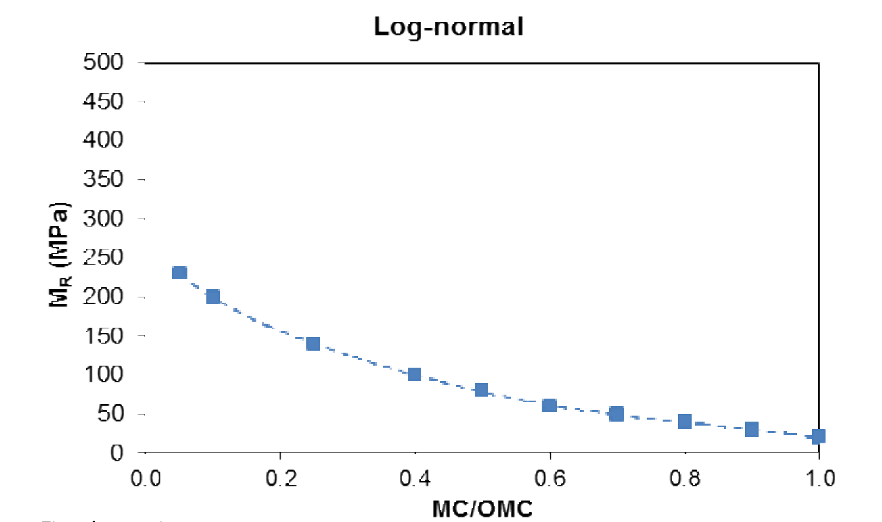



Figure 2: Family of Log-normal distributions when MC/OMC ratio is varied




Fitted equation:
$y = 1908x^6 - 6994.4x^5 + 9993.6x^4 - 7188.7x^3 + 2979.1x^2 - 948.75x + 271$
$R^2 = 0.9999$

Figure 3: $M_R$ versus MC/OMC relationship for a specific material

density level and moisture content than the LTPP data, which resulted in a wider range of measured $M_R$ values.

The measured resilient behaviour was evaluated to determine which statistical distribution best fits the resilient behaviour, using a Kolmogorov-Smirnov (K-S) process. Weibull and Log-normal distributions were selected, because these distributions only allow non-negative outputs, as would be expected for the resilient behaviour of an unbound granular material. The parameters of the statistical distributions were analysed to develop equations that can be used to generate the statistical parameters for the Weibull and Log-normal distributions by using the basic engineering properties of a material as input.

To test the equations developed in the previous section, the measured resilient behaviour and basic engineering properties from the two materials also obtained from the LTPP database (but excluded from the development database) were evaluated. The Log-normal distribution obtained from the input equations is shown in Figure 1. A parametric study was also conducted to determine how the various basic engineering properties affect the resilient behaviour.

## DEVELOPMENT OF A FAMILY OF DISTRIBUTIONS PREDICTING $M_R$

Using the developed equations and applying it to a material with a GM of 1.2, $P_{max}$ of 26.5 mm, $P_{0.425}$ of 65%, MDD of 1 880 kg/$m_3$, and varying the MC/OMC ratio between 0.05 and 1, a family of distributions can be generated estimating the $M_R$ obtainable at each MC/OMC ratio (Figure 2).

When the $M_R$ estimated in Figure 2 by the Log-normal distribution at each MC/OMC ratio is evaluated as indicated in Figure 3, a graph is generated from which the $M_R$ can be estimated for that material, given the specific MDD used as input. Previously in South Africa, $M_R$ values had to be determined through tri-axial testing (Level 1) or through the use of tables containing upper and lower $M_R$ limits for a specific material classification, taking into account a wet or dry condition (Level 2 and/or 3). If a family of distributions can be generated to be summarised in a graph such as Figure 3 for any material of which the basic engineering properties are known, a better estimation of the $M_R$ value can be made by incorporating the basic material properties for that specific material.

## CONCLUSION AND RECOMMENDATIONS

This initial investigation showed that the Weibull and/or Log-normal statistical distributions can be used to estimate realistic $M_R$ values for a material. The investigation focused on LTPP data obtained from the LTPP database. A broader database incorporating South African materials data will be used to expand the applicability of the approach and develop equations for South African conditions.

## REFERENCE

Van Aswegen, E & Steyn, W J vd M 2013. Statistical Modelling of Resilient Behaviour of Unbound Granular Material. *Slovak Journal of Civil Engineering*, XXI (1): 9–16. Bratislavia, Slovakia. ISSN 1210-3896.