

Appropriate Roads for Rural Access

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Abstract: Many rural villages still have inappropriate access consisting of earth tracks or at best gravel roads, neither of which necessarily provides all-weather access. These types of road can have a significant impact on the economic well-being of the affected communities and also result in unsustainable environmental impacts. The road networks can be significantly improved by providing engineered gravel roads and optimizing the material selection for these roads. Although material replacement needs can be reduced, the result remains environmentally unsustainable.

Low cost but appropriate techniques for upgrading these roads cost-effectively to sealed standards have been implemented in many countries recently. These techniques optimize the use of local materials, reduce the pavement thickness requirements and make use of thin but effective bituminous surfacings such as sand, Otta and graded aggregate seals. Examples of appropriate design, material selection and construction procedures are provided in the paper

Key words: Rural access roads, local materials, appropriate seals.

1. Introduction

In the majority of developing countries, there are still many villages and settlements in remote areas that are not connected, or do not have all weather access, to the regional road network. Where roads do exist, they typically consist of earth tracks, with portions or possibly entire lengths graveled with local natural materials.

The condition and passability of these roads can have a severe impact on the communities that they serve in terms of economic well-being as well as access to health services (particularly emergency facilities and clinics), education and markets. In addition, the environmental impacts associated with such roads are often severe and result in the unsustainable use of materials that could be more beneficially employed during upgrading of the roads to a more sustainable sealed standard.

The construction of engineered unsealed roads with improved material selection processes alone can result in significant improvements in road performance and reductions in material usage but unsealed roads remain environmentally unsustainable in the long term. Where the traffic volumes in rural areas are low and consist mostly of light vehicles, the need to construct high quality sealed pavements using conventional design techniques is usually unnecessary. Very light and economical pavements can be constructed to provide highly appropriate accessibility in rural areas.

This paper summarizes and synthesizes various southern African low volume road pavement design developments from the past decade or so into a single paper and attempts to relate them to their possible use and implementation in the international rural access road situation.

2. Unsealed roads

The materials used for the construction of wearing courses for unsealed roads need to fulfill a number of functions and comply with a number of basic engineering properties (Paige-Green and Netterberg, 1987). The most important of these are to:

- have sufficient cohesion to resist raveling and erosion;
- have a particle size distribution that facilitates a tight interlock of the individual material particles, and
- have sufficient strength to support the applied traffic loads without significant plastic deformation.

Deficiencies in any of these properties result in poor riding quality and high maintenance requirements as well as an increased loss of material from the road. It is thus essential that the best available material is used for construction of unsealed roads. Such materials are, however, usually not suitable for use as structural layers in sealed roads.

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Typical specifications for unsealed road materials (eg, M147 in AASHTO, 2001) are very similar to those for subbase materials for sealed roads. These do not necessarily provide the best performance in the unsealed road situation (depending on the climate) and often require high maintenance inputs. They also utilize materials that should perhaps be better conserved for future upgrading of the roads.

Specifications for wearing course gravels have been derived from a large performance-related study of 110 sections of unsealed road in southern Africa (Paige-Green, 1989). These use standard South African test methods (CSRA, 1979 & 1986) and fulfill the requirements described above and are summarized in Table 1 and illustrated in Figure 1.

Table 1. South African unsealed road material specification (Paige-Green, 1989; CSRA, 1990)

Maximum size (mm)	37,5
Oversize index (Io)*	< 5 %
Shrinkage product (Sp)**	100 - 365
Grading coefficient (Gc)***	16 - 34
CBR (at 95 % AASHTO T180)	> 15 %
Treton impact value (%)	20 - 65

