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**A Framework for the Appropriate Use
of Marginal Materials**

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INTRODUCTION

Unpaved gravel roads often constitute around 70 to 90 per cent of the designated road network in developing countries, whilst earth roads and tracks dominate the undesignated network. These roads, generally connecting the productive agricultural areas to the primary road network, play a vital social and economic role in the development of rural areas where the majority of populations live.

During the past 20 years or so, DFID and other Donors have supported research on various aspects of low volume roads specifically with the aim of reducing costs and increasing the effectiveness of the provision of such roads for rural and peri-urban communities. Much of this research has been highly successful, resulting in innovative and unconventional approaches that can provide highly beneficial and cost effective solutions for low volume roads in these counties, for example, the use of alternative road surfacings. Innovation in design, construction and maintenance practice, as well as more appropriate appraisal procedures now provide increased opportunities for the provision of sealed roads than was previously thought possible.

Key to the success of these innovative solutions is recognition that conventional assumptions regarding road design criteria need to be challenged and that the concept of an appropriate, or environmentally optimised design, approach provides a way forward. Low volume road standards and designs need to support the function that the road is providing as well as recognising the important influences of the deterioration mechanisms. The use of locally available, but frequently non-standard, pavement construction materials plays a significant role within this concept.

LOW VOLUME SEALED ROADS

The Requirement for Low Volume Sealed Roads

There is an increasing drive toward improving the sustainability of the existing rural networks by provision of first generation bitumen-surfaced roads, even as short sections through population centres or where difficult soil or terrain conditions require an improved surfacing. This can be achieved by adopting innovative and low cost sealing technologies (e.g. labour intensive approaches) and by using materials that may only meet a gravel wearing course standard.

Unpaved roads demand constant maintenance to arrest damage by both traffic and the environment. Re-gravelling is usually needed after only one or two years service, putting considerable strain on local financial, manpower and natural resources. There is now an appreciation that more attention needs to be paid to assessing the circumstances appropriate for gravel surfacing and the consideration of other options for low volume roads, particularly for rural communities.

There has emerged over the last 10 years a proven suite of sealed surfacing options that can provide appropriate and sustainable solutions for low-volume roads within sub-tropical and tropical regions, Table 1 (Petts, 2001). These options provide a real and sustainable alternative to the conventional approach of a gravel wearing course, (WSP-DFID, 2001). Low volume sealed roads (LVSRs) using thin bituminous seals or other alternative surfacings can,

Seal/Surface	Advantages	Disadvantages/Constraints
Bamboo Reinforced Concrete Surface	Labour-based. Durable with low maintenance costs. Good load spreading capabilities.	Bamboo availability and condition. Cement costs. Quality control on construction (joints in particular). Poor flexibility
Bituminous/Tar Sand Seal Surface	Good service record in S. African climate when regularly maintained and re-sealed periodically.	Requires smooth sound tight road-base. Requires regular maintenance. Requires bedding-in and skilled operatives.
Ottaseal Surface	Successful performance in tropical and sub-tropical Africa. Marginal aggregate quality can be accommodated.	Limited information for high rainfall tropical environments. Requires skilled operatives.
Bitumen/Tar Surface Dressing	Common intermediate technology option. Good performance record if well constructed (4-14 years)	Good construction control on base preparation and on binder & aggregate spreading. Suitable supply of quality aggregate
Bitumen Slurry Seal Surface (and "Cape" Seals)	Suitable for labour-based approach	Needs good quality road-base finish. Limitation on high gradients and tight curves. May require traffic >50vpd for best performance. Requires skilled operatives.
Bituminous Premix Macadam Surface	Suitable for steep gradients. Requires less maintenance than some seals (eg 15, 16).	Cost. Quality control on temperature at mixing and placement. Suitable supply of quality aggregate. Requires skilled operatives.
Semi-Penetration Macadam Surface	Well understood procedure. Suitable for labour-based construction and maintenance.	Bitumen costs. Road base grading and tightness
Full Penetration Macadam Surface	Well understood procedure. Suitable for labour-based construction and maintenance.	Bitumen costs. Road base grading and tightness

Table 1 Typical Low Volume Sealing Options

in appropriate circumstance, provide a cost-beneficial option in whole-life terms. The principal benefits of LVSRs are associated with the following

- Less periodic maintenance and whole-life cost benefits
- Conservation of natural resources
- All weather passability
- Reduction of environmental impact

Table 2 summarises the key issues surrounding the use of LVSRs in preference to the more conventional gravel road approach.

