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ALTERNATIVE SURFACING FOR STEEP HILL SECTIONS IN GHANA- PHASE I

Final Report

ReCAP Project Activity Number: GHA2065A




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Cover Photo: *Surfacing Problem and Proposed Solutions*

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ABSTRACT

Over the past two decades, the provision of all-weather access to rural communities has become a priority of the Department for International Development (DFID) in support of poverty alleviation and the stimulation of economic growth in Africa and other countries. DFID has, therefore, funded research and knowledge transfer projects in developing countries through Research in Community Access Partnership (ReCAP). The outcomes of this successful research include innovative and unconventional approaches that can provide beneficial and cost-effective solutions to improve low-volume rural roads in the African Community Access Programme (AfCAP) partner countries, through for example, the use of alternative road surfacings.

The Council for Scientific and Industrial Research (CSIR) in South Africa, in partnership with the Building and Road Research Institute (BRRI) of Ghana, was appointed by Cardno Emerging Markets (UK) Ltd to undertake Phase I of a two-phase study on alternative surfacing for steep slopes in Ghana. The objective of the current study was to provide practical information on the suitability of alternative road surfacings and paving techniques that are cost-effective and that offer sustainable solutions for road surfaces on steep gradients (higher-risk road sections). As part of the study, the project team engaged fully with assigned counterpart staff within the Department of Feeder Roads (DFR) of Ghana to ensure that the knowledge acquired in the course of the project was transferred and entrenched within the DFR.

A major outcome of the project is a matrix of three alternative surfacing options (i.e. concrete, bituminous and stone setts/cobbles) for comparison with the gravel wearing courses currently used by the DFR. These surfacings will be placed over road base materials, which comprise either mechanically stabilised lateritic gravel or a mixture of laterite gravels with different additives such as lime, pozzolana and quarry dust. The three surfacings and the two different base layer materials provided 18 different combinations of pavement solutions to address problems affecting steep sections of feeder roads in Ghana. In addition, various options of erosion control treatments and alternative drainage structures to kerbs are proposed for the study. The 18 pavement options were scaled down to six key options that were ranked for the demonstration sections to be designed, constructed and monitored under the Phase II project. Under limited budget condition, four key options are recommended for the demonstration sites. These are; (1) 70 mm ultra-thin continuously reinforced concrete on 200 mm stabilised laterite base, (2) 50 mm asphalt concrete with processed lateritic gravel and AC-10 bitumen on 200 mm stabilised laterite base, (3) interlocking paving blocks on 150 mm stabilised laterite base, and (4) Otta seal [14-25 mm aggregates] on 100 mm stabilised base and 150 mm stabilised subbase.

This is the final report on the work carried out under Phase I of the project. Three separate reports (i.e. an inception report, a draft report, and a workshop report) have been submitted to the client as technical outputs of this project. The findings and overall outcomes of the study, including the outcomes of the inception study, detailed study, workshop, and feedback from the DFR and AfCAP, as well as recommendations and scoping for Phase II of the study are incorporated into this final report.

Key words
Low-volume roads, Steep gradients, Concrete surfacing, Bituminous surfacing, Stone setts/cobbles surfacing

AFRICAN COMMUNITY ACCESS PROGRAMME (AfCAP)

Safe and sustainable transport for rural communities

AfCAP is a research programme, funded by UK Aid, with the aim of promoting safe and sustainable transport for rural communities in Africa. The AfCAP partnership supports knowledge sharing between participating countries in order to enhance the uptake of low cost, proven solutions for rural access that maximise the use of local resources. AfCAP is brought together with the Asia Community Access Partnership (AsCAP) under the Research for Community Access Partnership (ReCAP), managed by Cardno Emerging Markets (UK) Ltd.

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Acronyms

AfCAP	African Community Access Programme
BRRI	Building and Road Research Institute
CSIR	Council for Scientific and Industrial Research
DFID	Department for International Development (UK)
DFR	Department of Feeder Roads
GSA	Ghana Standards Authority
GSSRB	Ghana Standard Specifications for Road and Bridge Works
HVR	High Volume Roads
KNUST	Kwame Nkrumah University of Science & Technology
LVR	Low-Volume Roads
LVSRs	low volume surfaced roads
MoT	Ministry of Transport
MRH	Ministry of Roads and Highways
R&D	Research and Development
RCC	Roller Compacted Concrete
ReCAP	Research for Community Access Partnership
SATCC	Southern Africa Transport and Communications Commission
SEACAP	South East Asia Community Access Programme
TOR	Terms of Reference
vpd	Vehicles per day

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1. EXECUTIVE SUMMARY

1.1 Summary

Over the past two decades, the provision of all-weather access to rural communities has become a priority of the Department for International Development (DFID) in support of poverty alleviation and the stimulation of economic growth in Africa and other countries. DFID has, therefore, funded research and knowledge transfer projects in developing countries through Research in Community Access Partnership (ReCAP). The outcomes of this successful research include innovative and unconventional approaches that can provide beneficial and cost-effective solutions to improve low-volume rural roads in the African Community Access Programme (AfCAP) partner countries, through for example, the use of alternative road surfacings.

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The following activities were completed for this first phase of the study:

- Detailed review of all available data, evaluation of existing guidelines and standards for low-volume roads, and detailed information on naturally occurring local materials for the study
- A detailed review of related technical documents used in Ghana and other Sub-Saharan African countries (i.e. Malawi, Mozambique, Ethiopia, South Sudan)

- Interviews, meetings and consultations with key officials of the DFR and other stakeholders so as to obtain technical information to support the study
- Site visits and reconnaissance of potential project sites for inclusion in Phase II of the study
- Assessment of good practices from the sub-Saharan African countries and evaluation of alternative surfacing options that have been used in these countries
- Visits to material sources in two regions in Ghana, to assess their potential use for design and construction of demonstration sites
- Visits to three material testing laboratories to assess their respective capabilities
- Detailed inventory of available construction materials to highlight the challenges encountered during their preparation
- Determining the scope of Phase II study; main objectives, role of the consultant, detailed scope of work (e.g. technical services), expected deliverables, project plan and milestones. Detailed scoping for Phase II forms part of this report.