* Io = Per cent retained on 37.5 mm sieve but less than 75 mm,

** Sp = Linear shrinkage x per cent passing 0.425 mm sieve,

*** Gc = (Per cent passing 26.5 mm - per cent passing 2.0 mm) x per cent passing 4.75 mm/100

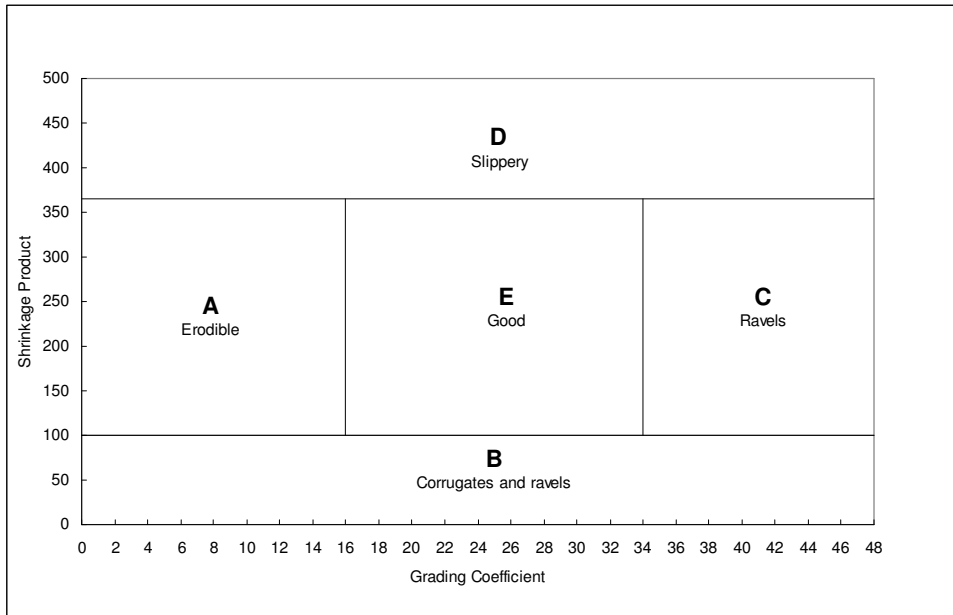


Figure 1. Wearing course specification for unsealed roads

The specifications were developed from roads selected using a factorial design including material types, traffic and climate and cover a wide range of environments and conditions (Paige-Green and Netterberg, 1987). The major advantage of the specification illustrated in Figure 1 is the ability to identify potential problems associated with materials not meeting the specifications. This allows the implementer to make judgments regarding the consequences of using material outside the specifications and to assess whether these can be accommodated in terms of the local traffic, climate or maintenance capacity. Typical examples of this are the application of different maintenance strategies to control corrugation/washboarding (eg, more frequent but possibly lower cost techniques, such as dragging), or making use of potentially slippery materials in areas with minimal rainfall.

A very important aspect is to control the amount of oversize material. Excessive oversize material is one of the major contributors to road roughness (and increased vehicle operating costs associated with tire and suspension damage to vehicles) as well as making routine grader maintenance difficult and less effective. Although an Oversize Index of up to 5 per cent is specified, the maximum size of the oversize material should not exceed about 75 mm. This can be controlled at source using simple equipment such as a “grizzly” screen.

The applicability of the specifications over a wider area than that from which they were derived has been confirmed during their implementation in a number of countries (primarily in Africa, the Middle East and Asia). However, local calibration may be necessary, not only to cater for

regional differences in materials and climate, but also to take the differing test methods into account, eg, South African versus British and United States Standards. This would usually involve the monitoring of the performance of road sections to determine whether the shrinkage products and grading coefficients demarcating the borders of the zones in Figure 1 need any adjustments to differentiate among the various modes of performance.

Where only materials with unsuitable gradings are available locally, two (or more where necessary) materials may be blended to produce one with the correct grading (mechanical stabilization). This can reduce the haulage costs associated with using better sources at greater distances from the project. The process is illustrated in Figure 2. It is more difficult to blend materials to correct the plasticity but this can often be done using materials with a high silt and clay content as illustrated in the example. On the figure, coarse material with a grading plotted at A lacks fines. If blended with a fine silty clay material B in the ratio of BC:AC gravel : fines, ie, about 4 coarse material (A) to one fines (B), the resultant material will have a grading represented by C thus falling within the grading requirements of the “good” envelope shown as E in Figure 1.

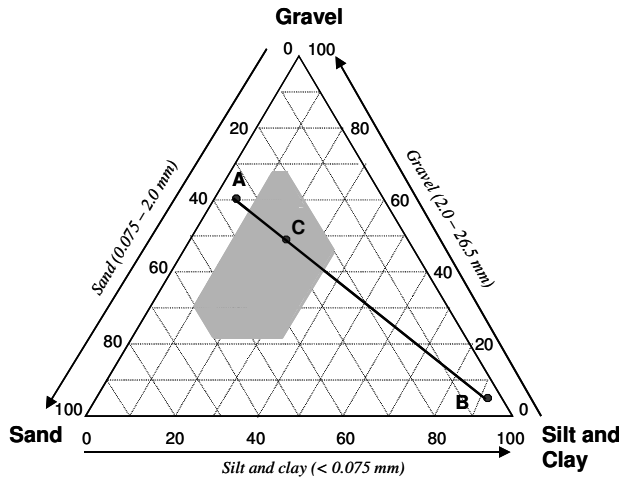


Figure 2. Example of blending technique

In order to improve material performance, all compaction should be carried out at optimum moisture content for the material and to refusal for the plant utilized. The heavier the plant, the lower the compaction moisture required and the higher the density achieved.