Perceived Difficulties of Implementation: - The Challenge

A number of factors combine to pose a major challenge to the development and implementation of LVSRs. These factors include:

- Standards and Specifications.** Insufficient research has been carried out to justify any change in the current standards and specifications. Where research has been carried out, limited funding is made available for effective dissemination and implementation of change is often inadequate. There is often reticence to transfer technology across borders without further local proof.
- Engineering uncertainty.** There is still reluctance, particularly by expatriate consultants and Donors, to utilize non-standard approaches (design, local materials, construction technology) because of a greater perceived risk of problems or even failure. This often emanates from a weakness in the condition of the contracting industry and the maintenance capacity is such that low maintenance-high standard options are needed.

- Political and public expectations.** These are conditioned by standards adopted for high volume trunk roads and acceptance of a lower, albeit more appropriate, standard on a LVSR is often deemed to be “sub-standard”.

Issue	Summary
Economic evaluation	Justifying upgrading of unpaved roads to a sealed road standard solely on conventional economic criteria often requires traffic levels in excess of 200 to 300 vehicles per day. This traffic threshold reflects the costs of using inappropriately high design and construction standards that are often applied to these types of road. However, by adopting a more realistic, flexible and innovative approach to the road design and construction, significant cost savings can be achieved and sealed roads can be justified at much reduced traffic levels.
Traffic	Existing LVR conditions may constrain and camouflage the traffic volume demand. Traffic volumes may also be relatively low but vehicle loads are often be high, with significant over-loading.
Maintenance demand	Unsealed gravel is a high-risk surface. A residual thickness, typically about 8-10cm is required for the gravel layer to function as a protection to the underlying sub-grade. When the residual gravel wears below this critical thickness the surfacing fails, forming potholes and rutting, and the remaining gravel is contaminated with the underlying soil. From the initial appearance of potholes (which signals immediate problem), this usually leaves insufficient time to mobilise funds, resources or contractors to carry out re-gravelling.
Maintenance costs	Conventional unsealed gravel roads require frequent re-gravelling to keep a network in reasonable condition. As a general rule undiscounted maintenance costs over the typical life of a low volume rural network will equal the initial construction costs. As gravel becomes increasingly scarce, haul distances and cost will continually increase.
Conservation of natural resources	Gravel is a non-replaceable natural resource and in many developing countries, naturally occurring reserves are scarce. It could be considered inappropriate to use such a natural resource as a wasting surface when there is the option to use it in a more permanent form of surfacing.
Construction and maintenance technology	The costs of gravelling and re-gravelling generally have a very high equipment component. For maintenance these funds flow out of the local communities to the large contractors and equipment suppliers. Some of the alternative surfaces could allow the maintenance to be carried out by small, district-based, enterprises using labour and low-cost simple equipment, with better retention of expenditure within the communities and possible related poverty alleviation benefits
Environmental impact	Gravel creates dust in the dry season, causing pollution for road users and also to people living adjacent to the road, their property and crops. It can lead to cleanliness and health problems. There are also road safety issues associated with poor visibility. The continuous development of borrow areas for maintenance and re-gravelling has significant health and safety issues for the local communities as well as impacting on future land-use.

Table 2 Low Volume Road Surfacing Issues

(Modified from: Gourley & Greening, 1999; Lebo & Schelling 2001; WSP-DFID, 2001)

These factors are commonly argued conservatively in terms of risk and presented as reasoning why the status quo should be maintained.

The effective promotion of LVSRs within an appropriate end-use environment needs a holistic and inclusive understanding of demands and benefits outside of those that are exclusively technical. It requires full acceptance from stakeholders at many levels, from governments, and funding agencies, through to consultants, contractors and road users.

Government policy will set the legal and regulatory framework against which responsibilities can be delegated, risks shared and change implemented. Government is best placed to influence and educate political and public perceptions on road types and standards and to demonstrate socio-economic and other benefits to local authorities and communities e.g employment creation, community involvement and participation in planning and resource management (small contractor development). Evaluation

tools should quantify both the social and economic costs/benefits). Road selection and priority setting must be carefully managed, with funding sources sustainable and robust.

The implementing institutions have a central role in managing change. Design and construction standards and specifications will fall under their responsibility. Flexibility to revise and implement change along with development of appropriate local training and capacity building is needed together with a strong local maintenance capability to adopt appropriate maintenance schedules. Budgetary allocations for maintenance must be rigidly committed.

The construction industry as a whole, from academic training institutions through to implementing authorities must have the capacity and knowledge to design, construct and maintain sealed roads.

Appropriate Design

Construction costs of the upper pavement layers (roadbase and sub-base) are typically about 30 to 40 per cent of the total road construction cost and it is clear that cost of construction and maintenance are crucial to the argument regarding LVSRs and that appropriate design approaches are essential.

The principal elements in the design process are the choice of materials and their thickness within each pavement layer. The design engineer, however, also needs to understand all other external impacts on the design, and to recognise the influence exerted by these other parameters. It may be "assumed" for example that adequate maintenance is carried out during the design period of the road. In practice this may not be the case.