1.2 Outcome

The main outcome of this project is 18 pavement options comprising three alternative surfacings and two base/sub-base materials.

1.2.1 Surfacing layers

1. Concrete surfacings
    - ultra-thin reinforced concrete
    - interlocking concrete block paving
    - roller compacted concrete
2. Bituminous surfacings focusing on naturally occurring materials
    - lateritic gravel modified with sand / quarry dust + AC-10 bitumen
    - Otta seal
    - surface dressing (double seal)
3. Stone setts /Cobbles (granite, quartzite and sandstone)

1.2.2 Base / Sub-base layers

1. Mechanically stabilised lateritic gravel
2. Mixture of laterite gravels with different additives such as lime, pozzolana and quarry dust

Thus, a total of 18 potential pavement options have been identified. It is possible that different surfacing types could be adopted by regional or district feeder road authorities in Ghana; hence many surfacing options may be beneficial to the DFR. One of the fundamental principles behind this study is 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. If large quantities of local material with marginal properties are available, the selected pavement options would be designed to make optimal use of these materials.

It is common practice to use the life-cycle cost to determine the most cost-effective options for road construction projects. However, for this project, which focuses on only the steep gradient sections of feeder roads, life-cycle cost analysis may not suit the budget of the available funds. Therefore, an initial (construction) cost assessment was carried out on six selected pavement options for ranking purposes. The main cost components include the surfacing and base/sub-base layer materials, construction activities, local labour, and appropriate equipment for low-volume roads. Additional costs (common to all pavement options) for the assessment include the cost of the proposed drainage structures for the study and the preliminary cost of typical road construction projects.

Based on a 250 m (length) by 6 m (width) steep section, a 70 mm ultra-thin continuously reinforced concrete surfacing placed on mechanically stabilised lateritic gravel provided the lowest initial cost (ranked # 1) and a 50 mm hot-mix asphalt surfacing with processed lateritic gravel with AC-10 bitumen had the highest cost (ranked # 6).

Comments

1. It is possible to replace crushed stones used in the concrete surfacings with screened naturally occurring lateritic gravels. However, it should be noted that the replacement will require a new mix design for the respective surfacings.
2. A separate project is being undertaken to conduct a desk study of the international practice related to roller-compacted concrete (RCC) and investigate concrete materials types and properties currently used in Ghana. To avoid duplication of effort, the outcomes on the RCC project will be used for the current project.
3. Concrete and bituminous surfacing techniques have been predominantly used to mitigate erosion and drainage problems of steep slope sections (gradient > 12%) of low-volume roads in Mozambique and the eastern region of Ghana. Stone setts and cobbles are rarely if ever used on feeder roads in Ghana, but they are included in the list of alternative surfacings because they are viable, and have a wide range of advantages.

1.3 Main findings emanating from the study

1.3.1 Review of available standards and documents

1. Ghana standard specifications for road and bridge works

- Specifications for pavement layer materials are based on empirically derived structural design charts in which the quality of the specified materials is determined from standard laboratory tests, including parameters such as grading, plasticity and CBR, which serve as the criteria for selecting materials to be used in the pavement structure.
- Criteria for material selection may be too stringent and lack the methods or procedures for optimisation of new or unconventional pavement materials.
- There is a lack of specifications for alternative surfacing options to gravel and bituminous surfacings that have been traditionally used on feeder roads.

2. Road design guide of Ghana highway authority

- This document is purposely prepared to serve as design standard on any class of road. However, this guide does not detail much information on geometric design considerations such as difficult terrains (i.e. steep sections) of low-volume roads.

3. DFR design standards

- This document is still in a preparatory stage. Similar to the other standards (above), this document does not have a section that focuses specifically on steep sections of feeder roads. It must be noted that more than 50% of feeder roads in the eastern and Volta regions in Ghana for instance, are located in hilly terrain, and thus one would expect that efforts are made to capture their characteristics particularly in this important document.

Comment: The current standards and specification documents do not focus much on the steep sections of feeder roads although they are the reference documents for the DFR road designs and material selection. This study offers the DFR an opportunity to develop guidelines and specifications that can be incorporated into the existing documents.

1.3.2 Existing road surface types

- Predominantly, sealed and un-sealed (gravel or earth) surfacings were observed on steep slope sections (gradient > 12%) of the feeder roads that were visited. Gravel loss and erosion-related problems (sheets, rills and gullies) were common on these unpaved roads.
- Sealed-surfaced sections (very few) are of two types: bituminous seals and reinforced concrete. The bituminous surfacings were single seals with a nominal aggregate size range of 10 mm to 14 mm, and the concrete surfacings were continuously reinforced concrete slabs with a thickness of 200 mm. Whereas the current concrete surfacings could be considered as 'over-design', the emulsion-treated bituminous surfacings are inappropriate for hilly sections.
- Predominant defects observed on bituminous surfaced roads include spalling; disintegration of sealing material, cracks, potholes, depressions and "premature failure". For example, sections of one of the roads visited had failed while it was still under construction.

1.3.3 Factors contributing to observed problems with steep sections

The following were found to be most probably the main contributory factors to poor performance on the steep sections of the feeder roads visited:

- **Terrain:** Many sections of the feeder roads visited are in hilly and winding terrains. Gradients were as high as 22%. This terrain had aggravated erosion and drainage problems.
- **Sharp curves:** Some of the identified sections are in sharp vertical curves. Turning effects of vehicles, particularly heavy trucks, have caused significant damage to the pavement surfacing and structure, and present safety hazards to road users.
- **Slippery surface:** The steepness of roads could render road surfaces more slippery during the raining seasons, particularly as observed on the gravel roads. In worst cases, some sections could be cut off due to excessive moistening of road material or even ponding at the trough (base) of steep sections.
- **Traffic:** Traffic volumes on most of the roads are best assessed on market days when the traffic volumes are relatively high – in the range of 100 to 200 vehicles per day (vpd) (source: the DFR, eastern region), whereas the volumes could decrease to less than 50 vpd on non-market days. The terrain and road surface conditions are the main factors affecting the levels of motorised traffic on the roads. Generally, these roads are used by a wide variety of users, from heavy vehicles to motorcycles and bicycles.
- **Poor drainage systems:** Kerbs have been used by the DFR for controlling drainage on all sections of the feeder roads visited, including the steep sections, yet with little to no success. For the large volumes of runoff water normally expected on roads sections in the eastern region of Ghana (for example with high annual rainfall (>1 800 mm) and steep sections), it was not surprising to observe a significant number of deep gullies (erosion problem) on the majority of the roads visited. At the stakeholder workshop, participants agreed that concrete u-drains could be a better option than kerbs to address drainage problems.

