AFCAP

Low Volume Rural Road Surfacing and Pavements

A Guide to Good Practice

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The programme is currently active in Ethiopia, Kenya, Ghana, Malawi, Mozambique, Tanzania, Zambia, South Africa, Democratic Republic of Congo and South Sudan and is developing relationships with a number of other countries and regional organisations across Africa.

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Preface

This Guideline is aimed at engineers, road managers and others involved with the planning, design, construction or maintenance of Low Volume Rural Roads in developing and emerging regions in temperate and tropical climates. It is intended to provide key knowledge and guidance on a range of proven road surfacing and paving techniques that offer relatively low cost and sustainable solutions for road works, focusing on the optimal use of local resources, in often challenging physical and operational environments.

This Guideline compiles the lessons learnt from the design, construction, supervision and monitoring of a range of surface and paving types trialled and investigated in the Cambodia, Laos and Vietnam SEACAP projects, together with the knowledge compiled in the SADC Guideline, and other relevant programmes such as the ongoing AFCAP research. Its scope ranges from Engineered Natural Surfaces (earth roads), through gravel to the various unbound, natural stone, bituminous, cement-based and clay brick surfacing and pavement layers.

One of the fundamental principles behind the recent pavement research output has been the requirement for locally orientated solutions based on available local resources and the local road environment. This approach is seen as crucial in the development of affordable and sustainable rural road infrastructure.

Undertaking pavement and surfacing research and developing likely solutions are not in themselves enough if any practical outcomes are to be achieved. There has to be a dissemination framework within which solutions can be mainstreamed and a vital part of this framework is the production of practical and locally relevant guidelines. There was therefore a need to compile and synthesise the recently acquired LVRR knowledge into a concise international LVRR Surface and Pavement Guideline (LVPG). This will aid rural road practitioners in the development and implementation of local “good-practice” pavement and surfacing designs and construction procedures which best suit conditions within individual countries or regions.

Experience has indicated the advantages of drafting a document presenting issues and procedural guidelines unencumbered with excessive technical detail, whilst at the same time making reference to technical methodologies which can be adapted to local conditions and resources.

The approach adopted by the LVPG of providing general guidance within an overall framework together with key references is therefore considered the best approach for the development and application of locally relevant good practice. The adoption of a web-postable strategy was seen as adding important elements of increased flexibility and easier access to information. In a dynamic research and knowledge accumulation environment the approach also allows regular review and update.

A good practice rural road surfacing and pavement guideline must be aimed at local application. An inclusive rural pavement design manual covering all developing country regions is not considered a practical approach. For example, a comprehensive LVRR design manual that sought to include options for sparsely populated roads in mountainous Nepal; heavily populated low lying flood areas in the Mekong Delta in Vietnam or the low rainfall near-desert areas of Botswana would either be very cumbersome or too inflexible for practical use.

This guideline is based primarily around recent research in Sub-Saharan Africa and S. E. Asia and is therefore principally of use in tropical and sub-tropical regions in Africa, Asia and possibly South America. It contains no reference to the special conditions governing rural roads in cold climates.

Acknowledgements

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ABBREVIATIONS, ACRONYMS

AADT	Annual Average Daily Traffic
ADB	Asian Development Bank
AFCAP	African Community Access Programme
AfDB	African Development Bank
CBR	California Bearing Ratio
CD	Compact Disc
CRRR	Climate Resilient Rural Road
DCP	Dynamic Cone Penetrometer
DfID	Department for International Development
DVD	Digital Versatile Disc
EDCs	Economically emerging and Developing Countries
EIA	Environmental Impact Assessment
ENS	Engineered Natural Surface
EOD	Environmentally Optimised Design
esa	equivalent standard axle
FS	Feasibility Stage
FED	Final Engineering Design
gTKP	Global Transport Knowledge Partnership
GWC	Gravel Wearing Course
Km	kilometre
LVPG	Low Volume Road Surfacing and Pavement Guideline
LCS	Low Cost Surfacing
LL	Liquid Limit
LVRR	Low Volume Rural Road
LVSR	Low Volume Sealed Roads
NMT	Non-Motorised Transport
OPC	Ordinary Portland Cement
PED	Preliminary Engineering Design
PCU	Passenger Car Unit
PI	Plasticity Index
PL	Plastic Limit
PMU	Project Management Unit
RRSR	Rural Road Surfacing Research

RRST Rural Road Surfacing Trials

RT3 Rural Transport 3 Project (Vietnam)

SADC South African Development Community

SDMS Surfacing Decision Management System

S E South East

SEACAP South East Asia Community Access Programme

TA Technical Assistance

ToR Terms of Reference

WLAC Whole Life Asset Costs

WLC Whole Life Costs

WBM Water-Bound Macadam

Glossary of Technical Terms

Aggregate (for construction)
A broad category of coarse particulate material including sand, gravel, crushed stone, slag and recycled material that forms a component of composite materials such as concrete and pre-mix asphalt.

Asphalt
A mixture of inert mineral matter, such as aggregate, mineral filler (if required) and bituminous binder in predetermined proportions (Sometimes referred to as Asphaltic Concrete or Asphalt Concrete). Usually pre-mixed in a plant before transport to site to be laid and compacted. Expensive and usually only used on main roads. Also used as an alternative term for Bitumen in some regions, and may be a petroleum processing product or naturally occurring in deposits.

Binder, Bituminous
Material used in road construction to bind together or to seal aggregate or soil particles, can be bituminous, cement or polymer based.

Bitumen
A non-crystalline solid or viscous mixture of complex hydrocarbons that possesses characteristic agglomerating properties, softens gradually when heated, is substantially soluble in trichlorethylene and is usually obtained from crude petroleum by refining processes. Referred to as Asphalt in some regions.

Bitumen, Cutback
A liquid bitumen product obtained by blending penetration grade bitumen with a volatile solvent to produce rapid curing (RC) or medium curing (MC) cutbacks, depending on the volatility of the solvent used. After evaporation of the solvent, the properties of the original penetration grade bitumen become operative.

Bitumen, Penetration Grade
That fraction of the crude petroleum remaining after the refining processes which is solid or near solid at normal air temperature and which has been blended or further processed to products of varying hardness or viscosity.

Bitumen emulsion
A mixture of bitumen and water with the addition of an emulsifier or emulsifying agent to ensure stability. Conventional bitumen emulsion most commonly used in road works has the bitumen dispersed in the water. An invert bitumen emulsion has the water dispersed in the bitumen. In the former, the bitumen is the dispersed phase and the water is the continuous phase. In the latter, the water is the dispersed phase and the bitumen is the continuous phase. The bitumen is sometimes fluxed to lower its viscosity by the addition of a suitable solvent.

Bitumen Emulsion, Anionic
An emulsion where the emulsifier is an alkaline organic salt. The bitumen globules carry a negative electrostatic charge.

Bitumen Emulsion, Cationic
An emulsion where the emulsifier is an acidic organic salt. The bitumen globules carry a positive electrostatic charge.

Bitumen Emulsion Grades
Premix grade: An emulsion formulated to be more stable than spray grade emulsion and suitable for mixing with medium or coarse graded aggregate with the amount smaller than 0.075mm not exceeding 2%.
Quick setting grade: An emulsion specially formulated for use with fine slurry seal type aggregates, where quick setting of the mixture is desired.
Spray grade: An emulsion formulated for application by mechanical spray equipment in chip seal construction where no mixing with aggregate is required.
Stable mix grade: An emulsion formulated for mixing with very fine aggregates, sand and crusher dust. Mainly used for slow-setting slurry seals and tack coats.

Blinding
a) A layer of lean concrete, usually 5 to 10 cm thick, placed on soil to seal it and provide a clean and level working surface to build the foundations of a wall, or any other structure.
b) An application of fine material e.g. sand, to fill voids in the surface of a pavement or earthworks layer.

Borrow Pit
An area where material is excavated for use within another location

Brick (fired clay)
A hard durable block of material formed from burning (firing) clay at high temperature.

California Bearing Ratio (CBR):
The value given to an ad-hoc penetration test where the value 100% applies to a standard sample of good quality crushed material

Camber
The road surface is normally shaped to fall away from the centre line to either side. The camber is necessary to shed rain water and reduce the risk of passing vehicles colliding. The slope of the camber is called the Crossfall. On sharp bends the road surface should fall directly from the outside of the bend to the inside (superelevation).

Cape Seal
A multiple bituminous surface treatment that consists of a single application of binder and stone followed by one or two applications of slurry.

Carriageway
The road pavement or bridge deck surface on which vehicles travel.

Cement (for construction)
A dry powder which on the addition of water (and sometimes other additives), hardens and sets independently to bind aggregates together to produce concrete. Cement can also be used to stabilise certain types of soil. Cement is also sometimes used as a fine filler in bituminous mixes.

Chippings
Clean, strong, durable pieces of stone made by crushing or napping rock. The chippings are usually screened to obtain material in a small size range.

Chip Seal, Single
An application of bituminous binder followed by a layer of stone or clean sand.

Chip Seal, Double
An application of bituminous binder and stone followed by a second application of binder and stone or sand. The second seal usually uses a smaller aggregate size to help key the layers together. A fog spray is sometimes applied on the second layer of aggregate.

Cobble Stone (Dressed stone)
Cubic pieces of stone larger than setts, usually shaped by hand and built into a road surface layer or surface protection.

Compaction
The process whereby soil particles are densified, by rolling or other means, to pack more closely together, thus increasing the dry density of the soil.

Concrete
A construction material composed of cement (most commonly Portland cement, but occasionally using other available cementitious materials such as fly ash and slag cement), aggregate (generally a coarse aggregate such as gravel or crushed stone plus a fine aggregate such as sand), water, (and sometimes chemical admixtures to improve performance or for special applications).

Crossfall
See Camber

Crushed Stone
A form of construction aggregate, typically produced by mining a suitable rock deposit and breaking the removed rock down to the desired size using mechanical crushers, or manually using hammers.

Curing
The process of keeping freshly laid/placed concrete or stabilised soil moist to prevent excessive evaporation with attendant risk of loss of strength or cracking. Similarly with cement or lime stabilised layers.

Design speed
The assessed maximum safe speed that can be maintained over a specified section of road when conditions are so favourable that the design features of the road govern the speed.

Distributor
A vehicle or towed apparatus comprising an insulated tank, usually with heating and circulating facilities, and a spray bar capable of applying a thin, uniform and predetermined layer of binder. The equipment may also be fitted with a hand lance for manual spraying.

Ditch (Drain)
A long narrow excavation designed or intended to collect and drain off surface water.

Drainage
Interception and removal of ground water and surface water by artificial or natural means.

Dressed Stone
See Cobble Stone

Dry-bound Macadam
A pavement layer constructed where the voids in a large single-sized stone skeleton are filled with a fine aggregate, vibrated in with suitable compaction equipment.

Earth Road
See ENS.

Embankment
Constructed earthworks below the pavement raising the road above the surrounding natural ground level.

ENS (Engineered Natural Surface)
An earth road built from the soil in place at the road location, and provided with a camber and drainage system

ESA (Equivalent Standard Axle)
A design concept to enable the damaging effect of a range and number of different axle loads, to be considered in the structural design of a pavement. The equivalent standard axle imposes a load of 8,200 Kg.

Expansive soil
Typically clayey soil that undergoes large volume changes in direct response to moisture changes.

Filler
Mineral matter composed of particles smaller than 0.075mm.

Formation
The shaped surface of the earthworks, or subgrade, before constructing the pavement layers.

Geocells
Typical cellular confinement systems are made with ultrasonically-welded high-density polyethylene (HDPE) or Novel Polymeric Alloy strips that are expanded on-site to form a honeycomb-like structure which may be filled with sand, soil, rock or concrete..

Gravel (Construction Material)
A naturally-occurring, weathered or naturally transported rock within a specific coarse particle size range. Gravel is typically used as a pavement layer in its natural or modified condition, or as a road surface wearing course. Suitable gravel may also be used in a graded gravel seal in appropriate circumstances.

Hand Packed Stone
A layer of large, angular broken stones laid by hand with smaller stones or gravel rammed into the spaces between stones to form a road surface layer.

In Situ
Taken in position (i.e. test undertaken on the material within its natural state, rather than a sample taken for a lab test).

Intermediate Equipment
Simple or intermediate equipment, designed for low initial and operating costs, durability and ease of maintenance and repair in the conditions typical of a limited-resource environment, rather than for high theoretical efficiency.

Laterite
Residual deposits formed under tropical climatic conditions. Laterite consist of iron aluminium oxides.

Lime
Lime in a material derived from the burning of limestone or chalk. It is normally obtainable in its 'hydrated' form (slaked) as Calcium Hydroxide. It can be used for the drying, improvement and stabilisation of suitable soils, as an anti-stripping agent in the production of bituminous mixes and as a binder in masonry or brick work mortars.

Local Resources
These can be human resources, local government, private, NGO, and community institutions, local entrepreneurs such as contractors, consultants, industrialists and artisans, local skills, locally made or fabricated intermediate equipment, local materials such as local produced aggregates, bricks, timber and marginal materials, locally raised finance or provision of materials or services in kind.

Low Volume Road
Roads carrying up to about 300 motor vehicles per day and intended to carry less than about 1 million equivalent standard axles over their design life.

Macadam
A mixture of broken or crushed stone of various sizes (usually less than 6cm) laid to form a road surface layer. Bitumen macadam uses a bituminous binder to hold the material together. Tarmacadam uses tar for the same purposes. Bound macadams are usually expensive for use on LVR.

Otta Seal
A carpet of graded (natural gravel or crushed rock) aggregate spread over a freshly sprayed hot bituminous 'soft' (low viscosity) binder and rolled in with heavy roller.

Pavé
See Sett

Paved Road
A paved road is a road with a Stone, Bituminous, Brick or Concrete surfacing.

Pavement
The constructed layers of the road on which the vehicles travel.

Peri-urban
Immediately adjoining an urban area or village area.

Penetration Macadam
A pavement layer made from one or more applications of coarse, open-graded aggregate (crushed stone, slag, or gravel) followed by the spray application of bituminous binder. Usually comprising two or three applications of stone each of decreasing particle size, each grouted into the previous application before compaction of the completed layer.

Plasticity Index (PI):
LL – PL, an indication of the clay content of soils; the larger the PI, the larger the clay content.

Plasticity Modulus
The product of Plasticity Index (PI) and percentage fraction passing 425 micron sieve.

Reinforced Concrete
A mixture of coarse and fine stone aggregate bound with cement and water and reinforced with steel rods or mesh for added strength.

Reseal
A surface treatment applied to an existing bituminous surface.

Road Base and Sub-base
Pavement courses between surfacing and subgrade.

Road Maintenance
Suitable regular and occasional activities to keep pavement, shoulders, slopes, drainage facilities and all other structures and property within the road margins as near as possible to their as constructed or renewed condition. Maintenance includes minor repairs and improvements to eliminate the cause of defects and avoid excessive repetition of maintenance efforts.

Roadway
The portion within the road margins, including shoulders, for vehicular use.

Seal
A term frequently used instead of “reseal” or “surface treatment”. Also used in the context of “double seal”, and “sand seal” where sand is used instead of stone.

Sett (Pavé)
A small piece of hard stone trimmed by hand to a size of about 10cm cube used as a paving unit.

Shoulder
Paved or unpaved part of the roadway next to the outer edge of the pavement. The shoulder provides side support for the pavement and allows vehicles to stop or pass in an emergency.

Slope
A natural or artificially constructed surface at an angle to the horizontal.

Slurry
A mix of suitably graded fine aggregate, cement or hydrated lime, bitumen emulsion and water, used for filling the voids in the final layer of stone of a new surface treatment or as a maintenance treatment (also referred to as a slurry seal).

Squeegee
A small wooden or metal board with a handle for spreading bituminous mixtures by hand.

Stringer
Longitudinal beam in a bridge deck or structure.

Sub-base
See Road Base.

Subgrade
The natural material or earthworks formation underneath a constructed road pavement.

Surface Dressing
A sprayed or hand applied film of bitumen followed by the application of a layer of stone chippings, which is then lightly rolled.

Surface Treatment
A general term incorporating chip seals, slurry seals, micro surfacing, or fog sprays.

Surfacing
The road layer with which traffic tyres make direct contact.

Sustainability
A term relating to the capacity of a structure to endure

Template
A thin board or timber pattern used to check the shape of an excavation.

Unpaved/Unsealed Road
A road with a soil or gravel surface.

Waterbound Macadam
A pavement layer constructed where the voids in a large single-sized stone skeleton are filled with a fine sand, washed in by the application of water.

Wearing Course
The upper layer of a road pavement on which the traffic runs and is expected to wear under the action of traffic. This applies to gravel and bituminous surfaces.

ANNEXES

Low Volume Rural Road Surfacing and Pavements

A Guide to Good Practice

1 INTRODUCTION

1.1 Background

It is an established maxim that effective transportation plays a crucial role in rural socio-economic development and in reducing poverty (205). The typical situation in most low-income countries is one of a large rural population with agricultural-based economies where the imperative is to provide rural communities with safe and sustainable access to basic services. In these countries, a high percentage of the rural road network remains unpaved (Table 1.1) with conventional road-building materials often scarce or available only at high cost (194).

Table 1.1 Comparisons of Rural Road Status

Country/Region	Rural Roads (km)	% Unsealed
Indonesia	291,00	46
Philippines	168,700	80
Cambodia	21,700	96
Lao PDR	21,700	85
Vietnam	130,000	82
Bangladesh	205,100	86
Mongolia	37,900	97
Kenya	37,370	94
SADC	410,000[1]	95

Data source (136, 194)

Unsealed roads usually have a running surface consisting of earth or natural gravel and require relatively high levels of regular maintenance. Often there are insufficient resources or capacity to provide adequate maintenance of these unsealed routes and users and communities consequently suffer poor access and/or high transport costs. It is, therefore, increasingly important to encourage further development of rural road networks in an affordable and sustainable way by efficiently utilising local resources to provide cost-effective transport infrastructure.

Decision makers and road asset managers need access to the available knowledge on good practice regarding the construction and maintenance of proven road surface and paving options so that the best use can be made of the available limited resources to maintain and further develop effective and affordable rural transport access.

[1] This SADC figure does not include approximately 396,000 km of unsealed main roads many of which are low volume.

During the past 20 years, DfID and other donors and agencies have supported research and knowledge transfer on various aspects of rural infrastructure specifically with the aim of reducing costs and increasing the sustainable effectiveness of the provision of road access for rural and peri-urban communities. Much of this targeted research has been highly successful, resulting in innovative and unconventional approaches that can provide highly beneficial and cost effective solutions for low (traffic) volume roads in these counties through, for example, the use of alternative road surfacings.

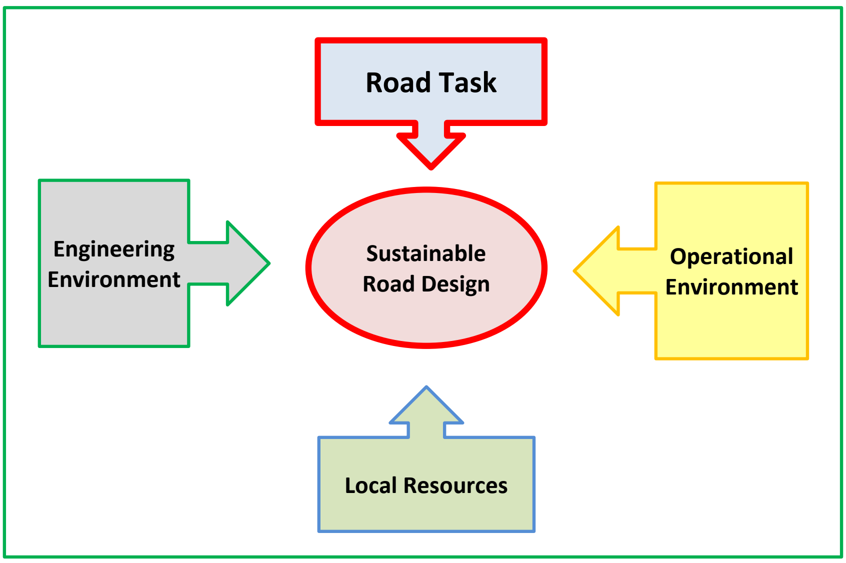
DfID and World Bank funded research under the South East Asia Community Access Programme (SEACAP) has developed a considerable amount of knowledge on Low Volume Rural Road (LVRR) paving and surfacing techniques suitable for application in resource constrained conditions, whilst, research in the Southern Africa region enabled a Low-Volume Sealed Roads Guideline (LVSR Guideline) to be developed. Surfacing and road pavement investigations continue under the Africa Community Access Programme (AFCAP) and the World Bank in cooperation with the Government of Vietnam.

1.2 Guideline Principles

The objective of the LVPG is to provide road practitioners, including non-engineering decision-makers, with a practical source document on the planning, design, construction and management of LVRRs, which is authoritative and contemporary. As such it lays out a key framework, defines key issues and clearly signposts procedures that may usefully be followed in order to respond to regional and user specific challenges. The Guideline is set within the principle that the roads should be designed to be compatible with the local governing factors; as outlined below and illustrated in Figure 1.1:

1. **Task based;** roads must suit their identified function and the nature of the traffic (the people as well as the vehicles) which will pass along them, by applying appropriate standards.
2. **Environmentally compatible**; suitable for, and if necessary adapted to, the local road environment factors.
3. **Local resource based**; road design guidance must be compatible with the construction materials that are readily available within appropriate specifications, within the capacities of the engineers and technicians who will design the roads and the contractors and labourers who will construct them, and within the means of communities or local organisations to maintain them.

Figure 1.1 Local Factors Governing Sustainable Design



1.3 The Structure of the Guideline

The LVPG comprises two principal elements:

1. A electronic text document which provides a framework of key issues, general procedures, recommendations and key reference links, that is linked to:
2. A database of selected references emphasising recent research that provides detailed practical information on the processes relating to the selection and design of sustainable LVRRs.

Both components are available to download free of charge from sector-recognised websites, and are available on DVD for practitioners and others without easy internet access.

Following this Introduction the document contains sections on:

Guideline Use: A summary of how the best use may be made of the Guideline.

Key Issues: A summary of the key issues which are central to the objectives of the Guideline with key references and recommendations.

Good Practice: A series of sections describing good practice procedures linked to the main elements of the Pavement Life Cycle.

Annex A: Pavement and Surfacing Options**:** Summary sheets highlighting advantages and drawbacks for the range of unsealed, flexible sealed, block and concrete pavement options suitable for LVRR application.

Annex B: Environmentally Optimised Design (EOD**):** A stand-alone summary of the key principles behind EOD and Spot Improvement.

Annex C: Example Surface Option Selection Process**.**

2 GUIDELINE FRAMEWORK

2.1 General Application of the LVRR Surfacing and Pavement Guideline

The Guideline has been designed for use by a wide spectrum of LVRR practitioners such as:

- Funding agencies;
- Ministries or Local Road Authorities;
- Infrastructure planners;
- Road owners;
- Road designers,
- Road builders (contractors);
- Road managers (responsible for maintenance and upgrading);
- Road users (communities).

Each of these groups may have a range of uses for the Guideline which may be broadly divided into the separate but linked general categories of Project-Use and General Use (non-specific project use) as illustrated in Table 2.1.

Table 2.1 Typical Guideline Usage

Categories	Example of Use
Project Uses	Overall assessment and development of rural road programmes.
	Development of project specific guidelines, design catalogues or specifications.
	Selection and design of pavement options for specific roads or groups of roads.
	Rationalise surface options for sections of a road link using an EOD strategy to optimise investment and maintenance resources.
General Use	Development of national or regional policies, classifications, standards and specifications.
	Development of national or regional design catalogues.
	Drafting of national or regional LVRR design or construction manuals.
	Updating of existing design, construction or asset management manuals.
	Technology transfer and dissemination of good practice at national, regional or local authority levels.

2.2 Project Use - The Pavement Cycle

Many of the features of the development of a rural road project can be related to the need to take a series of important decisions during the early life of the project. These decisions have to be taken in a particular sequence. As regards to surfacing and pavement issues, these are likely to be, in chronological order:

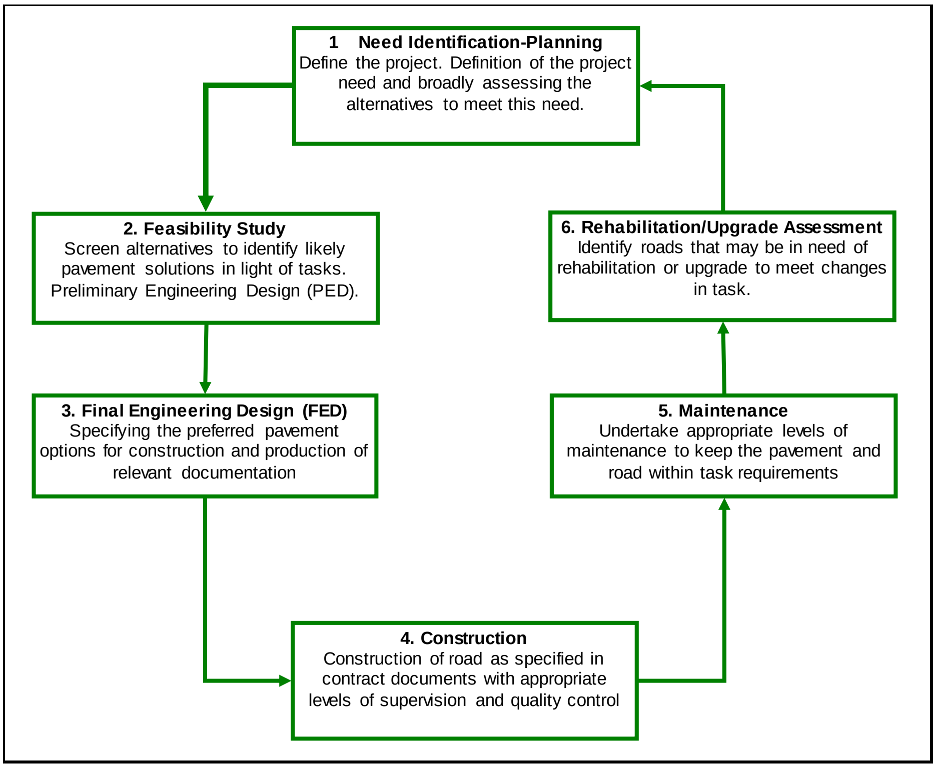
Decision Stage 1: What is the project task and what are the local resources?

Decision Stage 2: What are the options to meet the task within the available resources?

Decision Stage 3: What final designs are feasible in engineering and cost terms?

This decision process can be developed and extended into what may be termed The Pavement Life Cycle (*83*), Figure 2.1.

Figure 2.1 The Pavement Life Cycle



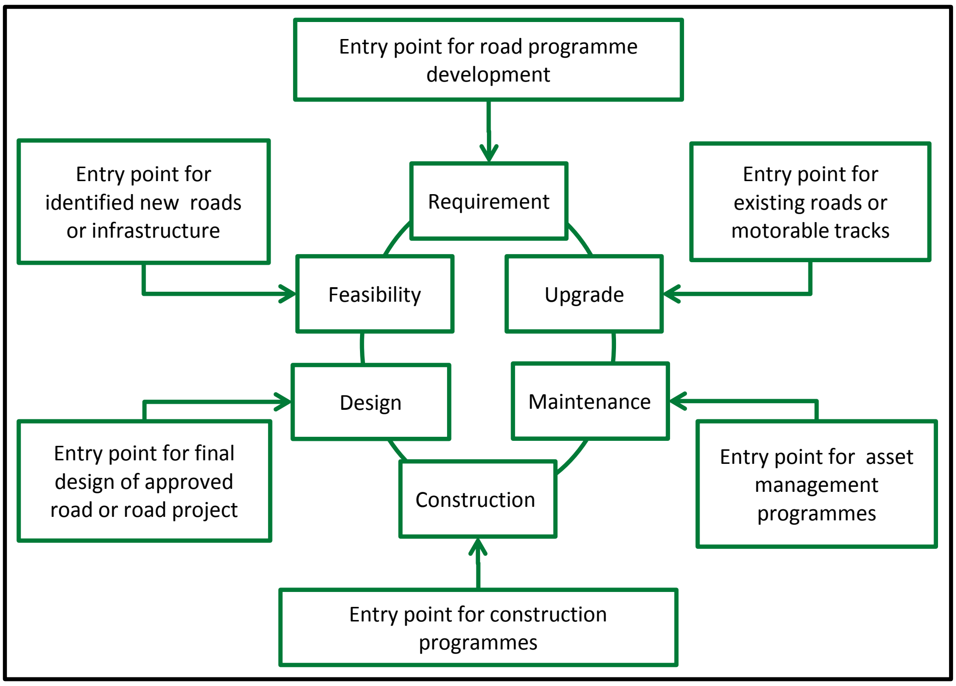
This Pavement Life Cycle can act as a route map to the relevant knowledge and the appropriate levels of information and procedures required for making knowledge-based decisions (see sections 4 to 9). The use of the pavement life cycle also allows practitioners flexibility in terms of entry point. For example, only a minority of rural projects are likely to start with new alignments, with most rural road projects being based on the upgrading of existing unsealed roads. Hence, a more appropriate entry point for this type of project may be at Stage 6 (Rehabilitation and Upgrade Assessment); although when upgrading trails or pedestrian tracks it may be considered that they constitute "new roads".

There are a number of similar entry points to the cycle, as shown in Figure 2.2.

2.3 Information Links

One of the fundamental purposes of this document is to guide rural road practitioners to relevant sources of information held within currently available websites. At the time of preparation of this Guideline, a permanent web-base of the LVPG database of selected references has not yet been agreed. As an interim measure the freely available database documents may be accessed from the DVD accompanying this document. The database contains additional references that may not be freely available in electronic format.

Figure 2.2 Application of the Pavement Life Cycle



3 KEY ISSUES

3.1 General

The following sections deal with topics fundamental to the development of good practice procedures. These issues form a framework that should be understood before regional or project-specific good practice documentation can be realistically developed.

3.2 LVRR Classification

Suitable LVRR Classifications are a primary step to providing the context and control framework within which local resource-based pavement options may be assessed and selected for appropriate use. The classification of rural roads in many countries is currently based on administrative or political criteria and not on the characteristics of the traffic that the road has to carry. However, from a sustainable engineering point of view, rural roads need to be designed for the task that they are expected to perform, namely to carry the types of vehicles, their volume and numbers of non-motorised users. An administrative classification is necessary to enable ownership, responsibilities, resources and management to be assigned, but such a classification should not be the basis of engineering design.

> ***Recommendation: LVRR classifications should be based on road task rather than administrative or political considerations***.
>
> A task-based road classification allows for a consistent treatment of all similar roads within the infrastructure system in terms of their design, construction, maintenance requirements, users expectations, and safety.
>
> References: 35, 207.

There clearly has to be an upper limit to the roads that may be included within the LVRR approach to rural road design and construction. In general terms, this limit is taken as being a road environment below which traffic is not the dominant factor influencing road deterioration and in most situations an upper limit of 200 to 300 motorised vehicles per day would be appropriate. Where there are commercial vehicles using the route, the LVRR approach will be applicable for traffic of up to about 1 million equivalent standard axles (esa)[2] during the design life of the road pavement. This recommendation needs to be assessed and adapted for specific regions.

3.3 Geometric Standards

The availability of appropriate LVRR geometric standards allied to a suitable road classification is a key information input to the feasibility, design and construction phases of the Pavement Life Cycle.

Geometric design is the process whereby the layout of the road in the terrain is designed to meet the needs of the road user. The geometric design standards provide the link between the cost of building the road and the benefits to road users. Usually, but by no means always, the higher the geometric standard, the higher the construction cost and the greater the road user benefits. A national 'standard' is not a specification, although it could, and often is, incorporated into specifications and contract documents. Rather, a standard is a minimum level of service that should be achieved at all times for the particular category of road.

[2] A standard axle is 80kN. Actual axle loads are converted to esa for pavement design purposes.

The geometric design standards are intended to provide minimum levels of safety and comfort for drivers by provision of adequate sight distances, coefficients of friction and road space for manoeuvres. They provide the framework for economic design and ensure a consistency of alignment. Geometric design covers road width, crossfall, horizontal and vertical alignments and sight lines.

The principal factors that affect the optimum geometric design of a rural road are:

- Cost;
- Terrain;
- Pavement type;
- Traffic (volume and composition, including "design vehicle");
- Roadside population (open country or populated areas);
- Safety.

