Improved material specifications for unsealed roads

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Abstract

Performance-related specifications for the selection of gravel materials for use in unsealed roads were developed in South Africa in the late 1980s along with associated deterioration models. The implementation of these has shown that, when the material fully complies with these specifications, and the materials are compacted to a high density, the actual performance of the road is even better than predicted by the models. These specifications have subsequently been tested and implemented in other countries in the southern African region. However, whereas in South Africa test methods are based upon ASTM methods, the test methods used in other countries are often based upon the British Standard methods. The inherent differences in these test methods need to be taken into account so that the specifications can be effectively applied. A revised material selection guide and performance prediction chart have been developed for use when the materials are tested using the British Standard test methods.

During the late 1980s a comprehensive field study of the performance of unsealed roads related to the material properties was carried out in South Africa and Namibia (Paige-Green 1989). The result of this study was the development of performance-related specifications for unsealed roads, which were published for general use in South Africa under the State Road Authority banner (CSRA (Committee of State Road Authorities) 1990). These specifications were based on the South African standard test methods (CSRA 1976, 1986) and were partly (not all of the criteria were strictly adhered to) implemented during most subsequent routine regravelling operations. Many of the performance problems previously associated with unsealed roads were subsequently reduced or even eliminated (Van Zyl *et al.* 2003).

Together with the specifications, prediction models for gravel loss and road roughness deterioration were also developed (Paige-Green 1989; CSRA 1990). These have been successfully implemented in various Gravel Road Management Systems (GRMS) in the southern African region (Van Zyl *et al.* 2003).

The specifications have since been included in the South African Transport and Communication Commission (SATCC) specification for Roads and Bridges, which was endorsed for use by the SATCC Ministers of Transport for general use in SATCC countries (SATCC 1998). However, many of the countries within SATCC were still using British Standard Methods for testing. The high cost of converting all testing to the South African (equivalent to the ASTM) test methods (CSRA 1976, 1986) and the implications of this on other local specifications effectively eliminated the possibility of the more widespread use of the, then new, specification. Testing was thus carried out using local methods, resulting in poor transferability of the specifications.

This paper describes some of the recent developments regarding implementation of the specifications and a calibration of the specifications for use with the equivalent British Standard test methods.

Geological materials

The original research used a factorial design with geological material type, climate, traffic and road geometrics as the factors. The geological material factor made use of the engineering geological classification of materials developed by Weinert (1980). This system is based on the mineralogy and weathering characteristics of the parent rock and is used extensively in the design of roads in southern Africa. This classification system divides the parent rock into nine groups that will either decompose or disintegrate into nine significantly different material types as follows:

(1) basic crystalline rocks (e.g. basalt, gabbro, dolerite, amphibolite);
(2) acid crystalline rocks (e.g. felsite, granite, gneiss);
(3) high-silica rocks (e.g. chert, quartzite, hornfels);
(4) arenaceous rocks (e.g. arkose, sandstone, mica schist, conglomerate);
(5) argillaceous rocks (e.g. shale, mudstone, phyllite);
(6) carbonate rocks (e.g. dolomite, limestone, marble);
(7) diamictites (e.g. tillite, breccia);
(8) metalliferous rocks (e.g. ironstone, magnesite);
(9) pedogenic materials (e.g. laterite, ferricrete, calcrete).

The 110 sections of road used to develop the specification (Paige-Green 1989) made use of natural gravel wearing course materials from all groups except the diamictites and metalliferous rocks, which are only used for unsealed roads in southern Africa in very limited quantities. A typical example of a poor unsealed road constructed of weathered sandstone is shown in Figure 1.

Specifications

The basic specifications that were originally developed for rural roads (CSRA 1990) (slight variations were

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Fig. 1. An unsealed road constructed of weathered sandstone.