1.3.4 Existing drainage systems and erosion problems

- Excessive erosion (sheet, rill and gullies) was observed on the steep sections of the gravel roads visited. This could probably be attributed to high runoff velocities on these sections.
- Where the steep sections run in the cut-side of the road, there is lack of proper protection ("slope stabilisation") of the cut face to minimise erosion.
- Kerb drains had been used unsuccessfully to address drainage problems on the roads visited (as indicated under 1.3.3)
- Concrete drain structures such as inlets (very few) were common, but are poorly maintained.

1.3.5 Road construction materials

- A wide range of construction materials including lateritic, calcareous and quartzitic gravels, river gravels, residual gravels, and granular materials resulting from the weathering of rocks are available for use as road base and/or sub-base materials in Ghana.
- The availability of natural gravel deposits throughout Ghana provides opportunity to maximise its use for the identified pavement options. However, most of these gravels would need screening or re-processing for bituminous and concrete surfacings.
- Natural gravel deposits (pits) are at about a 10-20 km haulage distance from project sites, based on past projects in the eastern region of Ghana.
- A composite mixture of lime and pozzolana has been recommended. Use of other stabilising agents such as quarry dust, natural sand and sugarcane ash (among others) has been reported.
- Cement as a key material for concrete is readily available throughout Ghana. Furthermore, it was found that a composite mixture of ordinary Portland cement and pozzolana could be used to produce acceptable concrete and masonry products.
- Paving blocks are readily available for ordering from accredited concrete production companies in Ghana. Commonly, the rectangular blocks with average compressive strengths of 30N/mm^2 are available. However, an innovative paving block that enhances interlocking has recently emerged as an alternative to the traditional paving blocks.

1.3.6 Traffic factors

For this study, environmental rather than traffic loading factors would determine the performance of the steep hill sections under consideration. The following facts on traffic were, however, gathered during the site visits:

- Vehicular classification data is collected periodically on some selected roads of the DFR (Source: DFR eastern region).
- Very low volumes of traffic were observed during the site visits. As noted under 1.3.3, DFR sources indicate that traffic volume could be as low as 50 vpd during non-market days, while on market days (in many cases, one day per week) traffic volume can reach 200 vpd.

1.4 Potential research areas

The following potential research areas have been identified for future study by the DFR:

- Mapping of naturally occurring construction materials for feeder roads (lateritic gravel, quarry deposits, etc.).
- Use of sugar cane and cocoa pod as stabilisation agents in natural gravels.
- Optimisation of construction waste materials, such as steel slag, recycled asphalt, demolition concrete, and others. Steel slags, for instance, can be used in two forms: aggregates or fines (i.e. < 0.075 mm size, as stabilisation agents for marginal lateritic gravel).
- Innovative techniques for low-volume road maintenance, for example, the use of marginal materials to develop pavement solutions for spot improvements, crack sealing and pothole patching on the bituminous surfaces.

1.5 Challenges

The main challenges that the project team faced in the delivery of this project can be summarised as follows:

1 Some of the pertinent data or information required for the study was not available in the country. It appears that the DFR has not adopted a systematic approach to prospecting and mapping the sources of naturally occurring materials.

2 Sourcing and acquisition, as well as record keeping of the relevant data and information was challenging since a structured database was non-existent.
3 In many cases where the data or information was gathered, it would be outdated or shallow in substance and/or content.

1.6 Conclusions and recommendations

1.6.1 Conclusions

The following conclusions are made based on the outcomes of the study:

- The current standards and specification documents used by the DFR require considerable update to bring them to address steep slope problems. Similar documents developed for low-volume rural roads (e.g. *Low Volume Rural Roads Surfacing and Pavements - A Guide to Good Practice, Cook et al., 2013; Guideline: Low Volume Sealed Roads; SATCC, 2003; Design Manual for Low Volume Sealed Roads in Malawi, 2013; Rural Roads in Sub-Saharan Africa - Lessons from World Bank Experience;* and *Design Manual for Low Volume Roads (Part B) in Ethiopia 2011*) can be used as a starting point to develop standards for the DFR.
- Currently, there is no accepted method of prospecting for materials in Ghana for low-volume roads. This remains an issue that needs to be resolved in future projects. It is believed that equally good or better materials exist than those that are currently used, but there is no systematic approach to prospecting and mapping their sources.
- Significant quantities of naturally occurring materials exist in Ghana for utilisation in the construction of steep sections of feeder roads. Although they do not meet the conventional requirements and specifications for road construction, it is possible to mechanically stabilise them to improve their properties.
- Gravel surfacing is inappropriate for steep sections of the feeder roads visited. Gravel loss was common to these sections, and thus a gravel wearing course was found to be unsustainable. Some road sections had suffered extensive forms of erosion due to intensive rainfall.
- Although bituminous seals and reinforced concrete surfacings have been used on some sections of the roads visited, they are plagued with poor workmanship, over-designs (concrete), under-designs (bituminous surfacing), as well as premature failures.
- All 18 pavement options identified through this project are feasible for the current and future studies, but the ultra-thin continuously reinforced concrete pavement option was found to be the most cost effective (based on initial cost assessment) and to involve labour-intensive technologies that can be explored for steep sections on feeder roads. However, extensive consultations would be required to determine the appropriate pavement options that will meet the needs and budget of the DFR.
- Notwithstanding, the nationwide availability of naturally occurring gravel materials, it is difficult to get natural gravel to meet the G80 (material with minimum CBR of 80%) for base materials.
- The various surfacing techniques identified in this project provide the necessary opportunity to advance the application of innovative engineering solutions or technologies for the provision of feeder roads in Ghana.
- The DFR would need technical assistance in mix designs for the selected bituminous and concrete surfacing options for Phase II. This is obvious as many of the proposed surfacings are new, and the technologies are not locally available at the moment.