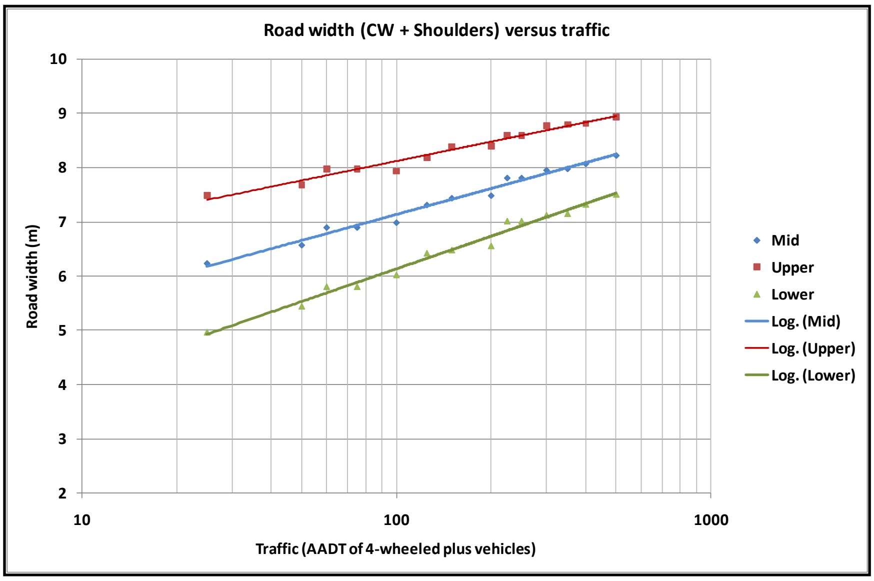
Recommendation: Road user safety is of prime importance and LVRR geometric standards should be compatible with the safety of <u>all road users</u> including Non-motorised Traffic (NMT) and pedestrians.

There are sound arguments on safety grounds for keeping traffic speeds slow in mixed traffic environments rather than aiming for higher design speeds as is the case for larger, high-flow roads.

References: 205; 290.

Road width (running surface and shoulders) is one of the most important geometric properties, since its value is directly related to cost (construction and maintenance). A review was carried out under SEACAP *(35)* of the standards adopted by a range of countries or organisations with LVRRs having mixed and non-motorised traffic. Results from this review are shown in Figure 3.1 and indicate a logical relationship between road width and traffic.

Figure 3.1 Daily Traffic – Road Width



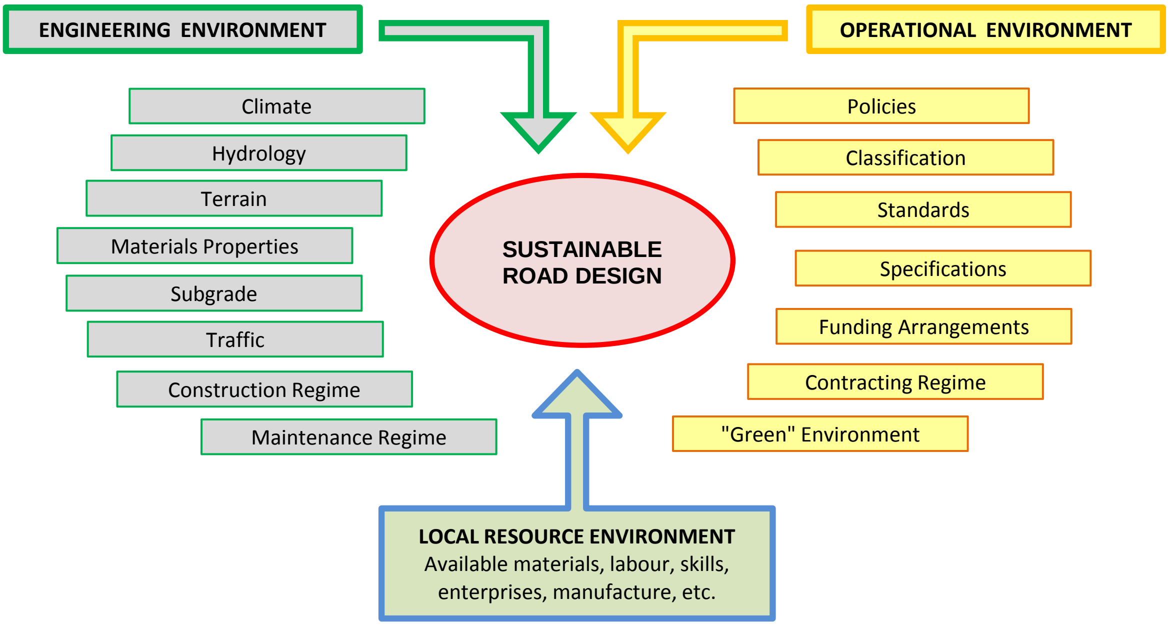
An appropriate assessment of traffic is obviously a key aspect of geometric design and it is worth emphasising the difference between the nature of traffic data required for road width design and the nature of the data required for pavement design. The latter is generally based on a cumulative assessment of the traffic load (axle loads) that a road pavement will have to withstand, as opposed to the numbers of and types of vehicles and other non-motorised traffic that a road will have to physically accommodate on a daily basis.

Severe terrain may necessitate some compromise on road width and/or running width-shoulder combination for LVRRs, otherwise costs and environmental impact may be excessive.

3.4 The Road Environment

It has become increasingly recognised that the life-time performance of LVRRs is influenced to a greater extent than higher volume roads by the impacts of what is termed the 'Road Environment' and, in particular, the Engineering Factors within that environment as indicated diagrammatically in Figure 3.2 and considered in more detail in Tables 3.1 and 3.2.

Figure 3.2 Road Environment and Impact Factors



The need to take into account a range of road environment factors when selecting rural road pavements and surfacing, and other road components has been an important conclusion of SEACAP and AFCAP and their outputs (*31*, *65*).

Recommendation: An early assessment of the road environment should be used to ascertain the suitability of unsealed surfacing options and the desirability of alternative options.

SEACAP research has indicated that rainfall, gradient, material, construction practice and maintenance regime have significant impacts on the sustainability of unsealed gravel roads.

References: 28; 32

Table 3.1 Road Engineering Environment Impact Factors

Impact Factor	Description
Climate/rainfall .	The prevailing climate will influence the supply and movement of water and impacts upon the road in terms of direct erosion through run-off and the influences of the groundwater regime. Climatic indices can have a significant influence on the selection of pavement options and their design using “wet” or “dry” design parameters. Unpaved surface performance is particularly influenced by quantity and intensity of rainfall, and the runoff arrangements.
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 performance of pavements, earthworks and drainage structures. Seasonal moisture variations will influence pavement behaviour adjacent to unsealed shoulders. Changes in near-surface moisture condition are the trigger for significant sub-grade and earthwork volume changes in pavements underlain by “expansive” clay materials.
Terrain	The terrain reflects the geological and geomorphological history. Apart from its obvious influence on the long section geometry (grade) of the road and earthwork requirements, the characteristics of the terrain will also reflect and influence the availability of materials and resources.
Materials Properties	The nature, engineering character and location of construction materials are key aspects of the road environment assessment. For LVRRs, where the use of local materials is a priority, the key issue should be; ‘what design options are compatible with the available materials?’ rather than seeking to find material to meet standard specifications, as is the case with higher level roads. Specifications need to be appropriate to the local environment.
Sub-grade	The sub-grade is essentially the foundation layer for the pavement and the assessment of its in-service condition is critical to the pavement design.
Traffic	Although recent research indicates that the relative influence of traffic on LVRRs is often less than that from other road environment parameters, consideration still needs to be given to the influence of traffic and, in particular, the risk of axle overloading on light road pavements. Traffic is a major influence on the performance of unpaved surfaces.
Construction Regime	The construction regime governs whether or not the road design is applied in an appropriate manner. Key elements include: • Appropriate contractual framework; • Experience of contractors or construction groups; • Skills and training of labour force and supervisors; • Availability, use and condition of appropriate construction plant; • Selection and placement of materials; • Quality assurance; and compliance with specification • Technical supervision,;
Maintenance Regime	All roads, however designed and constructed, require regular maintenance to ensure that their basic task is delivered throughout the design life. Achieving this depends on the maintenance strategies adopted, the timeliness of the interventions, and the local capacity and available funding to carry out the necessary works. When selecting a road design option it is essential to assess the actual maintenance regime that will be in place during its design life so that designs may be appropriately adjusted where necessary, and/or the maintenance regime may be enhanced if necessary.

Table 3.2 Road Enabling Environment Factors

Impact Factor	Description
Policies	National or local policies will provide guidelines, requirements and priorities for the decision making processes. There will also be legal requirements with which to comply.
Classification	Road classifications based on task or function provide road planners and designers with a practical guidance framework to initially select and cost appropriate road options. Having a clear rural road classification linked to relevant standards facilitates design and construction within acceptable performance criteria.
Standards (Geometry and Safety)	Geometric standards will influence not only the comfort and safety of road users but also the impact of water management on and across the road and the effects of earthworks on the local terrain and environment. LVRRs are likely to be required to accommodate a wide range of users from pedestrians through to trucks. The traffic mix should be taken into account in the basic road geometry including the use of wide shoulders for pedestrian or bicycle use.
Technical Specifications	Technical specifications define and provide guidance on the design and construction criteria for roads to meet their required level of service within the classification-standards framework. Specifications appropriate to the local engineering environment are an essential element of an effective enabling environment.
Funding Arrangements	Available funding has an over-arching influence on the scale and nature of the roads and their pavements that are feasible. Funding available for on-going road management and maintenance is also a key issue.
Contracting regime	The nature of the general contracting regime can influence a road project through the following issues: • Local legislation and contract documentation; • Governance and level of bureaucracy; • State-owned or private contractors; • National or international contractors; • Arrangements for facilitating local SMEs, • Local resources and low-capital approaches.
The "Green" Environment	Road construction and on-going road use and maintenance have an impact on the natural environment, including flora, fauna, hydrology, slope stability, health and safety. These impacts have to be assessed and adverse effects mitigated as much as possible by appropriate design and construction procedures.

Each factor within the road environment requires assessment, although the level of detail required will vary with the stage of a project. This variation in detail is discussed further in sections 4 to 6 of this guideline together with reference to procedures for accessing or collecting information.

3.5 Surfacing and Pavement Options

A wide range of surfacing and pavement options have been established for use on LVRRs, each of which has its own advantages and disadvantages depending on the particular circumstances in which it is to be used. Annex A summaries these options broadly grouped as; unsealed surfaces; surface seals; concrete pavements; block/stone pavements and flexible pavements.

The selection and eventual design of these options, which should take into account task, whole-life costs and the governing road environment, is dealt with in a two-stage logical process as outlined in sections 5 and 6. An example of the process of selecting pavement and surface option is provided in Annex C

> ***Recommendation: Assess a range of surfacing and pavement alternatives based on road task, whole-life cost and the road environment.***
>
> A range of proven alternative options to unsealed gravel are available.
>
> References: 28; 90; 122; 192; 236

3.6 Whole Life Costing

Whole Life Costing is a process of assessing all costs associated with a road over its intended or design lifetime. The aim is to reduce the sum of these values to obtain the minimum overall expenditure on the road asset whilst achieving an acceptable level of service from the asset. Usually an assessment of the residual value of the asset at the end of the assessment period is included. There are two basic approaches to the assessment of whole life costs for rural roads that can each reflect discrete objectives and may result in different conclusions depending on the local circumstances. These can be characterised as:-

- Whole Life Costs for the Road Asset (Whole Life Asset Costs);
- Whole Life Transport Costs.

Whole Life Asset Cost (WLAC) assessment aims to define the costs of Construction and Maintenance of a particular road and pavement over a selected assessment period. The principal cost components are the initial investment or construction cost and the future costs of maintaining (or rehabilitating) the road over the assessment period selected (for example, 12 years from construction).

Whole Life Asset Cost (WLAC) is the cost of the road for the road asset owner or manager.

Since the purpose of the road is to cost-effectively transport the local road users, Whole Life Transport Costs assessment will, in addition, include a component for the savings in Vehicle Operating Costs for the road users under the various investment and maintenance strategies. This component can be substantial on higher traffic rural roads. Other socio-economic factors may also be included in the assessment. The aim is to minimise the overall transport costs (infrastructure and means of transport) over the assessment or design lifetime and will usually incorporate cost savings or other benefits to the road users and community.

> ***Recommendation: Use Whole Life Asset Costs (WLAC) as a tool for initially filtering-out unsuitable surfacing and pavement options and then in the detailed assessment or ranking of the resulting short list.***
>
> In applying a WLAC model within the LVRR sector it is essential to have realistic costs for construction and maintenance and pragmatic assumptions as to the amounts of maintenance required and deliverable for different options.
>
> References: 31, 46, 65, 121

Any assessment will only be as good as the data and knowledge used in the relationships incorporated in the evaluation. For many rural road evaluations the confidence in the cost data is generally good for construction components but often less so for maintenance costs and road performance. The knowledge and confidence may be poor for local Vehicle Operating Costs (VOCs) under the range of possible road conditions and for the range of transport vehicle types, hence, practitioners tend to use Whole Life Asset Costs (WLAC), initially at least.

A draft Microsoft-EXCEL-based model entitled "Whole Life Asset Costs" was first developed in Vietnam under SEACAP 1 (*31*) and later modified for use in Lao under SEACAP 3 (*65*). Its practical application in the context of this Guideline is primarily as a tool for deciding between options for road construction or rehabilitation. The model incorporates a logic diagram developed under the SEACAP 4 (*28*) investigations on gravel road performance in Vietnam and suggests exclusion of the use of gravel as a road surface under unsustainable circumstances, for example, due to steep gradients or high rainfall, or inadequate maintenance capacity. Part of this approach is incorporated in the decision management system example presented in Annex D. Sabita Manual 7, "SuperSurf – Economic warrants for Surfacing Unpaved Roads" (334) can also be used as a tool for the same purpose.

3.7 Environmentally Optimised Design

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 (EOD), approach provides a pragmatic way forward in constrained resource situations. EOD covers a spectrum of solutions for improving or creating low volume rural access – from dealing with individual critical areas on a road link (Spot Improvements) to providing a total whole rural link design (Whole Length Improvement). EOD provides a framework for the effective application of the recent research outcomes, particularly for the common situation where aspirations of local communities have to be balanced with very limited budgets.

Recommendation: Use a Spot Improvement solution in cases where there is insufficient budget to supply a sustainable whole road link solution, but enough to focus on key areas to ensure all year access.

It is in many cases a more sustainable option to concentrate available funds on paving key sections rather dissipate funds on unsustainable unsealed options throughout a road link length.

References: 46; 74; 293

Whole Length Improvement applies the principle of adapting roads designs to suit environments to individual segments of road alignment. This allows differing pavement options to be selected in response to different impacting factors along an alignment. Most rural roads are designed using standard national designs along their entire length. However, this can be expensive and sometimes does not meet the needs of the users.

The EOD approach is cost effective and appropriate for the users of low volume rural roads. Under the EOD approach, each road or road section is designed to meet their specific environment conditions and allows available budget resources to be concentrated on areas that may, for example:

- Be at high engineering risk;
- Have significant safety issues;
- Have high maintenance liabilities;
- Have high socio-economic priority.

This approach optimises the application of available investments resources along a route.

Spot Improvement involves the appropriate improvement of specifically identified road sections. When funds are limited and it is not possible to improve an entire road, it may be necessary to prioritise the improvement works along the road. The improvements can be prioritised according to certain criteria, typically the importance of safe and reliable access, or a dust-free road through a village. Therefore, in some cases a section of unformed road that provides access and is not critical may be left alone while other sites are improved. A road may vary from unformed track to gravel to a sealed, concrete or block pavement up a hill. Improvement works that are not connected to each other are referred to as 'spot improvements'. It is perfectly feasible, therefore, to balance low cost surfacing solutions such as gravel or even engineered natural surfaces for low risk areas with higher cost solutions for the at-risk areas. This approach should ensure at least basic access when investment resources are very limited.

Within the context of LVRR Standards and Specifications it is important to distinguish Spot Improvement applications from routine, periodic or emergency maintenance. Spot Improvement is engineering-based and involves pavement options and other solutions compatible with the design life of the road.

3.8 Pavement Drainage

Moisture is the single most important factor affecting pavement performance and long-term maintenance costs. Thus, one of the significant challenges faced by the designer is to provide a pavement structure in which the detrimental effects of moisture are contained to acceptable limits in relation to the traffic loading, nature of the materials being used, construction and maintenance provisions and degree of acceptable risk. This challenge is accentuated by the fact that most low volume roads will be constructed from natural, often unprocessed materials which tend to be moisture sensitive. This places extra emphasis on drainage and moisture control for achieving satisfactory pavement life. Effective drainage is a critical issue in LVRR pavement design and construction and one which, while emphasised in manuals and guidelines, is all too frequently poorly addressed in practice.

The basic costs of protecting a road from the effects of water are largely independent of traffic. Hence, for LVRRs the cost of the drainage system can comprise a larger proportion of the costs of the road than for higher volume roads. There are, of course, different levels of protection associated with the risk of serious damage to the road. For principal trunk roads little risk can be tolerated and so expensive drainage measures must be employed. For LVRRs the consequences of failure in the drainage system are correspondingly lower but, within the range covered by LVRRs, there are some significant differences depending on the length of the road and the availability of an alternative route.

> ***Recommendation: Road designers should aim to provide a pavement structure in which the detrimental effects of moisture are contained to acceptable limits.***
>
> Effective pavement drainage is a critical issue in LVRR design and construction but one which, while emphasised in manuals and guidelines, is all too frequently poorly addressed in practice.
>
> References: 272

Those elements of overall road drainage that are most closely associated with pavement design are:

- Pavement layer permeability;
- Crown height;
- Pavement camber (cross-fall);
- Side drainage.

It is impossible to guarantee that roads will remain waterproof throughout their lives, hence it is important to ensure that if any layer of the pavement, including the subgrade, consists of material which is seriously weakened by the presence of water, then the water must be able to drain away quickly. To facilitate this, correct camber should be maintained on all layers that are impermeable and a suitable path for water to escape must be provided, either by extending a permeable pavement layer right through the shoulder or by including a permeable layer within the shoulder.

3.9 Appropriate Use of Locally Available Materials

The appropriate use of locally available materials is a fundamental issue in the design and construction of sustainable LVRR pavements and surfacings.

Key factors to be considered are:

- Material location, quality and quantity;
- Variability;
- Behaviour characteristics;
- Suitability for road task;
- Processing requirements;
- Quality control on excavation and delivery;
- Environmental impacts.

> ***Recommendation: It is important to assess all possible options in order to utilise locally available materials.***
>
> Where an apparent lack of appropriate local material exists it may be necessary to overcome the issue by flexibility in design:
>
> References: 249; 279

The apparent lack of suitable local materials may be overcome by:

- Adapting the specification and road design to suit local materials; or
- Adapting or modifying the materials to suit a realistic specification.

3.10 Maintenance

Maintenance is the range of activities necessary to keep a road and associated structures (culverts, drifts, bridges and retaining walls) in an acceptable condition for road users to achieve the economic and social benefits of access and travel, as intended when the road works were designed and constructed.

It is important to appreciate that ALL roads and structures deteriorate over time due to the effects of weather (particularly the resulting water flows and movements) and traffic, and require maintenance from time to time. The amounts and types of maintenance required depend on a number of factors including: surface type, standard and quality of construction, road width, rainfall and intensity, terrain, road gradient, and traffic. Roads are expensive but vital assets and, as such, their maintenance and preservation are simple common sense as well as being economically justifiable.

> ***Recommendation: There is no such thing as a "No-Maintenance road" and assessment of existing and expected road maintenance arrangements and capability should be an integral part of the design process.***
>
> Maintenance arrangements, resources and funding will have a significant impact on road performance and Whole Life Costs, and whether the construction investments will generate the intended benefits.
>
> Reference: 300

LVRRs are constructed with relatively limited resources and budgets so that more roads can be constructed for the funds available. However it is vital to know the maintenance liabilities of the road assets belonging to, or under the care of, an authority or organisation so that maintenance can be properly planned, funded, resourced and implemented in a timely way. If this is not done, there will be a high risk of rapid road deterioration and even failure, and the wasting of the investments made at the time of construction. This is, of course, in addition to the higher vehicle operation costs and implications of poor or severed access suffered by road users if maintenance is deficient.

It is therefore recommended that assessment of the existing maintenance regime and possible development of maintenance capacity should be an integral part of the road project design process.

It may be appropriate to incorporate maintenance capacity assessment and the development of capacity enhancement initiatives in the design and implementation phases of a project. The maintenance capacity for the constructed road will certainly have an impact on the Whole Life Cycle Cost considerations of any investment.

Chapter 3: Relevant Attached References

Topic	Available	Additional Recommended
LVRR Classification	195, 206,	207, 240, 260, 275
Geometric Classification	35, 65, 84, 90 196, 205, 239	18, 26, 99, 172, 207, 260
The Road Environment	31, 65, 240	8
Surfacing and Pavement Options	40, 70, 81, 85, 222, 236	90, 289,
Whole Life Costing	31, 41, 65, 138, 195, 197, 334	289
Environmentally Optimised Design	46, 65,	260, 273
Pavement Drainage	272, 304	102, 260,
Appropriate Materials	46, 88, 177, 249, 279, 297	29, 104, 184
Maintenance	144, 264, 265, 300, 305	23, 96, 116

4 PROJECT IDENTIFICATION AND PLANNING

4.1 Description

In general terms this is the stage at which the overall project and its strategic objects are determined, potential budgets are defined and strategic financial and engineering risks are identified. This stage is carried out either for or on behalf of Funding Agency and Donor project planners, Ministry or road authority planners or PMUs. This process takes into account government policies and programmes that impact on road development which is, therefore, examined in a very wide socio-economic and policy-orientated context. There will normally be an initial assessment of the project against previously defined criteria and projects that do not meet selection criteria are screened out or modified.

> ***Recommendation: Road projects based on doubtful pavement assumptions should be rejected at an early planning stage (and before the feasibility stage).***
>
> *They can gain a 'momentum of their own', and hence, become increasingly difficult to stop at the later stages in the cycle when minor changes of detail are often all that are possible.*
>
> References: 83

For low volume road projects this first stage in the Project Cycle is likely to include many of the aspects of what is often termed the Pre-Feasibility Study in larger projects or programmes. Specifically, as regards pavements and surfacings, this is the stage when the general road task is defined. This should be in terms of access rather than mobility, the latter being essentially a higher road task.

Design, construction and maintenance decisions will impact on local communities and other sector activities, e.g. agriculture, water, health, and education, as well as commercial activities such as local transporters, suppliers and traders. Consideration of these impacts and consultation with stakeholders at this early stage will help mobilise support and maximise the beneficial impacts of the road works.

Figure 4.1 presents general flow chart of the actions in this project phase.

4.2 Key Decisions

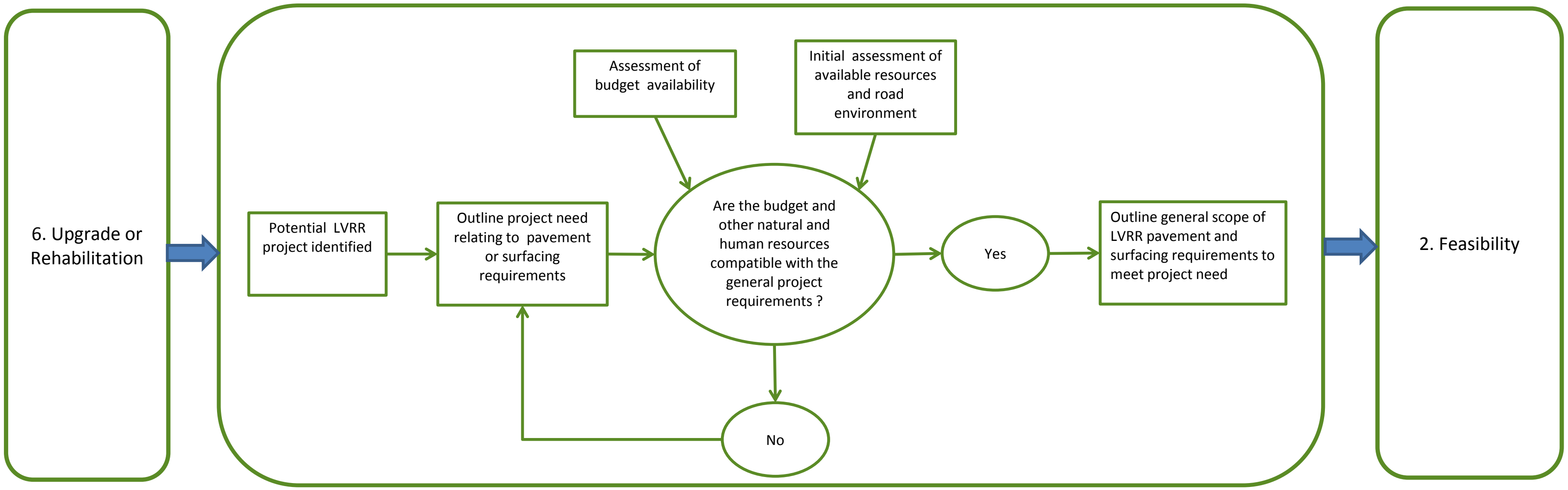
A number of key issues require clarification at this early planning stage and many of these revolve around the level of service required by the project. Depending on the strategic aim of the project this may vary from limited access, through basic access to full access as follows:

Limited Access may be the aim of the project in some budget-constrained situations and it may be accepted that, where no current access exists at all, access may be severely limited at certain times of the year due to flooding or combinations of severe terrain and rain impact.

All-Season Basic Access: Reliable all-season access for the prevailing means of transport with limited periods of inaccessibility (typically for a period of up to about 24 hours during/after rain when the road can be impassable to motorised traffic).

Full Access: Uninterrupted all-year, good quality low surface roughness access. No closures in the rainy season.

Figure 4.1 Identification and Planning Actions



In practical terms the decision on level of access is critical in initially defining the geometry and style of pavement and surfacing that will have to be considered in the later phases of the project, with general strategies ranging from an Engineered Natural Surface (ENS), through unsealed gravel to sealed pavement options, with or without the incorporation of a Spot Improvement approach.

This level of access will also determine appropriate levels of maintenance and, at this early stage, it is important to pragmatically establish the likely general maintenance regime as this will impact on the future selection of pavement options.

Decisions on the level of access to be provided by the pavement and surfacing are closely linked to the wider project issues of economic viability and financial sustainability.

4.3 Activities and Data Requirements

Data acquisition procedures at this stage of a project should be aimed at proving the appropriate information to establish the following strategic information:

- Whether the road falls within the "Low Volume Road" category for design of the pavement and surfacing;
- Whether this is essentially a "new road" or an upgrade;
- A general picture of the likely road environments to be encountered;
- Whether there are likely to be any major technical challenges;
- General outline costs/km for the pavement and surfacing elements.

> ***Recommendation: Roads should not be taken to feasibility stage for upgrading to an access standard that is clearly beyond the available or anticipated funding.***
>
> Preliminary financial assessment for sustainability should include outline design life costs for operation and maintenance as well as construction.
>
> References: 83

Collation of technical information within a preliminary road environment assessment framework, as summarised in Table 4.1, should provide the required level of information.

Additional information at this stage will include:

- Funding: Identification of the funding sources and scale for construction and maintenance;
- Policies: Identification of national or local policies that will impact on the project.

4.4 Data Collection – Overall Approach

It is worth noting that in assembling some of this 'broad' data, more detailed data will often be obtained as a matter of course. Such data will be used in the feasibility or even final design stage. There is therefore a degree of commonality between the various phases regarding some data collection. This may be particularly relevant for some small or time-constrained road programmes where it may be cost or time-effective to collect some data sets (eg traffic) in one exercise.

Table 4.1 Levels of Road Environment Information

Impact Factor	Project Definition and Planning Data
Construction Materials	A general assessment of whether or not there are likely to be any major construction materials issues in terms of quality or quantity.
Climate.	Regional climate pattern and identification of data sources.
Surface and sub-surface hydrology.	Indications of any major problems in terms of flood impact or, alternatively, potential water shortages.
Terrain	Broad classification of project terrain and identification of mapping sources.
Sub-grade	Identification of reported issues with previous projects.
Traffic	General levels of traffic – for example, within any existing road classification system.
Construction Regime	Initial assessment of construction strategy – machine-based; intermediate technology or labour based, or a combination.
Maintenance Regime	Initial assessment of the prevailing maintenance regime. Identification of relevant government or local authority existing or future policies and funding capacity.
Classification	Ascertain if any formal road classification exists and identify the appropriate levels for the proposed project. If none exists than it may be necessary to outline temporary guidelines.
Standards and Specifications	Ascertain the relevant standards and specifications that are legally in place and review whether or not they are appropriate. If no formal standards and specifications exist it may be necessary to initiate procedures to adapt from other sources.
The "Green" Environment	Identification of general legal requirements and any likely major constraints and issues.
Road Safety Regime	Identification and assessment of the implications of any governing safety policies.

4.5 Key Outcomes

By the end of this Identification and Planning stage, there will be clear evidence whether or not the road project will be worthwhile. If positive, this stage will normally identify the levels of service required, and provide sufficient information needed to commission a feasibility study. As regards pavements and surfacings the key outcomes are:

- A general outline of the relevant road environment;
- An initial view on the likely style of paving options to be considered;
- Identification of major challenges that need to be addressed;
- Relevant items for the Feasibility Study ToR drafted.

Chapter 4: Relevant References

Topic	Available	Additional Recommended
Project Identification and Planning Issues	58, 83, 195, 205, 325	27, 48, 49, 118
Access Decisions	205,	26, 52, 240, 260
Preliminary Data Collection	65, 251	20, 87

5 FEASIBILITY STUDIES

5.1 Description

In the context of the overall project this is the stage where a more detailed economic and engineering assessment is made. It is at this stage that the main engineering problems and any other issues affecting the route are identified and likely alignments for the proposed road selected.

> ***Recommendation: The Feasibility Stage should assess potential pavement and surfacing options to take forward to Final Engineering Design.***
>
> Options should be identified that are most likely to provide a sustainable solution within the governing road environment and within the expected budgets.
>
> References: 83;195

The feasibility stage of a rural road project assumes that a need has been identified and that the construction of a LVRR pavement or surfacing is an essential element to meeting this need. In general terms the Feasibility Stage assesses potential pavement and surfacing options and identifies those options most likely to provide a sustainable solution within the governing road environment and within the expected budgets. This is generally seen as a critical stage by road authorities and external funders and donors such as the World Bank, ADB or AfDB. Relevant Ministry planners and Central PMUs, Local authority PMUs and Consultants are normally closely involved at this stage.

As part of the feasibility study it is important to identify and investigate the major technical, environmental, financial, economic and social constraints in order to obtain a broad appreciation of the viability of the competing options. For low volume roads, one of the most important aspects of the feasibility study is communication with the people who will be affected by the road. SEACAP reports *(31, 247)* provide examples of community surveys on involvement in rural road development and in selected pavement options in particular.

At feasibility stage sufficient data are required to identify the most suitable options appropriate to the particular road requirements. Data are generally required that are sufficient to obtain likely costs to an accuracy of better than about ±25%. Figure 5.1 presents a simplified flow chart of actions and procedures.