In reality the performance of a road depends on a whole range of factors that cumulatively can be described as the "road environment". Factors important to the road environment can be broadly grouped as

- Natural environment factors – largely uncontrollable
- Project-related factors: - largely controllable
- Design response factors: - the tools for appropriate design

These factors, as defined in Table 3, together describe the matrix of road environment impacts that needs to be addressed by design response factors such as pavement type and thickness, road geometry, and earthwork and drainage arrangements that are in effect the tools for an overall appropriate design strategy. The road performance can be seen as a direct function of the road environment and its interaction with an appropriate design. In this respect, there is now an increasing amount of evidence to suggest that greater use can be made of natural gravels for pavement construction rather than the more expensive and commonly adopted options of crushed stone or stabilised materials.

NON-STANDARD MATERIALS

Definition

PIARC has previously defined non-standard and non-traditional materials as:

"...any material not wholly in accordance with the specification in use in a country or region for normal road materials but which can be used successfully either in special conditions, made possible because of climatic characteristics or recent progress in road techniques or after having been subject to a particular treatment." (Brunschwig, 1989)

For the purposes of this paper the discussion on non-standard materials has been limited to naturally occurring granular road-base and sub-base materials that do not comply with accepted specifications but which can perform adequately in service within identifiable limits.

Factor	Description
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Uncontrollable	Construction Materials	The nature, engineering character and location of construction materials are key aspects of the road environment assessment.
	Climate.	The prevailing climate will influence the supply (precipitation, water table), evaporation (temperature ranges and extremes) and movement (temperature gradients) of water. Climate impacts upon the road in terms of direct erosion through run-off, influence on the groundwater regime (hydrology), the moisture regime within the pavement, and accessibility for maintenance
	Surface and sub-surface hydrology.	It is often the interaction of water, or more specifically its movement, within and adjacent to the road structure that has an over-arching impact on the road performance.
	Terrain:	The terrain, whether flat, rolling or mountainous reflects the geological and geomorphological history. Apart from its obvious influence on the long section geometry (grade) of the road, the characteristics of the terrain will also reflect and influence the occurrence and type of soil present, type of vegetation, availability of materials and resources (location, type, suitability, variability)
	Sub-Grade Conditions	The sub-grade is essentially the foundation layer for the pavement and as such the assessment of its condition is fundamental to an appreciation of the road environment.
Controllable	Traffic	Findings from recent research indicate that the influence of traffic is often less than that from other road environment parameters in low volume roads. However, even for these roads due consideration still needs to be given to the influence of traffic on the performance of the structure
	Axle Loads	The deterioration of paved roads caused by traffic results from both the magnitude of the individual wheel loads and the number of times these loads are applied. For pavement design purposes it is necessary to consider not only the total number of vehicles that will use the road but also the wheel loads (or, for convenience, the axle loads) of these vehicles
	Construction Regime	The construction regime governs whether or not the road design is applied in an appropriate manner. Key elements include: <ul style="list-style-type: none"> • Appropriate plant use • Selection and placement of materials • Quality assurance • Compliance with specification • Technical supervision
	Maintenance Regime	All roads, however designed and constructed will require regular maintenance to ensure that the design life is reached. Indeed good maintenance can often extend the period that the road can function, well beyond the design life. Achieving this will depend on the maintenance strategies adopted, the timeliness of the interventions, the local capacity and available funding to carry out the necessary works

Table 3: Uncontrollable and Controllable Road Environment factors**The Role of Local Non-Standard Materials**

The nature, engineering character and location of construction materials are essential aspects of the road environment assessment. The adoption of an appropriate design approach carries with it a recognition that established criteria for road materials need to be looked at closely in terms of actual engineering purpose within individual road environments.

For low volume sealed roads we now recognise that there is a greater need to view the application of specifications and construction practices in terms of a “whole road environment”, rather than in terms of individual pavement layers. There is scope in some cases, and this is particularly so for low volume sealed roads, to consider a reduction in specification standard when considering particular material types within defined environments. Recognising “fitness for purpose” and an approach that “works with nature” is central to assessing the appropriate use of non-standard materials within defined road environments.

Basic general requirements for pavement materials are summarised in Table 4. Detailed specification to ensure these requirements are generally defined in terms of properties such as grading, compacted

strength and plasticity (TRL, 1993, Toole & Newill, 1987) The limiting criteria set out in traditional specifications for roadbase and sub-base materials are based on universal standards related to traffic levels. Where the materials fail to meet these criteria they are normally termed “marginal” and frequently, by implication, therefore “sub-standard.

Key Engineering Factor	Material Requirements
Strength	Aggregate particles need to be load resistant to any loads imposed during construction and the design life of the pavement.
Mechanical Stability	The aggregate as a placed layer must have a mass mechanical interlocking stability sufficient to resist loads imposed during construction and the design life of the pavement.
Durability	Aggregate particles need to be resistant mineralogical change and to physical breakdown due to any wetting and drying cycles imposed during construction or pavement design life
Haul Distance	Reserves must be within physically and economically feasible haulage distance.
Placeability	Material must be capable of being placed and compacted by the available plant.
Environmental Impact	Material reserves must be capable of being won and hauled within any governing environmental impact regulations.