1.6.2 Recommendations

The following recommendations are made for Phase II of the study:

- There should be a conscious effort to incorporate the outcomes and outputs of the study in hand into the current DFR standards as guidelines for and specifications of steep sections. In this regard, there will be a need to address all identified gaps of the current DFR technical documents.

- Further investigation is needed into the use of lateritic gravels on steep sections of feeder roads in Ghana. It appears that limited investigations have been undertaken to develop specifications for their use in such terrains. The DFR should seriously consider using Phase II of this study for further investigation of these natural materials.
- The pavement design for cost-effective pavement options should be done in a holistic manner, i.e. attention should be paid to the compatibility between the pavement structure, the materials used, type of surfacing, construction processes and maintenance or rehabilitation techniques.
- Based on the inputs from stakeholders at the workshop, it is recommended that the mapping of locally available materials should be considered as a separate project.
- The DFR should strictly adopt the following drainage system and erosion control measures:
    - Road surface: Surfacing (sealing) the road surface with up to 5% camber is the best way to provide adequate channelling of surface runoff.
    - Proper side drains, preferably lined with concrete, must be provided at steep road sections. This should be based on the characteristics of the natural material of the side drains. Where the in-situ material of the side drains is rocky, only scour checks placed at intervals of less than 6 m may be required. The DFR should experiment with the use of worn-out tyres (waste material) with stone setts/cobbles for scour checks.
- For a project of this nature, where research is a significant and important component of the process, it is recommended that the current DFR process or criteria for the selection of contractors should be reviewed.
    - Selected supervisors and contractors should be adequately trained to execute the demonstration projects.
    - Training will focus on the transfer of new road-building technologies and the use of marginal materials contrary to the conventional practices they are used to.
- There is a need to review the capacity of the potential road material laboratories that will be utilised in this study. Equipment, personnel, historical test data and any previous reports should be reviewed to determine whether or not these laboratories are capable of conducting all the tests that will be included in Phase II. The laboratories should be accredited by the National Standards Board. It is recommended that, where feasible, test samples should be selected for comparative and verification tests in the selected laboratories.
- Based on the fact that sourcing for data and information was a challenge in Phase I, it is recommended that the DFR initiates a study to establish Technical Data Management Systems (TDMS) for low-volume roads.
- The prospective communities should be sensitised from the start of the project to express their opinions, especially in any decisions that may have an impact on their economic and social activities during the construction stage.
- Innovative maintenance strategies should be invented for hilly sections on the feeder roads in Ghana.

2. INTRODUCTION

2.1 Background

More than 70% of feeder (low-volume) roads in Ghana are either built on mountainous or rolling terrains. Feeder roads constitute approximately 62% of the entire 68,124 km of road network, but only five per cent of the total feeder road network in Ghana is reported to have bituminous surfacings. The remaining 95% is either earth or gravel roads. The Department of Feeder Roads (DFR) is responsible for the administration, planning, control, development and maintenance of feeder roads in Ghana. Rehabilitation and maintenance of feeder roads is seen as a crucial part of Ghana's efforts to support the socio-economic development of the country.

Steep sections of feeder roads in Ghana are at high risk of failure/erosion due to the high rainfall conditions (annual rainfall ranges from 780 mm to 2160 mm). They are also adversely affected by slope failure, erosion, drainage-related problems that ultimately affect the rural communities in respect of traffic delays, safety, damage to natural resources, and economic activities (market days for example). Prolonged rainy seasons (especially in southern Ghana), coupled with weak natural (lateritic) soils, exacerbate the problems facing the hilly sections of the feeder roads in Ghana. Hence, the identification of appropriate surfacing options for higher-risk sections on feeder roads is seen as an important component of Ghana's strategy for ensuring sustainable all-season rural access.

A study had to be conducted to identify cost-effective surfacing options as alternative to the current gravel wearing courses in order to improve the sustainability of rural road networks in Ghana. To this effect, the Africa Community Access Programme (AfCAP) through Cardno Emerging Markets (UK) Ltd engaged CSIR to carry out the first phase of a study (to be completed in two phases) that is aimed at establishing optimal surfacing solutions for steep sections (gradient > 12%) on feeder roads. The overall objective of the project is to identify, define and select appropriate surfacing options for steep terrains (higher risk sections). For low-volume roads, ideally, surfaces and pavement layers should be built from local materials. It is the main reason why a greater emphasis is placed on the use of naturally occurring materials for the selected pavement options in this project, as it provides an affordable and sustainable utilisation of local resources for cost-effective rural roads.

The project proposal for Phase I was accepted on 25 January 2016, and the contract was signed into effect on 29 January 2016 with a start date of 1 February 2016 and a completion date of 31 May 2016. The project was undertaken by the CSIR in partnership with the Building and Road Research Institute (BRRI) from Ghana. As part of the study, the project team engaged fully with assigned counterpart staff from the DFR to ensure that the knowledge acquired throughout the project would be transferred to and entrenched within the DFR. The methodology adopted for the study included a detailed review of technical documents (from Ghana and other sub-Saharan African countries), informal interviews and consultations with personnel from the DFR, site visits, and a stakeholder workshop.

The document in hand is the final report of Phase I and constitutes the main output of the project. Three separate reports (i.e. inception, draft, and workshop reports) have been submitted to the Client as technical deliverables for the project. This final report contains the outcomes, findings, conclusions and recommendations of the study. It presents the proposed surfacing options for the identified steep slopes on the feeder road sites visited for Phase II of the project. Detailed discussions are presented on identified surfacing options such as interlocking concrete paving blocks, concrete slabs, hot-mix asphalt surfacings, double seals, stone setts/cobbles, and so forth. In addition, a summary of the outcomes of the inception phase and the stakeholder workshop that was held to discuss the draft report, as well as the outcomes of consultations with personnel from AfCAP and the DFR, are included in this report.