5.2 Information Required

5.2.1 The Road Environment

The importance of taking account of the various impacting factors within the Road Environment has been discussed previously. The general levels of information required at feasibility level are indicated in Table 5.1

Table 5.1 Outline of Feasibility Studies

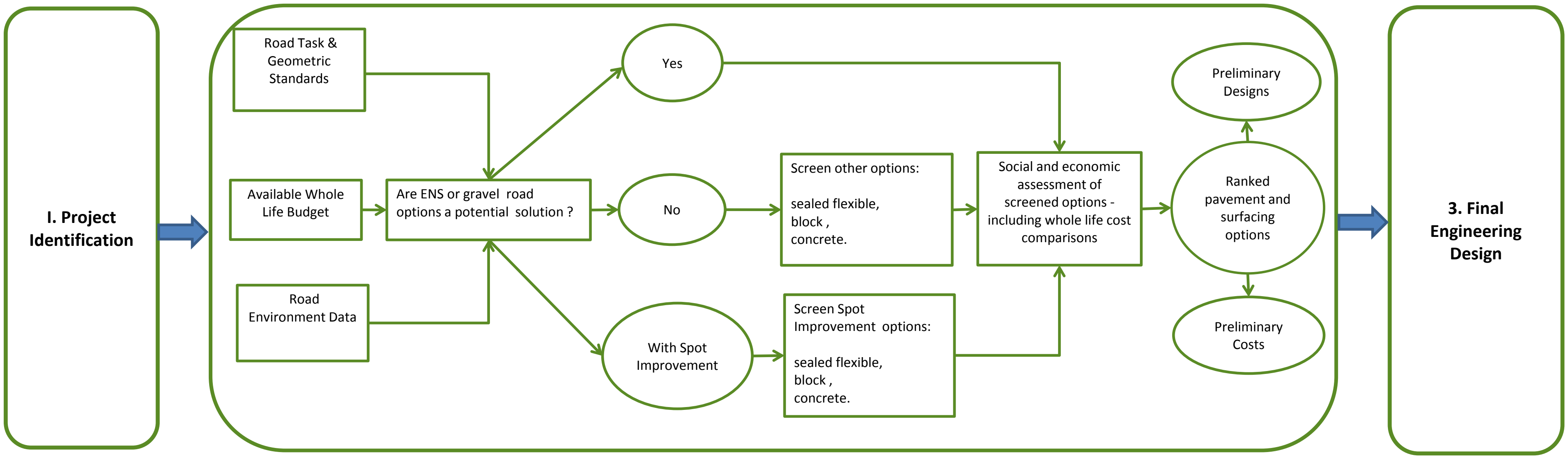
Impact Factor	Project Definition and Planning Data
Construction Materials	Identify likely sources of material in terms of location, quality and quantity and note any particular shortfalls or material sources that have caused problems in the past.
Climate.	Establish annual climatic patterns from existing records as well as the historical incidence of severe climatic events. Undertake an assessment of the likely climatic impacts and hence the likely level of Climate Resilience required.
Surface and sub-surface hydrology.	Identify the general hydrological conditions, and variability, prevailing over the proposed alignments by walkover survey, examination of available records and discussion with local groups.
Terrain	Define the overall relative percentage of terrain groups along the alignment. Identify any high risk critical areas.
Sub-grade	Establish likely minimum strength values for subgrade along alignments. Identify problem areas likely to impact significantly on pavement design.
Traffic	Establish the general traffic regime including likely traffic volumes in terms both of PCUs[3] and esa. Identify potential "design vehicles". Define equivalent axle loads for prevailing vehicles either from existing data or preliminary axle load surveys if no data are available.
Construction Regime	Identify the level of experience of the potential contractors in terms of the likely pavement and surfacing options. Identify potential training needs for local contractors.
Maintenance Regime	Identify existing maintenance programmes within the project area and assess the general effectiveness. Clearly identify agencies or groups responsible for particular elements of maintenance and its management. Estimate costs of management and maintenance over the envisaged project lifetime. Maintenance funding trends and forward budgets should be identified.
The "Green" Environment	Assess the environmental impacts of the proposed pavement and surfacing options within the framework of governing regulations and prepare draft environmental management plans.
Road Safety Regime	Identify or draft road safety standards relevant to the geometric design of the proposed pavement options. Link these standards to the identified non-motorised traffic elements that will use the proposed roads.

An assessment of available resources is generally required both to confirm the feasibility of a proposed LVRR and to identify sustainable and appropriate strategic design options within a sustainable framework.

Key data collection actions related to the road environment assessment are summarised in the following sections.

[3] PCU : Passenger Car Unit.

Figure 5.1 Feasibility and Preliminary Design Flow Chart



Construction materials

Recommendation: Make an early determination of the likely location and quality of construction materials.

Amongst the most common reasons for construction costs to escalate are that the locally available materials are found to be deficient in quality or quantity.

Key References; 43; 88; 104

An early assessment of construction materials will require an initial materials survey that is able to identify existing sources of material and determine their quantity and quality through in situ examination and a limited amount of relevant index testing *(88,181)*. The appropriate use of locally available materials is a key issue in cost-effective LVRR design and construction (179, 249). Information on the performance of materials from sources which were used for existing roads would be very useful at this stage. Particularly important would be knowledge of any potential problems with existing sources *(43)*. If there are no existing materials sources then more detailed materials exploration investigations need to be initiated *(79, 80, 297, 328)*.

Sub-grade

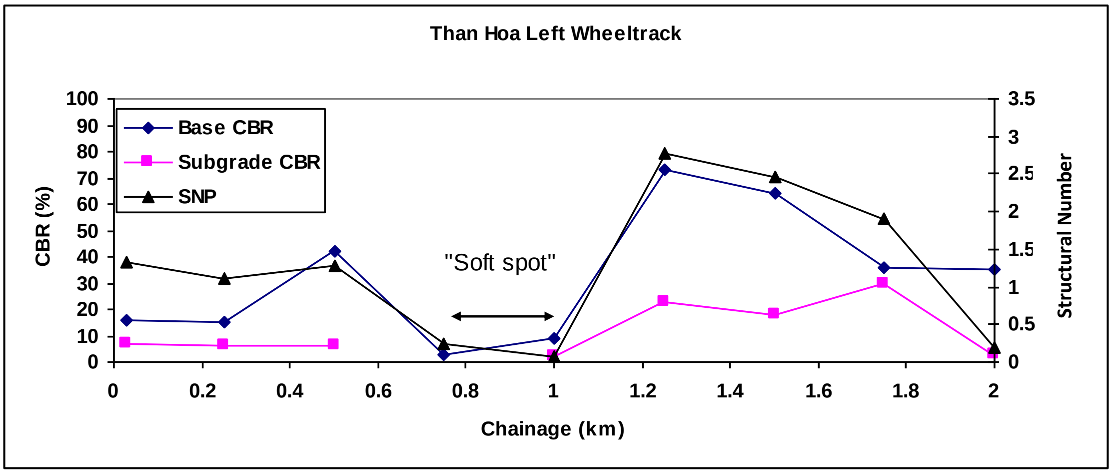
Recommendation: The DCP is a particularly useful tool for rapidly estimating likely CBR conditions at Feasibility Stage.

The DCP is low-cost procedure that can be easily accommodated within walkover surveys to identify general foundation conditions as part of preliminary investigations.

References; 201; 269

Assessment of subgrade strength at Feasibility Stage should be in its worst case (soaked condition unless otherwise guaranteed); that is, for in situ testing at the end of the rainy season and for CBR laboratory testing in its 4-day soaked condition. The DCP provides a rapid and low cost means of assessing sub-grade strength or existing pavement strength *(201)*. It must be emphasised that the DCP test assesses the material conditions at their current in situ density and moisture content. This needs to be taken into consideration when interpreting the results of the DCP survey at Feasibility Stage for pavement selection, particularly when surveys are undertaken in the dry season. Near surface DCP-CBR values will be higher in the dry season than when materials are saturated in the rainy season. Unless a series of correlation tests are undertaken to establish density/moisture-DCP relationships then some caution is required in interpretation. Nevertheless the test allows an assessment of likely minimum in situ strength values and provides a rapid, low cost, method of identifying variations in near surface strength along an alignment. Figure 5.2 presents typical outputs from a DCP survey for preliminary design (72).

Figure 5.2 Typical Longitudinal Trial Road Profile



Traffic

> ***For Feasibility studies traffic should be assessed under three headings:***
>
> **Normal traffic:** which would pass along the existing road being considered by the project if no investment took place.
>
> **Diverted or reassigned traffic** which changes from another route to the project road.
>
> **Generated or developmental traffic**: Is that which occurs in response to the provision or improvement of a road.
>
> Key references: 18; 196; 205

Existing and future traffic volume and composition is required for the purposes of geometric design and the evaluation of economic benefits as well as, later, for the structural design of the road pavement layers and selection of surfacing. For the latter only the number and axle loading of the heavier vehicles need be considered as lighter vehicles contribute little to pavement damage. The deterioration of pavements and surfaces as a function of traffic results from both the magnitude of the individual wheel loads and the number of times these loads are applied. It is necessary to consider not only the total number of vehicles that will use the road but also the axle loads of these vehicles. For unpaved surface options, deterioration may be more related to number of vehicle passes and consequent surface material losses/displacement, rather than directly to axle loading.

There are essential links between traffic, road classification and geometric standards. For geometric design it is the daily traffic that is important. There are essentially three ways in which the design traffic is estimated. Two of the methods require a value for the 'design life' of the road. LVRR recommendations for design life vary widely from 10 years to 30 years *(38)*. It is normally considered prudent to opt for a shorter design life in areas where future growth is uncertain and a value of 10-15 years is commonly assumed for LVRRs. The three methods are:

1. Designing for the traffic expected to use the road in the middle of its design life. This requires an estimate of the growth rate. This was the method used in SEACAP projects *(206)*.
2. Designing for the traffic expected to be using the road at the end of its design life, which is necessary where traffic is high. For LVRRs this is very unlikely, hence this method is not recommended. This requires an estimate of the growth rate but, in view of uncertainties in long term predictions, the true traffic after 10-15 years might be considerably in error.
3. The third method, described in ORN 6 *(84)*, relies only on knowledge of the current traffic. It is based on defining carefully the traffic ranges for each class of road in terms of traffic increments. The method then requires the user to estimate the current traffic and then to carry out the design based on the next higher class of road. Whilst this method is simple, it can lead to significant errors when traffic is near to the class boundaries.

> ***Recommendation: For LVRR studies the use of portable weighbridges is recommended.***
>
> A key aim of an axle load survey is to estimate the number of 'equivalent standard axles' currently using the existing road. It is unwise to assume that axle loads on all roads in a country are similar. It is therefore advisable to carry out independent axle load surveys when planning paved road projects.
>
> References: 142

Where there is no existing road of any sort, estimating the initial traffic is not easy and estimating future traffic especially so. Nevertheless, the arguments in favour of designing for the traffic level rather than an administrative class are strong and will ensure more roads are designed to an appropriate standard and that the available funds are used effectively.

One of the most common causes of premature pavement failure is incorrect estimates of traffic loading. Overloading is common in most developing countries and therefore very large errors are likely to occur if it is assumed that legal axle load limits are upheld. It is also unwise to assume that axle loads on all roads in a country are similar. It is, therefore, essential to carry out independent axle load surveys when planning paved road projects. In many developing countries trucks carrying construction materials, extracted minerals or timber are particularly prone to being overloaded.

The choice of Standard Vehicle depends on the use of the road and is normally the common vehicle that makes the most demands on the road in terms of engineering standard. For example, a Standard Vehicle for a village carrying considerable agricultural produce might be a 3-tonne truck, but a pick-up or even a motor tricycle might be the Standard Vehicle for a village-to-farm road where heavier vehicles are rare.

5.2.2 Road Task and Road Geometry

Standards are set to ensure quality and safety. However, there will be circumstances in which full compliance with the normal standards would lead to very high costs or environmental impact. This is likely to occur in rural areas where there are significant topographical barriers and geotechnical or other hazards. When planning a road improvement project it is often necessary to trade off some of the quality, operational and safety benefits of the normal standards in order to reduce the costs or environmental impact to an acceptable level. In such cases it is necessary to consider what the implications of various degrees of reduced standards would be in terms of operation and safety.

Carriageway and shoulder widths will vary with the relative amounts of traffic, their characteristics and the terrain. In view of the relatively high costs normally involved in road widening, care should be taken to ensure that only those sections of shoulder are widened which are justified by local demand (*38*, *65*, *196*).

> ***Recommendation: Consideration should be given to the movement of pedestrians, cyclists and animal drawn vehicles as well as motorised vehicles.***
>
> Conflicts between slow and fast moving traffic need to be assessed and increased widths of both shoulders may be necessary.
>
> References: 58; 59; 196; 205

5.3 Decisions on Pavement and Surfacing Options

5.3.1 Unsealed surfaces

Engineers have traditionally relied on the use of unsealed natural gravel/laterite as the 'default' low volume rural road surface due to its low initial costs and simplicity of construction. However, recent regional research confirms the serious problems relating to maintenance and sustainability of such surfaces in many road environment situations common in S. E. Asia and Sub-Saharan Africa. There are also health and environmental concerns regarding the widespread use of gravel as a road surface (*28*, *85*, *310*).

> **Recommendation: Gravel Wearing Course (GWC) should only be seriously considered as an option where:**
>
> - Maintenance is guaranteed;
> - Gravel quality adequate;
> - Gravel quantities are available;
> - Haul distances are short;
> - Low to moderate rainfall;
> - No steep gradients;
> - No road-side dust constraints;
> - Low traffic levels.
>
> Key references: 28; 221

Even in simple combinations of some of the key factors listed in the adjacent box, gravel can be lost from the road surface at more than 30mm per year. This leads to the need to re-gravel at frequent intervals. The funding, resources and capacities are usually not available to achieve this and the surface will invariably deteriorate and revert to an earth surface.

Engineered Natural Surface (ENS) and stone chipping surfaces may be appropriate alternative unsealed surfaces in some circumstances.

In summary, unsealed surfaces can be considered as low initial cost options and may provide cost-effective solutions in appropriate rural road environments, particularly those with low traffic, low rainfall, low gradients and where appropriate materials are in situ or close at hand for construction and/or maintenance. These options should not be considered as sustainable without a clear commitment to relevant maintenance. These are low capital investment - high maintenance surfaces.

A range of crushed, broken or shaped stone surfaces provide relatively low cost options without the requirement for expensive bituminous or cement based binders. Most provide scope for application or development of local skills and employment and include:

- Waterbound Macadam;
- Drybound Macadam;
- Hand Packed Stone;
- Telford Paving.

Further details of these surface options are provided in Annex A.

5.3.2 Sealed or Paved Options

Much recent SEACAP and AFCAP research has been aimed at deriving local specifications, designs and techniques for improving the cost-effective provision of low volume roads sealed with a bituminous or alternative, non-bituminous surfacing *(31, 46, 270, 311)*. Innovative construction techniques and methods have also been identified that optimise the use of local labour, introduce intermediate equipment techniques and increase opportunities for the local private sector to participate in road construction and maintenance *(255)*.

The appropriate design options for low volume roads, therefore, need to be responsive to a wider range of factors captured in the road environment.

In the past, flexible pavements with a bituminous surfacing have normally been used in most tropical countries. However, there are wide differences in the relative price of bitumen and cement and so the cost of using rigid pavements constructed with Ordinary Portland Cement (OPC) concrete can sometimes be favourable, particularly in those countries that import bitumen but manufacture their own cement. The choice between unsealed, flexible (bituminous) and rigid (concrete) pavements should be made on consideration of the likely cost of construction and maintenance, the pavement life and effect on road user costs.

The general characteristics of the sealed and paved road groups are summarised below. Summary details of these options are also provided in Annex A.

Sealed flexible pavements

Sealed flexible pavements are a common upgrade option for unsealed roads at moderate cost. They are dependent, however, on the economic availability of suitable construction materials, in particular for surface seals and road-base. They require a realistic assessment of likely axle-loads if early deterioration is not to occur. Moderate to low maintenance is a requirement.

Experience on SEACAP and AFCAP has shown that durable seals are critical for the achieving the intended design life of the road. In many developing countries the maintenance regime is not sufficiently responsive to ensure timely crack sealing, pothole patching and reseals. This leads to premature failure of the pavement due to moisture penetration and base/sub-base weakening as a result of failure of the seal. Therefore designers of LVRRs should select seals that will be robust in the expected maintenance regime.

The sealed flexible pavement options include the following seal and base/sub-base options summarised in Table 5.2.

Table 5.2 Common Flexible Pavement Options

Seals	Base/Sub-base Options
Bituminous Chip Seal,	Natural gravels
Bituminous Sand Seal,	Graded crushed stone
Bituminous Slurry Seal,	Dry-bound macadam
Bituminous Cape Seal,	Water-bound macadam
Bituminous Otta Seal,	Chemically Stabilised soils
Cold Pre-Mix	Mechanically stabilised soils
Penetration Macadam.	

Apart from labour-based cold pre-mix options the use of asphalt concrete, pre-mixed bitumen macadams and other heavy duty asphalt surfaces, such as hot rolled asphalt, are usually believed to be too expensive and capital intensive for LVRR application and are not considered in this Guideline.

Block/stone pavements

Brick (concrete or fired clay) pavements provide an acceptable moderate cost solution in areas with a scarcity of aggregates or gravels. They also have the advantage of promoting and utilising local industry. Stone blocks are a cost-effective potential solution in areas where stone such as limestone or granite may be won and shaped easily by local entrepreneurs, predominantly with hand tools. These options require moderate to low maintenance and are resistant to erosion or high axle loads provided the surfacing materials are sufficiently strong and durable and they are constructed on adequate sub-bases (70).

These 'incremental block' paving options include:

- Fired Clay Brick, Unmortared/mortared joints;
- Concrete Brick;
- Cobble Stone;
- Stone Setts or Pavé;
- Dressed stone.

Concrete pavements

Concrete pavements have a high initial cost but very low maintenance requirement. If they are well constructed they will be highly resistant to flood-erosion provided they are constructed on adequate sub-bases (69, 70, 312).

Concrete paving options for LVRR include:

- Geo Cell Paving;
- Non-reinforced Concrete.

Reinforced concrete paving is normally considered too expensive for general application in LVRRs, except as part of structures such as drifts. The Ultra-Thin Reinforced Concrete option (335) has been used successfully within S Africa; however, it does require a high level of construction expertise and quality control which may make it inappropriate for use in many other LVRR environments.

5.3.3 Appropriate Selection

Summaries of the advantages and concerns, together with key references, relating to the above groups as well as unsealed options are contained within Annex A. Some of the options are suitable for wheel-track-only paving treatment where traffic is very low with few passing movements. Particular care needs to be taken in the design of the central strips and shoulders to minimise erosion of this low cost option.

Recommendation: A rational method needs to be employed for the selection of the most appropriate LVRR surface or paving option.

At feasibility stage the first objective should be to screen out those options that are incompatible with the sustainability of the project within the governing road environments.

References: 31; 81; 222; 236

The various factors that typically affect the choice of a paving and surfacing can be grouped under the following headings:

- Available materials;
- Operational environment;
- Road task;
- Natural environment.

A number of LVRR pavement and surfacing selection procedures have been developed including a screening process developed for SEACAP *(31)* and outlined further in the South Sudan Low Volume Roads Design Manual as the Surfacing Decision Management System, *(260)*. An alternative and potentially useful points system is suggested by the Word Bank *(81)*. The SABITA "SuperSurf" package has been developed using Excel spreadsheets as a simple mechanism for carrying out cost comparisons between maintaining an existing unpaved road and improving it by using various upgrading alternatives (334).

These approaches provide a method for assessing the various factors that influence the suitability of surface-paving options for a specific section of rural road. The key objective in the SEACAP approach is the elimination of unsuitable or high risk options using a series of road environment related "screens" before proceeding to Final Engineering Design (FED) for the surfacing/paving and their Whole Life Costing. The procedure has been developed based on two key principles:

1. The pavements must be fit for purpose in terms of local needs, traffic volume and axle loads.
2. The pavements should be compatible with the governing road environment factors.

A two-phase selection approach has been developed and trialled in SE Asia *(31, 65)* that is compatible with the Road Cycle and comprises:

1. Phase I: General assessment of appropriate pavement option(s) compatible with the road environment and budget constraints – at the FS of the Road Cycle.
2. Phase II: Detailed design of the selected pavement components (e.g. layer thicknesses) compatible with engineering standards and requirements – at the FED stage of the Road cycle.

The general process recommended for selecting an appropriate surfacing is as follows:

1. Obtain all relevant information.
2. Divide the road into sections of similar condition and required surfacing.

3. Identify suitable surfacing solutions for each section.
4. Compare initial costs and life cycle costs.
5. Compare the contracting resource in terms of knowledge, skills and available plant.
6. Carry out final selection.

The recent AFCAP document on bituminous seals (*235*) includes a series of tables that guides road designers towards the initial selection of appropriate bituminous surfacings.

5.3.4 Spot Improvements

At Feasibility Stage the road or track is surveyed and critical sites are identified. Table 5.3 lists a typical ranking of spot selection criteria as used in recent SEACAP trials in Lao *(74)*. These definitions can be used to identify critical sites at Feasibility Stage.

Table 5.3 Typical Ranked Spot Selection Criteria

Priority criteria	Description
1 Unsafe – high risk	Safety concerns put road users or others at high risk of injury or death.
2 Impassable at any time	Road users are unable to pass along the road at any time of the year.
3 Impassable in wet season only	Road users are unable to pass along the road in the wet season, although closures up to 24 hours after rainfall are accepted.
4 Unstable slope	The slopes above or below the road are unstable and at risk of slipping.
5.Condition likely to deteriorate	Vehicles or rainfall are likely to cause significant deterioration of the road in the next year.
6 Health risk	The health of road users and others is at risk, typically due to dust from a gravel road.
7 Drainage in poor condition	Drainage capacity or performance is reduced and retained water is likely to damage the road.
8. Unsafe – medium risk	Safety concerns put road users at medium risk of injury.
9 Environmental concerns	Construction or future usage may cause environmental concerns along the road such as erosion of bare soil, disruption of a water course or contamination of a water supply.
10 Very slow travel	Vehicles travel very slowly along the road due to its poor condition.
11 Geometric cross section below standard	The width and camber of the carriageway and shoulders do not meet the required standard.
12 Geometry below standard	The curvature, sight distance or gradient of the road do not meet the required standard.
13 Surface below standard	The surface is dusty, slippery or gravel on a steep hill.
14 Pavement below standard	The pavement although passable does not meet the required design specifications.

Critical sites may be water crossings, lengths of sunken road, short steep unpaved sections, eroded sections or areas of clay, sand or weak soil. The 'Standard Vehicle' may be used to identify critical sites, but not to define the standard of the improvement works. In general, the Standard Vehicle should be the largest that is likely, or permitted, to travel along the road in significant numbers.

.

5.3.5 Socio-economic Issues

There are socio-economic issues that are closely linked with feasibility stage decisions on pavement and surfacing design. Where possible these decisions should:

- Be compatible with road safety in the local and communities;
- Encourage local enterprise;
- Support cost-effective methods of construction and maintenance such as labour-based or intermediate technology approaches that benefit the community;
- Minimise adverse impacts on the community.

5.3.6 Environmental Issues

The feasibility assessment of low volume roads should take note of the need to:

- Minimise the physical impacts of construction and maintenance activities on the natural environment;
- Ensure that any temporary works or quarrying sites are reinstated or left in a safe and environmentally stable condition;
- Take account of socio-cultural impacts (community cohesion);
- Minimise the carbon footprint arising out of various construction and maintenance methods;
- Optimise resource management and allow for possible recycling of non-renewable materials.

The key topics to be considered for an Environmental Impact Assessment (EIA) relevant to the FS stage of a road are summarised in Table 5.4.

Table 5.4, Likely Environmental Impacts *(83)*

Stage	Pre-construction	Construction	Associated development	Operation	Maintenance
Environmental Issues	Quarries Borrow Pits	Earthworks; drainage Site clearance Equipment/Site camps	Ribbon development Commercial development	Traffic	Resurfacing Quarries Borrow pits
Water resources	1	1	1	1	2
Soil usage	1	1	1	2	2
Air pollution	2	1	1	1	2
Natural resources	1	1	1	2	2
Safety	2	2	3	1	2
Noise and vibration	1	1	2	1	2
Biodiversity	2	1	1	3	2
Resettlement	2	1	1	3	3
Socio-economic impacts	2	2	1	1	3
Cultural heritage	1	1	1	3	3

Notes: 1: Potential major impact; 2: Potential minor impact; 3: Impact unlikely

5.4 Maintenance Issues

At the project Feasibility Stage it is necessary to identify existing maintenance arrangements and programmes within the project area and assess their general effectiveness. Agencies or groups responsible for particular elements of maintenance and its management should be identified. Available and expected maintenance funding and resources should be quantified. Costs of management and maintenance of the proposed paving options should be estimated in order to ensure that adequate funds are likely to be in place to cover their whole-life costs.

5.5 Essential Outcomes

By the end of the Feasibility Stage there should be a clear recommendation for a specific short list of pavement and surfacing options, including whether or not EOD or Spot Improvement approaches are to be used. These decisions will have been taken in the light of the perceived road environments and likely available budgets.

The study will have provided evidence that the particular option or options provide the most suitable solution, taking into account WLC assessments, and their environmental and socio-economic implications. The study will also provide a detailed project description and a preliminary engineering design (PED) and associated outline drawings of the proposed paving solutions to enable costs to be determined at a level of detail to enable funding decisions to be made. Recommendations on design procedures and significant assumptions will be included.

Identification of economic and engineering risk is an essential output from this stage so as to ensure that any project progressing to design stage will not be compromised by the later discovery of any foreseeable fundamental problems that cannot be solved satisfactorily within the budget constraints.

The Feasibility Stage should also provide ToR for the FED stage, including an estimate of the requirement for detailed pavement and materials investigations. From the road maintenance capacity assessment, recommendations should be made regarding any necessary enhancement of maintenance arrangements, funding or capacity, to be developed at the FED stage.

Chapter 5: Relevant Reference Summary

Topic	Available	Additional Recommended
Feasibility Study Principles	83, 195	
Construction Materials	43, 88, 297, 328	158, 171, 174, 181, 203,
Initial Sub-grade Assessment	82, 239, 269, 285	72
Traffic Studies	65, 74, 142, 206	64, 240
Road Task and Geometry	58, 84, 196, 206,	18, 23, 26, 101, 207, 240
Pavement Options	31, 69, 70, 85, 221, 222, 306, 311, 326, 335	19, 240, 260
Appropriate Selection	31, 81, 235, 334	237
Spot Improvement	46, 74, 293	270
Socio-economic Issues	206, 247	48, 49, 240
Environment Impact	83, 150, 195, 295	52, 163, 234,
Maintenance Assessment	144, 305	23, 257

6 FINAL ENGINEERING DESIGN (FED)

6.1 Description

The FED stage requires sufficient data for preparation of the contract documents including technical specifications and Bills of Quantities. A final detailed cost estimation is also likely to be required. The FED stage requires more investigation and considerably more data than has been required hitherto. The entire process of project design should now be completed with sufficient accuracy to minimise the risk of changes being required after the works contract has been awarded.

For the particular case of the pavement and surfacing elements, the FED stage incorporates the Phase I (Options Selection) outcomes into the Phase II detailed designed procedures. This will include the design and specification of the pavement structural layers and any overlying surfacings together with associated shoulders and pavement drainage. Funding commitments for both construction and maintenance phases should be confirmed.

Figure 6.1 outlines the key actives at FED stage.

6.2 Design Principles

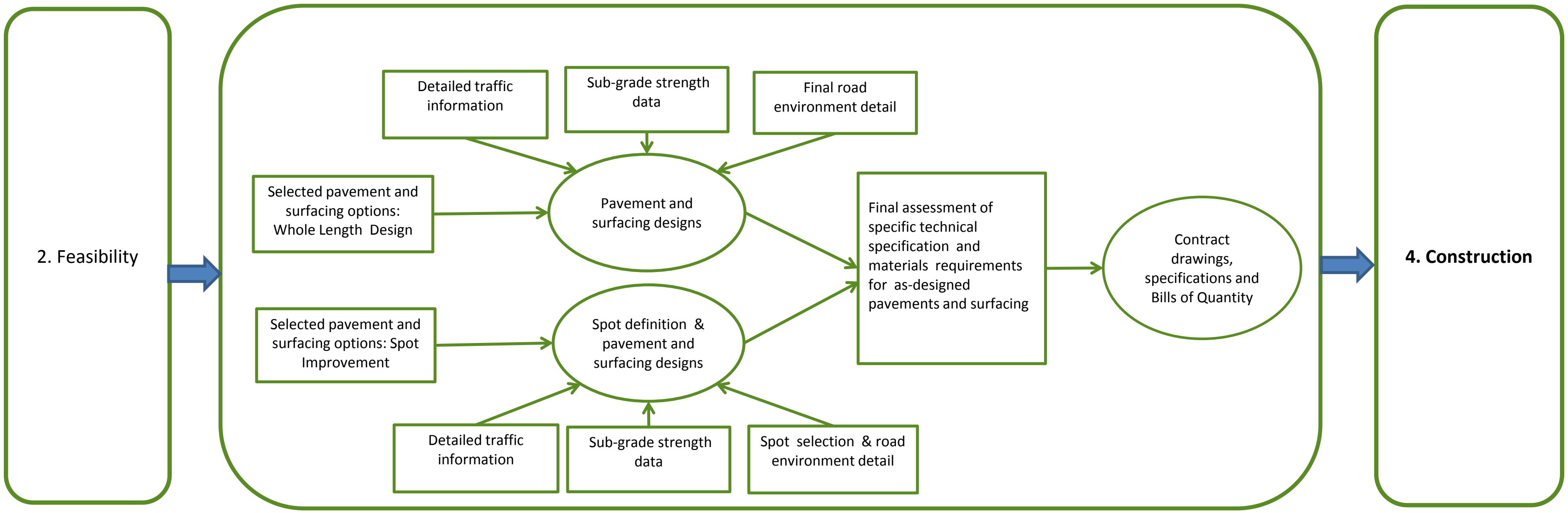
It is well understood that a road pavement is generally necessary because travelling on most alignment soils usually leads to deterioration, rutting and deformation such that the route becomes impassable. Therefore the primary purpose of structural design of road pavements is to disperse the loads created by vehicle tyres and reduce the stresses on the subgrade (the alignment soils) to such a level that the subgrade does not deform. This is done by means of a road pavement designed to reduce subgrade stresses to tolerable levels whilst at the same time ensuring that the pavement layers themselves are strong enough to accommodate the stresses and strains to which each layer is exposed *(37, 82, 197, 326)*. However, some stronger in situ materials will satisfactorily carry low flows of traffic throughout most of the year if formed into a camber and properly drained, and maintained.

> ***Recommendation: The LVRR design engineer must achieve the required level of service, using appropriate engineering approaches, whilst minimising costs over the whole life of the road.***
>
> This should be done in a context sensitive way that recognises the needs of the client, the road environment and the prevailing maintenance management regime.
>
> References: 197

The structural or pavement design of a road is the process in which the various layers of the pavement are selected so that they are capable of supporting the traffic for as long as required. The principal elements in this process are the choice of materials and their thickness for each pavement layer, and this is essentially the output of the structural design process. It is necessary to design a road that will do its job of carrying traffic and resisting the environment satisfactorily for a specific length of time, remaining in an acceptable condition with the expected level of maintenance.

Whilst the behaviour of road pavements is complex, it is clear that subgrade stresses from traffic loading are reduced by increasing the thickness of the road pavement, and the risk of the pavement failing itself is reduced by specifying materials of adequate strength for each pavement layer. Pavement design needs to be concerned with the risk of failure at its weakest point. A pothole every 20 metres can be considered as very poor quality road but the area covered by such pot-holes is likely to be only about 0.5% of the total surface area.

Figure 6.1 Key FED Actions



In summary the structural design of road pavements depends primarily on the following factors,

- Strength of the subgrade;
- Traffic loading;
- Properties of the materials;
- Variability and uncertainty in the above items.

6.3 Required Information

The information data set required for the FED is essentially a more detailed version of that assembled for the Feasibility Stage. Table 6.1 outlines these requirements.

Table 6.1 Outline of Engineering Design

Impact Factor	Project Definition and Planning Data
Construction Materials	Sources of material should be defined in terms of location, quality and quantity such that it is clearly established that the road or roads can be built to the required specification with the available materials. Source, haulage, processing and placement costs need to be investigated and any inflation factors considered.
Climate.	Climatic patterns and the incidence of severe climatic events should be confirmed. The levels of Climate Resilience that may be required should be defined.
Hydrology	Ground water levels should be established and areas and depths of flooding defined.
Terrain	Alignment gradients should be established based on the topographic survey. These may be critical in terms of Spot Improvement strategy.
Sub-grade	Design sub-grade strengths should be selected based on updated or more detailed site work building on the feasibility data.
Traffic	Feasibility assumptions on traffic patterns should be cross-checked and, if required, additional surveys undertaken aimed specifically at obtaining data for each vehicle category and axle loading for the pavement layer design.
Construction Regime	Contractors or contracting groups capable of undertaking the works should be identified and short-listed where required. Any required training programmes for local contractors or labour-based organisations must be defined.
Maintenance Regime	Confirm maintenance commitments by relevant agencies, authorities or groups within the project area and assess any shortcomings. Design any maintenance capacity building initiatives required. Define any required training programmes. Confirm costs of management and maintenance over the envisaged project lifetime.
The “Green” Environment	Undertake any further required environmental impacts studies.
Road Safety Regime	Confirm road safety standards are relevant to the final geometric design of the proposed pavement options.

Key data collection actions related to the road environment assessment are summarised in the following sections.

Materials

The likely variability of identified sources should be assessed. This is of particular importance with respect to, for example, hill gravel or laterite sources where no processing is involved. Sampling must be realistically representative of the material being won. Materials should be taken from stockpiles or already excavated material rather than from borrow pit faces. If the material is being processed then the capability of the plant to consistently produce satisfactory material in sufficient quantities should be assessed (*88, 181, 329*).

Subgrade

Subgrades are traditionally classified for design in engineering terms on the basis of the laboratory CBR tests on samples. These will be either in soaked or unsoaked condition depending on the road environment. Stronger, unsoaked, CBR strengths should only be used for design if it is clear that the final working moisture condition of the subgrade will not be in a soaked condition during the road's design life.

