Heavy Vehicle Simulator and laboratory testing of a light pavement structure for low-volume roads

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Abstract

Developing countries such as South Africa have an urgent need to create road infrastructure for rural access and urban mobility. Many of these roads will operate under low traffic volumes and only require a sealed, light pavement structure. Conventional material selection criteria often prevent the use of materials that may have sufficient stiffness and strength to provide good performance. This paper presents full-scale accelerated test and laboratory results from a study done on such a light pavement structure with a marginal base layer material. Two accelerated tests were done with a Heavy Vehicle Simulator (HVS) and the pavement and base layer performed well during these tests. The good performance of the test sections is supported by the better than expected mechanical properties of the material obtained from laboratory testing. The results show that conventional material selection criteria may be too strict for application to low volume roads and that performance related properties should be tested on a project by project basis.

Introduction

The Road Infrastructure Strategic Framework for South Africa (NDoT, 2002) identified the provision of basic road infrastructure for rural access and urban mobility as one of the major challenges to the road infrastructure sector in South Africa. This infrastructure needs to be provided at an affordable cost and in a socially and environmentally responsible manner.

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Although not a new concept, (Maree, 1982) the upgrading of existing gravel roads to a paved standard with limited improvements to the pavement structure offers one affordable option for the provision of rural access roads. The quality of the base layer material on these existing gravel roads do not necessarily meet the minimum requirements (CSRA, 1984) for use in the base layer of the upgraded, light pavement structure if conventional criteria are applied. The upgrading also normally includes the application of only a surface treatment for sealing the pavement and Steyn et al (1998) found that the surfacing layer often determines the life of this type of pavement structure.

The light pavement structure of Road 538 in the Western Cape which was upgraded from an existing gravel road, presented an ideal opportunity to asses:

- The use of a marginal material in the base layer of the sealed, light pavement structure; and
- The performance of a single surface treatment under accelerated loading conditions.

The focus of this paper is on selected results from a comprehensive laboratory study and Accelerated Pavement Testing (APT) using the Heavy Vehicle Simulator. A full report on the study is available elsewhere (Theyse, 2004).

Test pavement and material information

Figure 1 shows the nominal pavement structure of Road 538 after upgrading to a paved standard. The subbase (original gravel wearing course) consists of residual quartzitic sandstone fragments in a matrix of residual and windblown quartzitic sand. There is a small proportion of fine binder consisting primarily of quartz with a small amount of calcite, which appears to be self-cementing to a degree. A simple qualitative test indicated that there is no phosphate, indicating that the material was essentially a residual soil. This has become compacted and slightly self-cemented during use as an unsealed road. The base material is also primarily quartzitic sandstone in a fine quartz and calcite matrix. The material has been derived from limited crushing of residual gravel derived from the Table Mountain Group sandstones in the area.

The engineering properties of the pavement materials are summarised in Table 1. The base layer material did not satisfy the grading and CBR requirements (CSRA, 1984) to be classified as a G4 material and the material was hence classified as a G6 material based on CBR. Figure 2 shows the CBR data for the base layer material and the minimum CBR requirement for G6 to G4 material at the relevant densities.

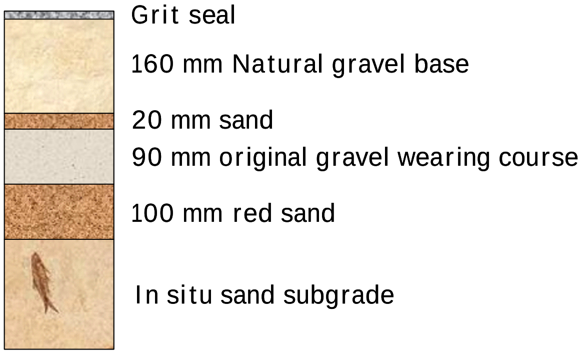

Figure 1. Nominal pavement structure of Road 538 after upgrading.