Most natural gravel materials will result in dust being generated from the road under traffic, and even during windy periods. Apart from the social problems associated with this dust (safety, health and pollution), the natural soil fines (binder) in the wearing course material are lost and the material properties slowly deteriorate. The effect of this

is that the wearing course properties slowly move down both the vertical and horizontal scale in Figure 1, resulting in a good material becoming increasingly prone to corrugation and erosion.

The use of material complying with the specifications in rural areas will reduce the required frequency of grader maintenance and regravelling but not the need. It is still essential that this be regularly and carefully carried out. It is possible, however, in many cases to carry out the maintenance using labor (preferably from the local communities making use of the roads). This is discussed further in Section 8.

Despite the best material selection and construction techniques, roads in mountainous terrain (a frequent occurrence associated with rural access) are likely to erode on steep grades. Careful control of the camber to remove the water laterally from the road surface as quickly as possible can assist in reducing erosion, but a point is achieved where erosion is inevitable. Small water control humps can also assist with reducing erosion but these need to be designed and maintained carefully.

Various proprietary soil stabilizers and dust palliatives have become available on the market in recent years, with claims to reduce dust, strengthen the wearing course and reduce erosion. There is no doubt that some of these have performed successfully on selected materials under certain environmental and traffic conditions, but in general the performance of the products is highly material and climate dependent. The performance of those that are successful is also highly dependent on the application rate of the product and this needs to be assessed and controlled continuously during construction.

Those products that are professionally marketed (with relevant technical documentation) should be tested on typical materials in the laboratory using appropriate test techniques before use and should be supplied with an acceptable (to the supplier and consumer) performance guarantee. It is also important that the cost-effectiveness of the products is compared with that of low cost upgrading to sealed standard as discussed in the following section of this paper.

3. Sealed Roads

As described above, irrespective of the degree of material selection and engineering, unsealed roads are unsustainable in the long term. It is not possible to keep replacing materials continually, either from the engineering (good materials become depleted) point of view or the environmental (scarring, erosion, siltation, dust) viewpoint. The only way to minimize this problem of unsustainability is to place a protective seal on the road and thus conserve these materials for between 10 and 20 years. This typically comprises a bituminous surfacing but could include concrete, interlocking blocks or cobblestones.

Unfortunately, it is seldom possible to place a surfacing directly on an unsealed road as neither the materials nor the pavement structure are usually suitable. The conventional practice is to develop a pavement structure based on structural number, catalogue or mechanistic empirical methods. Many of the current techniques used, particularly the common catalogue procedure, have been developed from structural pavement performance studies of conventional roads. The performance of roads with light traffic is dictated far more by the environment (particularly moisture and drainage conditions) than by the traffic loading characteristics (Paige-Green, 1996; SADC, 2003).

Recent research has shown that even lightly trafficked unsealed roads are compacted (or probably more correctly molded) in service and have an inherent structure that can be utilized when upgrading the road.

Many instances have been noted where the in situ materials (particularly weathered siliceous materials and pedocretes) are stronger than the imported gravel wearing courses or subbase materials. In such cases, shaping and

reworking of the in situ materials or those adjacent to the road (particularly during simultaneous side drain construction) should be carried out, minimizing disturbance of the existing “pavement” structure as far as possible. This can then be used as a base course ready for the application of an appropriate bituminous surfacing, after constructing appropriate side-drains.

It is important, however, that the relationships between the moisture, strength and density for the materials are clearly understood. Determination of the CBR on each mold prepared for the maximum dry density and optimum moisture content determination should be done in addition to the standard CBR determination. The results can then be assessed to determine the moisture and density sensitivities of the strength (Figures 3 and 4), which are important in designing the drainage and defining the density requirements. It is strongly recommended, however, that all compactions are carried out to refusal using the heaviest plant available. The individual point labels on the Figures are the CBR values at those points and under the specific moisture and density conditions.