Table 4 Fundermantal Roadbase Selection Factors

Studies by DFID and others have shown that the use of locally available materials can play a crucial role in the appropriate design context in terms of cost-saving, resource management and environment protection, Table 5. The following are seen as crucial points with respect to the ability of a material to carry out its assigned task within a road pavement:

- Knowledge of the key engineering properties of the material
- The task required of the material
- The governing road environment
- Future alterations to the road environment

By necessity, general specifications must cover a very wide range of material types and cater for extreme climatic environments. As a consequence they are likely to contain significant in-built factors-of-safety. By implication this means that proven specifications drawn-up for specific materials for particular environments need not be so conservative in approach and hence may allow the use of previously non-conforming or marginal materials.

There is a need to shift away from classifying such materials as “marginal” or using the term “marginal” as an all-encompassing descriptor, when in fact there is a real prospect of their effective use within an appropriate design. Marginality in the eyes of engineers infers a substandard product. This need not be the case if materials are appropriately assessed, used and promoted, hence the preferred use of “non-standard” as a description. At the same time there is an apparent need to assess the suitability of these materials in a manner that is technically justifiable and demonstrable to funding agencies and key stakeholders

Description and Classification

Marginal granular materials that could be considered for use in the upper pavement layers can effectively be grouped within a five tier system (TRL, 2002)

- **Group I: Hard Rocks:** usually comprising materials that require crushing and processing but retaining properties that result in the material does not fully meeting the requirements of a crushed stone base.
- **Group II: Weak rocks:** materials derived from weakly cemented, poorly consolidated or partially weathered parent deposits.
- **Group III: Natural Gravels:** transported and residual soils and gravels not meeting the minimum material standards for natural gravel roadbase.
- **Group IV: Duricrusts:** indurated or partially indurated soils not meeting the minimum material standards for natural gravel roadbase.
- **Group V: Manufactured materials:** include a range of man-made materials that could effectively be re-processed as granular pavement materials.

Figure 1 gives examples of materials that would commonly be associated with each of the groups and provides a summary review of typical non-standard aspects within each group.

Theoretically, guidelines and other specifications refer to the material in its compacted/laid state on the road. Conflicts, however, can arise between material acceptability as defined by the specification and material suitability in terms of its actual engineering performance as a road making material. This occurs because of:

- Inappropriate application of test methods
- Testing materials that are not in the final compacted/as-built state
- Inability to measure or assess the environmental influences
- Inherently non-standard engineering characteristics

THE EVALUATION FRAMEWORK

Objectives of an Evaluation Framework

Within the context of appropriate design, whole life road costing and the wider strategy of rural infrastructure development, decisions on the use of non-standard materials can involve a complex matrix of engineering, economic and socio-environmental issues. An evaluation framework is useful, therefore, to support the road practitioner in making and subsequently justifying decisions regarding the use or otherwise of non-standard materials.