2.2 Project objectives

The main objective of Phase I of the project was to provide practical information on the suitability of alternative road-surfacing and paving techniques that offer relatively low-cost sustainable solutions for road surfaces on steep gradients. The key objectives of Phase I were the following:

- Identifying the factors that have an impact on steep sections of feeder roads
- Identifying options for mitigating these factors in terms of pavement surfacings and/or effective drainage that can provide an acceptable level of service
- Proposing a programme to demonstrate and try out a suitable range of the identified pavement surfacing and drainage options on steep hill sections of feeder roads in Ghana

2.3 Scope and methodology

The scope of the work comprised five main tasks. Each task is outlined below with the approach that was used to achieve the objectives of the study.

2.3.1 Task 1

This task constituted the inception phase of the project. It involved a desk study and a site reconnaissance for the project. A comprehensive literature survey was conducted on a wide range of surfacings options (e.g. concrete strips, interlocking concrete paving blocks, concrete slabs, single, double, slurry seals, etc.) for low-volume rural roads. Documents on previous research, technical documents, government reports and other relevant publications were reviewed for a better understanding of appropriate erosion control and surfacing measures on steep slopes that are used locally and internationally. A full assessment was made of problems (e.g. erosion, steep gradients, slippery surface, soft wet areas, sharp bends, etc.) on identified road sections through field investigation. Selected road sites in the eastern region were visited to determine a full range of external factors such as traffic volume, surfacing types, drainage types (kerb vs. shoulder for example), climatic conditions, and pavement structure. The main output of this task was an Inception Report that was submitted to the Client on 14 February 2016.

2.3.2 Task 2

This task was carried out in parallel with Task 1. The goal was to review and analyse all available national and international guidelines and standards, and to provide a means of grouping and identifying drainage measures and erosion control techniques used in low-volume roads, design, construction, and maintenance interventions. The outcomes of this task were incorporated in a draft report for the project.

2.3.3 Task 3

The goal of this task was to expand on the information obtained from site visits and the available documents to prepare a draft scoping report. The main activities that were undertaken were the following: a detailed review of the related documents, data and reports; analysis and documentation on alternative surfacing materials and techniques for low-volume roads; evaluation of the existing guidelines and standards including soil classification systems for feeder roads in Ghana; inventory of naturally occurring local materials for low-volume roads and database; and assessment of all available information sources (including previous road materials investigations, quarry and borrow pit data), and the conducting of a gap analysis.

As part of this task, there were consultations with personnel from the DFR to capture their views on the project. These views were combined with expert opinion to establish guidance for Phase II of the project. The main outcome of Task 3 was a matrix of alternative surfacing options, and a scoping for Phase II of the study, both of which were incorporated into the draft project report. More detailed findings and a range of areas that needed further study for Phase II were summarised and included in the draft report. Various drainage options and erosion control treatments were also highlighted in the draft report.

2.3.4 Task 4

Under this task, a stakeholder workshop was organised to discuss the findings on the proposed surfacing options for comparison with the gravel road option currently used on feeder roads in Ghana. One of the goals of the workshop was to transfer the knowledge and experience acquired through the project to the DFR. The project scoping and constraints for Phase II were extensively discussed at the workshop. The main output of this task was compiled commentary that was incorporated into a Workshop Report.

2.3.5 Task 5

The main goal of this task was to present outcomes and findings of Tasks 1-4 in a final project report.

2.4 Revision of the terms of reference

The terms of reference (TOR) for the project were well understood. However, it was suggested that a project of this kind would require an internal technical reviewer of the output reports. A recommendation was approved for the Consultant to be included as Non-Key personnel in the project team.

2.5 Deliverables

The four main deliverables for this project were the following:

1. Inception Report that provided the overall framework for the study, and the outcomes of Task 1 and Task 2.

2. Draft Project Report that incorporated the proposed pavement options for the steep slope sections and scoping for Phase II of the project

3. Workshop Report on the proceedings and outcomes of the stakeholder workshop

4. Final Report that incorporates the overall outcomes and recommendations from the study

2.6 Expected benefits

A number of benefits are based on the overall outcomes and outputs of this project. These include:

- Economic justification for alternative surfacings to gravel roads
- Selection of appropriate surfacings that will provide good performance under the prevailing gradient, traffic, climatic conditions, road maintenance capability, etc.
- Development of a more cost-effective paved-road network, reducing the length of environmentally unsustainable unpaved roads
- Greater use of local materials and alternative materials (Ghana currently has four steel plants that produce significant tonnes of slags)
- Simplified site investigations and material testing procedures
- Capacity building and improved knowledge amongst Ghanaian practitioners, researchers at BRRI and DFR staff related to improved solution to problems with steep slopes in Ghana

2.7 Implementation of findings

This project will be implemented via the DFR with an overseeing role by the AfCAP Steering Committee in Ghana.

2.8 Challenges

The main challenges that the Project Team faced in the delivery of this project can be summarised as follows:

- Some of the pertinent data or information required for the study was not available in the country. It appears that the DFR has not adopted a systematic approach to prospecting and mapping the sources of naturally occurring materials.
- Sourcing and acquisition, as well as record keeping of the relevant data and information was challenging since a structured databased was non-existent.
- In many cases where the data or information was gathered, it would be outdated or shallow in substance and/or content.

2.9 Structure of the report

The report covers the following nine main sections:

- Executive summary – presenting the overall outcomes, the main findings emerging from the study, potential future research areas and recommendations.
- Introduction – presenting a summary of the project background, key findings of the inception stage, objectives, scope and purpose of the report.

- Inception phase – presenting the objectives and key outcomes of the inception phase of the study.
- Stakeholder workshop summary – presenting the main points discussed during the workshop.
- Review of documents and material sources – presenting all documents reviewed during the inception phase of the project that were critically assessed and used to scrutinise three main reference documents used by the DFR. An inventory of locally available construction materials, their sources, the availability and sustainability of potential local materials for the project, together with the limitations of some local materials, are discussed in this section.
- Drainage systems and erosion control measures – presenting drainage and erosion issues with a particular focus on the challenges encountered at the study sites.
- Development of alternative surfacing types – presenting a matrix of surfacing techniques (solutions) as well as appropriate base/sub-base layer materials for the selected surfacings.
- Scoping for Phase II of the project – presenting the framework to guide and direct Phase II of the project.
- Conclusions and recommendations – presenting a summary of the identified surfacing options for the steep hill sections by highlighting key findings from the reviews and making recommendations to stakeholders and the Client of the project.