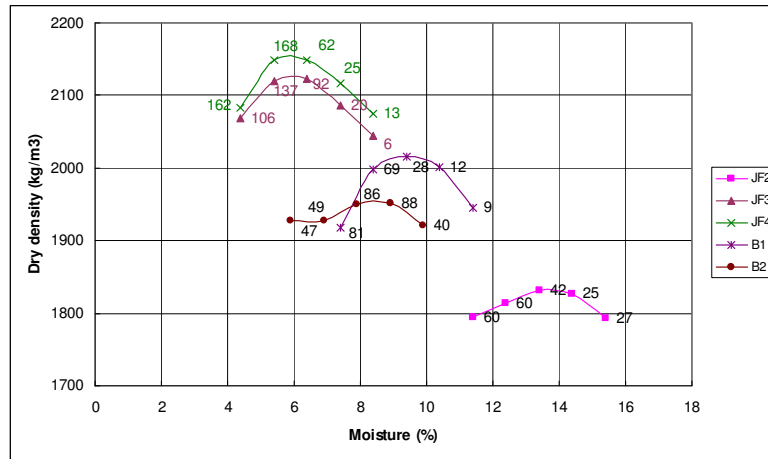


Figure 3. Moisture and density sensitivity (unsoaked)

Those materials with strongly peaked density moisture curves and steep strength density or strength moisture curves show high susceptibility of their strengths in relation to the density and moisture and cognizance should be taken of these during the design and construction processes.

These data need to be considered in relation to the in situ material properties. These are best assessed using test equipment such as the Dynamic Cone Penetrometer (DCP) which is an essentially non-destructive, quick, easy and robust test. The test determines the in situ shear strength of the material under the prevailing moisture and density conditions. It is essential that these conditions are taken into account when interpreting the results. It is also important when

assessing materials with a relatively high proportion of large stones (the test is essentially only a rough indicator of strength for very stony materials) that the mean strength of the matrix is considered and the effect of stones should be excluded from the overall layer strength. The data obtained from the DCP test can be converted to equivalent CBR strengths using various models, but for low volume roads, design penetration rates (based on CBR) need only be utilized. The DCP profile can then be related to a pavement structure profile for the specific traffic in terms of the penetration rates (Figure 5). Various design profiles can be developed for different traffic categories. The diagram shown in Figure 5 indicates in situ equivalent CBR strengths of the base, subbase and upper subgrade as 110, 55 and 20 per cent respectively

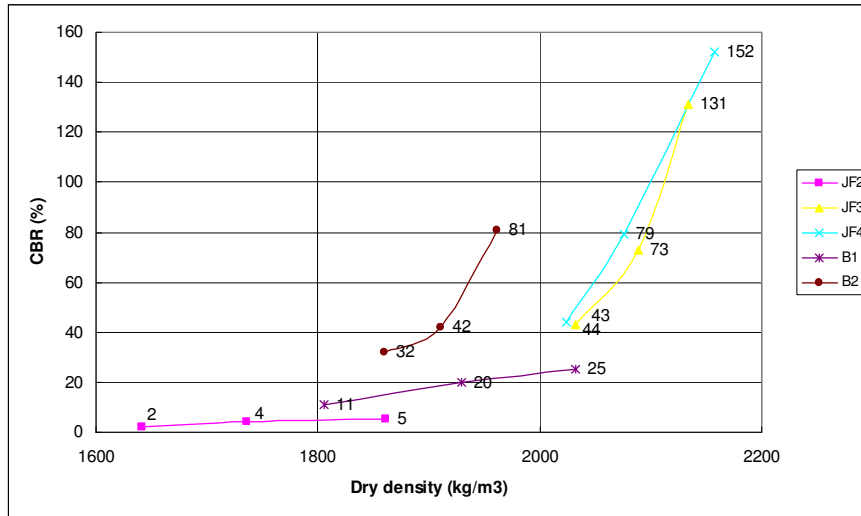


Figure 4. Sensitivity of soaked strength with density

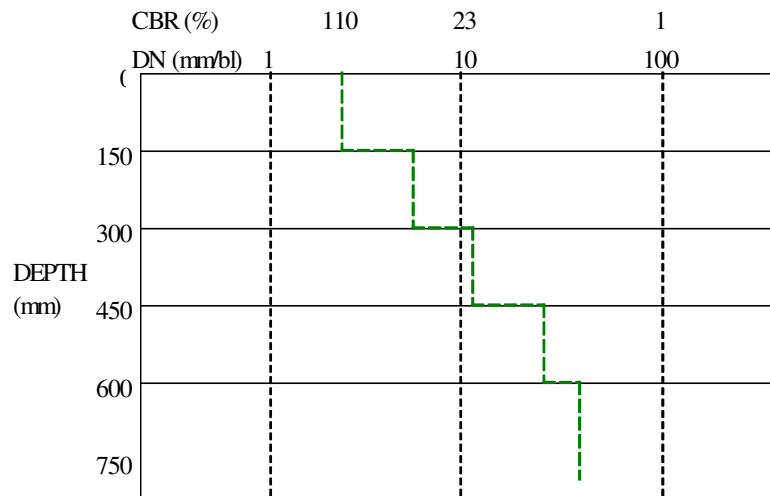


Figure 5. Typical layer strength requirement diagram for very light traffic pavement