Material & Reference	Location	Climatic Environment	Material Characteristics	Utilisation	Comment
Calcrete Lionjanga et al (1987) Greening and Rolt (1997)	Botswana	Semi-arid	Low particle strength Low compacted strength Poor grading High plasticity	Roadbase: Revised specifications developed for both sealed and unsealed shoulder designs. Successfully used as roadbase with acceptable performance (0.3×10^6 esa) for materials with soaked CBR >35% and PI <30 if shoulders are sealed.	Specifications proven only for dry and semi-arid climatic regions on roads constructed over strong (soaked CBR >25%) subgrade.
Laterite Grace and Toll (1987) Gourley and Greening (1997) CIRIA (1988)	Malawi	Seasonally wet tropical	Low particle strength Low compacted strength Poor grading High plasticity	Roadbase: Construction procedure modified to allow traffic to run on roadbase for one rainy season before proof rolling, shaping and sealing in the following dry season. All sites well drained and with crown-height at least over 1m.	Trials successful on trunk roads carrying traffic up to 1.0×10^6 esa. Crown height and provision of good drainage essential component of performance.
Marl Woodbridge et al (1987)	Belize	Wet humid tropical	Low particle strength Poor grading	Roadbase and sub-base: Embankment construction (600-750mm of fill) used throughout due to seasonally high water-table. Only non-plastic or slightly plastic materials selected. Controlled heavy compaction used to lock material and achieve >98% MDD. Good maintenance regime adopted including regular clearing of drains and unsealed shoulder maintenance.	After 20 years' service and traffic amounting to about 1.4M esa, the pavement is still in good condition, with negligible rutting. To prevent shoulder erosion, moisture ingress and preventable maintenance problems sealed shoulders must be considered.
Basalt Pinard & Jakalas, (1987).	Botswana	Sub-tropical	Crushed material (with added fines) passed specification criteria; but had demonstrably poor in-service durability.	Roadbase. Addition of plastic (active) fines to improve the grading along with modification using too low a percentage (below ICL) of lime (lime also suspect i.e. inactive) led to early failure due to moisture interaction/volumetric change in the road base material. Unsealed shoulder design.	Overburden fines, derived from basalt weathering should not be used to improve grading. Lime modification should exceed ICL. Sealed shoulder design recommended.
Weathered Basalt Gourley and Greening (1999)	Botswana	Sub-tropical	Ripped weathered (Grade III+) basalt selected. Grading out of recommended specification; PI <12 and soaked CBR >55.	Roadbase: Normal construction methodology adopted. 1m embankment and sealed shoulders.	Performed well with 0.25×10^6 esa over 14 years.
Coral Cardno & Davies (1994) Beavan (1971)	Papua New Guinea	Wet humid tropical	Low particle strength Poor grading (including oversize) High plasticity	Roadbase: Modified specification based on the requirement of high compaction giving dense layers (max. 150mm). Selection of appropriate compaction plant vital (a function of grading and PI)	Adequate for low volume sealed roads for the defined coral types only. Different corals may require different specifications.
Cinder Gravels Newill et al (1987)	Ethiopia	Semi Arid	Low particle strength and high porosity Poor grading	Roadbase: Procedures developed to control selection; mechanical stabilisation with ash fines and selection of appropriate compaction plant vital.	Successful in LVSR environment. A recent (2000) survey confirmed excellent performance with little deterioration in 20 years and approx. 3.0×10^6 esa.
Schist/Phyllite Fookes & Marsh 1981)	Nepal	Monsoonal sub-tropical	Poor aggregate shape	Modified processing procedure to ensure better shape	For labour intensive operations hand-crushing techniques proved effective for improving overall shape.

Table 5 Examples of the Use of Non-Standard Materials in Low Volume Sealed Roads

The evaluation framework, presented in Figure 2 and Table 6, is primarily aimed at practitioners within the low-volume sealed roads sector who are seeking to utilise locally available materials to reduce construction and other costs, whilst recognising and catering for any associated risks to the road structure. The approach is founded on a synthesis of current knowledge, practice and experience gained over many years in the tropics and sub-tropics. On the basis of a solid platform of knowledge, the aim is to give engineers the confidence to adopt and promote appropriate, cost effective options for low volume sealed roads. This level of confidence stems from an understanding of the demand on the material in the context of a load bearing layer and any modifying influence that the local environment and other external factors can have on its performance. The procedure aims to provide a technical resource on which local champions can develop sound engineering-based arguments to influence Government and other funding agencies so that “appropriate material selection” strategies can be developed and implemented.

Description of the Evaluation

Figure 2 presents an evaluation framework for assessing the suitability of roadbase and sub-base materials that have failed standard compliance criteria but are thought, nevertheless, on the basis of sound engineering judgement or experience, to have the potential for satisfactory in-service performance. The framework sets out a logical series of actions and outcomes that leads from problem identification through to the assessment of whether or not there is an acceptable level of risk for the selection of the material.

The aim of the flowchart is to highlight key issues that must be addressed in the assessment before a decision is made to utilise, modify or reject the material. This procedure follows a sequence of modules

- Identification of requirement for use
- Definition of non-standard properties
- Evaluation of existing information
- Evaluation outcomes
- Evaluation of engineering uncertainty
- Road trials
- Approval or non-approval for use

Table 6 summarises the key activities within each of these modules

At the start of the assessment approaches there will be a requirement to justify the investigation of the non-standard material and its use. This justification can involve economic, technical, social and environmental issues. At other key points during the evaluation where there are significant cost or time related implications there will be a requirement to justify the continuation of the investigation. This may require a re-evaluation of original issues and assumptions. Failure to justify proceeding will lead to the exploration and assessment of alternative material resources.

Justification Issues

Economic

- Alternative sources involve long hauls
- Higher quality materials are required for longer term developments
- Alternative sources carry development cost and time implications

Environmental

- There are environmental impact issues associated with alternative sources (health, safety, pollution, erosion, natural beauty)

Technical

- There is at least some evidence that the non-standard material may perform adequately
- There are no better alternative sources of sufficient quantity