Table 1. *Recommended material specifications for unsealed rural roads*

Property	Value
Maximum size (mm)	37.5
Maximum oversize index (I_o)	5%
Shrinkage product (S_p)	100–365 (maximum of 240 preferable)
Grading coefficient (G_c)	16–34
Soaked CBR (at 95% modified AASHTO compaction)	>15%
Treton impact value (%)	20–65

I_o, the oversize index, is the percentage retained on 37.5 mm sieve. S_p = linearshrinkage × (percentagepassing 0.425 mmsieve). G_c = ((percentage passing 26.5 mm − percentage passing 2.0 mm) × (percentage passing 4.75 mm))/100.

included for urban and industrial roads) were improved over time by the addition of an improved criterion for strength (Jones & Paige-Green 1996), passability (Paige-Green & Bam 1991) and an upper and lower requirement for the hardness of the aggregate component (Paige-Green & Bam 1995) using the Treton Impact test (CSRA 1976, 1986) (Table 1).

Plotting the shrinkage product against the grading coefficient provided the added advantage of allowing the prediction of the expected field performance of the materials as shown in Figure 2.

Use of material plotting in Zone E provides the optimum performance, and the dominant problems that can be expected when using materials outside this zone are indicated in the other four zones. This figure does not include roughness problems related to excessive oversize material nor potholing caused by excessively weak materials. However, materials with the correct combination of shrinkage product and grading coefficient (Zone E) have generally been found to have adequate strength to resist potholing when effectively maintained (i.e. good road shape with crown and camber is retained).

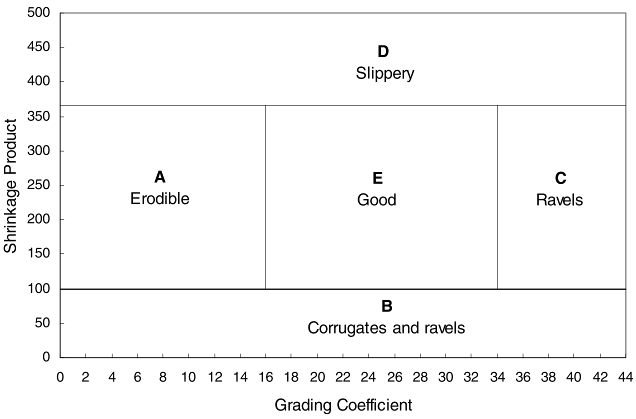

Fig. 2. Diagrammatic indication of expected performance (using SA–ASTM methods).

Table 2. *Tanzanian and Ugandan specification for unsealed roads*

Property	Tanzania	Uganda
Shrinkage product	120–400	120–400
Grading coefficient	16–34	16–34

For optimum performance the removal or breakdown of oversize material was considered essential, as was sufficient compaction (CSRA 1990), preferably compaction to refusal for the available plant.

Implementation

The gravel road material requirements were included in the South African Standard Specifications for Roads and Bridges (CSRA 1998), followed by inclusion in the SATCC Standard Specification for Roads and Bridges (SATCC 1998). They have also been included in the Tanzanian (MoW 1999, 2000) and Ugandan (MoWHC 2005) standard specifications. It is noted that they were modified for these two documents; the basis of these modifications is not clear but they were an apparently arbitrary correction for different test methods (C. Overby, pers. comm. 2004). This modification and inclusion was carried out independent of input of the author of the original specification and of this paper.

The Tanzanian and Ugandan specifications are essentially the same, defining the limits as shown in Table 2.

It should be noted that the definition of the specification properties varies in these documents; it is understood that this may be at least partly due to probable typographic errors. The most significant issue is in the Ugandan specification where the grading coefficient (G_c) is defined as

$$G_c = (D_{30})^2/(D_{60} \times D_{10}). \tag{1}$$

Fig. 3. Good unsealed road constructed from materials complying with the specification.

This is in the author's opinion incorrect and limits the values determined to between zero and one.

The cohesive, grading and material strength components of the specifications were implemented by most of the provincial road authorities in South Africa from the early 1990s onwards. The control of oversize material was, however, seldom carried out and roads were often poorly shaped and compacted. Generally, little process or acceptance control has been the norm for gravel roads. Despite this, the general performance of the roads appeared to improve and the deterioration models gave predictions of the gravel loss and surface roughness deterioration sufficient to programme the regravelling and grader blading requirements successfully (Van Zyl *et al.* 2003). However, budget constraints resulted in an inability to annually replace sufficient gravel to maintain the status quo and over the medium to long term, the average gravel thickness on the road network decreased significantly.