Plotting the actual (in situ) layer strengths on this diagram indicates depths that have insufficient strength as shown in Figure 6. Where the layer strength (solid red trace) plots to the right of the design profile (broken green line) the material has inadequate shear strength. In these areas of the profile, the material strength needs to be improved. This would normally require excavation to those depths, compaction, stabilization or replacement of the material and then reconstruction of the overlying layers. It is usually more cost-effective to provide

additional cover material at the surface thus effectively lowering the weak area in the pavement.

In the example shown (Figure 6), the upper 150 mm is too weak (CBR of 100 instead of 110) as is the material between 300 and 600 mm deep. By adding a 150 mm layer of selected base material (in situ CBR greater than 110 % or soaked CBR of about 45 per cent if the in situ material is at a moisture content of about 75% OMC) to the top of the structure, all of these areas become lower layers in the pavement and then fall within the design requirement.

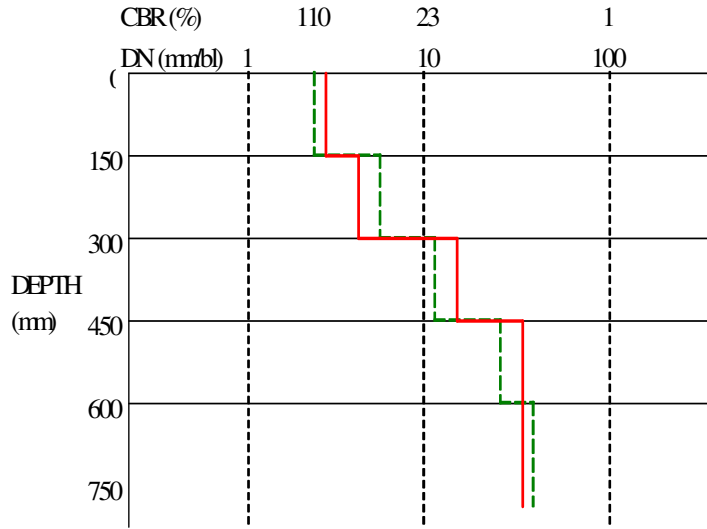


Figure 6. Trace of layer strength diagram and design curve

The layer between 150 and 300 mm has an average in situ CBR strength of about 70 per cent, considerably higher than the required 55 per cent and the two layers between 300 and 600 mm have strengths of about 15 and 5 per cent instead of the required 20 and 10 per cent.

4. Structural Adequacy

The structural adequacy of light pavement structures can be analyzed using conventional mechanistic empirical analysis (CSIR Transportek, 2004). Field experience has shown, however, that this may be slightly conservative for light pavement structures as there is evidence of non-linear behavior under traffic where rutting does not continue indefinitely but reaches a point (varying with the stress conditions) after which no additional rutting develops (Wolff, et al, 1995). Most mechanistic empirical analysis techniques define a terminal rutting condition resulting from cumulative permanent plastic strain as the failure criterion. This too may not be particularly applicable to light pavement structures, where pavements with more than 50 mm of rutting have been observed to be giving good (structural) performance – functional issues are a separate problem and must be assessed for each specific road and related to among other properties, the environment, traffic, and maintenance capacity.

It is suggested that where the heavy truck traffic using the road is minimal (as is the case on most rural access roads) a different approach to design may be more relevant. When one considers that vehicles up to 5 tons

in mass exert a contact stress of only about 300 kPa on the pavement surface compared with stresses in excess of 1000 kPa for fully loaded heavy vehicles, the required structural capacity necessary for rural access roads carrying few heavy vehicles is quite low. It must be remembered that conventional pavement designs have been developed to cater for heavy trucks (typically 80 kN axle loadings). In fact, a shear strength of the material slightly in excess of the applied load (ie, with a small safety factor) is probably all that is necessary to avoid one-off failures of the pavement. Cumulative deformation under the majority of the traffic, ie, cars, will be minimal, especially if the materials are compacted to refusal, and can usually be corrected by routine maintenance using slurry seals or resealing, or both where necessary.