Module	Purpose
A Requirement for Use of Non-Standard Material	Identify clear technical, economic or environmental reasons for considering the use of non-standard materials. <i>Leading to</i> justifiable reasons for considering further the use of the non-standard material.
B Definition of Non-Standard Properties	Identification and quantification of the engineering properties causing a material to fail compliance criteria and to be defined as non-standard <i>Leading to</i> a definition of the non-standard characteristics of the material
C Evaluation of Existing Information	Evaluation of all technical, economic and environmental data relevant to the possible use of the material in question as pavement aggregate. <i>Leading to</i> identification of the options for continuing the investigation into use or non use of the material.
D Evaluation of Options	Evaluation of the option, or options, identified on the basis of existing information <i>Leading to</i> a decision to pursue one of the following: <ul style="list-style-type: none">• An evaluation of engineering uncertainty• A re-evaluation with a modified environment• A recommendation for non-use.
E Evaluation of Engineering Uncertainty	Define the uncertainties associated with the use of the non-standard material and identify any consequent engineering and socio-economic risk <i>Leading to</i> a decision on whether the engineering uncertainties are an acceptable project risk or not, namely <ul style="list-style-type: none">• Acceptable risk provided materials that comply with a modified design or construction specification• Do not approve for immediate use but recommend that full scale trials be undertaken may be approved for downgraded use in the interim)• Risk unlikely to be acceptable in any event
F Road Trials	Identify the construction and long-term performance characteristics of the non-standard material. <i>Leading to</i> a decision as whether the material is capable of performing the assigned task in the road based an actual road performance data.
G Approval or Non-Approval for Use	To decide, on the basis of the information now available, whether to use or not use the non-standard material within the defined road environment. <i>Leading to</i> a recommendation for use or non-use

Table 6 Evaluation Modules for Non-Standard Materials**AN EXAMPLE OF THE ASSESSMENT PROCEDURE****The Project**

The Roads Department of the Ministry of Works and Communications of Botswana (MOWC) and TRL carried out a research programme on the performance of calcrete road base materials between 1978 and 1993, within the Kalahari, on the Jwaneng-Kanye road involving full-scale

experimental road trials. The following sections to illustrate how Figure 2 can be utilised as a decision making aid in the context of non-standard material usage for a LVSR

Background

Calcrete forms as the result of precipitation of carbonate solutions within a host granular material (e.g. sand or other soil). Carbonate in solution can be transported into an environment where these solutions become increasingly unstable and concentrated to the point where precipitation takes place. In conditions of sustained high temperature and low humidity, evaporation rates are high, contributing to the precipitation of dissolved carbonates. Fine particles of precipitated carbonate coalesce and concentrate over time to produce soft nodules within the host material, cementing together the soil particles. As the host material becomes increasingly cemented by carbonate particles and voids are infilled, so the soil structure becomes increasingly dense. Depending on the degree of induration the resulting calcrete can vary from a loose calcareous sand through to a nodular or massive sheet-like deposit. The degree of induration will influence the resulting engineering properties and can be used to broadly classify types of calcrete. Although five broad calcrete groups can be defined, engineering characteristics within these groups can be very variable (Netterberg, 1971). The nature of the deposit, method of selection and extraction, mode of operation and type of plant used on site, as well as the engineering test methods themselves can all influence the reported test results.

Description of Assessment Modules

Key activities, based on Figures 2 and Table 6 are outlined below:

A. Requirement for use

- I. Existing proven sources of basalt aggregate for roadbase involved 300-500km of haulage. Significant cost and environmental implications were associated with these long hauls There were no other specification-compliant materials at closer locations.
- II. Some evidence existed for the satisfactory engineering performance of gravelly calcrete from rural and un-surfaced road projects.
- III. Investigation of the use of calcretes was therefore considered justified and agreed by the Botswana Ministry of Works and Communications (MOWC, 1982)

B. Definition of Non-Standard Properties

- I. Test procedures were assessed as acceptable in terms of procedure and relevance. Tests of special relevance were identified as linear shrinkage, total soluble salts and the pliers particle strength test. An assessment chart was derived for calcretes in terms of specification criteria
- II. Potential calcrete sources were defined as being highly variable in character and frequently out of standard specification in terms of grading, plasticity and particle strength. A capacity to breakdown under compaction was also noted.

C. Evaluation of Existing Information

- I. Several specifications were reviewed in the context of the road environment and the engineering characteristics of calcrete. The MOWC specification was assessed as being the most applicable as a starting point for developing a new acceptability criteria
- II. Key issues regarding the engineering properties of the calcrete were perceived to be the percentage of weak particles, its moisture susceptibility and the poor grading

characteristics. These, which could lead to poor load bearing capacity, collapse or shear failure and degradation under traffic

- III. The review concluded that there was insufficient information available to enable relaxation of specifications without further research (Option D2).

D. Evaluation of Options

- I. Further laboratory testing was undertaken, concentrating on moisture susceptibility and its impact on compacted strength. To this end a programme of Texas triaxial testing was initiated.
- II. No similar calcrete roads existed to use for performance data gathering. However, the additional laboratory test results were sufficiently promising to justify proceeding with an engineering uncertainty and risk evaluation.