Table 1. Engineering properties of the material from the main pavement layers on Road 538

Engineering properties		Pavement layer			
		Base	Subbase	Imported Sand	In situ sand
Grading Modulus (GM)		2.101	1.422	1.179	1.030
Liquid Limit (LL)		17	SP	NP	NP
Plastic Limit (PL)		14	-	-	-
Plasticity Index (PI)		3	-	-	-
Bar Linear Shrinkage (BLS)		2	0.6	0	0
Apparent Relative Density (ARD)		2.627	2.652	2.611	2.650
Bulk Relative Density (ARD)		2.535	2.517	2.552	2.629
Water absorption (%)		1.23	1.96	1.25	0.3
Mod. AASHTO maximum Dry Density, mDD (kg/m^3)		2198	2078		
Optimum Moisture Content, OMC (%)		7.6	8.3		
CBR (%) at density relative to mod. AASHTO maximum dry density	100	72			
	98	57			
	95	33			

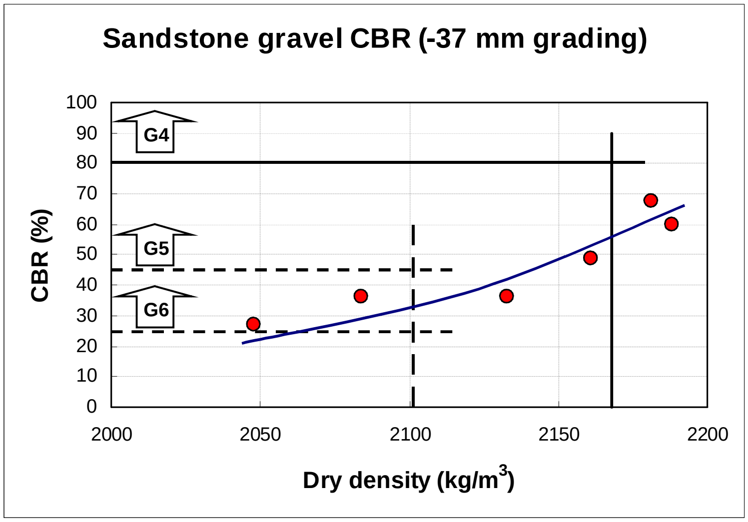

Figure 2. CBR data of the base layer material.

HVS tests results

The first light pavement section on Road 538 (419A5) was tested over a three week period from mid July 2003 to end July 2003 and the second section (420A5) was tested from the beginning of August 2003 to early October 2003. Relatively low moisture contents existed in the pavement layers but field moisture content data showed that the moisture collected in the red sand layer below the subbase layer. Both test programmes consisted of an initial 40 kN; 620 kPa load cycle followed by an 80 kN; 820 kPa load cycle up to the end of each test. The test programmes are summarised in Table 2.

Table 2. Summarised test programmes for HVS tests 419A5 and 420A5

		Trafficking wheel-load and tyre pressure			
		Dry Conditions		Wet conditions	
		40 kN 620 kPa	80 kN 820 kPa	40 kN 620 kPa	80 kN 820 kPa
Test section	419A5	0 to 15 268	15 268 to 310 000		
	420A5	0 to 400 000		400 000 to 1 040 903	1 040 903 to 1 099 400

Both sections were in an excellent condition after completion of the test. No cracks were visible and the rutting was minimal. The surface was fairly uneven with small depressions occurring at regular intervals. These depressions may result in water ponds on the surface during rain and if the seal is broken, potholes may develop. Figures 3 and 4 summarise the surface deflection and rut data for the two test sections.

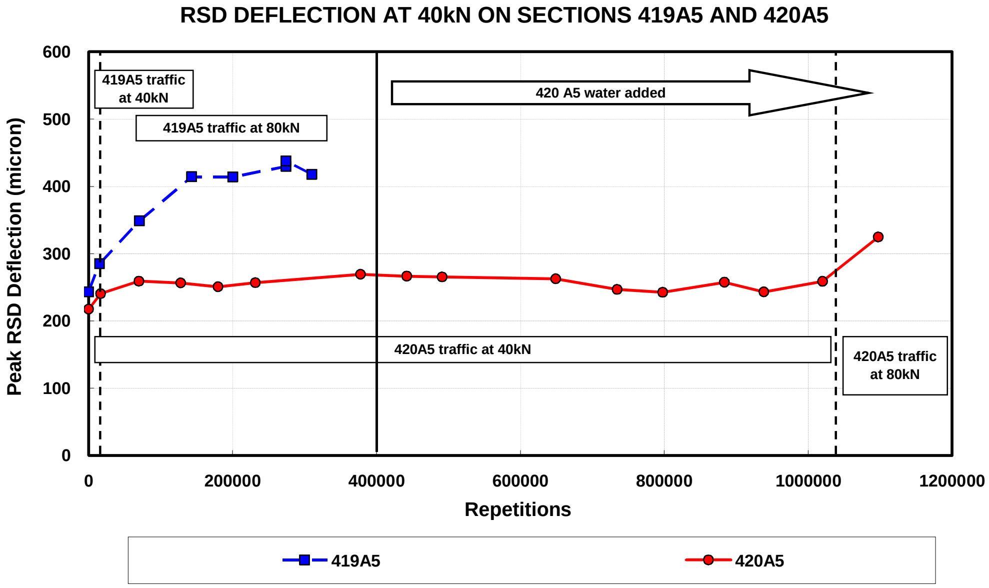

Figure 3. Surface deflection recorded during the HVS tests.