A plot of the stress required to produce the 2.54 mm penetration (noting that this is usually neither pure shear failure nor pure compaction) at which the CBR is determined for a range of materials with CBR values between 10 and 70 per cent is shown in Figure 7. From this it can be seen that a stress of about 0.75 MPa is necessary at a CBR of 45% and a stress of about 0.40 MPa at a CBR of 25%. Although the deformation is considerably higher than could be accepted on roads in practice, if these data are converted to stiffness (the strain is taken as 2.54 mm), the results obtained are comparable with the typical values of resilient modulus (stiffness) suggested for use in the SA mechanistic empirical pavement analysis system (Table 2). The equivalent stiffness for the CBR of 80 per cent, however, is significantly higher than conventionally assumed.

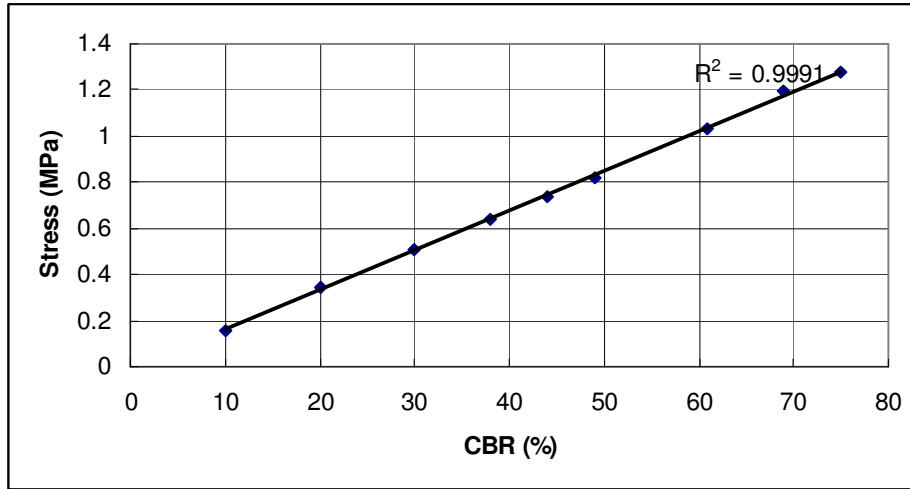


Figure 7. Plot of stress at 2.54 mm penetration versus CBR of various natural gravels

Table 2. Stiffness calculated from CBR curves versus default stiffness used in mePADS software

CBR (%)	Calculated stiffness (MPa)	mePads resilient moduli (MPa)
10	63	30 - 180
15	100	30 - 200
25	155	150 (30 - 200)
45	295	200 (40 - 300)
80	540	225 (75 - 350)

Although only preliminary assessments of these relationships have been developed and considering the inherent problems with the CBR test (Paige-Green, 2003) the correspondence here with field observations indicates that the use of the shear strength may be more relevant to low volume roads (Oloo and Fredlund, 1997) and is presently being assessed further.

Various scenarios related to traffic on light pavement structures have been analyzed using mechanistic empirical techniques. These are used to illustrate the impact of increasing axle loadings and better compaction on the carrying capacity of a pavement with 150 mm of CBR 45 base material over 150 mm of CBR 25 subbase over an infinite soil subgrade (CBR 15%). The results are summarized in Table 3.

It can be clearly seen how increased axle loads reduce the carrying capacity of the pavement significantly, particularly with respect to the subgrade performance. The impact of compacting to refusal (assuming a 10 per cent increase in stiffness) has a marked effect on the performance under heavier axle loads. The assumed pavement, although constructed of typical local materials has adequate structural capacity for the type of road providing sustainable all-weather access.

Table 3. Structural capacity of various light pavement scenarios (numbers of vehicles)

Scenario	Base	Subbase	Subgrade
Car 1	1.52×10^8	8.93×10^{11}	2.54×10^{14}
Car 2	1.62×10^8	9.19×10^{11}	3.39×10^{14}
3 ton axle 1	6.60×10^7	1.41×10^7	7.61×10^9
3 ton axle 2	7.31×10^7	1.41×10^7	1.01×10^{10}
8 ton axle 1	7.45×10^6	6.60×10^5	1.08×10^7
8 ton axle 2	6.39×10^8	2.59×10^5	8.02×10^5

1 - conventional analysis using mePADS defaults

2 - analysis using 10% increase in stiffness of base and subbase assumed through compaction to refusal

5. Surfacing

Once structural adequacy of the pavement has been achieved, the base should be primed with a low viscosity prime that penetrates the upper portion of the base. This has a significant impact on strengthening this critical area of the pavement (highest contact stresses) and results in reduced rates of deterioration should the seal develop any weaknesses.