The DCP in situ test approach outlined for feasibility studies may be taken forward in greater detail for final design. Once again the correlation with equivalent CBRs has to be undertaken with great caution for final design unless clear moisture-density-strength relationships have been established with the DCP-CBR testing. The correlation is also material dependent (320).

Recent work under AFCAP (*269, 271*) has indicated a way forward for LVRR pavement design using the DCP penetration rates directly as a design tool without the need for CBR correlation. The DCP may be used in the laboratory to establish the strength of imported materials for the upper pavement layers, as well as in the field to test the subgrade. Clear correlations should be established between DCP penetration rates and moisture-density relationships for the materials concerned unless pavement layers are assessed at their likely in-service moisture content. This DCP pavement design procedure is primarily aimed at the upgrading of existing gravel roads to paved standard and has been adopted as such by some ministries within the Sub-Saharan region. There is, nevertheless, the possibility of adaption of this approach to other regions with appropriate research and modification.

Recommendation: It is critical that the nominal subgrade strength is available to a reasonable depth in order that the pavement structure performs satisfactorily.

The concept of "material depth" is used to denote the depth below the finished level of the road to which soil characteristics have a significant effect on pavement behaviour. Depths of the order of 700-800mm are normal for LVRRs Below this depth the strength and density of the soils are assumed to have a negligible effect on the pavement.

References: 260; 269; 271

The in situ strength of any material is a function of the moisture (as well as the density), with some materials being more moisture sensitive than others. Therefore, the moisture regime at the time of any subgrade strength survey needs to be assessed in relation to the expected moisture regime of the planned road in service. The best solution is to carry out the subgrade DCP survey when the prevailing moisture regime is similar to that expected in the pavement, bearing in mind the effects of equilibrium moisture content beneath the pavement as well of seasonal moisture variation in the outer wheel track area of a road with unsealed shoulders. This is likely to occur at the end of the rainy season.

6.4 Detailed Design Issues: Un-sealed Roads

6.4.1 Engineered Natural Surface (ENS) Roads

An ENS road must withstand the loads imposed by traffic and the effects of climate, principally rain but possibly including the effects of the level of the water table and flooding. The ability of an ENS to support traffic depends on its inherent material characteristics, its level of compaction and the moisture conditions *(248)*. The ideal ENS will have the following characteristics. It will be:

- Strong - to support traffic;
- Impermeable - to shed water quickly;
- Erosion resistant;
- Smooth - so that the ride quality will be good;
- Durable ;
- Easy to maintain.

> ***Recommendation: Earth roads have no added pavement and are therefore not structurally designed.***
>
> Their design process essentially comprises designating an appropriate cross-sectional shape, assessing material properties, and ensuring adequate drainage facilities are incorporated in the design and, importantly, recommending a regular and timely maintenance programme.
>
> References; 37, 248

Research *(37)* has shown that impassability resulting from loss of traction between vehicle wheels and the road on a well-shaped ENS will occur on all roads whose surfacing comprises predominantly clay material whenever a minimum depth of rain falls onto the surface. This level of rainfall is typically the amount that would fall in an average intensity storm of more than about 30 minutes duration, although the precise impact will be a function of mineralogy, fabric and structure. Thus the number of days each year that such a road will be impassable for some of the time depends simply on the number of days that such a storm occurs. If such storms occur too frequently then there will be insufficient time for the road surface to dry and so the period of impassability will be correspondingly longer. If an ENS is well cambered and drained, it will normally dry out within hours of any storm sufficiently to satisfactorily bear light traffic on many soils. Regular surface and drainage maintenance is required to avoid any standing water.

SEACAP research concluded that, in the S E Asian environment at least, an ENS with a minimum soaked CBR of 15% at 95% of Proctor compaction is more than adequate to cater for light non-commercial traffic. This criterion was linked to the Grading Coefficient, which could be more easily used as a specification limitation than CBR *(38)*.

Engineered Natural Surfaces (ENS) are typically capable of carrying up to (AADT) 25 vpd if the above requirements are met. In some circumstances an ENS can satisfactorily accommodate higher traffic flows.

In areas of in situ expansive clays there are significant challenges. The soils generally lose most of their traffic bearing strength when wet or soaked. Where economically avoidable, ENS options should not be used on expansive clays. Where unavoidable, consideration should be given to preventing traffic passage during rain and until the expansive soil ENS has dried out to regain adequate bearing capacity. Road user and community involvement is essential if this procedure is to be adopted as part of the formal road management policy.

6.4.2 Unsealed Gravel Roads

A natural gravel surface is often considered as the usual upgrade option for ENS roads where improvement is justified. However, particular care should be taken in considering this option.

The recommendations (*28*) in the following paragraphs are for natural gravel or crushed stone LVRR surfaces carrying up to a maximum traffic flow (AADT) of 200 vpd. Traffic flow volume is usually the principal determining design criterion for this type of road surface in developing countries, although recent research has shown that local environment factors should further restrict the satisfactory use of natural gravel surface for sections of route that are affected by:

- Longitudinal gradient >6%;
- Annual rainfall >2,000mm;
- Excessive haul distances for initial and maintenance (re-)gravelling;
- Available gravel material does not meet relevant specifications;
- Dust emissions in settlements or adjacent to high value crops;
- Seasonal flooding.

Annual gravel loss rates or costs may be excessive in these cases or their combinations and other surface options should be considered.

Gravel roads passing through settlement areas, or with adjacent high value crops in particular, require materials that do not generate excessive dust in dry weather (*309*, *310*). Consideration should therefore be given to the type of gravel wearing course material to be used in particular locations such as towns or settlements, or adjacent to high value crops.

The designs of gravel and paved/sealed roads have the same objectives in that they have to be designed to protect the subgrade from excessive stresses imposed by traffic. Whereas this can be reasonably straightforward for sealed pavements because the pavement thickness remains constant throughout the life of the pavement, the approach to unsealed gravel pavement design is less straightforward. The stresses on the subgrade increase as gravel is worn away.

Recommendation: Gravel is a 'wasting' surface and its selection and design should focus on material quality, suitability, expected annual material 'losses', whole life availability and costs, and effective maintenance regime.

If any of these factors are compromised, then the risk of failure and waste of investment will be high.

References: 31; 90; 260;

A gravel road can be considered to consist of sacrificial gravel wearing course (GWC) and a structural layer which covers the in situ material and provides adequate structural protection for the road foundation. The GWC will suffer material losses due to traffic and natural erosion and should be regularly reshaped and replenished under the maintenance regime to ensure that the structural gravel layer retains at the minimum the design thickness. In most gravel road designs for LVRRs these two elements are considered to be one unit and are often composed of the same material and, in practical terms, will be laid and compacted in a similar manner as one or two layers depending on the total thickness.

A variety of design approaches exist for gravel surfacing; ranging from the simple use of a "standard" 150-200mm (*87*) to more detailed multilayer design as outlined by ARRB (*102*). Recent SEACAP research *(65)* in Lao included an approach specifically for light traffic. Both the Ethiopian and South Sudan manuals also present unsealed road thickness design procedures *(240, 260)*. This general design procedure consists of the following steps:

1. Assess likely maintenance regime.
2. Determine traffic (baseline flow and forecast).
3. Obtain material and geotechnical information (field survey and material properties).
4. Assess subgrade (classification, foundation for expansive soils and material strength).
5. Carry out thickness design (GWC plus structural thickness).

The Gravel Wearing Course (GWC) material losses will depend on a range of factors as previously discussed. It is important to assess the likely annual rate of loss to determine maintenance liabilities and ensure that adequate arrangements are in place for the relatively expensive periodic maintenance re-gravelling, and to assess Whole Life Costs. TRL and recent SEACAP research provide guidance on likely surface gravel loss rates for gravel surface material that is within specification and adequately maintained (*28*, *124*, *221*, *274,*).

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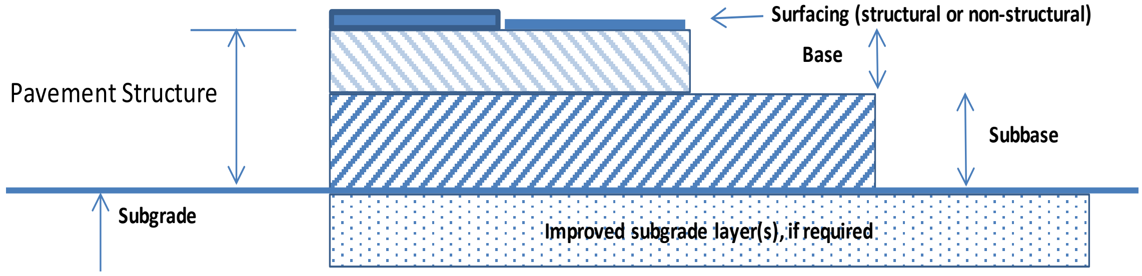
6.5 Detailed Design Issues: Sealed or Paved Roads

6.5.1 General

The structure of a paved road consists typically of one or more layers of material with different strength characteristics (Figure 6.2), each layer serving the purpose of distributing the load it receives at the top over a wider area at the bottom. The layers in the upper part of the structure are subjected to higher stress levels than those lower down and therefore need to be constructed from stronger material (269). The surfacing is most likely to non-structural in terms of its contribution to the overall strength of the road pavement (21).

Figure 6.2 Main Structural Elements of Road



6.5.2 Capping layer

The LVRR principles require the maximum use of locally available materials and the minimum use of more expensive higher quality pavement materials. Design charts for LVRs have been derived to minimise the thickness of the expensive materials and to maintain subgrade protection by using less expensive layers in the sub-base and capping layers. The capping layer uses a material quality that is significantly lower than the sub-base requirement. In the SEACAP Lao research *(34, 65)* these materials are typically about one third of the cost of sub-base materials and are usually more readily available near the alignment or as overburden or lower quality material at the placement sites. In this way, the thickness of the sub-base and road base materials and thereby their costs could be kept at a minimum.

Recommendation: A reduction in the use of expensive processed or imported base or sub-base materials is a necessary goal in order to lower costs in LVR construction.

This may be achieved in appropriate circumstance by the use of a capping (or improved sub-grade) layer and a consequent reduction in thickness of the overlying layers.

References: 34; 65

6.5.3 Structural Layer Design

There are a number of methods that have been developed for the design of flexible paved roads, ranging from the simple to the complex and based on both mechanistic/analytical and empirical methods. The purely empirical design methods are limited in their application to conditions similar to those for which they were developed, whilst the mechanistic/analytical methods require a considerable amount of material testing and computational effort. Their application to highly variable, naturally occurring materials, which make up the majority of LVRR pavements is questionable except in special cases. The SEACAP work in Lao (65) was an example of a special case where a mechanistic approach to specific light traffic regimes gave rise to significant potential cost savings by reducing base layer thicknesses.

Many pavement catalogues are based on the principles contained in ORN 31 (*82*) which includes design charts (catalogues) as a principal aid for pavement design. The design catalogue can also be used to cross check other pavement design procedures being put forward as part of a project analysis to ensure that the design being proposed is generally correct.

> ***Recommendation: Application of appropriate design charts or pavement catalogues is the simplest approach to pavement design.***
>
> All the practical and theoretical analysis has been carried out and different structures are presented in chart form.
>
> Key references: 82.

Manuals such those from Ethiopia and South Sudan have followed this catalogue approach, with modifications based on research undertaken in a number of countries in southern Africa *(125, 162, 211, 229)*. Recent documents, such as the Ethiopian manual, differ from the traditionally accepted criteria applied to the design of heavily trafficked roads in that they recognise the controlling influence of the road environment on the deterioration of lighter pavement structures. By incorporating a recognised climatic variable, the N-value *(186)*, the geographical transferability of the research findings can be undertaken with confidence.

Typical LVRR design processes for bituminous surfaced roads are outlined in the flow charts presented in the Ethiopian and South Sudan LVRR Manuals *(240, 260)*; in SEACAP reports *(311)*; as well as in various other manuals such as those from Malawi (239), South Africa (330) and Australia (101). This process indicates the sequence of steps that are required to produce a pavement design that is appropriate and adequate for an individual road.

6.5.4 Structural Layer Materials

Natural road base and sub-base material options for flexible road design include:

- Graded crushed stone;
- Waterbound Macadam;
- Drybound Macadam;
- Natural Gravel;
- Armoured Gravel.

> ***Recommendation: Many apparently marginal natural materials can be stabilised to make them suitable for use in road pavements.***
>
> This option is only economical when the cost of overcoming a deficiency in one material through stabilisation (or modification) is less than the cost of importing another that is satisfactory without stabilisation.
>
> References: 88; 182; 249

Stabilisation of materials, that in their natural state would not be suitable, can be carried out to achieve the following main objectives:

- To increase strength and bearing capacity;
- To control volume change when moisture content changes;
- To increase the resistance to erosion, weathering or traffic usage;

- To reduce the permeability of the stabilised soil.

There are three primary types of stabilisation used for improving the engineering properties of soils and gravels for road building. These are: mechanical stabilisation (compaction, and blending sources of aggregates with different particle size distributions); bituminous stabilisation (using bitumen in one form or another); and chemical stabilisation using cement, lime or pozzolans (often called hydraulic stabilisers because water is a necessary reagent in the process. *(39, 88, 137, 182, 199, 322, 324).*

Blending of two naturally occurring cohesive and granular materials is carried to:

1. Improve the stability of cohesive soils of low strength by adding coarse material, or
2. Improve the stability of otherwise unstable granular materials by adding a fine material.

6.5.5 Bituminous Surfacing

Relatively thick, pre-mixed bituminous surfacings, such as asphalt concrete or bitumen macadam, are usually uneconomic for LVRR applications. They generally require high (imported) capital equipment and high technical competence which are usually inappropriate for limited resource LVRR environments. This document focuses principally on guidance to the use of thin bituminous surfacings and local resource based options, although reference is made to on-site produced cold-mix options (*282*).

Recent comprehensive guidance manuals applicable to the design and construction of bituminous surfacing for low volume rural roads have recently been issued through AFCAP, SANRAL and SABITA *(235, 236, 237)*. The following paragraphs highlight key points from this guidance. The Feasibility Stage should have indicated a general option that includes a bituminous surfacing. The FED should finalise this design depending on the particular design options that are commonly used for LVRRs:

- (Double) Sand seal;
- Slurry seal;
- Single surface dressing;
- Single surface dressing with sand seal,
- Cape seal with one or two layers of slurry,
- Double surface dressing,
- Double surface dressing with two layers of finer aggregate (Triple seal in Vietnam),
- Otta seal (single or double),
- Cold mix asphalt concrete.

Recommendation: Final decisions regarding seal type and design should be are taken after re-evaluation of assumptions made during the feasibility stage.

Emphasis should be put on strategic issues such as :

- Purpose of the seal;
- Expected performance;
- Construction regime;
- Maintenance capability;
- Cost.

References: 151; 154; 260

Important factors affecting the selection of thin bituminous surfacing include:

- The anticipated traffic volume and types of vehicles carried by the road;
- The type of pavement and its strength;
- The characteristics of the materials available;
- The characteristics of the project, whether it is new construction or resealing;
- Environmental conditions of the site;
- Road geometry, sharpness of bends and steepness of gradients;
- Safety;

- Required surface texture;
- Experience of the contractor and consultant/supervisor;
- Reliability and capacity of future maintenance;
- Funds available for the initial construction and future maintenance.

The life of a thin bituminous surfacing treatment can vary widely in relation to a number of factors as indicated below *(260)*:

1. **Climate:** Very high temperatures cause rapid binder hardening and extreme brittleness through accelerated loss of volatiles, while at low temperatures binders are also brittle leading to cracking or aggregate loss resulting in reduced surfacing life.
2. **Pavement strength:** Lack of underlying pavement stiffness will lead to fatigue cracking and reduced surfacing life.
3. **Base materials:** Unsatisfactory road base performance and absorption of binder into certain base materials (e.g. pedogenic materials) will lead to reduced surfacing life.
4. **Binder durability:** The lower the durability of the binder, the higher the rate of its hardening, and the shorter the surfacing life.
5. **Design and construction of surfacing:** Improper design and poor construction techniques (e.g. inadequate prime, uneven rate of binder application or 'dirty' aggregates) will lead to reduced surfacing life.
6. **Traffic:** The higher the volume of heavy traffic the shorter the surfacing life.
7. **Stone polishing:** The faster the polishing of the stone, the earlier the requirement for resurfacing.

Recommendation: There are a number of key properties that the chippings used in surface dressings should ideally have:

- Strong, durable and sound;
- Not susceptible to the polishing action of traffic;
- Single sized within a practical tolerance;
- Clean and free from dust;
- Cubical in shape, not rounded or flaky;

References: 148; 235

The type of bitumen or emulsion used will be largely influenced by the availability of different types in the area where the surface treatment is carried out, together with the associated costs. The choice of bitumen for spray treatments is also affected by the following requirements.

The bitumen must:

- Be capable of being sprayed and wetting the road surface in a continuous film;
- Not run off the road surface on the camber or form pools in local depressions;
- Wet the chippings/aggregate and adhere to them at ambient temperature, the adhesion being strong enough to resist traffic forces at the highest ambient temperature;
- Remain flexible at the lowest ambient temperature, neither cracking nor becoming brittle enough to allow traffic to remove chippings.

It is not normally possible to fully satisfy all requirements; therefore the choice of binder should give the best possible compromise.

6.5.6 Concrete Surfacing

Concrete pavements are a common option for LVRRs in some regions, particularly for those with an aggressive natural environment and for steep slopes. Non-reinforced concrete (NRC) is the normal option. Steel reinforced concrete (SRC) may be used where very high wheel loads are anticipated or on high volume routes. It may also be used on LVRR roadway structures such as drifts or causeways. However, SRC is usually difficult to justify for extensive LVRR applications. NRC surfaces for LVRRs are commonly designed in 4m to 5m long slabs that may be full carriageway width or half width depending on the geometry of the road or the ease of traffic diversions (220). Steel dowels are normally required between slabs for load transfer except for the lowest traffic levels. The first and last slabs, adjoining unpaved or flexible surfacing, also require careful detailing to accommodate the impact loading of heavy wheels moving onto the slabs and to ensure a smooth surface transition. Slab thickening or local reinforcing can be used for this purpose.

Results from SEACAP and other trials have indicated the good performance of NRC slabs provided that a sound uniform sub-base is provided to prevent brittle failure in NRC slabs, particularly at slab corners, and that appropriate quality control is exercised in the mixing of the NRC and the placement of the inter-slab dowels and joint filling (69, 312).

The use of existing charts of tables is recommended as the best design approach for NRC rigid pavements for LVRRs. The ARRB document on sealed rural road design (101) provides comprehensive guidance and charts for both NRC and SRC options. SEACAP work in Lao PDR provides an example of a specific NRC design table for light traffic (65) and the Ethiopian and South Sudan design manuals provide design catalogues for NRC (240, 260).

6.5.7 Stone and Block/Brick Options

Stone block or manufactured brick/block options for LVRRs may be either mortared or provided with fine granular in-fill to the inter-block joints (31, 46). The latter are normally designed on the assumption that at least some form of “lock-up” is achieved by the infill between blocks and significant load spreading is achieved (94, 114, 140). The normal practice for LVRRs is to design these pavements with the stone or manufactured blocks over a sound sub-base, although some design procedures for higher traffic loads include base and sub-base (192). The bedding and jointing material (usually sand or fine crushed aggregate) should meet grading requirements. Underlying pavement layers should be designed to drain any moisture that penetrates the surface.

The use of a mortared joint option effectively turns the resulting pavement into a rigid structure with a more impervious surface using a design approach that can be considered akin to that of NRC.

The South Sudan and Ethiopian design manuals provide design catalogues for both mortared and non-mortared options (240, 260).

6.5.8 Hand-Packed Stone

No formal design procedure has been developed for Hand Packed Stone (HPS) or its mortared equivalent (115). This labour based technique is widely used both as a surfacing and as a surfaced road base, although use is poorly documented. It is a useful technique for a stage construction strategy; overlaying with a bituminous seal after bedding in. An example of its documented use as a typically 30cm thick surfacing, and road base with bituminous overlay is provided in (313). Specifications are currently being developed in Kenya based on widespread application there. Hand packed stone can provide a very rough surface, unless carefully constructed, and this may be unpopular with road users.

6.5.9 Shoulders

Shoulders are an essential but often under-designed element of the structural integrity of a road. They provide lateral support for the pavement layers and are especially important when unbound materials are used. Shoulders fulfill a variety of functions in the operation of LVRRs including:

1. Structural - to allow wide vehicles to pass each other safely on relatively narrow roads without damaging pavement edges.
2. Safety: to provide safe room for temporarily stopped or broken down vehicles; to allow pedestrians, cyclists and other vulnerable road users to travel safely.
3. Drainage: to allow rain water to drain from within the pavement layers and away from the road surface and into side drains and prevent ponding at the side of the carriageway.

Outcomes from some research have suggested *(197, 271)* that, wherever possible, shoulders of paved roads should be considered for sealing, for the following reasons:

1. Sealed shoulders provide better support and moisture protection for the pavement layers and also reduces erosion of the shoulders (especially on steep gradients).
2. They improve pavement performance by ensuring that the zone of seasonal moisture variation into the pavement is reduced.
3. They reduce maintenance costs by avoiding the need for reshaping and re-gravelling of the shoulders at regular intervals.
4. They reduce the risk of road accidents, especially where the edge drop between the pavement and the shoulder is significant or the shoulders are relatively soft.

It has to be recognised that the sealing of shoulders adds significantly to the construction costs and that this in some enabling environments is difficult to justify.

A number of shoulder options were trialled under the regional SEACAP programmes, all of which had one or more disadvantages. Key findings to arise from the trials are:

1. Unsealed macadam shoulders are unlikely to be suitable for most road environments, particularly those with moisture susceptible road-bases or sub-grades.
2. Adequate earthwork support to the outside shoulder edges is necessary.
3. Construction of shoulders should be integrated with carriageway construction where possible.
4. There are potential mixing difficulties with lime or cement stabilised shoulders constructed separately after the carriageway.
5. If regular re-shaping or grading is not undertaken on unsealed surfaces then water will be prevented from draining from these surfaces as soon as any differential erosion occurs relative to shoulders.

6.5.10 Drainage

Good drainage design incorporates a number of key features that work together to ensure good road performance. For the best performance the pavement surface should be impermeable and the shoulders sealed if possible (*200*, *239*). The correct camber should be maintained on all layers that are impermeable and a suitable path for water to escape must be provided, either by extending a permeable pavement layer right through the shoulder or by including a permeable layer within the shoulder. If it is too costly to extend the roadbase and sub-base material across the shoulder, drainage channels or 'grips' at 3m to 5m intervals should be cut through the shoulder to a depth of 50mm below sub-base level (*278*).

The design of the pavement cross section and the side drains are vital factors affecting pavement performance. The 'drainage factor' is the product of the height of the crown of the road above the bottom of the ditch (h) and the horizontal distance from the centreline of the road to the bottom of the ditch. It can be used to classify the type of drainage prevailing at the road site. Irrespective of climatic region, if the site has effective side drains and adequate crown height, then the in-situ pavement strength should stay above the design value. If the drainage is poor, the in-situ strengths will fall to below the design value as moisture enters the pavement layers. A minimum value, h, of 0.60 to 0.75m is recommended depending on circumstances (*271*).

When permeable roadbase materials are used, particular attention must be given to the drainage of the pavement layers. Ideally, the road-base and sub-base should extend right across the shoulders to the drainage ditches or edge of batter/side slope. In addition, proper crossfall is needed to assist the shedding of water into the side drains. A suitable value for paved roads is about 2.5 to 3% for the carriageway, with a slope of about 4-6% for the shoulders. Increased crossfalls of 4-6% are required at construction stage for unpaved roads (earth and gravel). It is important to maintain adequate crossfalls during the whole life of the road.

Lateral drainage can also be encouraged by constructing the pavement layers with an exaggerated crossfall, especially where a permeability inversion occurs. This can be achieved by constructing the top of the sub-base with a crossfall of 3-4% and the top of the subgrade with a crossfall of 4-5%. Although this is not an efficient way to drain the pavement it is relatively inexpensive and therefore worthwhile of consideration, particularly as full under-pavement drainage is rarely likely to be economically justified for LVRRs.

Trench (or boxed in) type of cross sections, where the pavement layers are confined between continuous impervious shoulders, should be avoided (*65*). This type of construction has the undesirable feature of trapping water at the pavement/shoulder interface and inhibiting flow into drainage ditches or side slope. This in turn, facilitates damage to the pavement and shoulders under even light trafficking. This ancient type of road construction is totally unsuited to modern traffic loading. “Boxed” construction is a common cause of road failure due to the reduction in strength and stiffness of the pavement material and the subgrade below that required to sustain the traffic loading.

6.6 Maintenance Regime Issues

6.6.1 General Approach

At the FED stage it is essential to carry out an assessment of road maintenance capability to feed into the design process. In the past, LVRR detailed design has often included insufficient consideration of the road maintenance regime and the likelihood that adequate maintenance will be carried out in a timely manner. This has often led to gross over-optimism regarding actual maintenance achievement with many investments subsequently failing prematurely before the economic and social benefits could be realised. This is an unacceptable failure of professional and management responsibilities regarding the road investments and assets.

An assessment of existing and required maintenance arrangements is necessary so that appropriate pavement and surface options can be designed. If necessary maintenance capacity building initiatives can be incorporated into the design and implementation process.

Recommendation: ***Each surface or paving option has varying maintenance needs and consequences for routine and periodic maintenance funding and resources.***

The assessment of these needs and the capacity to deliver them is an essential part of the design and selection process for surface and paving options and whole life cost assessment**.**

References: 31; 116; 261

6.6.2 Maintenance Capacity Assessment and Achievements

With an appreciation of good maintenance practice, a key input to the surfacing options assessment should be evaluation of the existing road maintenance performance on the target or other roads managed by the road maintenance authority or organisation. This should include data collection and assessment of:

- Maintenance responsibilities;
- Network lengths of each surface type;
- Maintenance funding available and forward budgets;
- Current maintenance implementation arrangements;
- Maintenance achievements/outcomes;
- Performance compared to requirements;
- Identified challenges/constraints.

Recommendation: ***If the current or expected road maintenance capacity is seriously deficient, then a capacity building component should be considered as part of the overall project.***

Inadequate maintenance funding or arrangements risk failure of the road and investment before the economic and social benefits can be realised.

References: 83; 262; 274

Guidance on maintenance capacity assessment and relevant assessment issues is provided by (*257*, *258*, *263*,).

6.7 Contract Documentation

The preparation of contract documents will be part of the FED process. To assist in project administration and to supervise the work of the contractor, it is sometimes the case that the owner or executing agency will appoint a firm of consulting engineers. Clear ToR for this appointment may also be required as part of the FED output.

The use of simplified bidding documents rather than standard international documents using numerous work items has been found to be a significant contributory factor to the cost savings offered by the LVRR approach.

When the process is open to competition from any company, irrespective of their country of origin, this procurement process is often referred to as 'international competitive bidding' (ICB). When competition is restricted to local firms, then the process is known as 'local or national competitive bidding' (LCB or NCB). In many cases the smaller individual LVRR road construction contracts will be on an NCB basis.

Recommendation*:* ***The use of simplified bidding documents should be considered for LVRR projects rather than standard conventional documents.***

This has been found to be a significant contributory factor to efficiency and cost savings.

References: 22; 155

There are two basic types of specifications that can be used in contracts:

1. Procedural' (or 'method') specification, where the employer defines details of how the work is to be carried out.
2. Functional' (or 'end-product') specification, where the employer defines the result to be achieved by the contractor in terms of a functional or performance requirement.

A mixture of end-product and method-type specifications can easily lead to confusion during construction unless it is made clear which requirement takes precedence.

Procedural specifications have been used traditionally for road works. These reflect the high degree of competence of road administrations and are relatively easy to specify and to measure. However, they have high supervisory requirements and do little to encourage contractor innovation, since there is little permitted flexibility for changing work methods, designs or materials.

The most widely recognised forms of standard contracts are produced by the Fédération Internationale des Ingénieurs-Conseils (FIDIC). FIDIC-based contracts have become increasingly common in recent years for implementation of road projects, although organisations such as the World Bank, The EDF, Asian Development Bank or the African Development Bank may use their own standard documents. The participants of the contract are usually:

1. The 'Employer' (owner), who arranges the project financing and the design of the works in addition to employing the 'engineer' and the 'contractor'.
2. The 'Engineer', who supervises the work of the contractor on behalf of the employer.
3. The 'Contractor', who's tender has been accepted by the employer for the works.

The contract may also be endorsed by the funding agency if it is a separate entity from the employer.

The roles of each of the three parties may vary significantly depending on the form of contract.

The contractor is usually required to submit detailed statements of the methods proposed for key items of work, complete with identification of plant and equipment. Contract documentation should incorporate any local or financier's policies for encouragement or development of Small and Medium Enterprises (SMEs), local materials use, local manufacture encouragement, intermediate equipment methods, local labour and community involvement, training and capacity development initiatives, and any complementary (non-road) initiatives to be included in the contract.

Technical specifications will normally contain detailed descriptions of test methods, often by reference to internationally acknowledged test designations, such as AASHTO (American Association of State Highway and Transportation Officials), ASTM (American Standards for Testing Materials) British Standard Methods, or Euro Codes. It should be noted that different standard test methods for the same parameter can give significantly different results (167).

Contract plant requirements should be realistic in stating minimum necessary plant holdings for the paving options used, and should permit plant hire options for competent/trained contractors.

> **Recommendation:** ***Well-defined test procedures are essential within technical specifications if disputes are to be avoided during the construction period.***
>
> For example, it is not sufficient to require that a class of concrete must have a seven-day strength of at least 30MPa. This requirement is meaningless unless characteristics such as the test specimens' shape (cube or cylinder) and dimensions are defined, along with the rate of load application and the curing conditions.
>
> References: 79; 156; 239

ToR for the appointment of a firm of consulting engineers to assist in project administration and to supervise the work of the contractor may also be required as part of the FED output.

6.8 Outcomes

The required outputs from the FED relevant to pavement and surfacings may be summarised as:

- Detailed pavement design procedures including drawings;
- Identification and design of sections for Spot Improvement (if EOD adopted);
- Bills of Quantities and associated cost estimations;
- Technical specifications for pavements, surfacings and associated materials;

- Requirements for Quality Control during construction;
- Training and capacity building requirements;
- Maintenance arrangements and assumptions on which pavements have been based;
- Any necessary maintenance capacity enhancement initiatives to ensure intended Whole Life performance of the works investments.

Chapter 6: Relevant Reference Summary

Topic	Available	Additional Recommended
FED Principles	37, 82, 197, 326, 330	50, 87, 123, 240, 260
Design Information	65, 142, 197, 269, 285	123
Material Selection	88, 249, 298, 235, 329	91, 171, 174, 181
Sub-grade at FED	65, 82, 269, 285	8, 72, 198, 260,
Unsealed Roads	28, 37, 38, 65, 124, 197, 221	101, 248, 260
Flexible Roads	34, 65, 82, 125, 211, 271	8, 50, 102, 203, 229
Bituminous Seals	89, 148, 235, 236, 237,282	20, 151, 154
Concrete Roads	31, 34, 46, 312, 337	102, 240
Stone and Block Roads	31, 46, 114, 283,284,	192, 240, 260
Shoulders	65, 197, 271	50
Road Drainage Design	200, 239, 272	278
Maintenance Regimes	144, 286, 305	49, 116, 263
Contract Documents	31, 46, 77, 139, 155, 304, 331	22

7 CONSTRUCTION

7.1 Description

The aim of this phase of the road cycle is the construction of road (or roads) as specified in the contract documents with appropriate levels of supervision and quality control. This phase should also include an as built survey as part of the completion certification.

The construction process itself is seldom as well-controlled as expected or desired. Sources of variability in quality arise in all aspects of the construction process and some are inherently more serious than others (*148*).

Figure 7.1 outlines key actions in this phase of the Road Cycle.

Recommendation: ***There are some construction issues that frequently cause concern and which need particular attention.***

- Degree of compaction achieved transversely across the road;
- The construction of adequate road cross-fall;
- Adequate pavement drainage construction;
- Quality of thin bituminous surfaces.