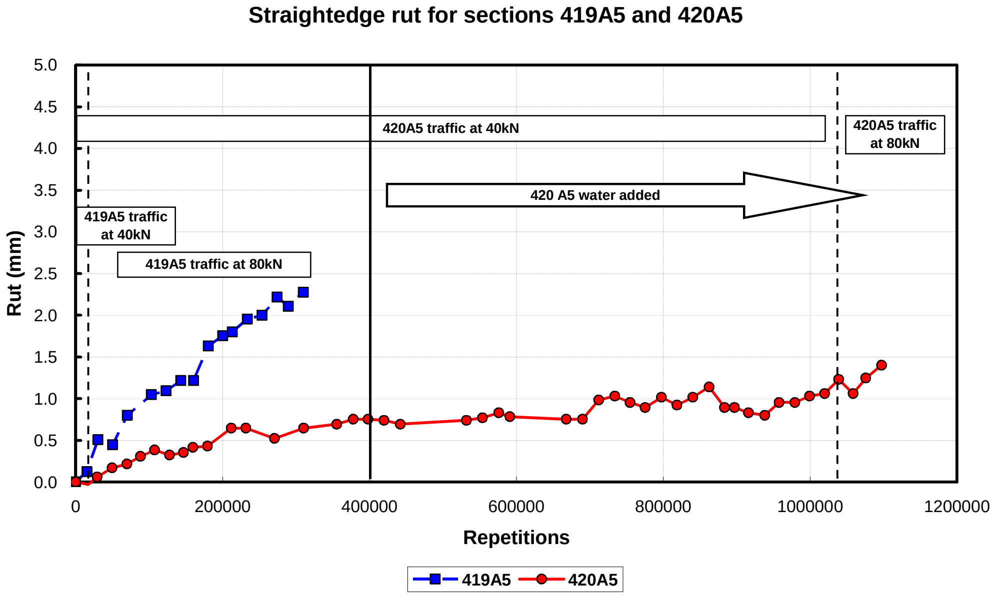

Figure 4. Surface rut recorded during the HVS tests.

The rut on section 420A5 was only 1.5 mm after 400 000 repetitions at 40 kN in the dry and 600 000 repetitions at 40 kN under wet conditions. This far exceeds the structural capacity required from such light pavement structures on low volume roads. Figure 5 shows the base layer resilient modulus back-calculated from multi-depth deflectometer data for the duration of test 419A5 and Figure 6 shows these results for test 420 A5. The resilient modulus of the base layer is well above the values that would normally be used (Theyse and Muthen, 2000) for a material with the same classification as that of the sandstone gravel from Road 538.

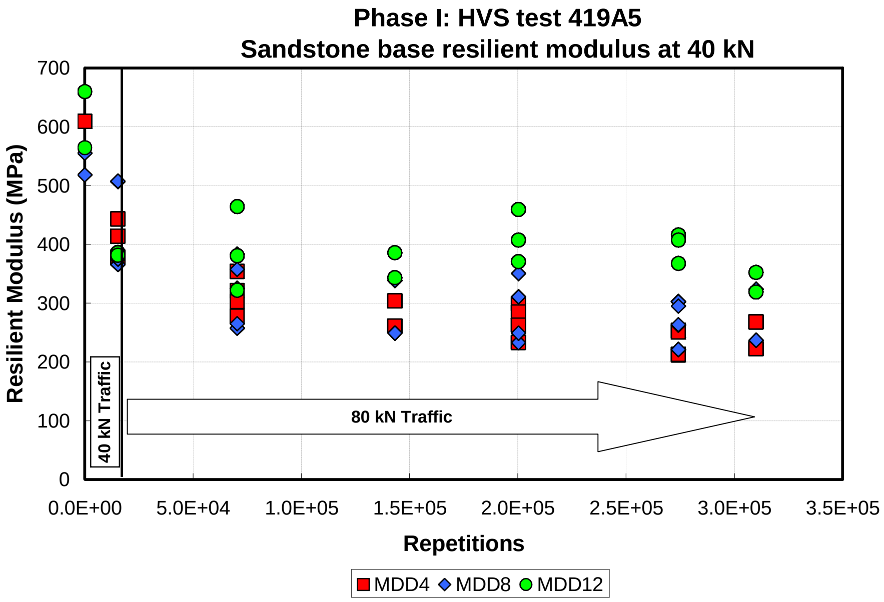

Figure 5. Base layer resilient modulus for test 419A5.