In order to minimize the life-cycle costs of the road, the most appropriate seal for the traffic and environment should be selected. This should be based on both technical and construction cost considerations. In certain cases such as on steep slopes or where the maintenance input is likely to be low, thicker, more durable surfacings (eg, asphalt) should be selected (Sabita, 1992). In the more general areas with low grades, light traffic, high maintenance capacity, etc, surfacings using sand and graded aggregate prepared from local natural sources can reduce the cost of surfacing considerably.

The use of innovative seals has improved considerably in the last few years as greater experience and understanding of their limitations has been gained.

Sand and Otta seals have the benefits over conventional chip seals of using natural materials with no or very little processing and do not utilize a rational design method. The balance between the binder and aggregate is achieved through brooming of loose aggregate back onto the exposed binder until the maximum amount of material has adhered to the binder. When using traditional chip seals on the other hand, it is imperative that the design achieves the correct balance between the aggregate and binder to ensure adequate adhesion of the stone but not to result in too much binder such flushing and bleeding occur. It should, however, be noted that it is better to have a slight excess of binder on roads carrying very light traffic than to be deficient (Paige-Green, 1999). This prolongs the life of the seal, decreases the permeability of the seal and ensures aggregate adhesion, but results in a possible decrease in skid resistance.

Good preparation of the base course is essential to ensure a smooth surface when applying thin seals such as sand seals. The seal is generally between 2 and 5 mm thick and any unevenness in the base surface will result in even thinner areas of surfacing that are likely to wear through rapidly. Thicker seals such as the Otta seal are less prone to such problems.

Sand seals

Aggregate for sand seals is generally restricted to clean sandy materials with a maximum size of about 6.7 mm. Although most specifications require a maximum of about 2 per cent passing the 0.150 mm screen, recent experience has shown that this can be increased up to at least 10 or 15 per cent where cleaner sands are not available. Penetration grade, cut-back or emulsified bitumen binders can be used, the emulsions generally being the easiest to use in more remote rural areas because of their reduced heating requirements.

It is necessary to place a second sand seal on the first one within a period of three to six months in order to develop some thickness and improve the wear resistance and durability of the seal.

Otta seals

The Otta seal was originally developed in Norway (Overby, 1999) and has subsequently been used in many sub-tropical and tropical countries with great success. The Otta seal consists of a graded aggregate (up to 19 mm maximum size) applied to a very soft binder (typically MC 30 with additional cutter). The combination is then intensively rolled to force the binder upwards through the aggregate resulting in a relatively thick, flexible and impermeable surfacing. The life of the seal can be considerably extended by placing a second Otta seal or a sand seal on the first seal a few months after its construction.

The performance of the Otta seal relies on a high degree of rolling and aftercare. The major advantage of this seal over the sand seal is that it is considerably thicker and a wider range of aggregate/material can be utilized. Typically scalping of a residual or transported material is the only processing necessary.

There has recently been an increase in the number of proprietary/commercial graded aggregate seals available, most of which make use of specifically developed modified binders. Generally these seals are constructed with commercially processed aggregates.

Other alternatives

Although the emphasis in this paper has been on low cost sand and Otta seals, situations exist where these seals alone are unsatisfactory. These include mountainous areas with steep grades, areas with frequent water crossings and areas where no suitable local materials occur. In these cases the design needs to assess options such as double chip seals, asphalt, concrete or even block/cobble paving. Thin bituminous seals will seldom be effective on grades steeper than about 8 to 10 per cent (Sabita, 1992): the use of asphalt, concrete or block paving (with special precautions) is usually necessary in these situations

6. Drainage

There is no doubt that the moisture content in a pavement (particularly light pavement structures) plays the major role in the performance of the pavement (Paige-Green, 1996; SADC, 2003). It is thus essential that moisture is kept from the pavement structure as effectively as possible. The predominant drainage problems noted to affect light pavement structures arise through poor shoulders and poor side drainage.

Unsealed shoulders should be constructed of appropriate materials that are as impermeable as possible and must be maintained with a good camber and no depression adjacent to the seal such that runoff from the seal does not seep into the shoulder. Sealed shoulders are an effective solution to this problem but are costly and can have problems related to attracting traffic that they were not designed for.