The Western Cape Province in South Africa, however, recently made a concerted effort to adhere to the specifications and to provide a high degree of compaction with a good road shape. Training of regravelling staff has also been instituted. Trial sections are routinely constructed at the beginning of each project or when the materials change to ensure that the processing and construction produces the required product. A high degree of quality control is thus implemented.

Observation and monitoring of a number of roads (Van Zyl *et al.* 2003) constructed to these standards has shown that the rate of deterioration of such roads is much slower than that predicted by existing models. This has significant savings in terms of maintenance costs.

Figure 3 shows an example of a road built with residual chert materials complying with the specification.

Use with British Standard test methods

Shrinkage product

It is well known (Sampson & Netterberg 1984) that there are significant differences between the results of the Atterberg Limit tests using the British Standard (BSI 1990) and the ASTM–AASHTO test methods on which the South African test methods are essentially based (ASTM 2002; AASHTO 2005). However, the South African bar linear shrinkage test (CSRA 1976), which is critical to the unsealed wearing course specifications, is based on an old Californian test method (Paige-Green & Ventura 1999), which differs significantly from the BS method (BS 1377:2 Test 6.5). The South African bar linear shrinkage is determined on material at the ASTM liquid limit (determined using the Casagrande device) whereas the British linear shrinkage is determined on material at the BS liquid limit (using the cone penetration device or the BS Casagrande bowl, with a softer rubber base) and is on average four percentage units higher than the liquid limit determined by the ASTM method (Sampson & Netterberg 1984). The shapes and dimensions of the two shrinkage troughs as well as the test methods also differ considerably.

A comparative study using the South African (SALS) and British Standard (BSLS) linear shrinkage tests on eight materials with a range of linear shrinkages between 1% and 15.5% was carried out. Each test method was followed explicitly and the results were correlated. The following relation was obtained:

$$\mathrm{BSLS} = 1.0104 \quad \mathrm{SALS} + 1.6022 \qquad (n = 8; r^2 = 0.947). \tag{2}$$

Only one of the sets of test results differed by more than two percentage units, this being a silty clay material with a difference of 4.3 percentage units. A black cotton soil with a liquid limit of 73% determined from the Casagrande device and 89% from the BS cone method, however, only differed by two percentage units in the two linear shrinkage tests.

As the shrinkage product is the product of the linear shrinkage and the percentage of material used for the shrinkage test it was necessary to develop this correction. This was done by developing two matrices of data comprising the product of the linear shrinkage and percentage passing the 0.425 mm sieve. The first was the conventional shrinkage product using a range of South African linear shrinkage values between 1% and 20% and a range passing the 0.425 mm sieve of between 18% and 75%, the limits of the original data from which the classification system was developed (Paige-Green 1989). The second matrix was identical but used the equivalent BS linear shrinkage values derived from equation (2). The corresponding pairs of values in the two matrices

Table 3. *Revised values for shrinkage product when employing BS test methods*

Shrinkage product	SA test methods	BS test methods
Lower limit	100	140
Upper limit	365	400

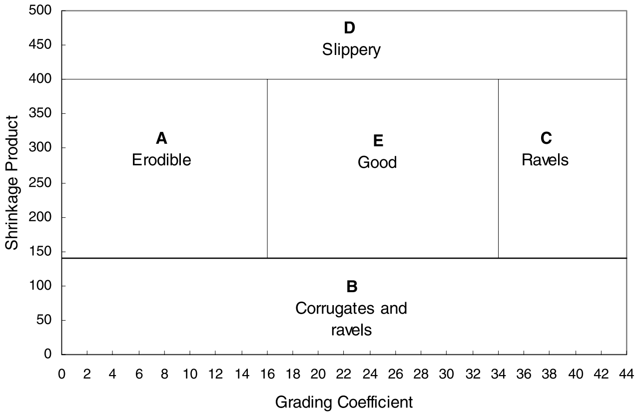

Fig. 4. Revised performance prediction diagram using BS shrinkage test results.

with values between 100 and 365 (the values defining the lower and upper performance limits for good materials in Fig. 2) were then extracted and regressed against each other. Eighty results were used and the following relation was obtained:

$$\mathrm{BSSP} = 1.0482 \quad \mathrm{SASP} + 37.07 \qquad (n = 80; r^2 = 0.996). \quad (3)$$

This relation was then used to develop new upper and lower limits for the shrinkage product (shift on vertical axis) using BS test methods. These are summarized in Table 3 and Figure 4.