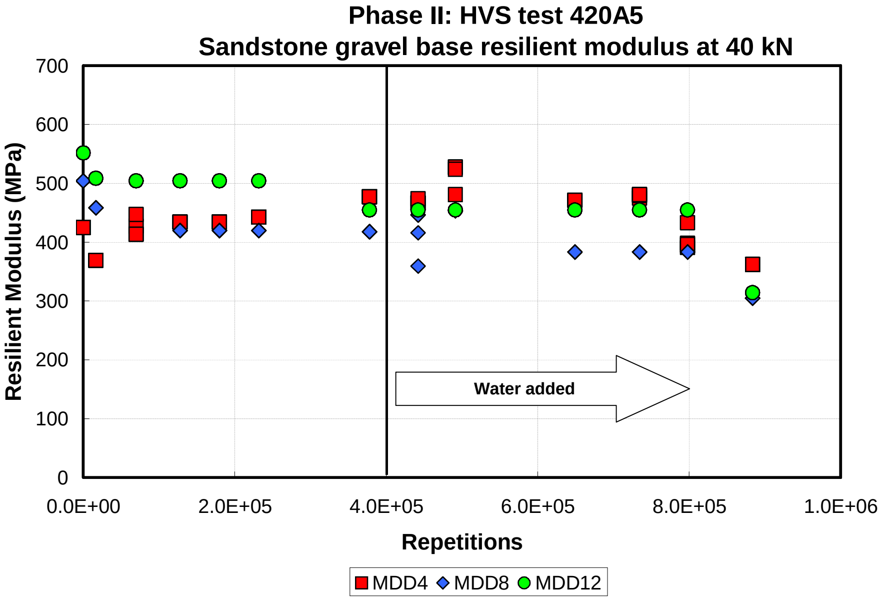

Figure 6. Base layer resilient modulus for test 420A5.

Laboratory tests results

Comprehensive laboratory tests were done in addition to the standard laboratory and HVS tests reported on in the preceding sections. These tests included static and dynamic tri-axial tests. The static tri-axial test results indicated that the sandstone gravel had a friction angle (ϕ) of between 46° and 49° and cohesion (C) between 126 and 170 kPa for dry density (2200 kg/m^3) and moisture content (2 to 4 per cent) conditions representative of that of the conditions during the HVS tests. This is well in excess of the values (ϕ = 37° and C = 27 kPa) recommended by the South African Mechanistic-Empirical Design Method (Theyse and Muthen, 2000) for a G6 type of material.

Figure 7 shows a summary of the resilient modulus results derived from the dynamic tri-axial data at different combinations of high and low density levels (HD and LD) and high and low saturation levels (HS and LS). These data were used to calibrate a resilient modulus model for the material. Both the dry density and degree of saturation were found to be significant variables in the model in addition to the stress dependency normally associated with unbound material. Figure 8 shows a comparison between the resilient modulus back-calculated from deflection measurements taken during the HVS tests and the laboratory derived resilient modulus model. Although there is not a one-to-one correlation between the field and laboratory resilient modulus results, both sources indicate that the resilient modulus of the sandstone gravel at representative dry density and moisture content values is well in excess of the values (50 to 200 MPa) normally recommended for G6 material (Theyse and Muthen, 2000).