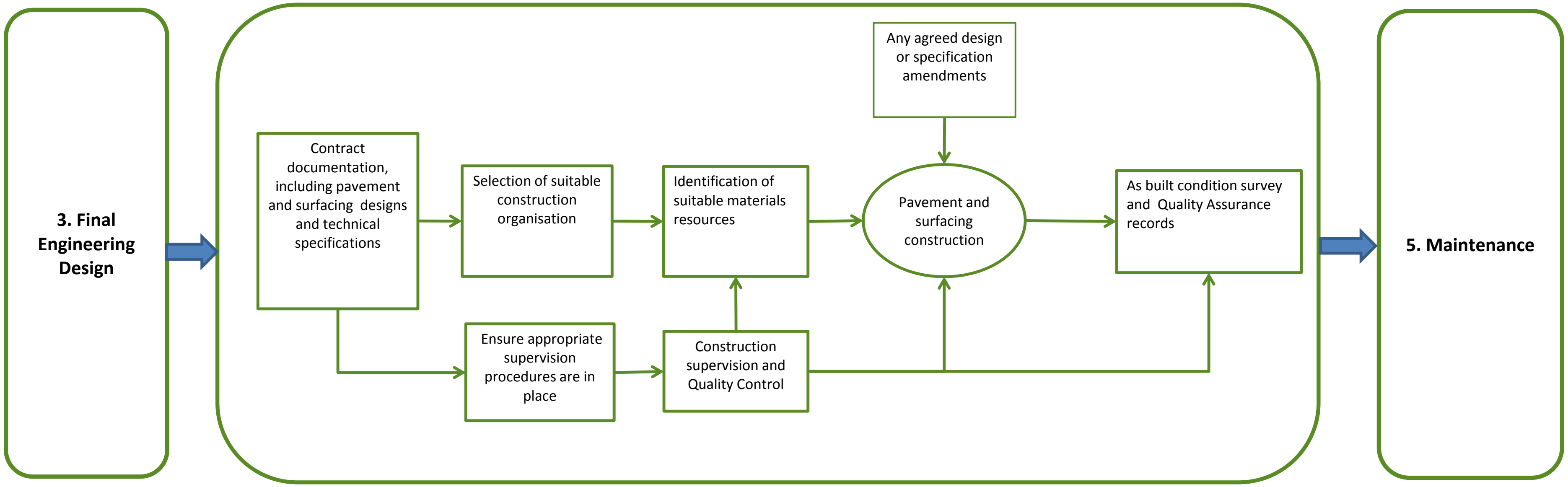
References: 31: 70

7.2 Some Key Issues

SEACAP *(31, 46, 72)* and more recently AFCAP (*270*) has highlighted a number of issues that are likely to require attention during the construction phase of the cycle:

1. Small scale contractors are generally not used to following technical specifications closely and may require a combination of easy-to-follow guidelines, training and initial close supervision, especially for newly introduced options.
2. There can be a general initial resistance to new procedures, with many contractors tending to use locally established practice as default procedures without reference to contract specifications.
3. Some new procedural options are likely to be best controlled by a tightly overseen method specification approach. This is particularly true of operations where control testing may involve significant delays, e.g. concrete surfaces and lime or cement stabilisation.
4. The role of site supervisors in controlling the contractors' procedures and material usage is not yet generally accepted in, for example, the rural road sector in S E Asia. Current practice appears to be concerned largely with observation and reporting of progress rather than technical control.
5. There are potential difficulties with supervisors being unable to exert influence on the contractors to abide by specifications and the unwillingness of contractors to heed advice from supervisors.
6. Small contractors in some regions may have limited plant resources; for example, they may rely heavily on the standard 8-10 tonne, 3-wheel, static rollers for compaction, which have limitations for certain types of materials.
7. Contractor performance and progress may be inhibited by severe cash-flow difficulties, which are not helped by unrealistic delays in processing agreed payment certificates. This may partly explain the reluctance to consider the plant-hire and labour based options.
8. Small Scale contractors may be reluctant to invest in supervisor and labour training for new techniques if there is little prospect of continuity for such works. There is a need to encourage the use of intermediate construction equipment (*277*).

Figure 7.1 Key Actions in the Construction Phase



The above issues highlight the need for appropriate training and guidance on construction and construction supervision to improve the effectiveness and efficiency of the considerable investments. Training, where provided, is usually confined to classroom based teaching processes with few opportunities for 'hands-on' work or practical application. This is a serious constraint to knowledge and capacity development. Demonstration of good practice through regional training-demonstration units may have a useful role (315, 316).

Appropriate training of key personnel (with proper accreditation, certification and official recognition) should be a requirement for pre-tendering. Training should be established on a sound commercial basis so that contractors may recover the costs through the expectations of reasonable workloads.

Recent AFCAP and SABITA reports *(235, 236)* outline particular issues with surface dressings and note that the majority of failures on sprayed seals are related to:

- Poor joint construction;
- Transverse distribution of the binder;
- Over or under spray.

7.3 Required Information

Appropriate and realistic technical specifications and construction drawings are an essential pre-requisite for a successful construction phase. Ideally, specifications should be concise and capable of being clearly understood by the contractors and supervisors alike. SEACAP *(31, 65, 307)* has produced a comprehensive list of technical specifications for a wide range of conventional and innovative pavement and surfacing operations aimed specifically at LVRR construction. These are backed by detailed construction guidelines *(220).*

It is important that the supervision organisation is already set up and functional when work is started. Information on the Quality Plan and associated responsibilities must be available. Preparations should include a clear organisation plan with lines of command and delineation of responsibilities. The number of the staff required will depend on the size and complexity of the project.

Recommendation: *Contractors should be required to prepare a clear programme and related method statement.*

This will provide not only a necessary guide to their intentions but also will give an indication of whether or not the contractor has read and understood the technical specifications.

References: 126, 136, 155

7.4 Key Decisions

A number of key decisions may need to be taken during the construction phase; these include:

- Approval of construction plant;
- Acceptance of pavement layers;
- Acceptance of materials;
- Modification in design;
- Variations in BoQ items;

Material approvals should be normally undertaken in two distinct phases:

Recommendation: The approval of construction materials must be on the basis of the materials as-delivered on site.

It is not unusual for delivered materials to have significantly different geotechnical characteristics from those approved at source during planning and design stages.

References: 156; 220

1. General approval of source materials.
2. Approval of materials as delivered to site.

It is not realistic to force contractors to meet inappropriate or unobtainable material standards. For overall cost-effectiveness and minimisation of environmental impact, the LVRR road specifications should take into account, where possible, locally available materials. Hence the need to make use of flexible material specifications that acknowledge local material variations (*88*, *249*).

Material approval for use should be accompanied by clear guidelines laying out the limits within which the approval is valid. These limits may take a number of forms, namely:

- Material characteristics after compaction (material specification);
- In situ moisture regime;
- Sub-grade design value and in situ moisture condition;
- Pavement layer thickness design;
- Construction methodology;
- Traffic level, type and loading.

7.5 Supervision and Quality Control

Quality control is the principal reason for having a supervision organisation on site. To guarantee the quality of works, it is necessary to establish control over the contractor's workmanship and materials. Quality supervision can be considered as comprising two principal elements.

Site Inspection: The works are inspected visually to detect any deviation from the specified requirements. Visual assessment is an essential element of pavement layer approval, particularly for example in the identification of oversize in lower pavement layers or gravel wearing course (220). Physical measurements of thickness, widths and crossfall are an essential element of this assessment. This activity is supplemented by simple in-situ checking of specified procedures; for example, temperature of bitumen and spray rates, concrete slump, etc.

> **Recommendation: *The supervision of construction and its quality control are essential elements in the road cycle and must be given a high priority.***
>
> Experience backed by recent research has clearly indicated that poor construction has major impact on early pavement deterioration.
>
> References: 22; 70.

Laboratory and in situ testing: Materials as well as the finished product are subject to laboratory testing for such characteristics as grading, plasticity, density and strength. Special testing may be required for specific pavement options; for example, cement or lime content in stabilised materials; crushing strength of bricks or the compressive strength of stone blocks. On larger projects it may be possible for the contractor to set up and maintain a basic Field Laboratory for routine tests for quality control required to be conducted on a day to day basis. The Field Laboratory will normally have test equipment that does not require electric power supply and is relevant to the project specifications. There are also portable field test kits that have been developed that are very suitable for testing of LVRs and provide the simple equipment for basic control tests (336).

Quality control based on absolute requirements and spot tests does not necessarily ensure a well-defined quality of the product. It is for this reason that a statistical approach to quality control should be adopted for larger projects within the manufacturing sector, where works and materials are accepted or rejected based on agreed average and standard deviations.

Supervision should be aided by the utilisation of on-site actions as outlined below:

1. The DCP test may be used as a control on quality as construction proceeds. It may also be used as quality check on already constructed layers. In some cases this may involve excavating overlying hard layers[4]. The DCP test may be undertaken in conjunction with in situ density testing and moisture content testing for correlation purposes.
2. The sand replacement density test is a common requirement in specifications (156). It may be replaced in some cases for quality control purpose by the DCP test, but only after satisfactory correlations have been established for the specific constituent materials.
3. Measurement of in situ density may be undertaken using a Nuclear Density Gauge. This is a quick method of determining the in-situ density of soil in which gamma rays are emitted from a small radioactive gamma ray source. The gamma rays which interact with electrons in the surrounding material and the density of material is then correlated to the number of gamma rays received by the detector. (156)
4. The slump test is an essential on-site test for supervisors to use as a general control on the concrete mix actually being produced Addition of excess water in the concrete mix is a common malpractice to ease placement. However, this reduces the final strength of concrete and increases the risk of shrinkage cracking. Concrete samples should be taken from the mixer at the specified intervals for slump tests as well as concrete cube testing (155).
5. Tray tests for bitumen and chipping spray rates are an essential element in the control of thin bituminous surfacings for either machine or labour based operations. An alternative for the latter can be tight control on volumes of bitumen and chippings used per known length of road. AFCAP, SABITA and SANRAL documents (*235*, *236*, *237*) provide examples and guidance on bituminous surfacing control.
6. Date and time-stamped photographs are an important part of supervision, particularly if local (non-professional) community or NGO staff are involved in supervision.

Specifications will include requirements for aftercare, such as curing of concrete or stabilisation layers, or remedial work on minor defects such as aggregate loss or bleeding of bitumen seals. These "aftercare" issues are an integral part of the construction process and it is important that supervisors ensure that these requirements are adhered to.

Many of the specifications require specific plant to be used in the construction procedures. Use of inappropriate plant, or plant in poor condition or with key functions inoperative, should not be approved. One particular point to emphasise is that it follows when constructing road pavements intended for only light commercial traffic that the movements of heavy construction trucks must be limited and avoided as much as possible. This can be achieved by "back-dumping" construction materials for each pavement layer and by being especially cautious when building the capping layer over weak natural subgrades. Back-dumping is a construction process where heavy construction equipment does not unnecessarily travel on the uncompleted or unprotected construction layer (*65*).

When using local community or casual labour from the location of the works, it is essential that the foremen are trained to identify, train up and mentor headmen/women to manage the unskilled labour. This can be much cheaper than importing and housing experienced labour for the duration of the works *(317, 318)*.

[4] The DCP test is not suitable for stronger bitumen premix or cement bound pavement layers, or layers with large aggregate (>20mm).

7.6 Technical Audit

The use of a formal technical audit initiated during construction allows road authorities to identify whether the parties involved in the contract have given the Client what it paid for. This involves a more detailed assessment than standard post-construction inspection in terms of compliance of the materials and construction with the design specification.

Project technical audits may be carried out in a number of phases:

1. An Initial Audit; usually shortly after construction starts or when work is 10-20% complete.
2. An Intermediate Audit when construction is approximately 50% complete.
3. A Final Audit when construction is complete

The Botswana Roads Department Guideline on Technical Audits (304) provides relevant advice on the various actions for each technical audit phase. These are summarised in Table 7.1

Table 7.1 Technical Audit Actions Relevant to Pavement or Surfacing

Phase	Actions
Initial	Check on • The Contractors project management procedures; • Capacity of site staff; • Construction quality of work completed; • Quality and appropriateness of the plant and equipment; • Operator skills; • Methods of working; • Materials and water supply; • Site organisation and site management; • Quality and detail of the construction programme; • Site safety;
Interim	• Review the Initial Audit and the subsequent actions; • Review of construction records and minutes of meetings; • Check both the completed work and work in progress; • Completed work should conform to the typical plans; • Assess the contractor's quality control procedures; • Assess construction methods; • Review progress against the programme; • Check the current estimate against the budget price; • Check measurement records; • Check materials on site; • Check that all payments to the Contractor.
Final	• Check contractor's construction/completion report; • Assess performance of the road to date; • Assessment of construction records; • Confirm (or not) construction as per specifications; • Check materials as per specification; • Assess overall construction quality; • Check drainage construction as per design; • Construction of pavement layers and shape;

7.7 As-Built Survey

An as built survey may be either part of the Technical Audit process or undertaken independently if no formal audit procedure is in place. Either way this survey is an important action leading to the collation of the as-built records that form the base level of knowledge for the future operational management, maintenance and potential eventual upgrade of the road. Small inspection pits can be used for measurement of layer thickness, in situ testing over lower layers, and excavated materials may be sampled for testing if required.

Recommendation: ***An as-built survey must be an integral part of the Quality Assurance plan for each road.***

This should not be limited to a casual drive over the road but involve a detailed examination and in situ testing of representative elements of the pavement, surface and associate drainage.

References: 220.

Supervision records will also form a key part of the management knowledge base and may broadly be divided into the following four categories:

1. Historical records; that is, work programmes and monitoring data, weather data, resident engineer's diary and daily inspection records.
2. Quality records; that is, test results, survey control, etc.
3. Quantity records; that is, measurements for payment, monthly statements, payment certificates and variation orders.
4. 'As built' records; that is, drawings and descriptions of all completed parts of the project.

7.8 Essential Outputs

These include:

- Pavement, surfacing and associated drainage built to specification within time and budget;
- A knowledge base of as-built information relevant to the future management of the road;
- Technical Audit Report.

- **Chapter 7: Relevant Reference Summary**

Topic	Available	Additional Recommended
Construction Issues	31, 70, 148, 155, 304, 307, 332	22, 50
Construction Decisions	155, 220, 249	
Supervision and Quality Control	155, 156 220, 235, 236, 237, 272, 304 , 332, 333	
Training	317, 318.	
Technical Audit	272, 296	

8 GOOD PRACTICE MAINTENANCE

8.1 What is Maintenance?

Maintenance is the range of activities necessary to keep a road and associated structures in an acceptable condition for road users as intended when it was designed and constructed to carry out its task.

From the moment that a road is constructed or upgraded, it will deteriorate due to the effects of weather and traffic. Maintenance is required from time to time to restore its condition to be close to its as-constructed state to meet its task requirements within an acceptable envelope of conditions. If maintenance is not carried out the road will continue to deteriorate making passage increasingly difficult, uncomfortable, unsafe and expensive to road users. The road may even become impassable for part or all of the year.

> **Recommendation:** ***Building a road is only part of the total whole-life cost and that this figure should include maintenance.***
>
> Typically, for every US $1 *not* invested in road maintenance, users waste US $3 on extra transport costs (and the road must *still* be repaired).'
>
> Reference; 300

8.2 Types of Maintenance

Routine Maintenance: These are the minor maintenance activities that are likely to be required somewhere on a road link every year. Most of the tasks may be carried out manually but mechanised or equipment-based alternatives are available for some tasks. It is preferable to restrict grading/reshaping activities to the rain season when the moisture in the surface materials will facilitate re-consolidation under normal traffic without the need for expensive (and usually unavailable) watering and compaction equipment.

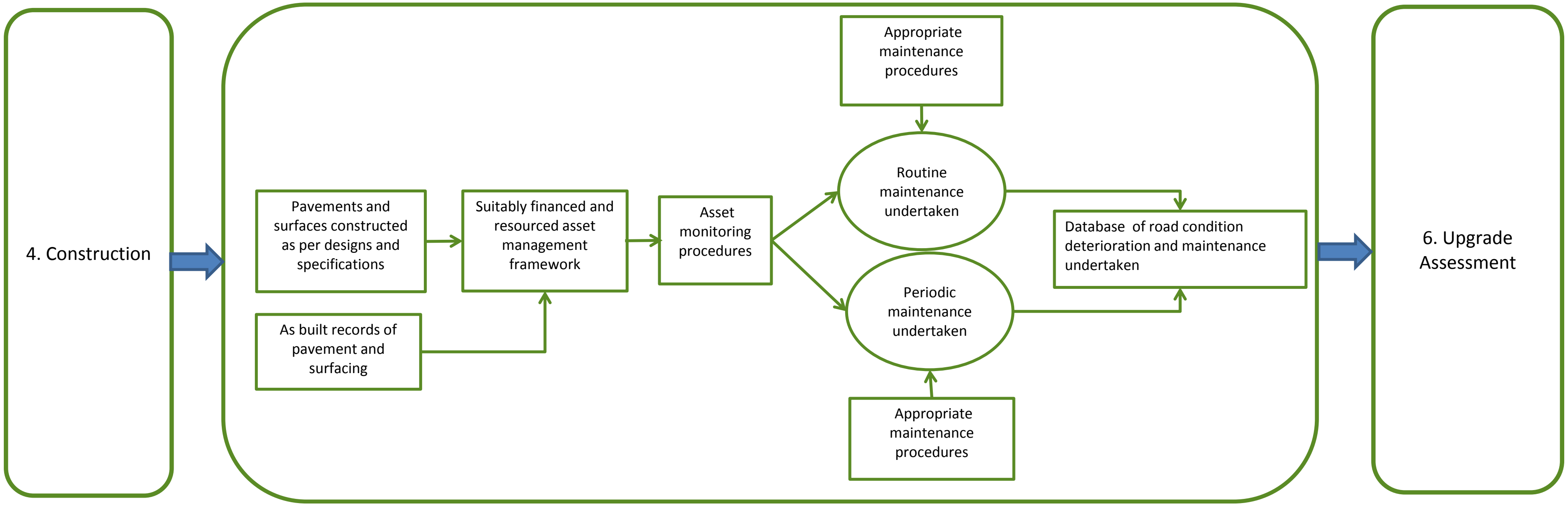
Periodic Maintenance: These are usually major maintenance activities that may be required somewhere on a gravel or paved road section or link after a period of a number of years (for example re-gravelling or re-sealing). The category of work depends on the type of road surface constructed. Periodic Maintenance tasks will usually require the mobilisation of equipment and involve the haulage of materials. The activities will require planning and specific mobilisation of the necessary resources.

Emergency Maintenance: These are unforeseen occurrences which, although they cannot be planned in detail, must be budgeted for and suitable implementation arrangements allowed.

Unpaved roads deteriorate quickly and regular surface and drainage inspections should be part of the routine maintenance regime. Paved roads generally deteriorate more slowly and annual inspections are usually sufficient to allow maintenance needs to be identified and remedial work to be planned for the coming year.

Figure 8.1 outlines key actions in this phase of the Road Cycle.

Figure 8.1 Key Maintenance Actions



8.3 Key Activities and Data Requirements

8.3.1 Maintenance Definitions, Standards and Specifications

Recommended definitions of road maintenance activities and good maintenance practice for the various surfacing and paving options are set out in documents such as: (*144*, *264*, *265*, *261*, *260*).

Contractors, supervisors and workers must be aware of the standards and specifications required for maintenance works through appropriate training and documentation. If local maintenance standards and specifications have not been developed, then the following documents will provide a starting point for development of local 'norms': (*144*, *264*, *265*).

8.3.2 Survey methods

Regular surveys are required to identify and quantify maintenance needs and, from these assessments, to develop the types and quantities of maintenance works. With experience, routine maintenance of unpaved roads can be developed into a procedure that avoids the need (and costs) for regular detailed surveys, and periodic maintenance requirements can be identified by the work gangs with appropriate training.

A knowledge base of maintenance needs, funding allocations, maintenance works carried out, costs and productivities should be compiled to allow maintenance performance to be monitored and value for money demonstrated.

8.3.3 Implementation Options and Productivity Targets

For discussion of the various maintenance implementation options and researched productivity targets, refer to: (*144*, *255*, *256*).

Community groups could be ideally suited to undertaking routine maintenance procedures if appropriately motivated, and experiences in Bangladesh and parts of Vietnam illustrate the role that women's' groups can play in "off-road" maintenance (286) This approach does need careful planning in terms of training, provision of simple guidance documentation, access to appropriate hand tools and sustainable low-level funding (247).

8.4 Essential Outputs

The following should be the outputs from successful maintenance of the constructed paving options:

These include:

- Pavement, surfacing and associated drainage maintained to standards and specifications to keep the road within the intended condition 'envelope' to realise the intended investment benefits;
- A knowledge base of information relevant to the maintenance of the road;
- Candidate sections of road identified for possible rehabilitation or upgrade;
- Reports on any shortcomings of the maintenance system and scope for improvement.

Chapter 8: Key References

Topic	Available	Additional Recommended
Maintenance Principles	265, 274; 300	24, 262
Maintenance Definitions	144, 264, 265, 260, 261.	259, 262
Maintenance Management	144, 265	255; 256
Maintenance Assessment	144	
Data Collection	144, 265	
Maintenance Procedures	264;	255, 256, 259; 260;
Community Maintenance	126; 247; 286;	49: 96; 246, 301

9 REHABILITATION OR UPGRADE

9.1 Objectives

This stage of the Road Cycle is primarily concerned with identifying roads or sections that may be in need of rehabilitation or upgrade to meet changes in task or because of significant degradation. This phase is of particular interest to strategic planners of Funding Agencies, Donors and relevant Ministries and Local Authorities.

Whatever is constructed, the condition of the road will not remain constant; it will deteriorate with time under the effects of traffic and the environment. The rate of deterioration and long-term effect of this will depend on a number of factors relating to the appropriateness of the original design and the actual maintenance input. If, for example, within the design life of a road the actual traffic or axle loading is observed to be in excess of that assumed at design stage, then measures can be taken to upgrade the carrying capacity of the pavement, for example, by the design and application of a strengthening overlay.

Recommendation: ***Two fundamental issues related to the upgrading of rural road pavements need to be assessed.***

- The justification for upgrading in economic terms and road-task performance.
- Choosing the appropriate upgrade solution or range of solutions.

Reference: 40, 81, 83, 195

LVRRs are designed to perform within a set engineering design life, usually 10-15 years, although in many cases economic analyses extend to 15-20 years. At or near the end of the engineering design life it may be necessary to evaluate the road for potential upgrading for one or more of the following reasons:

- Deteriorating condition and level of service;
- Increase or changes in traffic pattern;
- Increasing climatic impact;
- Changes in level of service required;
- Changes in government policy (e.g. to move away from unsealed to sealed network).

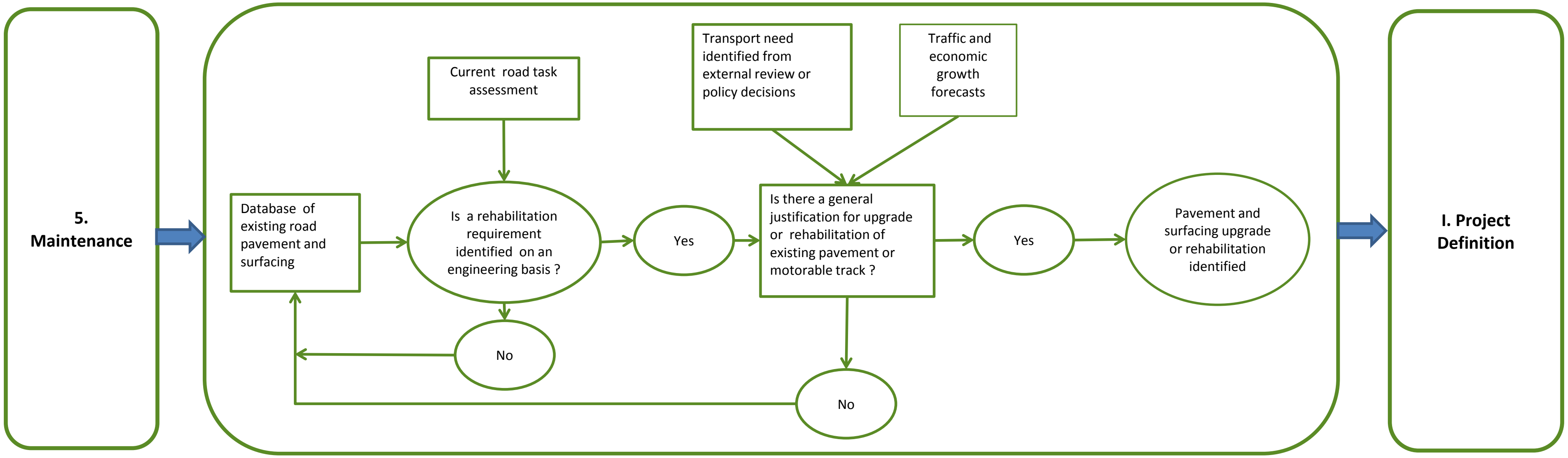
Figure 9.1 summarises key actions at this stage.

9.2 Data Requirements

If the road has been competently managed there may be a significant amount of existing construction and maintenance monitoring data available. Typical data sets that would be useful in upgrade evaluation are *(66, 67)*:

- Original investigation site visit notes and photographs;
- In situ and laboratory testing for original design;
- Pre-construction materials testing;
- Original road designs;
- Original traffic figures and calculations;
- In situ and laboratory testing during construction;
- Construction supervision notes;
- Completion report;
- Post construction monitoring data;
- Maintenance records;
- Updated traffic assumptions.

Figure 9.1 Key Rehabilitation or Upgrade Phase Actions



However it is frequently the case for LVRRs that records are far from complete and that significant amounts of new information will be required. The most crucial information required at this stage is:

1. The condition of the road and its residual structural strength.
2. The actual task it is carrying out in terms of traffic (which may differ from its design task).
3. Revised growth-traffic forecasts.

9.3 Data Gathering

9.3.1 Pavement and Surface Condition

Assessment of LVRR pavement condition and its deterioration level can be undertaken using a number of low cost procedures (*70*), as shown in Table 9.1

Table 9.1 Typical Condition Assessment Procedures

Deterioration Mechanism or Parameter	Techniques and Equipment	Derived Information	Pavement Types
Surface condition	Standard visual condition survey plus photographs	Type, intensity, width and position of cracking. Potholes and patching (145)	All options
Roughness	MERLIN (159, 254)	Derivation of standard measure of road roughness; International Roughness Index (IRI)	All options
Deformation	2m straight edge (145)	Load associated deformation, in terms of rutting	All options excluding concrete surfacing
Erosion	Engineering Level	Road cross section shape and comparative levels; leading to erosion rates	Unsealed carriageway sections and unsealed shoulders
Layer/ pavement strength	Dynamic cone penetrometer, DCP (285)	Relationships between DCP readings and strength established. (269, 285,)	Gravel and thin sealed granular base options. All shoulders
Moisture	Small disturbed samples (252)	Variation in moisture content	All options excluding concrete surfacing

Based on the outcomes from such data gathering it is useful to divide the road into sections with similar general condition levels (269, 285).

The manifestation of deterioration in road pavements depends to some extent on the type of structure but usually includes cracks visible on the surface, deformation in the wheel-tracks (ruts), potholes, erosion, loss of surface material, and general surface deformation. Whilst some of these symptoms are common to many types of failure, the type, extent, position and nature of the symptoms and their combination provide vital clues to the causes of the deterioration. For example, cracks can be transverse, longitudinal, block, parabolic or 'crocodile' in nature and can be located at edges, wheel-tracks, or centrally on the road. They may not be associated with ruts or they may occur before or after deformation begins. The precise symptoms and the timing of their occurrence leads to knowledge of the causes of deterioration and hence to an assessment of the seriousness of any problem and the approaches that may be required in terms of upgrade.

Structural failures require greater rehabilitation to correct whereas surfacing failures, at least in the early stages, require only a reseal or an overlay intervention. The assessment of these needs is an essential part of the design and selection process for surface and paving options and whole life cost assessment. If surfacing failures are not corrected, structural failures are likely to follow.

Recommendation: ***It is necessary to differentiate between structural failures caused by traffic loading and surfacing failures arising from combinations of traffic and environment effects.***

An appropriate analysis of the relevant data leads to appropriate upgrade options.

References: 68; 69; 145

9.3.2 Traffic

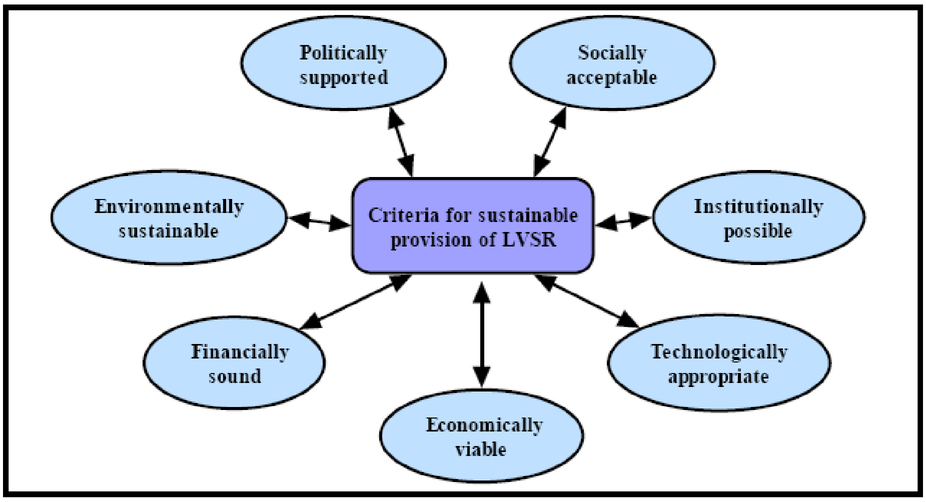
It will be necessary to re-visit the traffic assumptions made at the time of original design and see what changes in traffic patterns have occurred or are likely to occur. Procedure for traffic assessment and axle loading discussed early in Chapters 5 and 6 are equally applicable at this stage.

9.4 Sustainability

It is advisable that a review of the sustainability of the proposed upgrade or rehabilitation. The fact that a road has existed for a while should allow the review to be more accurate and meaningful because of the relevant historic information concerning the road

The term 'sustainability' in the context of rural infrastructure is often used purely in terms of technical or engineering solutions. This is misleading as there are many different components that contribute to the "sustainability" of a particular road project (Figure 9.2).

Figure 9.2 Components of Sustainability



The sustainability review should, therefore, be based not just on engineering issues but on a wider sustainability environment and may be based on the historical evidence of the operation and maintenance of the existing road or roads.

The issues in Figure 9.2 may be defined as follows:

1. Politically supported – the road project must be clearly supported at the relevant local authority level as well as at Ministerial level.
2. Socially acceptable – the local people (stakeholders) must benefit in the long-term from the road upgrade.
3. Economically viable – the economic benefits from using the upgraded road (for example, the development opportunities) must be greater than the economic costs.
4. Financially sound – there must be adequate funding in place for construction and long-term maintenance of the improved road.
5. Institutionally possible – the organisations and bodies responsible for constructing and maintaining the road must have the necessary resources and knowledge.
6. Technically appropriate – the proposed road design must be compatible with its intended function and its physical environment.
7. Environmentally sustainable – the road construction as well as its subsequent use and maintenance should not cause significant environmental damage.

It may be useful to rank each factor as an aid to identifying the sustainability risks. For example:

1. Not sustainable.
2. Significant sustainability concerns.
3. Moderate sustainability concerns.
4. Minor concerns.
5. No sustainability concerns.

Individual issues ranked 1-3 could be seen as posing potential significant risks to project sustainability in terms of long-term benefit to a rural community. This is likely to be of concern to potential funders. From the point of view of identifying a positive way forward, however, an early identification of these risk factors can allow modification of the project aims and objectives to reduce sustainability risk.

9.5 Essential Outputs

The principal output is a decision on whether a rehabilitation or upgrade is required and whether it can be justifiably put forward to the next Project identification stage.

Chapter 9: Relevant Reference Summary

Topic	Available	Additional Recommended
Upgrade Issues	40, 81, 195	50
Information Gathering	81, 83, 145, 159, 285	
Sustainability	195	50

Low Volume Rural Road Surfacing and Pavements

A Guide to Good Practice

ANNEXES

Low Volume Rural Road Surfacing and Pavements

A Guide to Good Practice

ANNEX A: Pavement and Surfacing Options

All of the techniques described in this Annex are proven for a range of environments.

Unsealed Pavements

- Engineered Natural Surface (Engineered Earth Road)
- Natural gravel
- Stone Chippings
- Hand Packed Stone
- Irregular Cobble Stone
- Telford Paving

Bituminous Seals

- Bituminous Chip Seal
- Bituminous Sand Seal
- Bituminous Slurry Seal
- Bituminous Cape Seal
- Bituminous Otta Seal
- Penetration Macadam

Block Surfacing

- Cobble Stone
- Stone Setts or Pavé
- Dressed stone Fired
- Clay Brick,
- Concrete Brick
- Mortared Option (to cover all above)

Base/Sub base

- Waterbound Macadam
- Drybound Macadam
- Graded Crushed Stone
- Natural Gravel
- Armoured Natural Gravel

- Lime Stabilisation
- Cement Stabilisation
- Bitumen Emulsion Stabilisation
- Mechanical Modification

Concrete

- Geo Cell Paving
- Non-reinforced Concrete

Additional

- Wheel Track Paving

NOTES: All pavement layers and surfacing should be laid on previously shaped and compacted formation or sub-base/road base layers of suitable type and adequate strength and drainage characteristics.