It is noted that the lower limit is 20 units higher than that used in the Tanzanian and Ugandan specifications but the upper limit is the same.

Grading coefficient

The grading coefficient was developed from test results based on the use of the standard South African test method (originally based on an AASHTO method (CSRA 1986)), which uses sieves of 26.5, 4.75 and 2.0 mm (Paige-Green 1999), whereas the conventional ‘equivalent’ sieves used in the BS 1377:2 Test 9 (BSI 1990) are 28.0, 20.0, 5.0 and 2.0 mm. An analysis of the impact of using the 28.0 and 5.0 mm sieves instead of the 26.5 and 4.75 mm sieves indicated that there is no statistically significant difference between these pairs of sieves at the 99% confidence level. The differences can thus be ignored as insignificant.

Table 4. *Revised values for grading coefficient when employing BS test methods*

Grading coefficient	SA test methods	BS test methods[a]
Lower limit	16	14
Upper limit	34	30

[a] Using 20 mm sieve.

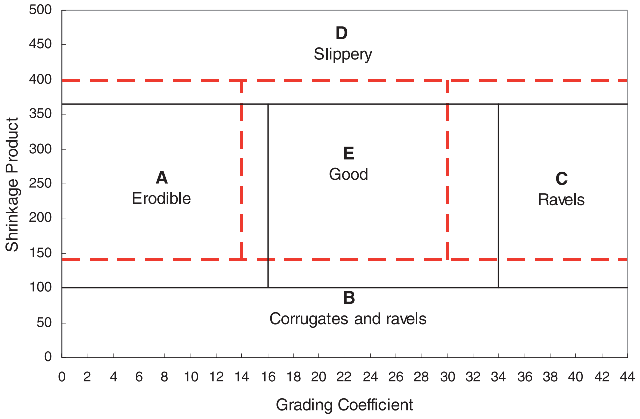

Fig. 5. Revised performance prediction diagram using BS shrinkage test results and 20 mm sieve; the original specification is shown by the continuous lines.

However, it has been noted in parts of Africa using the BS test methods that the 28 mm screen is often omitted and the material passing the 20 mm sieve only is used (i.e. that portion used for compaction and CBR strength testing). The effect of using the percentage passing the 20 mm sieve as opposed to using that passing the 26.5 mm sieve is significant. As a result of this, the grading coefficient calculated from the BS test results could differ significantly from the results used to develop the performance chart (Fig. 2).

A series of 37 gradings obtained from various unsealed roads was thus used to develop a correlation between the standard South African grading coefficient (SAGC) and that developed using the 20 mm sieve instead of the 26.5 mm sieve (BSGC). In fact, the results from the standard 19 mm sieve used in South Africa were used, as the difference between that and the 20 mm sieve is also insignificant. The following relation was obtained:

$$\mathrm{BSGC} = 0.9976 \quad \mathrm{SAGC} - 1.8763 \qquad (n = 37; r^2 = 0.919). \quad (4)$$

The impact of this redefinition of the grading coefficient on the horizontal boundaries of the ‘good’ zone in Figure 2 is tabulated in (Table 4) and plotted in Figure 5.

The overall effect of these modifications is to move the ‘good’ zone in Figure 2 higher up the vertical axis and down the horizontal axis. This results in a more realistic use of the specification when BS test methods are used, permitting slightly more plastic materials to be used without excessive slipperiness and eliminating more of the materials that will result in excessive corrugation and ravelling.

Conclusions

Performance-related specifications for wearing course gravels for unsealed roads developed in South Africa have been successfully implemented in a number of regions, resulting in significant improvements in the performance of unsealed roads. However, differences in test techniques from those used during the development of the specifications have resulted in transferability problems between countries. Comparative testing and calibration of the relationships has allowed the development of a slightly revised material performance relationship that can be used in countries using British Standard test methods.

The overall effect of these modifications is to increase the shrinkage product and decrease the grading coefficient values that define the zone that represents 'good' materials in the shrinkage product–grading coefficient plane. This results in a more realistic use of the specification when BS test methods are used, permitting slightly more plastic materials to be used without excessive slipperiness and eliminating more of the materials that will result in excessive corrugation and ravelling.

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