Side drains should be constructed on both sides of the pavement (unless a mono-camber is employed or the roads is in side cut or on an embankment) with drain invert levels at least 450 mm below crown height, but this will depend on the materials employed. Where fine materials, particularly silty materials are used in the formation or lower layers, the drain should be deeper as such materials have considerable capillary suction.

All side drains must lead into regularly spaced mitre drains that remove the water an adequate distance from

the pavement structure. It goes without saying that the regular and effective maintenance of all drains is essential.

7. Economic Analysis

In order to justify the upgrading of earth or any other unsealed road to a sealed road, an economic analysis needs to be carried out. Various techniques for this are available using software such as RED (Archondo-Callao, 1999). Obviously, the lower the construction, maintenance and rehabilitation costs of the road, the greater the benefits are (particularly in financial terms but also in economic terms). However, the major benefits resulting from improved access are social and these (together with environmental costs/benefits) are seldom taken into account in the cost/benefit analyses. The primary reason for this is that there are currently no acceptable models to estimate these benefits accurately. The value of benefits related specifically to all weather accessibility for rural communities is even more difficult to quantify.

Conventional economic analysis assesses both the financial costs (direct cost to the road authority) and the economic costs and benefits (total costs and benefits accruing to the national economy, ie, total costs and benefits irrespective of who incurs them). Where the conventional economic benefits, excluding social and environmental cost/benefits, determined as their present value after discounting and usually expressed as rate of return, are insufficient to justify upgrading of a road, the value of benefits required to make the rate of return equal to the discount rate (ie, the breakeven point) should be calculated. It is then a relatively simple process to assess this value in terms of the local population and environment and draw a conclusion as to whether the cost of upgrading can be justified on social or environmental grounds.

8. Sustainability

The effective provision of rural access roads must be sustainable in the long term. This sustainability includes environmental sustainability, technical sustainability and social sustainability.

Environmental sustainability

As has been briefly discussed earlier in the paper, unsealed roads are not sustainable in the long term. Apart from aspects related to depletion of gravel and environmental scarring, the unchecked generation of dust, erosion of surface aggregate and consequent pollution of the air and rivers cannot continue indefinitely. There is no doubt that sealing of unsealed roads with a bituminous (or concrete where necessary) layer reduces the direct environmental impacts.

Technical sustainability

Any project implemented must be technically sustainable. The engineered solution must cater for the traffic, environment and road users' needs in terms of capacity and road safety over the design life of the road.

Technical sustainability includes the appropriate maintenance capacity. All roads require regular maintenance, the frequency decreasing with pavement standard and cost. Unsealed roads typically require continual maintenance (frequent grader blading and periodic regravelling as well as intermittent maintenance related to exceptional precipitation events). Roads with bituminous surfacings require periodic resealing and ad hoc repairs of potholes, cracked areas, edge break, etc. The frequency of maintenance to asphalt and concrete roads is usually considerably less but where necessary, it must be rapidly and effectively carried out to avoid large-scale deterioration of the pavement.

Social sustainability

Once a community has roads providing all-weather access, it is not socially acceptable that this access is lost in time as a result of inadequate/poor maintenance, extreme hydrological events or as a result of any other cause. The biggest cause of loss of access is typically not related to the road pavement (unless maintenance is neglected) but is more likely the result of closures due to loss or damage to bridges and river crossings or closure due to instability and failure of cuts and fills. Neither of these is considered in this paper but these aspects should be considered during the project design.

Local communities should be actively involved in projects from the beginning including active participation in the decision making processes. They should also be involved during construction in order to develop a degree of ownership. Finally, the use of local communities for maintenance of the roads is essential to maintain this sustainability, particularly when labor-based construction techniques were used during construction. A good example of this is the use of the length-man maintenance system where individual teams are paid nominal amounts to maintain specific sections of the road to pre-defined standards.

Social sustainability has been found to be a particularly difficult problem when income is generated in the community during construction and is not extended after completion of construction into long-term maintenance activities.

9. Conclusions

The provision of all-weather access to rural communities should be a definite goal of all ruling administrations. The cost of providing all-weather roads

using conventional construction techniques is prohibitive resulting in many communities not having direct access to major transport routes or even facilities such as clinics and schools. Recent developments have shown that at least unsealed roads providing basic access can be economically constructed although they are not environmentally sustainable in the long term.

As the traffic in the majority of the areas without all-weather access is relatively light, only light pavement structures are generally required, even for sealed roads. These can be economically constructed using innovative designs and local materials as far as possible.

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