Suitable line, level and crossfall setting out measures (e.g. pegs and string lines, or profile boards and travellers) should be used for application and thickness control.

Finished surface crossfall should ideally be constructed at 5% and maintained at between 3% and 6% for unpaved roads. Paved surfaces should be constructed at a crossfall of 2 – 3%. Camber should normally fall away either side from the centre line, however on sharper curves superelevation should be applied to fall fully across the carriageway towards the inside of the curve at appropriate rates and transitions. Other cross sectional surfacing and shoulder details should be designed according to traffic and road environment factors.

Where mortar jointing techniques are used these are usually sand-cement based. However, historically sand-lime mortars were extensively used in road paving well before the invention of Portland cements (*233*). Sand-lime mortars may still be suitable for use where there are locally available lime sources at economic prices.

Where concrete or mortar are used in the various surfacing options, appropriate measures should be taken to ensure correct mix batching, water-cement ratios and adequate curing measures.

All surfacing and paving techniques require supervisors and operatives to be adequately trained to safely achieve the required quality of work in a cost-effective way.

All workers should be supplied with appropriate construction quality hand-tools, and necessary safety equipment and clothing.

Engineered Natural Surface (ENS)

General Description

Engineered Natural Surface (ENS) roads utilise existing or immediately adjacent materials along an alignment to form a shaped and drained low cost basic rural access road. The nature of these natural materials can vary from clayey/sandy soil to weathered rock. The suitability of this option must be assessed in the light of the likely impact of the Road Environment factors. The option involves the shaping and compaction of existing in-situ or immediately adjacent material to form a basic surface for traffic with a cross-fall of 3% to 6% away from the road centre line to disperse rainwater into side drainage. Alternatively the surface may be raised above surrounding ground on embankment. Problem sections of route should be considered for selective upgrading or spot improvement to other surface/paving types.

Key Resource Requirements

Local semi-skilled & unskilled labour with hand-tools to excavate & place material, and form drainage. Alternatively, use basic equipment (e.g. tractor & towed grader). Compaction at suitable moisture content by hand rammers, or a preferably static or vibrating roller to improve the surface performance.

Principal Advantages

- Very low cost option suitable for basic access light traffic.
- Does not require expensive equipment and suitable for local small contractors/communities.
- Camber and drainage arrangements can be achieved with labour and hand-tools.
- No imported materials (haulage) required.
- Easy to maintain using labour or simple, low cost, grading equipment.
- Can be used as an intermediate surface in a planned stage construction strategy.

Principal Concerns

- Requires as built in situ soaked CBR strength of greater than about 15%*[5].
- Only appropriate for light and low traffic (less than 50-100 motor vehicles equivalent per day).
- Requires regular maintenance including reshaping to keep crossfall between 3% and 6%.
- Reshaping in dry weather, without moisture or consolidation/compaction, is detrimental to performance.
- May be impassable in wet weather (may need to be intentionally closed during rain to protect against damage by vehicles).
- Unlikely to be practical to maintain economically in high rainfall areas (>2,000mm/year).
- May need to be protected from heavy vehicles by access restrictions.
- Possible dust pollution in dry weather.
- Rain water erosion on gradients, potentially serious if longitudinal gradient more than 6%.

Key References: 37, 38, 46, 222, (248)

[5] *The strength of the in-situ soil may be assessed using simple low cost equipment such as the Dynamic Cone Penetrometer (DCP).*

Natural Gravel / Laterite

General Description

One or more layers of compacted low plasticity natural gravel (for example; colluvium/laterite/calcrete). Before placing, the existing formation should be shaped and compacted with a camber (crossfall) of about 3 - 6% sloping down each side from the road centre line. The gravel should be laid to the same crossfall with a constant thickness. Maximum particle size is 40mm for good performance and to avoid high material loss and surface roughness problems. The overall constructed gravel thickness is typically 15 - 30cm. Individual gravel layer thickness usually up to 15cm (compacted) maximum. Natural gravel can be blended with selected soil/sand to improve quality.

Key Resource Requirements

Local semi-skilled & unskilled labour with hand-tools to excavate & place material. Alternatively, use equipment (e.g. dozer/digger/loader and grader). Haulage by truck, tractor trailer or cart. Watering equipment pump and bowser). Compaction at suitable moisture content possibly by hand rammers, but preferably static or vibrating roller.

Principal Advantages

- Proven performance in tropical and sub-tropical, gravel-rich environments.
- Suitable for light to medium traffic <200 motor vehicles per day (MVPD).
- Often lower initial cost than most other surfacing options, except ENS.
- Can be used as an intermediate surface in a planned and resourced 'stage construction' strategy.

Principal Concerns

- Natural gravel usually occurs in limited natural deposits of variable quality.
- Often difficult to meet standard grading and plasticity specifications.
- Gravel surfaces waste. Typically 10-50mm/year/100MVPD). It is essential to have a sustained maintenance programme and regular re-gravelling to replace gravel loss.
- Traffic, climatic and longitudinal gradient (<6%) constraints on use relating to rate of gravel loss.
- High maintenance costs; regular surface reshaping & re-gravelling.
- Unlikely to be practical to maintain economically in high rainfall areas (>2,000mm/year).
- Possible dust pollution in dry weather. Health & Environmental concerns.
- Not suitable for soaked or overtopping/flooding situations.
- Quality Assurance; particularly regarding testing, quality compliance and thickness control.

Key References: 28, 32, 78, 124, 131, 206, 221, 220, (86, 102)

Rolled-in Stone Chippings

General Description

Stone Chippings are normally hand or machine crushed from hard rock. The chippings are normally 10 – 20 mm in size. They are laid on the previously prepared and shaped in situ soil formation. Chippings are laid to a depth of 50 – 100 mm, depending on the strength of the formation. The chippings can be spread with a rake and only light or traffic compaction is required, with occasional re-shaping to correct in service surface irregularities. Stone Chipping surfacing is suitable for use as a surfacing on low traffic volume, low speed roads; where there is a need to avoid dust problems, for example where in situ soils and available gravel produce excessive dust close to habitation or crops. However, it is not usually advisable to use where bicycle or motorcycle traffic is common due to the loose nature of the surface. Ideal for agricultural access and cropping routes.

Key Resource Requirements

Rock excavation by hand or equipment. Hand crushing or equipment crushing and screening at the rock source. Haulage by truck, tractor trailer or cart. Spreading at site by hand using rakes. Local semi-skilled & unskilled labour, with hand-tools, to excavate; crush; screen; load/unload or place material; light roller.

Principal Advantages

- Simple, low cost, all-weather surface suitable for low traffic flows and low speeds.
- Does not require expensive equipment or skills.
- Labour breaking and laying of chippings can be used in remote areas with access problems for crushing equipment or heavy plant.
- Low dust surface, suitable near domestic buildings and crops.
- No standing water in rain as it dissipates in the stone chipping layer over the suitably cambered formation.
- Stone loss from the surface is usually low.
- Easy to maintain by occasional reshaping and adding more chippings.

Principal Concerns

- Requires good quality stone. Chipping should be angular, not rounded.
- Only appropriate for light traffic.
- Not suitable for bicycles and motorcycles or high speed traffic, due to loose surface and risk of accidents.
- Not suitable for medium or high speed traffic due to risk of flying stone chippings and stability.
- Not suitable on steep gradients.
- Not suitable directly over moisture susceptible sub-grades such as expansive clays.

Key References: 85

Hand-Packed Stone (HPS)

General Description

Hand Packed Stone paving consists of a layer (typically 200 – 300mm thick) of large broken stone pieces, tightly packed together and wedged in place with smaller stone chips rammed by hand into the joints using hammers and steel rods. The remaining voids are filled with sand. The Hand Packed Stone is normally bedded on a thin layer of sand/gravel. An edge restraint or kerb constructed (for example) of large or mortared stones improves durability. Infill of voids with sand-cement mortar is an option variation.

Key Resource Requirements

Supply of strong angular fresh rock and rock chips. Sand for infill. Cement mortar for edge restraints and surface where selected.

Masonry skills, local semi-skilled labour. Static or light vibrating roller.

Principal Advantages

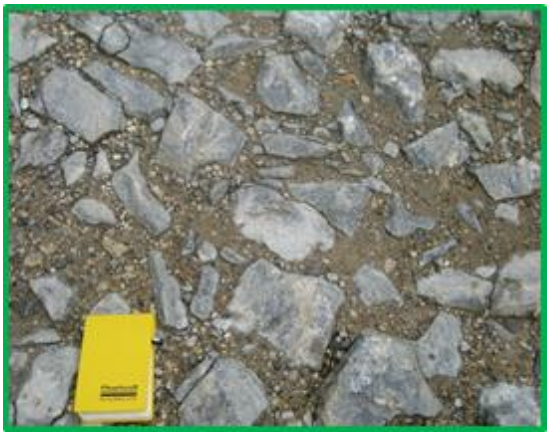
- Suitable for light to heavy traffic.
- Does not require expensive equipment to construct.
- Suitable for construction by communities or small contractors.
- Suitable for remote areas with access problems for crushing equipment or heavy plant.
- Can be constructed at steep gradients.
- Low maintenance, easily repairable.
- Can be later upgraded using a thin regulating layer and appropriate bituminous seal in a stage construction strategy.

Principal Concerns

- Requires strong, angular, stone to be available locally.
- Requires skill in lying to achieve a reasonable finished surface.
- For heavy traffic use, heavy compaction equipment should be used.
- Unmortared HPS Surface is porous, unsuitable for sub-base/subgrade susceptible to soaking.
- Medium – high surface roughness may be disadvantageous to bicycles and motor-bicycles.
- Mortared HPS less flexible and liable to cracking.

Key References: 32, 46, 115

IRREGULAR COBBLE STONE PAVING



General Description

Irregular Cobble Stone Paving consists of a layer of irregularly approximately cubic shaped stones of thickness about 100 - 120mm, laid on a bed of sand or fine aggregate of thickness 50 – 100mm. The individual stones should have at least one face that is fairly smooth and even, to be the upper or surface face when placed. The sand around each stone (or cobble) is adjusted with a small (mason's) hammer and the stone is then tapped into position and to the level of the surrounding stones. Coarse sand is brushed into the spaces between the stones. When a sufficient area of stones is placed, the layer is compacted with a vibrating or non-vibrating roller. Additional sand is brushed into the surface if necessary. An edge restraint or kerb constructed (for example) of mortared stone or concrete improves durability.

Key Resource Requirements

Strong durable fresh broken stone with at least one fair face to be used uppermost. Strength should be >75 MPa unconfined crushing strength (wet). Medium to coarse sand or fine aggregate.

Skilled and unskilled labour; heavy non-vibrating or vibrating roller.

Principal Advantages

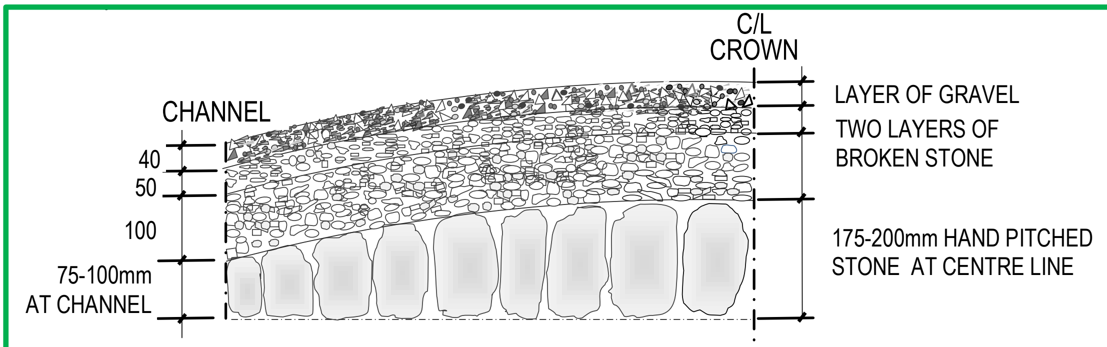
- Suitable for light to heavy traffic.
- Does not require expensive equipment to construct or maintain.
- Suitable for construction by small contractors or community groups, or in remote areas with access problems for crushing equipment or heavy plant.
- Can be constructed at any gradient.
- Low maintenance, easily repairable.
- Can be later upgraded using a thin regulating layer and appropriate bituminous seal in a stage construction strategy.

Principal Concerns

- Requires strong stone to be available locally.
- Cobble stones must have at least one fair face.
- Requires skill in laying to achieve a smooth finished surface.
- If non-vibrating equipment is used it should be heavy.
- Unsuitable over moisture sensitive sub-base/subgrade in moderate to high rainfall areas.
- Smooth to medium surface roughness.
- Stones that 'polish' by traffic, or are slippery when wet, must not be used.

Key References: 28, 94, 267, (266)

Telford Paving



See reference (253)

General Description

Telford Paving was developed by Thomas Telford (born UK 1757) as a major development in road construction. It involves placing by hand a layer of broken stone pieces of approximately 75/100 – 175/200mm in depth on a prepared and shaped ***level*** soil formation. The larger stones are placed at the centre of the road and the smaller at the edge to create the required crossfall (Minimum 1 in 45). Smaller stones are then packed between them, similar to the Hand Packed Stone technique. The initial layer is compacted and a second (100mm) and third (50mm) layer is placed on top with a combined thickness of 150mm of graded crushed stones. A blinding layer of gravel 40mm thick is then placed as the finished surface. For use by medium traffic, the layers should be compacted with a vibrating or heavy non-vibrating roller. An edge restraint or kerb constructed (for example) of large or mortared stones improves durability.

Key Resource Requirements

Supply of strong angular fresh rock and crushed stone/gravel. Cement mortar for edge restraints where selected.

Masonry skills, local semi-skilled labour. Heavy static, or vibrating roller.

Principal Advantages

- Suitable for light to medium traffic.
- Does not require expensive equipment to construct or maintain.
- Suitable for construction by small contractors or community groups, or in remote areas with access problems for crushing equipment or heavy plant.
- Easily repairable.
- Telford Paving can be later upgraded by covering with a sealing layer in a stage construction strategy.

Principal Concerns

- Requires strong angular stone to be available locally.
- Complex process and more expensive than macadams, requires skill in selection and placing of material.
- Not suitable for steep gradients (>6%) if unsealed.
- For medium traffic use, vibrating or heavy compaction equipment should be used.
- Medium surface roughness.
- Unsuitable over moisture sensitive sub-base/subgrade in moderate to high rainfall areas.
- Not suitable for high rainfall locations if un-surfaced (due to surface material losses).
- Medium maintenance requirements if un- surfaced.

Key References:.(253)

NOTE: *The original technique can be simplified by cambering the formation and using similar sized stones across the road width if available*.

Bituminous Sealing

Bitumen Chip Seals

General Description

Chip Seals act as a waterproof seal and running surface and comprise the application of a seal of bituminous emulsion binder material over the previously prepared road base. The seal is immediately covered with single sized stone aggregate chippings that are lightly rolled into the seal to form an interlocking mosaic. When one application of bituminous material and aggregate is placed it is termed as Single Bituminous Surface Treatment (SBST), with two applications it is termed as Double Bituminous Surface Dressing (DBST). In DBST the first layer chippings (typically 14-19mm) are larger than the second (typically 6-10mm). Where possible, for environmental and safety considerations, bitumen emulsion, containings penetration grade bitumen dispersed in water, is recommended. Following application at ambient temperature the water in the emulsion separates from the emulsion and evaporates leaving the residual bitumen in place to adhere to the roadbase and chippings. Technique can be used as an initial seal and for maintenance reseals. Chips seals can also be applied using penetration grade or cutback bitumen, however these methods require the binder to be heated, with consequent logistical and safety implications.

Key Resource Requirements

Supply of strong, single sized, fine aggregate, suitably shaped with adequate bitumen adhesion properties. Supply of binder that could be Rapid Setting (RS) bitumen emulsion, penetration grade bitumen or cutback bitumen. Semi-skilled labour. Light static roller, preferably rubber tyred.

Binder can be applied by hand using watering cans, by hand lance or from a towed/self-propelled distributor as required by the chosen binder. Chippings can be applied by hand, or using a manual chip spreader or from a truck with or without a tailgate chip spreader.

Principal Advantages of Emulsion Seals

- Proven performance in all climates, suitable for rural and urban situations.
- SBST suitable for light traffic, DBST suitable for heavy traffic.
- Construction does not require expensive equipment.
- Suitable for construction by small contractors or community groups.
- Easier quality control than hot bitumen.
- Safer for operatives and local village personnel for construction and maintenance than hot bitumen.

Principal Concerns of Emulsion Seals

- Requires sources of suitable emulsion.
- Emulsion (anionic or cationic) should be compatible with materials.
- Particular care required on controlling rates of spread of binder and chippings.
- Excess chippings to be swept away after a period of ‘bedding in’.

Key References: 31, 76, 89, 113, 148, 220, 235, 236, 237,282

Bitumen Emulsion Sand Seal

General Description

A sand seal consists of supply and application of a seal of bituminous binder material over a previously prepared road base. The seal is immediately covered with sand that is lightly rolled into the seal to form a weather proof matrix. Bitumen emulsion contains penetration grade bitumen dispersed in water. Following application at ambient temperature the water in the emulsion separates from the emulsion and evaporates leaving the residual bitumen in place to adhere to the roadbase and sand.

A sand seal may be used either to provide an additional layer of protection on a chip seal already laid, or as a single sealing to a block pavement.This treatment may also be used as a maintenance activity on existing asphalt or surface dressed road to seal minor cracks and extend the life of the surface. In some circumstances the technique can be used for maintenance reseals. Sand seals can also be applied using penetration grade or cutback bitumen, however these methods require the binder to be heated, with logistical and safety implications.

Key Resource Requirements

Natural sand or fine sand-sized aggregate that is clean, free from organic matter, with a low clay content (<2%) and a maximum size of 6mm. Supply of Rapid Setting (RS) bitumen emulsion.

Semi-skilled local labour; light static roller (preferably rubber tyred). Binder can be applied by hand using watering cans, by hand lance or from a towed/self-propelled distributor. Sand can be applied by hand, or from a distributor.

Principal Advantages

- Construction does not require expensive equipment.
- Suitable for construction by small contractors or community groups.
- Easier quality control than hot bitumen.
- Suitable as a second seal on top of single chip seal.
- Safer for operatives and local village personnel for construction and maintenance than hot bitumen.

Principal Concerns

- Not recommended as a single seal for even very low traffic
- Damaged easily by non-rubber tyred wheeled traffic.
- Requires sources of suitable emulsion.
- Particular care required on controlling rates of spread of binder.
- Requires regular maintenance.

Key References: 31, 32, 89, 148, 220, 235, 237

Bitumen Emulsion Slurry Seal

General Description

Slurry Seals are a mixture of well graded fine aggregate, Bitumen Emulsion, filler (usually Portland Cement), and additional water. They are mixed in a concrete mixer or purpose-built equipment, and are spread on a pre-prepared surface using wheelbarrows and squeegees or spreader box/drag spreaders. When freshly mixed the slurry seal can be spread to a thickness of 1.5 – 5mm. Following application at ambient temperature the water in the emulsion separates from the emulsion and evaporates leaving the residual bitumen in place to adhere to the pavement surface and aggregates.

Key Resource Requirements

Supply of graded, fine aggregate, suitably shaped with adequate bitumen adhesion properties. Supply of, preferably, Rapid Setting (RS) bitumen emulsion, cement or lime filler, water. Emulsion mixing and spreading equipment or concrete mixer, wheelbarrows and squeegees for transporting and spreading if labour based, Pneumatic tyred roller may be required in some cases. Skilled and Semi-skilled labour.

Principal Advantages

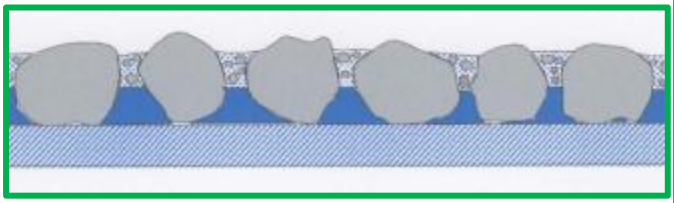
- Proven performance in all climates, suitable for rural and urban situations.
- Suitable for light traffic, can be used in combination seals and as maintenance treatment.
- Construction does not require expensive equipment.
- Suitable for construction by small contractors or community groups.
- Safer for operatives and local village personnel for construction and maintenance than hot bitumen.

Principal Concerns

- Requires sources of suitable emulsion.
- Emulsion (anionic or cationic) should be compatible with materials.
- Emulsion needs to cure before opening to traffic.
- Not recommended as a single seal for even low traffic
- Unsuitable for high rainfall without additional seal.
- Damaged easily by non-rubber tyred wheeled traffic.
- Requires regular maintenance.

Key References: 32, 89, 148, 235, , 237, 273, 282

Bitumen Cape Seal



General Description

A Cape Seal is a multiple surface treatment consisting of an application of a single bitumen chip seal followed by a single or double application of bitumen slurry seal. Usually a 13mm chipping first seal is combined with a single slurry application. A 19mm chipping first seal is normally combined with a double slurry application. The aim is that on completion the tops of the stone chips are just exposed above the slurry which fills the interstices between the stones. See the separate sheets for details of the component seals.

The Cape Seal technique is durable (typical initial life 8 – 16 years) and enables a heavy duty surfacing to be constructed with minimal equipment.

Key Resource Requirements

Supply of stone chippings and graded, fine aggregate, suitably shaped with adequate bitumen adhesion properties. Supply of, preferably Rapid Setting (RS) bitumen emulsion, cement or lime filler, water. Emulsion mixing and spreading equipment or concrete mixer, wheelbarrows and squeegees for transporting and spreading if labour based, Pneumatic tyred roller required. Skilled and Semi-skilled labour.

Principal Advantages

- Proven performance in all climates, suitable for rural and urban situations.
- Suitable for light to heavy traffic.
- Construction does not require expensive equipment.
- Suitable for construction by small contractors or community groups.
- Easier quality control than hot bitumen.
- Safer for operatives and local village personnel for construction and maintenance than hot bitumen.
- Easy to maintain and low cost maintenance.

Principal Concerns

- Requires sources of suitable emulsion.
- Emulsion (anionic or cationic) should be compatible with materials.
- Emulsion needs to cure in each application and before opening to traffic.

Key References: 76, 89, 148, 151, 235, 237..

OTTA Seal

General Description

An Otta seal consists of a relatively thick layer of bitumen binder followed by a layer of aggregate that is rolled into the binder using a heavy pneumatic tyred roller or loaded trucks. A graded gravel or crushed aggregate (19mm down) is used in comparison to single sized material used in conventional chip seals. Its success depends on the binder being squeezed up through the aggregate by the action of extensive rolling by pneumatic-tyred rollers followed by traffic. Single or double seal options may be employed depending on the road task.

Key Resource Requirements

Graded natural or processed fine aggregate. Soft bitumen (MC3000 cut-back or 150/200 penetration grade).

Hot bitumen spray equipment; 10-12 Tonne pneumatic tyred roller or suitably loaded trucks. Skilled and semi-skilled labour.

Principal Advantages

- Suitable for all LVRR traffic.
- Proven sealing technique in a number of road environments.
- Wide range of natural or processed aggregate may be used.

Principal Concerns

- Requires specific types of soft bitumen which may not be readily available in some regions.
- Uses greater amounts of bitumen than standard chip seals.
- Extensive rolling with heavy rubber tyred compaction plant essential, therefore not suitable for small contractor/community implementation.[6]
- Significant 2-axle rubber tyred traffic required after construction to bring up the bitumen.
- Excess aggregates to be swept away after a period of 'bedding in'.

Key References: 46, 110, 235, 276. (152),

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[6] *Where soft bitumens and heavy rollers are not available, consideration could be given to using a graded gravel seal (i.e. a chip seal, but with graded aggregate*

Penetration Macadam (Penmac)

General Description

Penetration macadam consists of 3 layers of successively finer broken or crushed rock interspersed with applications of heated bitumen to grout voids and eventually seal the surface. An initial layer of 40-60 mm aggregate is keyed-in and rolled onto the underlying base. A first penetration of bitumen (commonly at 5-6kg/m^2) is sprayed into the initial 40mm aggregate layer and immediately afterwards a second stone application is made by hand onto the grouted aggregate, using 10–20mm chippings. The application shall be sufficient to key all voids in the surface of the first aggregate layer. This followed by a second The second, coat of heated bitumen (2-3 kg/m^2) onto the surface of the layer. Immediately after the second application bitumen, the third stone application is made by hand onto the keyed aggregate, using 5 – 10mm chippings.

The effect is to achieve a matrix of keyed stones grouted and sealed with bitumen to a depth of about 60 – 80mm**.** It is laid as a surfacing on a previously prepared (typically macadam) roadbase.

Key Resource Requirements

Hand or machine crushed strong durable single size coarse aggregate (40mm) and nominal 10-20mm and 5-10mm finer crushed rock material.

Bitumen heater-distributor and an 8-10 tonne deadweight roller. Skilled and unskilled labour.

Principal Advantages

- Proven performance in all climates, suitable for rural and urban situations.
- Well known and established procedure.
- Robust performance if well constructed and maintained.
- Low initial maintenance if well constructed.
- Load spreading layer.

Principal Concerns

- Requires good site control on quality of materials and distribution of bitumen throughout layers.
- Costly use of bitumen at around 7-9 kg/m^2.
- Hot bitumen a significant health and safety hazard for local SME construction and maintenance.
- Initial surface cracking or ravelling if not repaired can rapidly deteriorate and pothole.

Key References: 31, 69, 76, 109, 220

STONE OR MANUFACTURED BLOCK OPTIONS

Cobble Stone Paving

General Description

Cobble Stone Paving is an historically well established option consisting of a layer of roughly cubic shaped or selected stones of thickness about 100 - 150mm, laid on a bed of sand or fine aggregate within mortared stone or concrete edge restraints. The individual stones should have at least **one** face that is fairly smooth, to be the upper or surface face when placed. Each stone (or cobble) is adjusted with a small (mason's) hammer and then tapped into position to the level of the surrounding stones. Sand or fine aggregates is brushed into the spaces between the stones and the layer then compacted with a roller.

Key Resource Requirements

Strong durable fresh stone that may be broken into a near cubical shape. Strength should be >75 MPa unconfined crushing strength (wet). Medium to coarse sand or fine aggregate.

Skilled and; unskilled labour; minimal compaction plant.

Principal Advantages

- Suitable for all climates and for light to heavy traffic in rural and urban situations.
- Construction does not require expensive equipment.
- Suitable for construction by communities or small contractors.
- Suitable for remote areas with access problems for construction plant.
- Can be constructed at steep gradient.
- Low maintenance, easily repairable.
- Can be later upgraded by covering with a sealing layer in a stage construction strategy.
- Erosion resistant, durable.

Principal Concerns

- Requires suitable stone to be available locally and .cobbles must be roughly cubical in shape.
- Requires masonry skill in laying to achieve a smooth finished surface.
- Requires some compaction plant.
- Unsuitable for moisture sensitive sub-base/subgrade in moderate to high rainfall areas.
- Surface is not smooth and medium roughness is normal (although this discourages high speed).
- Potential safety issue with polished stones in wet condition; (particularly 2-wheeled traffic).

Key References: 31, 70, 94, 114, 220 (260)

Stone Setts or Pavé

General Description

Stone Setts or Pavé consists of a layer of cubic shaped stones of approximate size 80 - 100mm laid on a thin bedding sand layer (20 – 50mm). The setts can be cut by hand from suitable hard rock such as granite or basalt, which easily breaks into smooth faced pieces. Sand is brushed into the joints between the laid stones and they are compacted using a vibrating plate or light roller. An edge restraint or kerb constructed (for example) of large or mortared stones is required for durability. Sand-cement mortar joints can be used to improve durability and prevent water penetrating to the foundation layers and weakening them. Stone Setts or Pavé is normally laid on a sub base layer over the in situ soil foundation.

Key Resource Requirements

Strong durable fresh stone that may be broken into a near cubical shape. Strength should be >75 MPa unconfined crushing strength (wet). Medium to coarse sand.

Skilled and; unskilled labour; minimal compaction plant.

Principal Advantages

- Suitable for all climates and for light to heavy traffic in rural and urban situations.
- Does not require heavy compaction equipment or any other expensive equipment to construct or maintain.
- It is suitable for construction by small contractors or communities themselves, or in remote areas with access problems for crushing equipment or heavy plant.
- Can be constructed at any gradient.
- Minimal maintenance required, easily repairable.
- High residual value; the materials can be recycled into other types of paving, or be overlaid with another surface.
- Erosion resistant, durable.

Principal Concerns

- Requires hard stone to be available locally.
- Stone must be suitable for forming cubic setts.
- Requires skill in forming setts and laying to achieve a smooth finished surface.
- Unsuitable for moisture sensitive sub-base/subgrade in moderate to high rainfall areas unless mortar jointed.
- Smooth to medium surface roughness.
- Stones that 'polish' by traffic, or are slippery when wet, must not be used.

Key References: 94, 114

Mortared Dressed Stone Paving

General Description

Dressed stone surfacing is an historically well-established technique that has been adapted successfully as a robust alternative option for low volume rural roads where there is a good local supply of suitable stone. Strong isotropic rocks such as granite that have inherent orthogonal joint stresses are ideal. Dressed stone surfaces have good load spreading properties.

This technique comprises 150-200mm thick dressed stones being laid to lines and levels between previously installed edge restraints and compacted into a sand bedding layer followed by cement mortaring of the joints. The dressed stones shall normally be hand cut from solid rock and trimmed (dressed) if necessary to form a regular rectangular shape, free from flaws and discontinuities with a reasonably smooth top surface.

Key Resource Requirements

Strong durable fresh stone that may be broken into a rectangular shape. Strength should be >75 MPa unconfined crushing strength (wet). Medium to coarse sand for bedding; sand-cement mortar for joints.

Skilled and unskilled labour; minimal compaction plant.

Principal Advantages

- Can be constructed at steep gradient.
- Low Suitable for all climates and for light to heavy traffic in rural or urban situations.
- Construction does not require expensive equipment.
- Suitable for construction by communities or small contractors.
- Suitable remote areas with access problems for construction plant.
- Can maintenance, easily repairable.
- Can be later upgraded by covering with a sealing layer in a stage construction strategy.
- Erosion resistant, durable.

Principal Concerns

- Requires suitable stone to be available locally.
- Requires skill in quarrying, dressing and laying to achieve a smooth finished surface.
- Requires some minimal compaction plant.
- Surface is not smooth and some medium roughness is normal.
- Stones that 'polish' by traffic, or are slippery when wet, must not be used.
- Cannot be used until the mortar joints have set and hardened sufficiently (usually about 5-7 days in hot/warm climate).

Key References: 31, 70, 94,114, 220 (260)

Fired Clay Brick

Herring-bone pattern

Sand brushed into joints

General Description

Fired Clay Bricks are the product of firing moulded blocks of silty clay and are commonly used in low cost road pavement construction in areas with a deficiency of natural gravel or rock materials. This surfacing consists of placing a layer of edge-on engineering quality bricks within previously installed edge constraints The bricks are laid in an approved pattern on a sand bedding layer or on a previously laid layer of flat-laid bricks ("soling layer"). Joints between the bricks may be either in-filled with suitable sand or the bricks may be mortared in. A seal may be specified to be used to waterproof the finished surface as a separate operation.

Key Resource Requirements

Consistent supply of good quality solid bricks with a minimum crushing strength of 20-25 MPa. Bedding sand, or sand-cement mortar. Light plate compactor.

Skilled and unskilled labour.

Principal Advantages

- Proven performance in all climates.
- Suitable for urban application if mortar jointed/sealed.
- Social and economic benefits to the communities through local brick manufacture.
- Good carbon footprint attributes if bricks are burnt using agricultural waste or sustainable fuel.
- Local labour employment both in construction and in ongoing maintenance.
- Good durability, load bearing and load spreading characteristics.
- Low cost maintenance procedures.

Principal Concerns

- The mortared joint option may be subject to erosion in high rainfall areas without maintenance.
- Requires consistent production of good quality engineering bricks of >20-25MPa crushing strength.
- Needs good control of construction using string lines within pre-constructed edge constraints (kerbs).

Key References: 31, 70, 192, 220, 284, 288 (168, 192, 275).