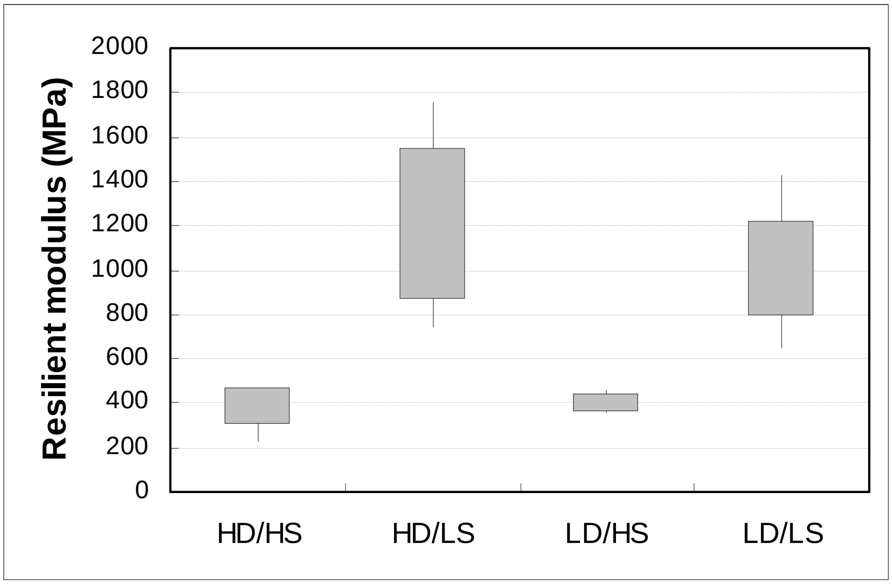

Figure 7. Resilient modulus results for the sandstone gravel base layer material.

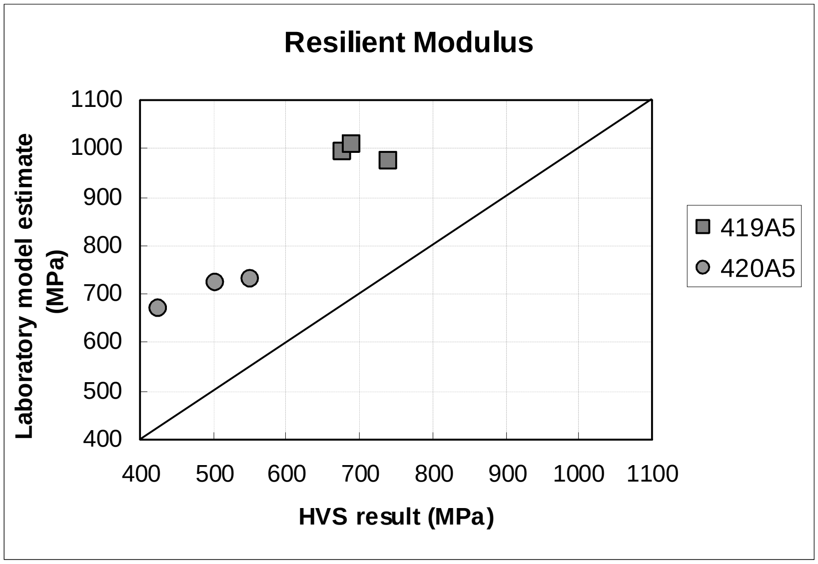

Figure 7. Comparison of field and laboratory resilient modulus results.

Conclusions and recommendations

The HVS test results indicated that a very light pavement structure may provide exceptional service in terms of resilient response (deflection) and permanent deformation (rut) for the structural capacity levels required by low volume roads.

The use of conventional selection criteria for base layer materials based on CBR results may exclude the use natural gravels that may perform very well in the base layer of light pavement structures for low volume roads. The material tested in this study had a CBR below 80 per cent at the highest realistic dry density that may achieved but performed exceptionally well under accelerated loading. This is believed to be related to the high resilient modulus and shear strength of the material which do not seem to be related to the CBR of the material.

The mechanical properties (resilient modulus and shear strength) of materials should be determined on a project by project basis if a mechanistic-empirical design method is to be followed. "Typical" published values based on material classifications systems do not seem to be sufficient for proper engineering design.

References

Committee of State Road Authorities, CSRA (1985). *TRH14 (1985): Guidelines for Road Construction Materials*. Department of Transport, Pretoria, South Africa.

Maree, J H. (1982). *Aspekte van die ontwerp en gedrag van padplaveisels met korrelmaterialkroonlae. (Aspects of the design and behaviour of road pavements with granular base layers)*. Ph D thesis. University of Pretoria.

National Department of Transport, NDoT (2002). *Road Infrastructure Strategic Framework for South Africa*. Department of Transport, Pretoria, South Africa.

Steyn, W.J.vdM, Sadzik, E. and De Beer, M. (1998). *Evaluation of superlight pavements under accelerated traffic (S702)*. Paper delivered at the 77th Transportation Research Board meeting, 11-15 January 1998, Washington, D.C.

Theyse, H.L. (2004). *HVS and laboratory testing of a light pavement structure on Road 538 between Leipoldtville and Lambertsbaai. Volume I: Report*. CSIR Transportek, Confidential Contract Report CR-2004/36, Pretoria, South Africa.

Theyse H L and Muthen M (2000). "Pavement Analysis and Design Software (PADS) based on the South African Mechanistic-empirical Design Method." *Proceedings of the Annual South African Transport Conference.* Pretoria, South Africa, July 2000.