3. INCEPTION PHASE OF THE STUDY

3.1 Introduction

During the inception phase activities were focused on obtaining available documents on a wide range of surfacing options and erosion and drainage control systems for steep sections on low-volume rural roads, as well as on conducting preliminary site visits to potential road sections to be included in the detailed investigation. A desk study was conducted to identify cost-effective and sustainable surfacing types that could be further assessed as part of the project. The inception phase was completed on 14 April 2016, and an Inception Report was submitted to the Client as one of the technical deliverables on the project (Anochie-Boateng and Debrah, 2016). The report provided the overall framework for the study, including the background, scope and methodology. In addition, minutes of project meetings were provided. A detailed implementation plan for the first phase of the study was provided with recommendations to guide the Project Team on how to effectively execute the project to meet the needs of the Client.

The main component of the inception phase was information gathering and field visits. A substantial amount of information was collected and is contained in the main body of the Inception Report. A total of ten road sections were identified for the project. The selection for candidate road sections was guided by several factors such as traffic, rainfall pattern, slope in excess of 12%, and socio-economic factors of the area. Based on these criteria, ten road sections were identified to be used for experimental trials (demonstration sites) in Phase II of the project.

3.2 Key outcomes from the inception phase

To achieve the goals of the study, three major surfacing options were identified as proposed solutions to mitigate erosion and drainage problems of the steep sections on low-volume roads with gradients of more than 12%. These are:

1. Concrete surfacings (e.g. ultra-thin continuously reinforced concrete, interlocking concrete paving blocks, roller-compacted concrete).
2. Bituminous surfacings focusing on naturally occurring materials (e.g. lateritic gravels, sand) and locally available bituminous binders, as well as non-traditional construction materials.
3. Cobblestone and stone setts (e.g. granite, quartzite or sandstone).

It is important to mention that all three candidate surfacing options use locally available materials, which makes them cost effective.

The main findings from the inception phase are summarised below:

- Natural earth and gravel roads and especially those located on steep terrains of the majority of road sites visited were the hardest hit by erosion. Seasonal rainfall (between May and July) could wash away a 100-200 mm thick gravel wearing course in its entirety. Gullies were formed on the road surface, thereby undermining the functionality, riding quality and safety of the road. On certain sections, the erosion had exposed natural stones with sizes ranging between 25 mm and 100 mm, thus posing safety problems for motorised and non-motorised transport. At steep sections where the road sides are in cuts, erosion of the cut surfaces deposited eroded material on to the road surface, undermining the road's functionality. Severe erosion rendered kerbs dysfunctional.

- Cuts on low-volume roads visited were found to be very close to the shoulder of roads. It was observed from the site visit that where the road is traversing cut sections, there is significant runoff. In these areas, Kerbs were found to be the drainage structures mostly used by the DFR to capture such runoffs. It was observed that these kerbs were inappropriate to capture large volumes of runoff water on the surfaces of the roads. Proper drainage structures must be used to intercept water and prevent it from entering the surface of road at these sections. Concrete u-drains, for instance, have been used successfully at cut sections.

- The DFR has successfully used marginal materials for feeder roads in Ghana. It was decided that the use of locally available materials must be encouraged to minimise construction costs. Although many naturally occurring local materials do not meet specification criteria, the DFR indicated that satisfactory performance has been observed in Ghana. In many parts of the country, these marginal materials are often within a reasonable haul distance from project roads. However, it was suggested that marginal materials should be included in this study in order to create a need to verify current specifications and standards.

  - Concerns were raised about the use of AC 10 and AC 14 bitumens since their performance has not been encouraging.

  - Although it was suggested that the use of modified binders in bituminous surfacings should be considered in this study, the Project Team noted that it is not viable to use modified binders (expensive and scarce in Ghana) for feeder roads.

- Inappropriate drainage structures for cut sections are a concern to the DFR. In most cases the number of kerbs to collect water from the surface of the roads is inadequate and has caused erosion problems. Proper drainage structures must be investigated for use on low-volume roads.

- The use of cost-effective concrete or bituminous surfacings for these feeder roads is viewed as an appropriate, resource-conserving and sustainable solution for many rural roads in Ghana.

4. STAKEHOLDER WORKSHOP

4.1 Introduction

As part of the study, a stakeholder workshop was organised to discuss the findings (documented in the draft project report) on the proposed surfacing options for comparison with the gravel road option currently used on feeder roads in Ghana. The main output of the workshop was a report submitted to the Client as a project technical deliverable (Anochie-Boateng and Debrah, 2016-c).

The workshop was held at the Department of Feeder Roads (DFR) offices in Accra on 20 April 2016. The goal of the workshop was to deliberate on the findings of the study and therefore gather the views of all stakeholders. The current status of the project and a detailed scoping for the follow-up study in phase II were presented. The main points of discussion on the identified alternative surfacing options, sources of locally available materials, available information, and scoping for phase II are presented in this report. Recommendations made by stakeholders were included in the workshop report that was one of the technical deliverables of this project. Overall, the workshop served as a vehicle to transfer the knowledge and experience acquired through the project to DFR.

4.2 Main points from the workshop on alternative surfacings

The following are the main points that emerged from the workshop, taking into consideration suggestions, comments and questions raised by participants:

- It was clear that there is no specific surfacing technique for steep sections on feeder roads in Ghana. However, one participant believed that single seals have worked to some extent. On the contrary, Dr Ampadu from the DFR hinted that the traction of vehicles, especially braking effects while descending a steep section, would definitely require a more durable surfacing techniques than single seal surfacing.

- Stakeholders were made to understand that a total of 18 possible surfacing options have been identified for consideration (three surfacing types – concrete, bituminous, and stone setts/cobbles placed on two base or subbase types). However, the project team indicated that only a limited number (i.e. three or four) of these options will be demonstrated in this project. It is possible that a wide range of different surfacing types could be adopted, depending on available materials in a specific locality. A participant from Ghana Highway Authority (GHA) suggested that a surfacing option that utilises a combination of stone setts/cobbles and bituminous binder should be included in the matrix. Dr Paulina Agyekum (AfCAP Technical Manager, West Africa) suggested that the 18 surfacing types identified could not just be discarded in favour of a few options, but should be categorised in the order of preference in the final report so that, should the DFR see the need for alternate road surfacing options in the future, it could be a point of reference. She suggested that a cost estimate (initial cost) could be made to assist in this categorisation.