E. Evaluation of Engineering Uncertainty

- I. The evaluation showed that significant uncertainty remained as to long-term performance, particularly as the additional testing had exposed the sensitivity of fine calcrete to wetting. In the light of this identified significant risk it was concluded that calcrete could not be recommended without further studies. It was also decided at this stage to include mechanical and chemical stabilisation options in any further studies.
- II. A recommendation for long-term road trials was made, incorporating both stabilised and unstabilised calcrete roadbase. The Botswana MOWC, as the principle stakeholder, agreed with this course of action.

F. Road Trials

- I. The trial design was based on minimal variability; all road environment factors were kept constant apart from material type and its stabilised state. Trials comprised four sections with unstabilised types of calcrete and one section each of lime, cement and mechanically stabilised fine calcrete. Construction and in service performance were monitored, the latter for 13 years.
- II. Analysis of the trial results enabled a definition of the limits of use for each of the unstabilised materials up to certain levels of traffic. The chemical and mechanical stabilisation trial sections performed poorly

G. Approval or Non-Approval for Use

- I. Based on the trial results it was possible to recommend the use of the four types of calcrete as roadbase within the defined road environment. Appropriate specifications and guidelines for use were drawn up this basis, Table 7.
- II. Chemically and mechanically stabilised fine calcrete was not recommended for use.

Usefulness and Application

The above back-analysis exercise has indicated the usefulness of a systematic approach to the assessment of non-standard road base materials. The principles established for assessing roadbase materials can reasonably be adapted to deal with earthwork and imported sub-grade (capping layer) materials. The appropriate selection and use of earthwork materials can be of particular importance in hilly or mountainous terrain where locally

available materials may not meet internationally accepted criteria for acceptability. A pragmatic approach to earthwork design allied to a rational assessment of the fill properties can lead to the materials being classed as suitable for use.

Material property	Original BRDM	Revised specification based on variable traffic (esa)					
Maximum traffic level (esa)		0.3 x10 ⁶	0.5 x10 ⁶	0.7 x10 ⁶	1.0 x10 ⁶	1.5 x10 ⁶	
Maximum size	53	75	75	75	75	75	75
Passing 0.425mm sieve (max)	10-30	80	70	60	50	50	50
Liquid limit (max)	25	70	65	60	50	40	
Plastic index (max)	6	30	25	20	15	12	
LS x % passing 0.425mm sieve (max)	170	1000	800	600	400	250	
Minimum CBR (4 days soaked)	80 ^(a)	35	40	50	60	60	

(a) At 98% mod. AASHTO compaction (AASHTO T180, 1986)

Table 7 Revised Specification for Calcrete Bases (sealed shoulders) compared with Original Botswana Road Design Manual (BRDM) recommendations (samples from borrow pits)

FURTHER DEVELOPMENT

The evaluation procedure outlined in the previous sections is purely a framework to collate existing information effectively and make decisions regarding additional research and assessment of risk. Its practical usefulness depends on the knowledge base with which it can be allied. The knowledge base on non-standard materials and their utilisation environments would benefit from further work in three key areas:

- *Back analysis and collation of archived research.* Substantial amounts of existing information on the properties and application of non-standard materials and their use is available, but needs collating and storing in easily accessible formats. There is also a need to link this information with separate data sets on road environments.
- *Fresh research into materials and road environments not yet investigated.* Although the existing body of information on non-standard materials is large, there are still substantial gaps, particularly with respect to their use in defined road environments.
- *Commissioning effective means of dissemination of research to a full range of road practitioners.* The effective transfer of research into practical road engineering benefit for developing countries continues to be a difficult step that requires increased attention. The use of a rational approach to non-standard material use can be seen as a means to unlock research knowledge, the dissemination of which will be aided by the use of websites such as the recently established transport-links website (transport-lonks.org). This could be a significant step towards overcoming dissemination barriers.

CONCLUSIONS

The use of an appropriate design philosophy can be effectively utilised for the provision sealed road options for low volume roads that would otherwise be deemed to be most suited to a gravel wearing course design.

The use of locally available non-standard natural gravels is a vital aspect within the appropriate design concept. It is necessary however to engender confidence in the use of materials that would normally have been classified unacceptable or, at best, marginal.

An assessment framework has been developed that seeks to provide a transparent and technically sound basis for making rational decisions on the use or non-use of non-standard materials. Back analysis of non-standard material use has confirmed the usefulness of the procedure.

Further development is required in terms of linking the assessment procedure to an accessible knowledge base and in ensuring its effective practical utilisation.