Concrete Brick

General Description

Concrete brick paving is a well-established technique used in many countries for a variety of applications including successful adoption as an option for low volume rural roads. The application is based on the proven ability of individual concrete bricks to effectively disperse load laterally to adjacent bricks through the sand joints. This option comprises rectangular concrete bricks (usually around 70mm thick) being laid in a herringbone or other pattern to camber within confining edge-kerbs (cast either before or after brick placement). They are compacted into place, with sand brushed-in at the joints. A sand cement mortar joint or bituminous seal may be specified to be used to waterproof the finished surface as a separate operation, although this is usually unnecessary on a well constructed sub-base. As a refinement, the concrete bricks may be cast with a top edge chamfer to assist surface drainage.

Key Resource Requirements

A consistent source of engineering quality concrete bricks, typically 200x100x70mm thick with a minimum 28 day cube strength of 20-25MPa. Small or large scale batching and pressing equipment available. Sand for bedding and joint infill. Light plate compactor.

Skilled and unskilled labour.

Principal Advantages

- Suitable for rural or urban application in all climates.
- Social and economic benefits to the communities through local block manufacture.
- Centralised brick production can facilitate good quality control.
- Local labour employment both in construction and in on-going maintenance.
- Suitable for construction by communities or small contractors.
- Good durability, load bearing and load spreading characteristics.
- Low cost maintenance procedures.

Principal Concerns

- The un-mortared joint option may be subject to erosion in high rainfall areas without maintenance.
- Requires consistent production of good quality blocks of 25MPa crushing strength.
- Needs control of construction using string lines within pre-constructed edge constraints (kerbs).

Key References: 31, 32, 46, 126, 192, 220, 283, 284, 288 (192, 314)

Mortared Block Options

General Description

Mortared Stone Paving consists of a layer of natural selected stones, laid on a bed of loose sand or fine aggregate with the joints filled with sand–cement mortar. The stones do not need to be dressed to a regular shape. The individual stones should have at least one face that is fairly smooth and even, to be the upper or surface face when placed. Stone size is typically from 100 – 300mm. The bedding sand around each stone is adjusted with a small hammer and the stone is then tapped into position and to the final level of the surrounding stones. Sand–cement mortar and small stones are used to fill the joints between the individual stones. When the mortar has set the layer should be covered in sand and kept wet for a few days to aid curing.

Key Resource Requirements

Strong durable fresh broken stone with at least one fair face. Strength should be >75 MPa unconfined crushing strength (wet). Medium to coarse sand for bedding; sand-cement mortar for joints. Skilled and unskilled labour; minimal compaction plant.

Principal Advantages

- Proven performance in all climates, suitable for rural and urban situations.
- Suitable for light to heavy traffic.
- Does not require expensive equipment to construct or maintain.
- Suitable for construction by small contractors or communities themselves, or in remote areas with access problems for crushing equipment or heavy plant.
- Can be constructed at steep gradient.
- Low maintenance, easily repairable.
- Light compaction equipment is only required for the foundation layers.

Principal Concerns

- Requires hard stone to be available locally.
- Stone requires having at least one smooth, even face.
- Requires skill in laying to achieve a smooth, even finished surface.
- Smooth to medium surface roughness.
- Stones that ‘polish’ by traffic, or are slippery when wet, must not be used.
- Formal design processes are not fully established.
- Cannot be used until the mortar joints have set and hardened sufficiently (usually about 5-7 days in hot/warm climate).

Key References: 32, 46

BASE AND SUB-BASE OPTIONS

Water-Bound Macadam (WBM)

General Description

A Macadam layer essentially consists of a stone skeleton of single sized coarse aggregate in which the voids are filled with another finer material. The stone skeleton, because of its single size angular composition will contain considerable voids, but will have the potential for high shear strength. The stone skeleton forms the "backbone" of the macadam and is largely responsible for the strength of the constructed layer. The material used to fill the voids provides stability and locks-in the stone skeleton but adds little bearing capacity. In Water Bound Macadam (WBM) the fine material is washed into the previously laid and static roller compacted coarser aggregate.

Key Resource Requirements

Hand or machine crushed strong durable single size coarse aggregate (nominal 35-50mm) with a Los Abrasion value of less than 35%. Well graded 5mm down fine non plastic material; crushed rock material or suitably graded natural sand. Good supply of water.

Static roller (normally10-12t); semi and unskilled labourers.

Principal Advantages

- Straightforward well-proven construction technique for sub-base and base layers.
- Local contractors able to undertake this procedure following initial guidance.
- Can use locally produced aggregate, does not require sophisticated crushing plant.
- Provides an appropriate base for bitumen or bitumen emulsion seals.
- Can be used as an interim running until overlaid.

Principal Concerns

- Unsuitable for moisture susceptible sub-grades.
- Requires good site control on materials and site procedures.
- Usually unsuitable as a permanent unsealed surfacing option.

Key References: 31, 69, 70, 77, 220 (260)

Dry-Bound Macadam (DBM)

Coarse aggregate skeleton

Placed fine aggregate before vibration

General Description

A Macadam layer essentially consists of a stone skeleton of single sized coarse aggregate in which the voids are filled with another finer material. The stone skeleton, because of its single size angular composition will contain considerable voids, but will have the potential for high shear strength. The stone skeleton forms the "backbone" of the macadam and is largely responsible for the strength of the constructed layer. The material used to fill the voids provides stability and locks-in the stone skeleton but adds little bearing capacity. In Dry Bound Macadam (DBM) the fine material is vibrated into the previously laid and static roller compacted coarser aggregate.

Key Resource Requirements

Hand or machine crushed strong durable single size coarse aggregate (nominal 35-50mm) with a Los Abrasion value of less than 35%. Well graded 5mm down fine non-plastic material; crushed rock material or suitably graded natural sand.

Static roller and vibrating roller; semi and unskilled labourers.

Principal Advantages

- Straightforward well-proven construction technique for sub-base and base layers.
- Local contractors able to undertake this procedure following initial guidance.
- Appropriate for weak moisture-susceptible sub-grades.
- Can use locally produced aggregate, does not require sophisticated crushing plant.
- Provides an appropriate base for bitumen or bitumen emulsion seals.
- Suitable in locations experiencing water shortages.
- Can be used as an interim running surface until overlaid.

Principal Concerns

- Requires the use of both static and vibrating compaction plant.
- Requires good site control on materials and site procedures.
- Usually unsuitable as a permanent unsealed surfacing option.

Key References: 31, 69, 77, 220 (260)

Graded Crushed Stone (GCS)

GCS base over natural gravel sub-base

GCS material

General Description

Graded crushed stone comprises hard-rock materials that have been crushed and screened to produce a continuously graded aggregate normally from 37.5mm down with minimal fines (usually <8%) and virtually no plasticity. GCS is commonly used as a strong, permeable base or sub-base in LVRRs as well as larger roads. The source rock may be in-situ fresh material or possibly coarse alluvial cobbles and boulders or other similar material (eg volcanic laharic debris as in Indonesia).

Key Resource Requirements

Source of sound fresh hard rock material together with crushing and screening plant capable of producing a continuously graded material. Mechanical compaction plant; a combination of static and vibrating rolling is recommended for this option. Compaction may be aided by a slushing process for which adequate water supplies must be assured.

Principal Advantages

- Low risk well proven option.
- Straightforward construction technique.
- Provides sound, strong and permeable base or sub-base layers if well constructed.

Principal Concerns

- Potentially high cost unless source material very close to site.
- Requires source not only of good rock but also crushing and screening plant.
- Requires mechanical construction plant.
- Care required with weathered materials due to risk of degradation and poor durability – for example some weathered basic igneous rocks.
- Requires a sound level foundation on which to compact the subsequent sub-base or base.

Key References: 298, 319 (79, 229,)

Natural Gravel

Natural gravel base

Variability of in situ natural hill-gravel (colluvium)

General Description

Many natural gravels such as colluvial, alluvial, lateritic, calcrete and weathered hard rock materials have been proven as suitable for LVRR base and sub-base layers that are compliant with appropriate specifications; usually well graded materials with maximum size < 40mm and acceptable plasticity.

Key Resource Requirements: Suitable sources of gravel materials within reasonable haul distance. Local semi-skilled & unskilled labour with hand-tools to excavate & place material. Alternatively, use equipment (e.g. dozer/digger/loader and grader). Haulage by truck, tractor trailer or cart. Watering equipment pump and bowser). Compaction at suitable moisture content possibly by hand rammers, but preferably preferably static or vibrating roller to improve performance.

Principal Advantages

- Sustainable utilisation of local gravel resources.
- A local resource based option.
- Suitable for labour based operations.
- Provides an appropriate base for bitumen or bitumen emulsion seals and for stone armouring (see Graded Crushed Stone and Armoured Natural Gravel options).

Principal Concerns

- In situ material may have considerable variability in profile.
- May require turning over in stockpile to reduce variability.
- Approval of as-delivered material very important.
- Some materials (eg laterites, calcretes) may have inadequate particle strength and be susceptible to degradation.
- Care required with weathered materials due to risk of degradation and poor durability – for example some weathered basic igneous rocks

Key References: 31, 220, 307

"Armoured" Natural Gravel

Crushed stone to be used as armouring

Crushed stone armouring on laterite

General Description

This activity has two components: an initial layer of a natural gravel road base laid to camber, watered and compacted followed by a thin layer or armouring (usually 50-75mm thick) of crushed/broken stone aggregate laid to camber, watered and compacted. The first component may consist of an existing gravel/laterite road surface, scarified and shaped and compacted. The intention is to provide a cost-effective road base using locally available natural gravels able to accept a thin bituminous surfacing.

Key Resource Requirements.

Good quality graded crushed stone 25-30mm down with low to non-plastic fines and moderate quality natural gravel equivalent to wearing course standard. Ideally light (1-3 Tonne) vibrating compaction equipment although heavier non-vibrating rollers could be used. Unskilled labour.

Also resources as for natural gravel base and sub-base.

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Principal Advantages

- Low cost solution for upgrading existing gravel road.
- Sustainable utilisation of local gravel resources.
- A local resource based option.
- Good cost-effective option for "Spot Improving" an existing unsealed road.
- Suitable for local LB maintenance if used with an emulsion seal.

Principal Concerns

- Light axle load traffic only (< 4-5 T).
- Susceptible to damage by axle overloading.
- Requires good wearing course quality gravel.

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Key References: 31, 34, 220, 307, 319

Lime Stabilisation

Lay-out of lime bags according to required % application rate

In situ mixing of lime and soil.

General Description

The stabilisation of sub-standard locally available materials may be achieved primarily by increasing their strength through addition of cement, lime, bitumen or a proprietary chemical. Lime is generally the more effective option for plastic clayey materials and in the context of rural roads this is predominantly slaked lime rather than the high health risk quicklime. In LVRR construction the lime, (normally 4-8% by weight depending on the strength requirement) is usually mixed on-site and then compacted at suitable moisture content and cured by keeping damp for about 14 days. The appropriate % of lime should be ascertained through laboratory testing of mixed materials for strength and for Initial Consumption of Stabiliser (ICS).

Key Resource Requirements.

Local soil compatible with lime modification. Source of consistent quality slaked or hydrated lime, calcium hydroxide - $Ca(OH)_2$. Supply of fresh water for compaction moisture control and curing.

Mixing plant – which may be a small agricultural tractor rotovator or larger purpose-built mixing equipment; light vibrating roller (1-3 t). Unskilled local labour.

Principal Advantages

- Suitable for improving sub-standard materials to sub-base or base quality.
- Suitable for producing a sub-grade capping layer with wet or unsuitable in situ materials.
- Utilises local or sometimes in situ materials.
- May be used as a low cost surface option for light traffic, basic access in low rainfall areas.
- Can be constructed by labour and simple, low cost equipment.

Principal Concerns

- Only appropriate for light traffic as a surface option.
- Requires testing to determine suitability and percentages of lime required for each soil type.
- Requires 14 days curing time before overlay sealing or opening to traffic.
- Requires good quality control to ensure effective mixing, moisture content, compaction and curing.
- Workers should wear appropriate protective clothing.
- Unsealed option subject to erosion on gradients and under high or intense rainfall.
- Poor construction procedures may result in surface reflection cracking if a seal laid directly on a stabilised base.
- Difficult to construct during the rainy seasons.
- Reported poor performance of stabilised weathered basic igneous rock materials and with calcretes.

Key References: 31, 39, 88, 220 (162, 182, 199)

Cement Stabilisation

Initial manual spreading of cement

Compaction by light vibrating roller

General Description

The stabilisation of sub-standard locally available materials may be achieved by primarily increasing their strength through addition of cement, lime, bitumen or a proprietary chemical. Cement is generally the more effective option for low to non-plastic sandy materials. In LVRR construction the cement, (normally 2-8% by weight depending on the strength requirement) is usually mixed on-site and then compacted at suitable moisture content and cured by keeping damp for about 7 days. The appropriate % of cement should be ascertained through laboratory testing of mixed materials for strength and for Initial Consumption of Stabiliser (ICS)

Key Resource Requirements

Local sandy soil compatible with cement modification. Source of consistent quality cement (normally Ordinary Portland Cement). Supply of fresh water for compaction moisture control and curing.

Mixing plant – which may be a small agricultural tractor rotovator or larger purpose-built mixing equipment; light vibrating roller (1-3 t). A small batching plant may be used as an alternative on larger projects.

Unskilled local labour.

Principal Advantages

- Suitable for improving sub-standard materials to sub-base or base quality.
- Suitable for producing a sub-grade capping layer with unsuitable in situ materials.
- Utilises local or sometimes in situ materials.
- May be used as a low cost surface option for light traffic basic access in low rainfall areas.
- Can be constructed by labour and simple, low cost equipment.
- Labour based maintenance/repair.

Principal Concerns

- Only appropriate for light traffic as a surface option.
- Requires testing to determine suitability and percentages of cement required for each soil type.
- Requires 7 days curing before overlay sealing or opening to traffic.
- Requires good site quality control to ensure effective mixing, moisture content, compaction, and curing.
- 6 hour time constraint on mixing, compaction and shaping.
- Unsealed option subject to erosion on gradients and under high or intense rainfall.
- Poor construction procedures may result in surface reflection cracking if a seal laid directly on a stabilised base
- Very difficult to construct during the rainy seasons.
- Workers should wear appropriate protective clothing.

Key References 39, 88, 220 (162, 182, 199)

Bitumen Emulsion Stabilisation

Manual application emulsion in panels

General Description

The stabilisation or, more correctly, the modification of sub-standard locally available materials may be achieved by primarily increasing their strength through addition of cement, lime, bitumen or a proprietary chemical. Bitumen emulsion can be an effective option for strengthening non plastic sandy materials. In LVRR construction the emulsion, (normally 4-8% residual bitumen depending on the strength requirement) is usually mixed on-site and then compacted at a suitable moisture content.

Key Resource Requirements.

Local sandy soil compatible with emulsion modification. Source of consistent quality Slow Setting emulsion. Supply of water for compaction moisture control.

Mixing plant – which may be a small agricultural tractor rotovator or larger purpose-built mixing equipment; light vibrating roller (1-3 t). Unskilled local labour.

Principal Advantages

- Suitable for improving sub-standard sandy materials to sub-base or base quality.
- Utilises local or sometimes in situ materials.
- Can be constructed by labour and simple, low cost equipment.
- Restricts development of potholes if surfacing damaged.
- Priming not usually required when overlain by bitumen seal.
- Less curing time than for cement or lime modified materials.

Principal Concerns

- Requires non-standard testing to determine percentages of emulsion required for each soil type.
- Requires good site quality control to ensure effective mixing, moisture content and compaction.
- Likely to require initial specialist advice to contractor on site.
- Higher cost linked to amounts of bitumen emulsion required.
- Not possible to construct during the rainy seasons.

Key References: 31, 39, 77, 220, 322 (199)

Mechanical Modification

Sub-base mixture of fine hill gravel and coarser alluvium.

Base: plastic fine lateritic gravel modified with crushed stone aggregate.

General Description

Mechanical modification involves the blending of two different materials to meet required base/sub-base strength, grading and plasticity criteria. The percentages of each material to be used should be determined by laboratory trials. Construction mixing can be undertaken either off-site by mechanical means (pugmill) or on the road. Mixing off-site by pugmill is unlikely to be used for low-budget LVRRs and the most common procedure is on the road when after placement of the materials the two materials can be uniformly mixed by graders or small agricultural rotovators. Labour-based mixing by hand tools is also possible. Following adequate mixing the modified material is then compacted and shaped as per standard procedures.

Key Resource Requirements

Laboratory facilities are required to determine the make-up of the modified material. If mechanical mixing is being undertaken then either a motor grader or rotovator is necessary. Standard shaping and compaction equipment is also required, for LVRRs a 3 tonne vibrating roller normally is sufficient. Skilled and un-skilled labourers.

Principal Advantages

- The option to use locally available materials that individually would not be suitable for base or sub-base.
- No requirement for expensive manufactured stabiliser.
- In situ material can be modified.
- No curing time required as per chemical stabilisation.
- Can be an unskilled labour based operation.

Principal Concerns

- Need to determine correct percentages of mix.
- On-site mixing requires careful supervision and quality control whether by mechanical or manual means.
- Off-site mixing using expensive plant may outside LVRR budgets.

Key References: 39 (240, 260)

CONCRETE OPTIONS

Geo Cell Paving

Geocells during construction

Geocell pavement 2 years after construction

General Description

Welded plastic geocells are stretched out over the area of prepared road base or sub-base and pegged in place. The geocells act as an in situ formwork to create an incremental block paving surface by placing and compacting pavement quality concrete into the geocells. The geocells remain as a sacrificial formwork which effectively creates an incremental block paving. The concrete requires to be cured as normal pavement quality concrete.

Typical concrete strength required is 20 MPa or more and a slump test recommendation of 150mm is used to facilitate placement and avoidance of collapse of the cells. A plasticiser is normally used to achieve this workability without compromising strength. The geocell thickness is normally 75mm or 100mm, although other cell thickness geocells are available. Cells are typically 150mm square in plan and may have indentations to improve 'interlock'.

Key Resource Requirements.

Supply plastic geocells. Fixing pegs and edge shuttering/kerbs. Coarse and fine aggregates/sand, and cement. (Plasticiser). Concrete mixer. Vibrating plate compactor or tamping board.

Concrete mixing and placing skills, local semi-skilled labour**.**

Principal Advantages

- Suitable for rural or urban application in all climates and steep gradients.
- Good durability, load bearing and load spreading characteristics.
- Suitable for light to heavy traffic.
- Low cost maintenance procedures, easily repairable.
- Does not require expensive equipment to construct or maintain.
- Simple concrete technology and suitable for construction by small contractors or community groups, or in remote areas with access problems for crushing equipment or heavy plant.

Principal Concerns

- Geocells may have to be imported and thus expensive.
- Process may be covered by copyright in some regions.
- Cement may be expensive and transported long distances.
- Usually requires plasticiser for acceptable workability.
- Medium surface roughness.
- Requires good site quality control of preparation, mixing, placing and curing.
- Needs control of construction using string lines within pre-constructed edge constraints (kerbs) or specific edge details.

Key References: 32, 46, 308

Non Reinforced Concrete


General Description

Non-reinforced cement concrete is a well established form of rigid pavement designed to spread the applied load due to traffic through a slab effect. The option as applied for LVRRs usually involves the casting of 5m long slabs between formwork normally with load transfer dowels between them. In some cases, where continuity of traffic demands it, these slabs may be half carriageway width. The concrete slabs are cast onto a previously prepared and compacted sub-base. The concrete requires to be cured, by covering with moisture retaining material kept moist, normally for a minimum period of 7 days.

It is most suitable for construction on high rainfall, steep gradient alignments and on routes liable to seasonal flooding and other major climatic impacts.

Key Resource Requirements

Suitable clean durable coarse and fine aggregate, supply of good quality Portand Cement, fresh water. Small concrete mixer and vibrating poker. Steel smooth reinforcing bar (normally 14mm) for dowels. Portable sunshade for intense high temperature sunlight work. Skilled and unskilled labour.

Principal Advantages

- Suitable for all climates and rural or urban application.
- Robust option suitable for high rainfall and flood prone regions.
- Generally resistant to axle overloading if well constructed and founded.
- General concreting procedures understood by local small contractors.
- Minimal maintenance if properly constructed and cured.
- No requirement for expensive construction plant.

Principal Concerns

- High initial construction cost in relation to most other options.
- Usually requires expansion and contraction joints with steel load transfer dowels.
- May be susceptible to shrinkage cracking unless well constructed and cured.
- Tendency for labourers/contractors to add too much water to the concrete mix to facilitate placement; thus weakening the slab and risking shrinkage cracks.
- Concrete must not be mixed or placed in ambient shade temperatures above 38 degrees centigrade, and protected from direct sunlight that would raise mix temperatures to the same high levels.
- First and last slabs of a section subject to impact loading as vehicles move on/off the edge of the slab; these slabs require to be designed accordingly.
- Requires at least 7-14 days curing time following initial construction.
- Susceptible to price fluctuation of cost of cement.
- Requires good sub-base and shoulders maintained against erosion.

Key References: 31, 32, 46, 69, 220, 312, 337

MISCELLANEOUS

Wheel Track Paving Strip Roads)

General Description

This is a low cost technique used for low volume rural access routes in a number of developed and emerging economies to achieve year round passability. Wheel track paving is particularly suitable for steep gradients on otherwise unpaved routes. It consists of constructing two durable wheel strips designed to support the wheels of the locally used vehicles. The area between the strips and shoulders are constructed of lower quality material, however of sufficient characteristics that erosion and maintenance will be minimised and that occasional passing movements can be accommodated. The wheel strips are commonly constructed of un-reinforced concrete or cobble stones. Bitumen seals on a suitable base have also been used. Centre strip and shoulders can be constructed of hand packed stone and should not be of easily erodible soil, gravel or macadam.

Key Resource Requirements

Supply paving strip materials: usually concrete or stone as appropriate. Supply of suitable infill and shoulder materials such as hand packed stone. Concrete mixing and placing, and stone paving skills, local semi-skilled labour.

Principal Advantages

- Suitable for application for all climates and gradients.
- Good durability and load bearing characteristics.
- Suitable for light traffic.
- Relatively low cost construction and maintenance, easily repairable.
- Does not require expensive equipment to construct or maintain.
- Simple concrete or stone works technology and suitable for construction by small contractors or community groups, or in remote areas with access problems for crushing equipment or heavy plant.

Principal Concerns.

- Cement where used may be expensive and transported long distances.
- Low to medium surface roughness.
- Particular care to be given to cross section and strip edge details to minimise erosion risk.
- Water shedding bars or cross strips are required on steep grades.
- Requires good site quality control of setting out, preparation and construction.

Key References: 270

APPENDICES

Appendix B Environmentally Optimised Design and Spot Improvement

B 1 ENVIRONMENTALLY OPTIMISED DESIGN (EOD)

Where the available resources will not initially allow for full link upgrade or rehabilitation, then it will be necessary to consider an Environmentally Optimised Design (EOD) approach on a network basis that allows:-

- Best use to be made of existing limited sector funds and resources;
- Provision of strategic/priority routes with year round (full) access;
- Provision of basic access to the majority of the population for most of the year;
- Roads that are suitable for the types of traffic that will use them;
- Roads that are serviceable and safe for the users and general public;
- Roads that are cost-effective in consideration of their life cycle investments in initial construction and maintenance costs, and indeed road user costs;
- Minimisation of the impact on the natural environment;
- The best use of available local resources, allowing a range of technology options;
- Encouragement of the development of local capacity.

Environmentally Optimises Design (EOD) allows all of these objectives to be met in the circumstances of very limited resources. Environmentally Optimised Design is the over-arching framework for the application of appropriate LVRR designs. It covers a spectrum of solutions for improving or creating low volume rural access, from Basic Access through to total whole rural link rehabilitation/improvement (Full Access).

Under an EOD approach, the road is designed to suit the variety of task and environmental factors such as rainfall, available materials, construction capacity, gradient, flood risk, maintenance regime and so on. Some of these factors vary from road to road and even from location to location along a road. Therefore a road design may vary along the length of a road with, for example, a sealed surface up a hill or gravel along a level section. This variable nature is referred to as 'variable longitudinal design.

The following concepts form components of the EOD approach.

Basic Access

Reliable all-season access for the prevailing means of transport with limited periods of inaccessibility (typically for a period of up to about 24 hours during/after rain when the road can be impassable to motorised traffic). In practical terms; the provision of Basic Access consists of taking or bringing back the route to a minimum motorable and maintainable standard by:

- Clearing of vegetation;
- Reforming or providing the running surface camber;
- Opening of drains and any existing culverts/drifts.

These are the basic requirements for a serviceable low volume traffic access road. In most cases the in situ soil will form the running surface for the road (Engineered Natural Surface – ENS). To ensure all-season access, it may be necessary to provide Spot Improvements at critical locations along the route. Typical spot improvements will be surfacing or pavement upgrades over limited sections of the route, or improvements in cross drainage provision such as culverts or drifts. Although relatively low initial cost to provide, Basic Access roads will require essential maintenance every year for continued access for traffic.

If additional resources become available over time, then further spot improvements can be initiated until the whole link is upgraded to a Full Access standard.

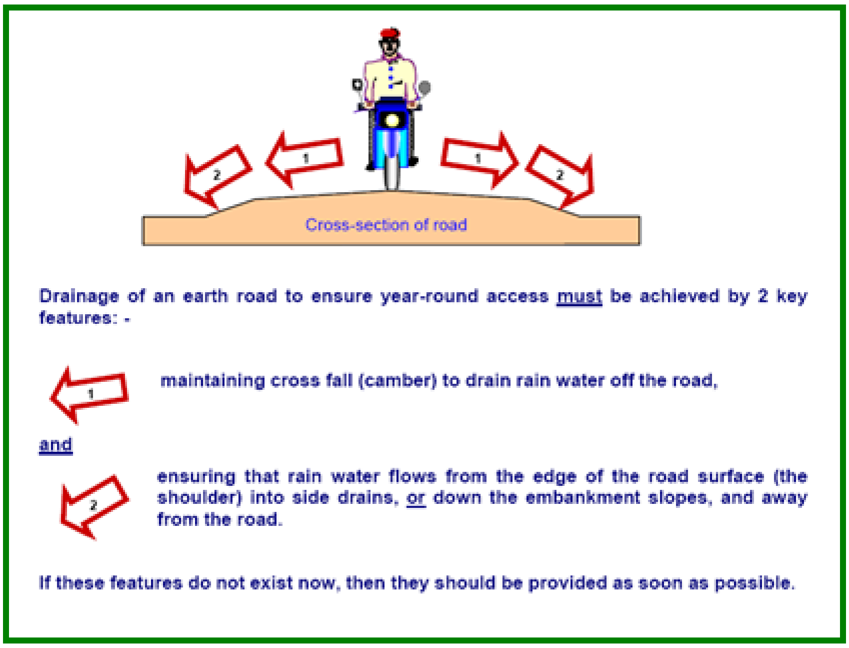
Basic Access is achieved to provide year-round passage to routes by turning them from weather-dependent tracks into proper roads. A proper road can be formed from the natural soil (ENS) in many locations.

The main features of a road are:-

- A camber to shed rainwater to each side of the road;
- Side drains, turnout drains, drifts and culverts (or other structures) to manage the water collected from the road surface and to discharge it carefully to avoid erosion or other problems.

This usually means that the road surface needs to be slightly higher than the ground at the road side.

Figure B1 Basic Access Engineered Natural Surface (ENS)



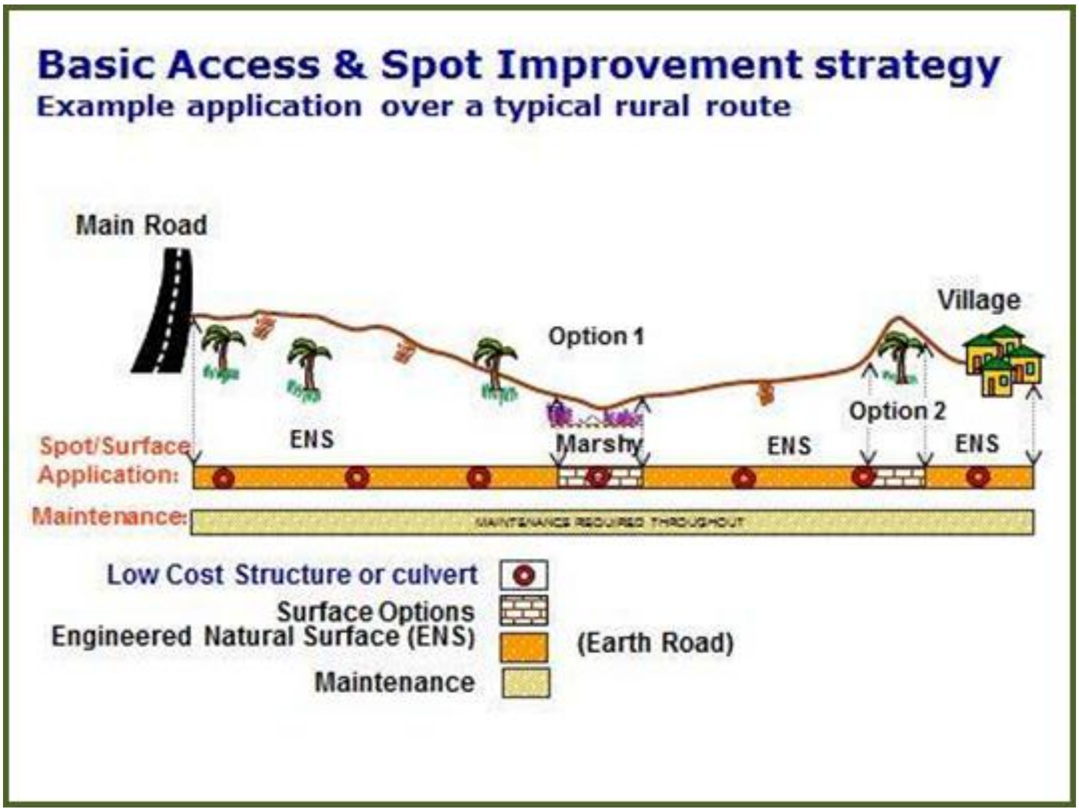
Most natural soils can be built into an (Engineered Natural Surface - ENS) Earth Road. However, for route sections with weak or expansive soils, or if traffic increases to more than about 50 motor vehicles per day, or on steep hills, it may be necessary to improve the road surface with various types of surface enhancement. This can be achieved at relatively low cost by applying a Spot Improvement approach to improve these limited problem sections, often using local labour and materials. The Spot Improvements at problem sections of the pavement may be selected from the following list of surface improvements:

- Natural gravel;
- Stone Chipping;
- Waterbound/Drybound Macadam;
- Hand Packed Stone;
- Stone Setts or Pavé;
- Mortared Stone;
- Dressed stone/cobble stone;
- Irregular Cobble Stone;
- Fired Clay Brick, Unmortared/mortared joints;
- Bituminous Chip Seal;

- Bituminous Cape Seal;
- Bituminous Otta Seal;
- Non-reinforced concrete;
- Geo cell paving;
- Wheel track paving;

For further details on the foregoing options, refer to Annex A.

Figure 10.2 Examples of Spot Improvement Surface Options



The choice of spot improvement should be based on the location features and the materials and skills available locally. Great care should be used in using gravel as a road surface in some circumstances. It is unlikely that it will be most suitable option in some locations due to high costs of routine maintenance and periodic replenishment of the surface material that will be lost due to rainfall or traffic.

Despite initial low construction costs, it is important to appreciate that under a Basic Access and Spot Improvement strategy it is essential to arrange the necessary Routine maintenance of the ENS and any gravel or other surface and drainage, and the periodic maintenance of the improved surface sections and structures, to preserve the initial construction investment.

Key references:

The following document introduces the concept of Basic Access

Design and appraisal of rural transport infrastructure. Ensuring basic access for rural communities. World Bank Technical paper 496 (*205*)

Low Volume Road EOD Manual – TRL-OTB-LTEC (74).

This manual provides a comprehensive guide to the processes and procedures involved in assessing road link for Spot Improvement upgrade.

A Guide to Good Practice

APPENDICES

Appendix C Example of Surface Option Selection Process

ANNEX C Example of Surface Option Selection Process

1. Introduction

This Annex summarises an example Surfacing Decision Management System (SDMS) that may be adapted for application to local environments depending on the range of influential factors. The importance or weighting of the various factors should be refined to be compatible with the local materials, conditions, resources, policies and operational environment.

The various factors that typically affect the choice of a paving and surfacing can be grouped under the following headings:

- Available materials;
- Operational environment;
- Road task;
- Natural environment.

These factors are illustrated in Figure 1.