- Part of the presentation was devoted to ultra-thin reinforced concrete and roller compacted concrete surfacings. The project team indicated it would be possible to replace crushed stones used in these two technologies with screened lateritic gravels (local materials). The importance of mix design was emphasised as the project team indicated that the material replacement will require a new mix design for these surfacings. The benefits of these technologies were presented for participants to discuss whether or not these surfacings would be appropriate to adopt them on the steep sections. Participants agreed that these two technologies are viable and could be included in the study.

- Participants suggested that steep gradients (>12%) should be grouped into three or more categories so that common surfacings can be assigned to groups instead of individual surfacings. It was suggested that this approach will cut down the number of surfacing options required for demonstration in phase II.

- It was acknowledged that the compressive strengths of the concrete surfacing options are not critical. DFR was of the view that concrete of 20 MPa compressive strength should satisfy the objectives of the project because of the low traffic volume on feeder roads.

- One participant asked the project team to explain why bituminous surfacing with modified bitumen was excluded from the proposed bituminous surfacing types. In response, the project team indicated that although it is proven that modified bitumen would perform better on steep sections than unmodified bitumen, bitumen modifiers are expensive and not readily available in Ghana.

- The Environmentally Optimised Design (EOD) approach was proposed for the implementation of phase II of the study, especially since it has been successfully used in other sub-Saharan African countries. EOD would allow the judicious use of marginal (e.g. lateritic gravels) and locally available materials, a balanced use of labour and equipment would be given prime consideration.

- Different techniques such as the use of some form of binder (bitumen, cement, etc. to keep stone setts/cobbles in position on steep slopes was discussed, especially in situations where heavy axle loading is expected on steep slope sections. The major concern according to the DFR is the traction of vehicles, especially braking effects while descending a steep section. These techniques may require further study to verify their potential use in holding the stones in place.

- Mapping of local materials, as proposed during initial scoping, was extensively discussed. Many participants acknowledged that extensive resources would be required for such an activity. Therefore, it was suggested that mapping should form part of a separate project. The general consensus was that mapping should not be included in the scoping activities for phase II. Dr Agyekum suggested that the mapping of local materials could be captured under any climate change study to be conducted by the Ministry of Roads and Highways (MRH).

- A five-minute movie was shown on roller compacted concrete (RCC) technology. This movie focused on the use of RCC on high volume roads. Based on the movie, a participant from the Building and Road Research Institute (BRRI) drew attention to how RCC could be an equipment-intensive technology for this study. To this, the project team indicated that the idea was to demonstrate that the current mix design for RCC can be modified to include screened lateritic gravels as a replacement material for crushed stones. Furthermore, lighter equipment such as a pedestrian roller compactor can be considered for the RCC technology in this study. Dr Agyekum indicated that there was an impending detail study on the use of RCC in Ghana. In addition, it was clearly communicated to participants that some surfacing options would require mechanisation and labour intensive construction methods to achieve the objectives of the project.

- A participant from the DFR enquired on improved geometrical features (road width widening) of steep slopes, especially sections in curves. Responding, Dr. Ampadu from the DFR indicated that such interventions may not be feasible depending on the nature of the in-situ material, e.g. in rocky environments, such widening to standards may be costly and could outstretch budget allocations.

- A participant suggested that cost-effectiveness analyses of the proposed surfacing options should form part of phase I of the project. The project team remarked that, at this stage only tentative initial capital cost could be captured. For instance, the cost of selected surfacing options per square meter (only materials) rather than a whole-life cycle cost effectiveness analysis could be incorporated in the final report. Dr. Agyekum requested for this to be included in the report to guide the selection of preferred options though they may only be indicative costs.

- Stakeholders hinted to the project team that viscosity grading instead of penetration grading is the current system used for bitumen classification in Ghana.

- It was suggested that drainage should be considered as a key component for the selection of surfacing options.

In conclusion, the workshop was successful. It is believed that it offered stakeholders an opportunity to fully participate in the process leading to the selection of suitable alternative surfacing options to the perennial erosion and drainage on steep sections of feeder roads in Ghana.

Several recommendations were made for phase II of the study. These include:

- The need to involve prospective communities from the start of construction to the implementation stage of the project

- The need to provide the DFR with technical assistance in the mix designs of surfacing options that may be included in the study

- The need to come up with innovative maintenance strategies for hilly sections on the feeder roads in Ghana

- The need to address all identified gaps of the current DFR technical documents and incorporate some of the outcomes of this study in those documents

5. REVIEW OF STANDARDS AND MATERIALS SOURCES

5.1 Introduction

For low-volume roads (LVRs), surfaces and pavement layers should ideally be built from local materials, yet this is not always the case or possible in most situations. Hence it is 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 (Cook et al., 2013). Notwithstanding the road pavement structure, in particular for this study on steep slopes, the road surface should be able to provide adequate traction for vehicles when wet and it should withstand common surface distresses. Natural gravel as road surface is thus inappropriate, especially for steep slope road sections and particularly in tropical environments with significant amounts of rainfall, both in intensity and duration. There have been concerns in the road sector about the appropriateness of the traditional material specifications, methods of testing, design and construction of LVRs. The major problems associated with LVRs relate to traffic-ability, especially during rainy seasons, sustainability, environmental degradation and scarcity of suitable construction materials. The use of marginal materials is therefore very important.

Extensive research has been conducted to investigate the performance of marginal materials and behaviour of LVRs. Research conducted in Africa (Richards, 1978; Overby, 1982; Gourley and Greening, 1999; Ethiopian Guideline for Low Volume Roads, 2011; Malawi Guideline for Low Volume Roads, 2013) shows that many local materials that do not meet traditional standards for road pavements are suitable for road construction, especially on roads with relatively low predicted traffic flows over their design life, that is LVRs. All these studies, however, indicate that performance of marginal materials is mainly affected by moisture, density and terrain (road environmental factors).