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		Non-Standard Material Groups																					
		Strong Rock		Weak Rock						Natural Granular Materials					Pedogenic Materials								
		Foliated Metamorphic Rocks	Basic Igneous Rocks	Recent Coral Deposits	Marls and weak Limestones	Weak Volcanic Breccias/Agglomerates	Weak Congolmerates	Weak Sandstones	Weak Volcanic Tuffs	Fractured/Weathered Limestones	Shales/Mudstones	Weathered Strong Rocks	Alluvial Sands	Alluvial Clayey Sand Deposits	Aeolian Sand Deposits	Colluvial Deposits	Alluvial Gravel Deposits	Volcanic Pyroclastics	Residual Clayey Sand Deposits	Residual Gravel Deposits	Laterite Deposits	Calcrete Deposits	Silcrete Deposits
Primary Specification Criteria	High PI Fines																						
	Low Particle Strength																						
	Poor Grading																						
	Poor Durability																						
	Poor Particle Shape																						
Additional Impacting Criteria	High Mica Content																						
	High Water Absorbtion																						
	High Variability																						
	In-service Deterioration																						
	Low PI Fines																						



Potential Problem Characteristics

Figure 1 Non Standard Material Groups and their Likely Problems

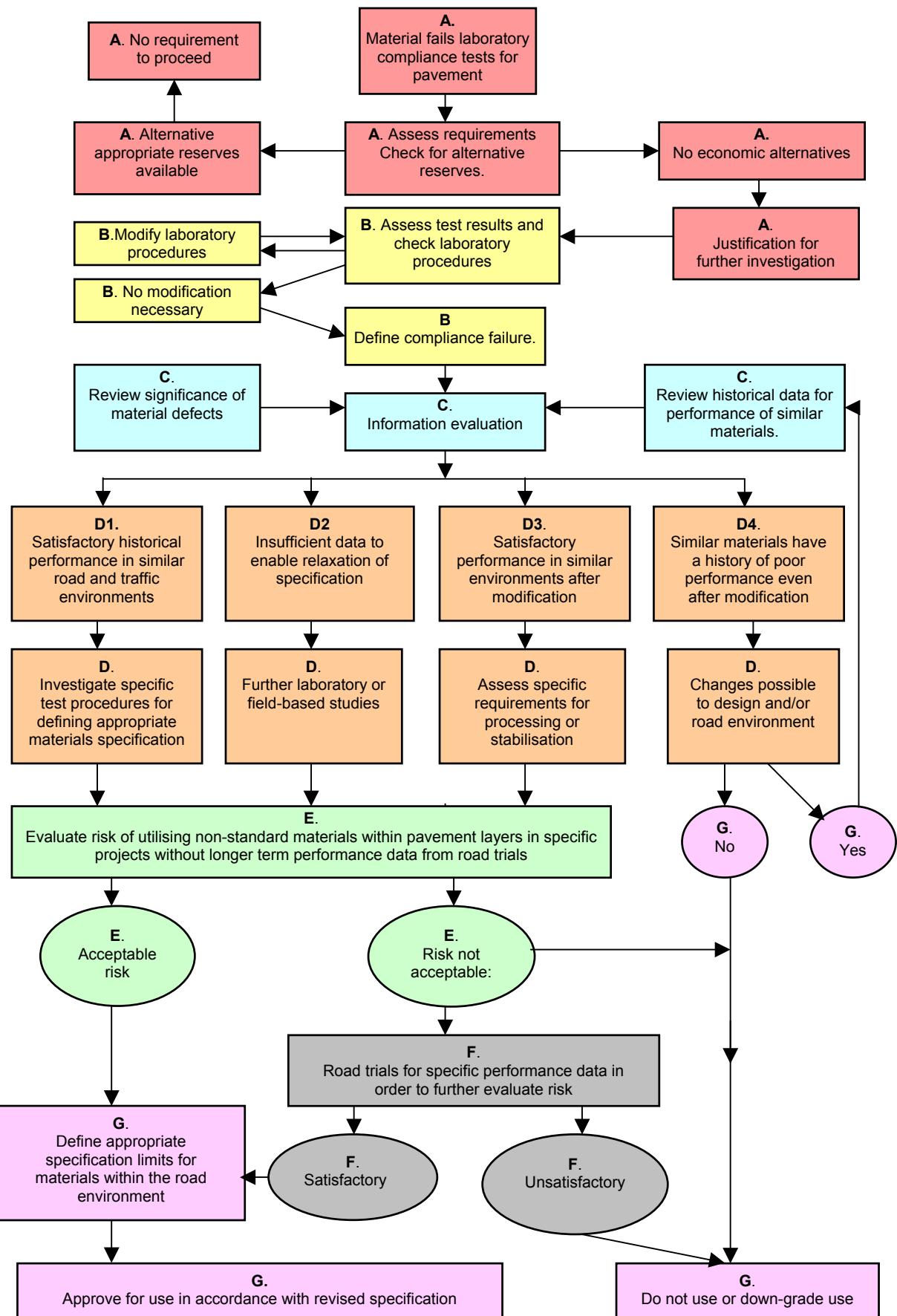


Figure 2 Evaluation of non-standard materials for use in pavements