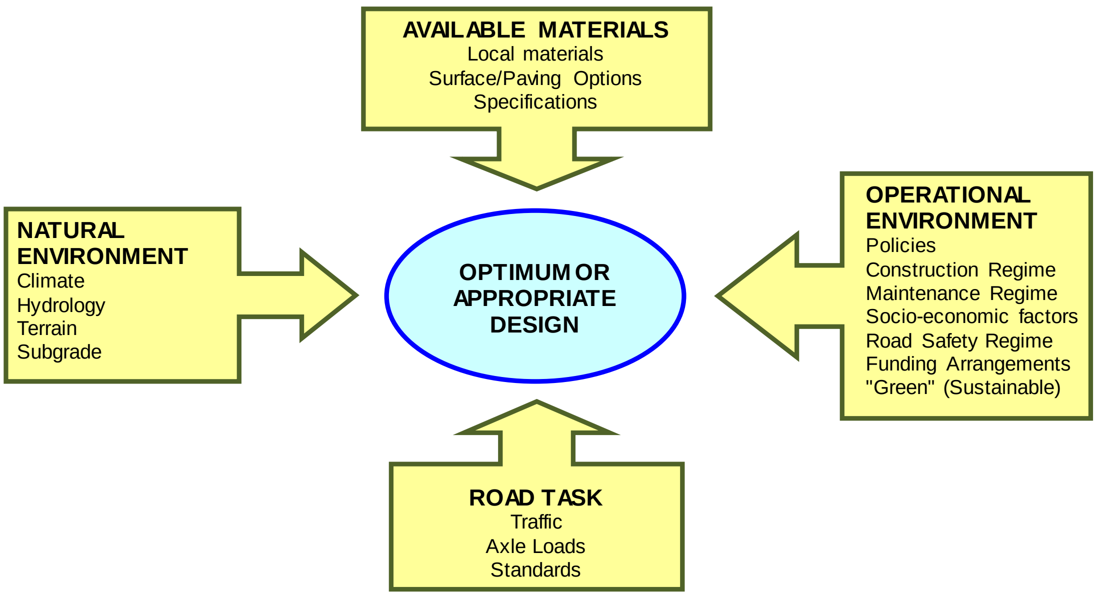


Figure 1: General Road Environment and Surface Selection Factors

More specifically, the following factors should also be considered in short-listing surfacing types for more detailed consideration:

- Existing subgrade/base/surface conditions;
- Design life;
- Materials (type and quality);
- Safety (skid resistance - surface texture, etc.);
- Riding quality required;
- Maintenance (capacity and reliability).

The final selection of surfacing should then be made on the basis of life-cycle costing.

The Surfacing Decision Management System (SDMS) is based on the recent research carried out in a number of countries and use of proven surfacing and paving options.

The SDMS is based on the selection of the most appropriate surface and paving options for a section of road. It is suggested that each route being considered for upgrading is broken down into sections with fairly homogeneous conditions of soil type, gradient, traffic and other environmental factors, which will allow a rational and uniform design through this section. This approach is part of the Environmentally Optimised Design (EOD) approach, and is appropriate for a limited resource environment. The SDMS guides the user to the shortlisting of surfacing-paving types that will result in the lowest whole life costs to the road manager. It does not include considerations of Vehicle Operating Costs or other community benefits, which should be considered separately.

The cheapest option on some sections of road, if certain criteria are met, is Engineered Natural Surface (ENS) or Engineered Earth Road. Natural Gravel is often the next cheapest method of upgrading to a better quality surface. However, a number of factors mean that in many circumstances gravel may not provide an appropriate or sustainable road surface. There are then a number of (initially) more expensive options, however these may be cheaper than ENS or Natural Gravel in Whole Life Cost terms.

The Surfacing Decision Management System guides the user through the objective process of assessing the various factors that influence the suitability of surface-paving options for a specific section of rural road.

When ENS or gravel is assessed not to be the most suitable option, the separate Matrices of Surfacing Options will further guide the user to identify the most appropriate surface options.

2. Evaluation framework

A rational method is required for the selection of the most appropriate surface or paving structure for a particular section of low volume rural or urban road. The Surfacing Decision Management System (SDMS) provides such a procedure for assessing the various factors that influence the suitability of surface-paving options for a specific section of rural road. When Engineered Natural Surface (ENS) or natural gravel are considered to be unsuitable options, the separate Matrices of Surfacing and Paving Options (Tables 3 to 6) will further guide the user to identify the most appropriate options.

The key objective is the elimination of unsuitable or high risk options using a series of road environment related “screens” or “filters” before proceeding to Final Engineering Design (FED) for the surfacing/paving and their Whole Life Costing. Figure 2 shows the basic steps in the SDMS procedure.

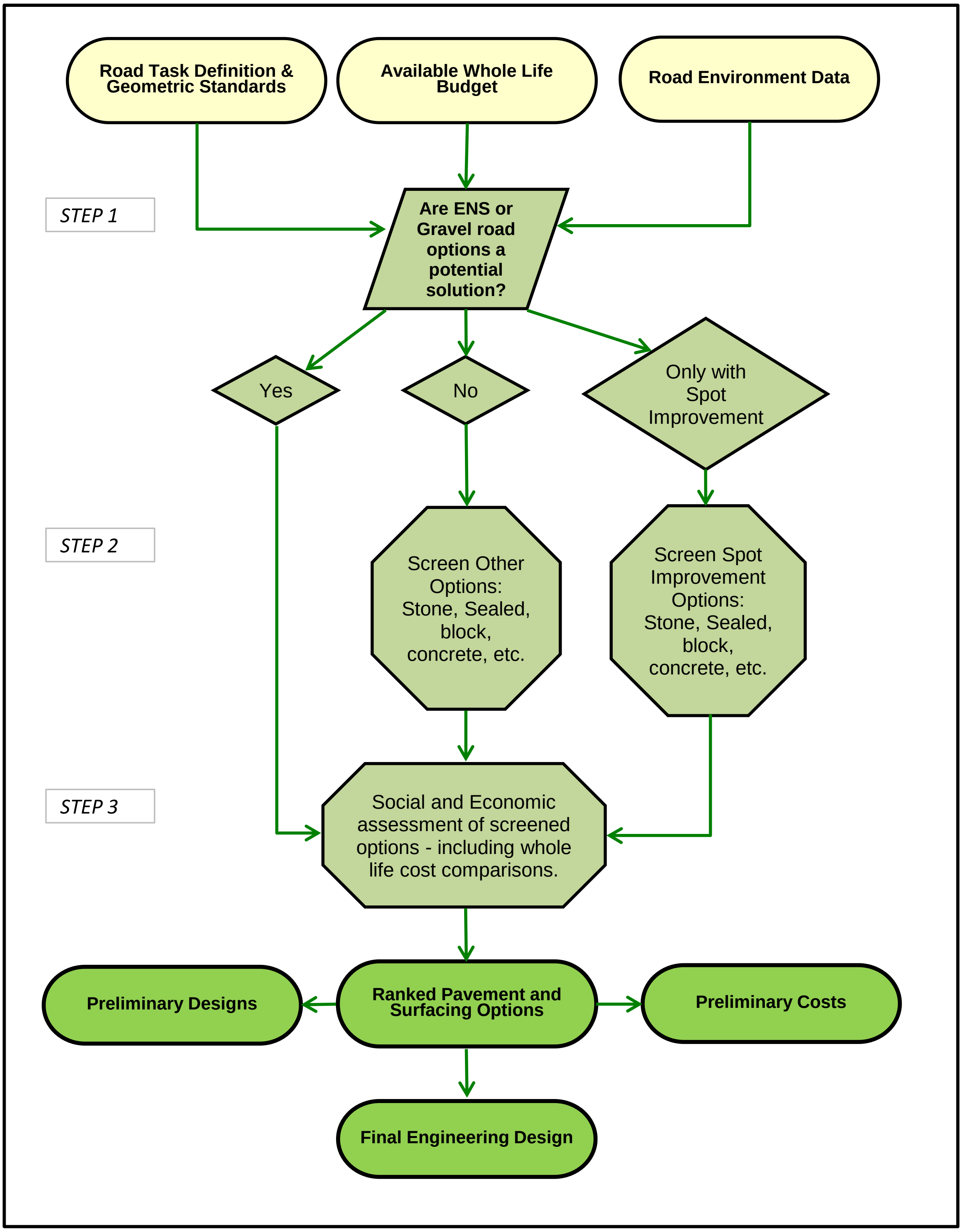


Figure 2: Overview of the SDMS procedure

3. SDMS Procedure

Steps 1 and 2 of the three-step SDMS procedure are illustrated in Figure 3 while each of the explanatory sheets (Sheets 1-3) supporting the Step 1 sequential activities regarding ENS and Gravel surface option assessment are presented in Figures 4 and 5.

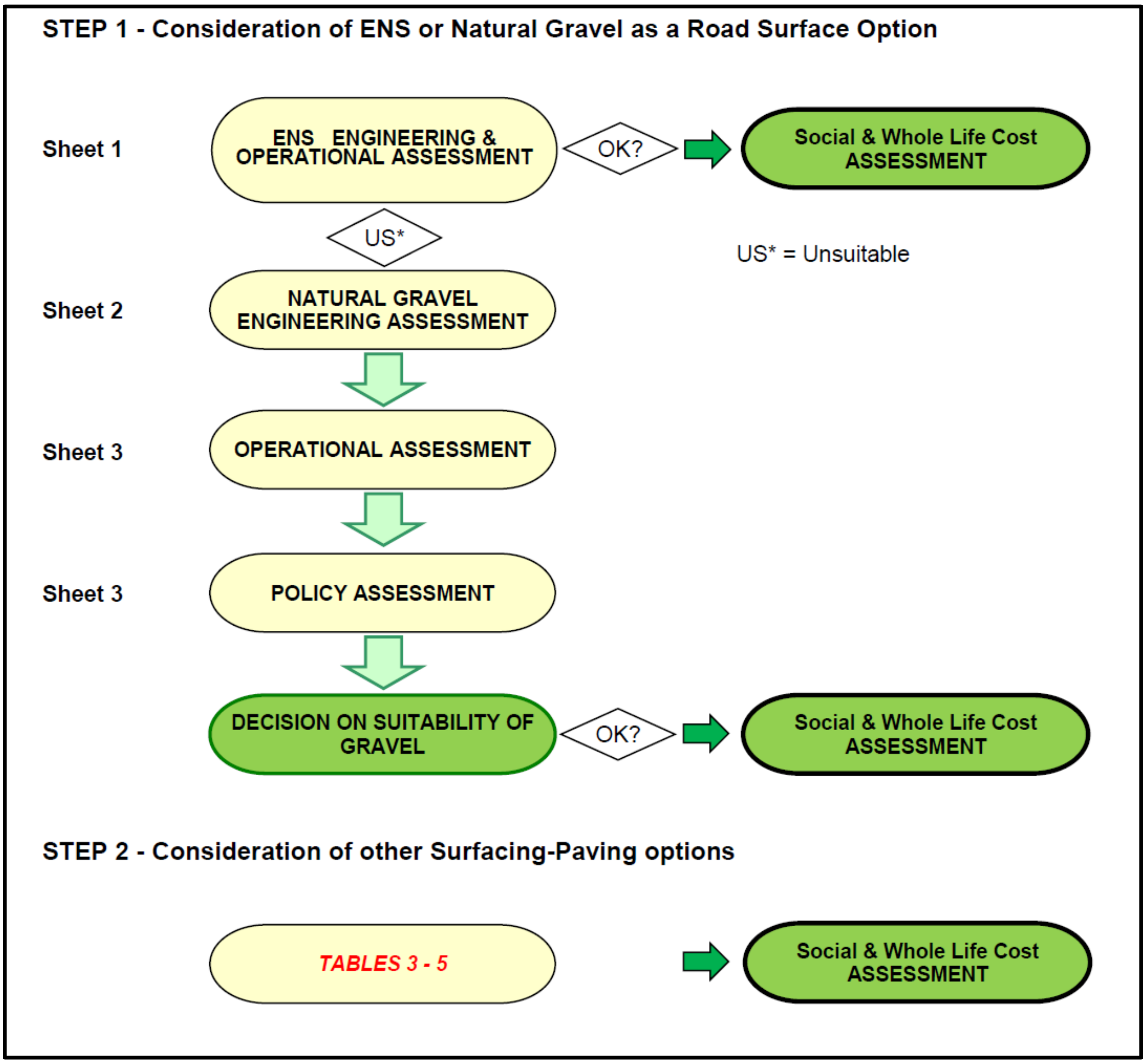
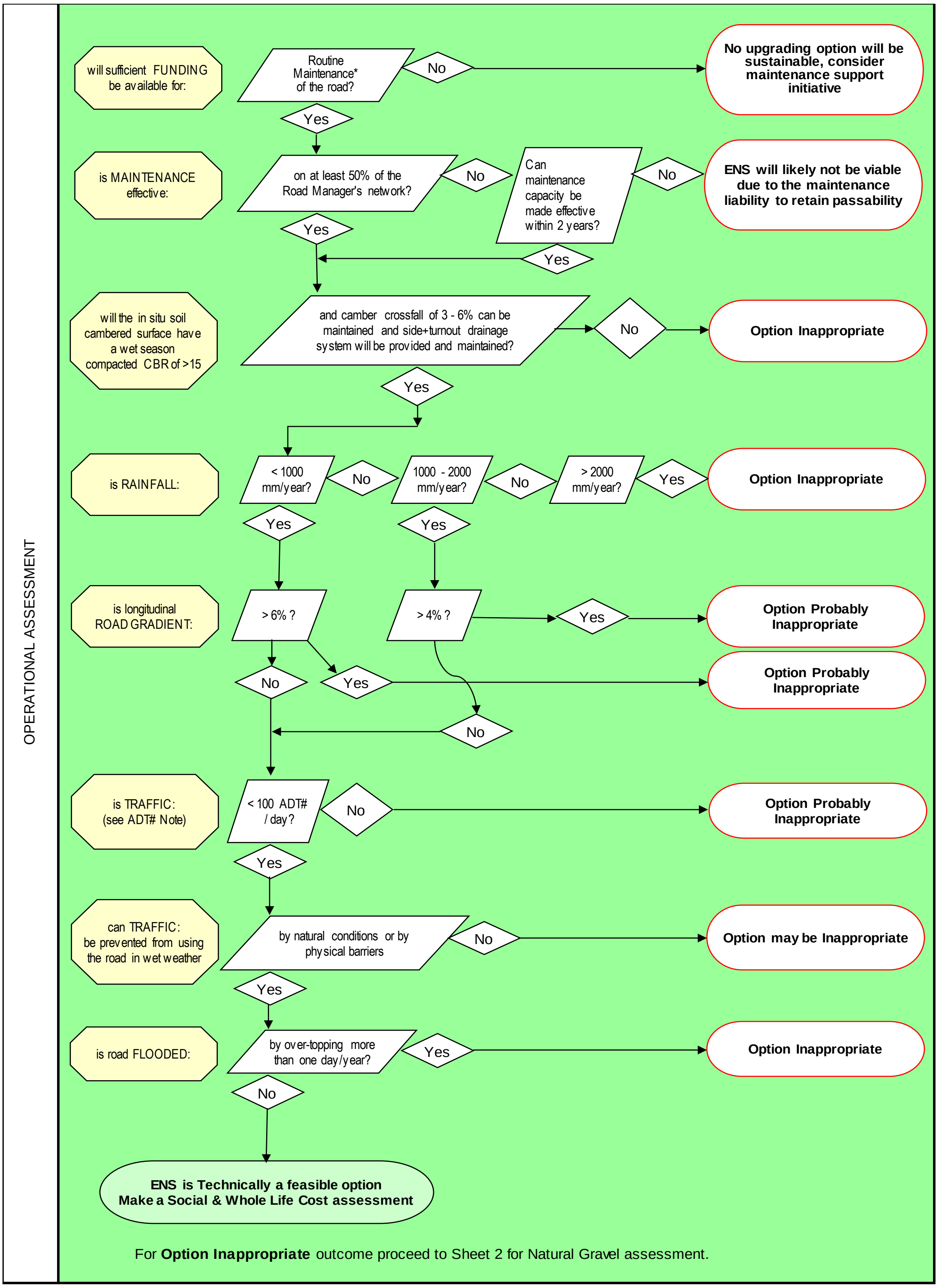


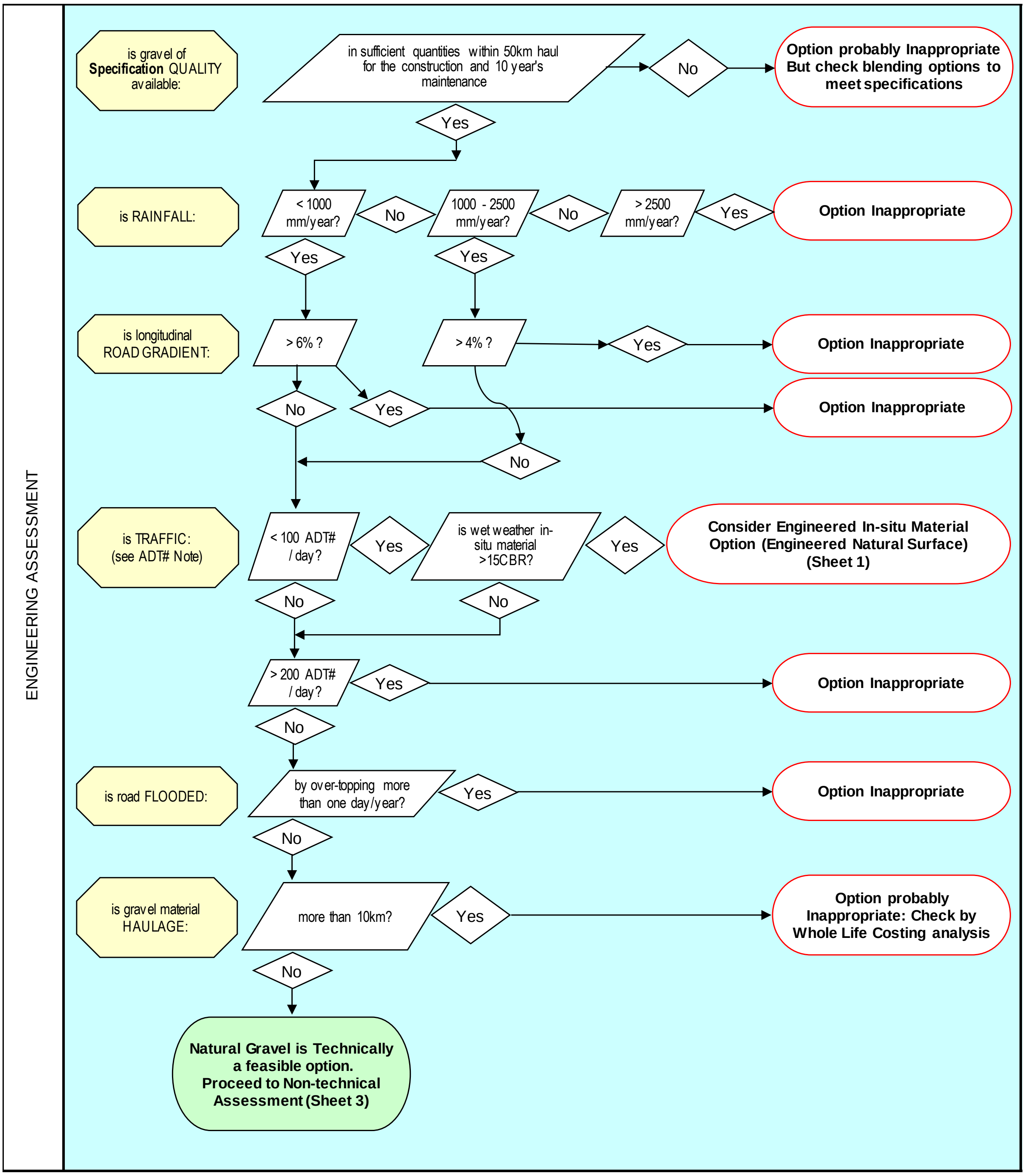
Figure 3: Steps 1 and 2 of SDMS procedure

SHEET 1 - Assessment of suitability and Engineered Natural Surface - ENS as a feasible option



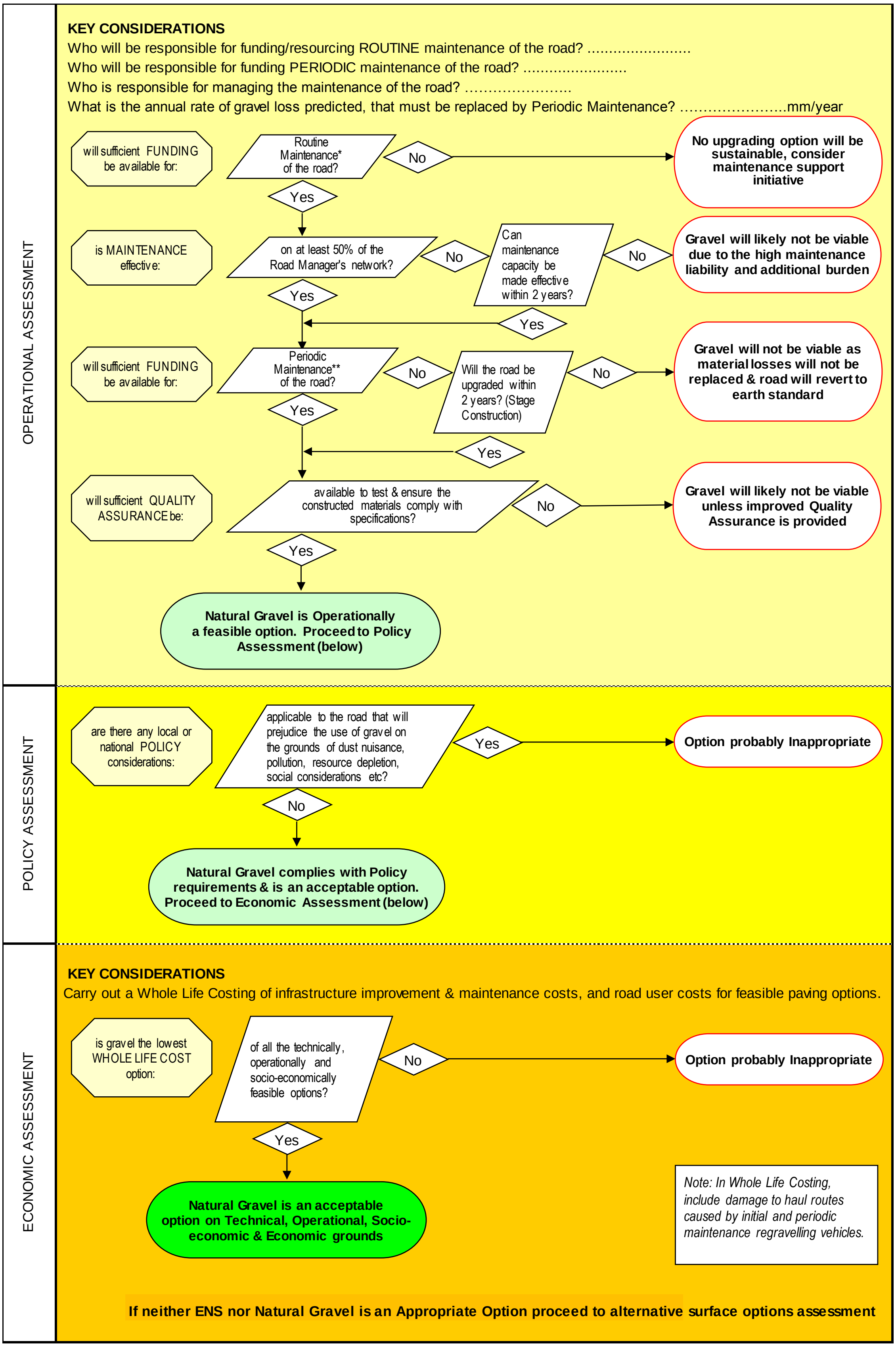
NOTES: Option Inappropriate: High risk of poor level of service or early failure and need to reconstruct
* Routine Maintenance funding includes voluntary or other labour contributions by the community
CBR = California Bearing Ratio - Strength in situ measured by DCP, or to be decided by visual assessment
DCP = Dynamic Cone Penetrometer
Engineered Natural Surface (ENS) = Earth Road Standard with maintained camber and effective drainage system
ADT#: Modified Average Daily Traffic of two axle vehicles in both directions for carriageways less than 5 metres wide
(Modification should be factoring of x2 for any vehicle of gross weight more than 5 tonnes)
(Determine from traffic surveys and maximum predicted daily flows for next 3 years)

SHEET 2 - Engineering Assessment of Natural Gravel Surface Option



NOTES: Option Inappropriate: High risk of poor level of service or early failure and need to reconstruct
CBR = California Bearing Ratio - Strength in situ measured by DCP, or to be decided by visual assessment
DCP = Dynamic Cone Penetrometer
Engineered Natural Surface (ENS) = Earth Road Standard with maintained camber and effective drainage system
ADT#: Modified Average Daily Traffic of two axle vehicles in both directions for carriageways less than 5 metres wide
(Modification should be factoring of x2 for any vehicle of gross weight more than 5 tonnes)
(Determine from traffic surveys and maximum predicted daily flows for next 3 years)
Gravel outside specification quality will deteriorate at a faster rate and increase the maintenance needs

SHEET 3 - Operational, Socio-economic & Economic Assessment of Natural Gravel as a surface option.



NOTES: * Routine Maintenance funding includes voluntary or other labour contributions by the community

** Periodic Maintenance includes the regular and timely re-gravelling to replace the predicted gravel losses

Step 2 involves the consideration of surfacing/paving options as listed in Annex A. Note that not all of the surfacing/paving options described in Annex A are included in this example SDMS.

If the Step 1 assessment indicates that neither ENS nor Natural Gravel are viable options for a particular road section, then the assessment should proceed to the 'screening' process (see Tables 3 to 6) to select a shortlist of appropriate and viable surface and/or paving options based on the evaluation criteria included in these tables. In the screening process the Tables 1 and 2 set out the suggested evaluation criteria in terms of indicative traffic regime and erosion potential.

Table 1: Definition of Indicative Traffic Regime

Indicative Category	Traffic Description
Light	Mainly non-motorised, pedestrian and animal modes, motorbikes & less than 25 motor vehicles per day, with few medium/heavy vehicles. No access for overloaded vehicles. Typical of a Rural Road with individual axle loads up to 2.5 tonne.
Moderate	Up to about 100 motor vehicles per day including up to 20 medium (10t) goods vehicles, with no significant overloading. Typical of a Rural Road with individual axle loads up to 6 tonne.
High	Between 100 and 300 motor vehicles per day. Accessible by all vehicle types including heavy and multi-axle (3 axle +) trucks, Construction & timber materials haulage routes. Specific design methodology to be applied.

Table 2: Definition of Erosion Potential

Road alignment longitudinal gradient	Annual Rainfall (mm)			
	< 1000	1000 - 2500	2500 - 4000	>4000
Flat (< 1%)	A	A	B	C
Moderate (1-3%)	A	B	B	C
High (3-6%)	B	C	C	D
Very High (>6%)	C	C	D	D
Note:	A = Low; B = Moderate; C High; D = Very High			

1. Areas prone to regular flooding should be classed as "High Risk" irrespective of rainfall.

In the following Tables

✓	**Indicates suitable for evaluation**	●	Mortared

Note: Cost ratings are indicative only and will depend on local factors.

Table 3: Preliminary Engineering Filter - Surfacing

PAVING CATEGORY	BASIC		STONE					BR	BITUMEN					CONC
	Engineered Natural Surface	Gravel Surface	Waterbound/Drybound Macadam	Hand Packed Stone	Stone Setts or Pavé	Mortared Stone	Dressed Stone/Cobble Stone	Fired Clay Brick Pavement: Un-/mortared Joints	Bituminous Sand Seal	Bituminous Slurry Seal	Bituminous Chip Seal	Cape Seal	Ottaseal	Non-Reinforced Concrete
Economically available Materials	S01	S02	S03	S04	S05	S06	S07	S08	S09	S10	S11	S12	S13	S14
Crushed stone aggregate			✓	✓						✓	✓	✓		✓
Stone pieces/blocks				✓	✓	✓	✓							
Natural gravel		✓											✓	
Colluvial/alluvial gravel		✓											✓	
Weathered rock		✓												
Fired clay bricks								✓						
Clay soil								✓						
Sand					✓	✓	✓	✓	✓	✓				✓
Cement						✓		●						✓
Lime										✓				
Bitumen									✓		✓	✓	✓	
Bitumen Emulsion									✓	✓	✓	✓		

KEY

BR = Brick **CONC = Concrete**

Table 4: Preliminary Engineering Filter - Pavement Layers / Shoulders

PAVING CATEGORY	BASES							SUB-BASES						SHOULDERS			
	Waterbound macadam	Drybound macadam	Natural gravel	Armoured gravel	Cement stabilised soil	Lime stabilisede soil	Emulsion s tabilised soil	Waterbound macadam	Drybound macadam	Natural gravel	Cement stabilised soil	Lime stabilisede soil	Emulsion stabilised soil	Stone macadam	Natural gravel	Cement stabilised soil	Lime stabilisede soil
Economically available Materials																	
Crushed stone aggregate	✓	✓		✓				✓	✓					✓			
Stone pieces/ blocks																	
Natural gravel			✓	✓						✓					✓		
Colluvial/alluvial gravel			✓	✓						✓					✓		
Weathered rock			✓	✓						✓					✓		
Fired clay bricks																	
Clay soil						✓						✓					✓
Sand					✓		✓				✓		✓			✓	
Cement					✓						✓					✓	
Lime						✓						✓					✓
Bitumen																	
Bitumen Emulsion							✓						✓				

Table 5: Secondary Engineering Filters – Surfacing

PAVING CATEGORY	BASIC		STONE					BR			BITUMEN					CONC
	Engineered Natural Surface	Gravel Surface	Waterbround/Drybound Macadam	Hand Packed Stone	Stone Setts or Pavé	Mortared Stone	Dressed Stone/Cobble Stone	Fired Clay Brick Pavement: Un-/mortared Joints	Bituminous Sand Seal	Bituminous Slurry Seal	Bituminous Chip Seal (single)	Bituminous Chip Seal (double)	Cape Seal	Ottaseal (single)	Ottaseal (double)	Non-Reinforced Concrete
Traffic Regime: (See Table 1)	S01	S02	S03	S04	S05	S06	S07	S08	S09	S10	S11	S11	S12	S13	S13	S14
Light traffic	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Moderate traffic		✓	✓	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓
Heavy traffic (overload risk)					✓		✓					✓			✓	✓
Construction Regime																
High labour content	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓
Intermediate machinery	✓	✓	✓	✓					✓	✓	✓	✓	✓			✓
Low cost	✓	✓		✓					✓	✓	✓					
Moderate cost			✓		✓	✓		✓				✓	✓	✓		
High cost							✓								✓	✓
Maintenance Requirement																
Low					✓	✓	✓	✓								✓
Moderate				✓					✓	✓	✓	✓	✓	✓	✓	
High	✓	✓	✓													
Erosion Regime (See Table 2)																
A: low erosion regime	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
B: Moderate erosion regime				✓	✓	✓	✓	✓				✓	✓	✓	✓	✓
C: High erosion regime					✓	✓	✓							✓	✓	
D: Very high erosion regime					✓	✓	✓							✓	✓	

Table 6: Secondary Engineering Filters - Pavement Layers / Shoulders

	BASES							SUB-BASES						SHOULDERS				
	Waterbound macadam	Drybound macadam	Natural gravel	Armoured gravel	Cement stabilised soil	Lime stabilisede soil	Emulsion s tabilised soil	Waterbound macadam	Drybound macadam	Natural gravel	Cement stabilised soil	Lime stabilisede soil	Emulsion stabilised soil	Stone macadam	Natural gravel	Cement stabilised soil	Lime stabilisede soil	Sealed
Traffic Regime: (See Table 1)																		
Light traffic	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓					✓
Moderate traffic	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓					
Heavy traffic (overload risk)	✓	✓						✓	✓	✓	✓							
Construction Regime																		
High labour content	✓	✓						✓	✓					✓				
Intermediate machinery	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Low cost			✓	✓						✓					✓			
Moderate cost	✓	✓			✓	✓		✓	✓		✓	✓		✓		✓	✓	✓
High cost							✓						✓					
Maintenance Requirement																		
Low	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓					✓
Moderate							✓							✓		✓	✓	
High															✓			
Erosion Regime (See Table 2)																		
A Low erosion regime	/	/	/	/	/	/	/	/	/	/	/	/	/	✓	✓	✓	✓	✓
B Moderate erosion regime	/	/	/	/	/	/	/	/	/	/	/	/	/	✓				✓
C High erosion regime	/	/	/	/	/	/	/	/	/	/	/	/	/					✓
D Very high erosion regime	/	/	/	/	/	/	/	/	/	/	/	/	/					✓