Testing methods and construction techniques influence the performance of marginal materials under field conditions. The degree of compaction to refusal (the maximum achievable density for a particular type of material, moisture content and compaction equipment) increases strength and stiffness; hence it increases life span. An appropriate testing method that closely simulates field performance is very important in understanding and characterising marginal materials.

The existing practice of LVR provision lacks innovative techniques to adequately improve the performance of local materials that do not meet the conventional specifications of road materials under operational road environments. This results in either poor performance or rejection of the so-called marginal materials. The immediate alternative is to opt for high standard materials, which are scarce and often more expensive. The impact of the rejection of marginal materials on the cost of a LVR project therefore becomes severe. The high construction costs may also frustrate LVR projects and can lead to backlog mobility and sustainability problems.

Consultations with the relevant road agencies (i.e. Department of Feeder Roads, Department of Urban Roads and Ghana Highway Authority) revealed that there is lack of adequate data to address the behaviour and field performance of marginal road materials in Ghana. This is due to the fact that research on LVRs in Ghana is relatively limited when compared to research on high-volume roads (HVRs). The traditional specifications for low-volume roads embrace material specifications for HVRs, a situation that intensifies the rejection of local marginal materials. In addition, the current practice is inadequate to address specific road environmental factors such as terrain, moisture and soil type, since the same type of materials and pavement structure are normally specified for the entire section, regardless of whether the subgrade strength is uniform or varies substantially over the design stretch. This results in either poor performance or unnecessary overdesign due to a lack of comprehensive procedures and guidelines that provide complete and comprehensive procedures and specifications for use of such materials, especially for construction of LVRs.

5.2 Current practice by road agencies (including DFR) in Ghana

From consultations with officials of the DFR and other professionals it emerged that the Ghana Standard Specifications for Road and Bridge Works (GSSRB) document is the main reference for road-related works that are currently carried out in Ghana by the road agencies, including the DFR. The DFR also uses the Ghana Highway Authority Design Guide, especially for geometric design purposes for their feeder road portfolio.

From a testing, design and construction point of view, the GSSRB has some caveats for LVRs. As indicated earlier, the GSSRB does not adequately address specific road environmental factors such as terrain, subsurface moisture and soil type. This situation often leads to inferior design on sections with excessive subsurface moisture, problem soils and steep slope sections and this normally results in early failures. On the other hand, sections with good drainage condition and subgrade strength in excess of 15% CBR are overdesigned, implying unnecessarily high construction costs. Furthermore, many locally available marginal materials are often rejected due to lack of innovative techniques to improve their performance. Dependence on the traditional standards, which focus more on high-volume roads (HVRs) than on LVRs, is also a factor for rejection of the marginal material. Appropriate material specifications, as well as improved testing procedures and design of materials for LVRs are needed to efficiently use marginal materials for the construction of LVRs in Ghana.

The DRF relies on the GSSRB document prepared for the Ghana Highway Authority (GHA). The emphasis of this document is on HVRs, hence the specifications for construction materials may be too stringent for LVRs. Again, attempts by the DFR to develop its own design standards (although currently only in a draft form) are silent on some critical issues on material specifications for rural and LVRs. The DFR usually also refers to other external documents such as *Overseas Road Note 31*. However, this document does not cover steep sections of LVRs.

The current practice does not adequately address the behaviour of marginal materials, despite the latter being mentioned to some degree. The current laboratory testing for characterisation of marginal materials is limited to the following:

- Compaction (standard and modified Proctor)
- California Bearing Ratio, CBR
- Atterberg limits
- Particle size distribution

5.3 Review of standard documents used by Ghana

5.3.1 Brief of Ghana standard specifications for road and bridge works (GSSRB)

The GSSRB (2007) document, which is a revision of a 1991 version, addresses comments made by the Ministry of Transport's (MoT) agencies (Department of Feeder Roads, Department of Urban Roads and Ghana Highway Authority), consultants, contractors and the Ghana Institution of Engineers. In this revision, ambiguities and conflicting clauses were streamlined. Furthermore, specifications on Superpave Asphalt Mix design and stabilisations involving cement, lime and bitumen were included.

The specification was prepared at the request of the Ghana MoT (now MRH) under the World Bank component of the Road Sector Development Programme (RSDP). The development was a joint effort between a Steering Committee composed of officials from the Ghanaian Ministry of Transportation and a joint venture of the CSIR and Stewart Scott International, who acted as the Consultant.

The GSSRB was approved in 2006 and adopted for use by the agencies of the MRH since 2007. It is made up of twenty-nine sections. Some sections of the GSSRB that are considered to be relevant to feeder roads have been assessed. This assessment was imperative due to the peculiar nature of road works and the traffic characteristics of feeder roads relative to highways and urban roads, which the whole GSSRB document also serves.

Sections and sub-sections of the GSSRB that are relevant to the scoping task for tackling the prime objectives of the project were assessed, as presented below. Relevant portions of the document are quoted (*italicised in Times New Roman font*) and comments and suggestions made with support from other reference documents, including tried and tested technologies are presented elsewhere.

5.3.2 Review of GSSRB Section 10 – gravel wearing course

This section covers the provision, laying and compacting of gravel as the wearing course on a road. The term "gravel" used throughout this Section means any material used as a wearing course on an unsealed road, and shall include lateritic gravel, quartzitic gravel, calcareous gravel, decomposed rock, soft stone, crushed rock, and any sands or non-plastic fines used to mechanically stabilise the wearing course.

A "gravel wearing course" means a top surfacing course constructed from one or a combination of these materials. It may be a course placed on the formation of a new road where no pavement and final bituminous surface is included in the Contract, or placed on the formation of a service road, deviation or access road.

Sub-section 10.4 of GSSRB stipulates the following:

The grading and plasticity requirements of gravel and mechanically stabilized gravel after placing and compaction are summarised in Table 10.1 (see below). The grading shall be a smooth curve within and approximately parallel to the envelopes with a grading coefficient in the range specified.

Table 10.1: Grading of gravel wearing course materials

Sieve size (mm)	% by mass passing	
	Class I	Class 2
37.5		100
20	95- 100	85- 100
10	65- 100	55- 100
5	45 -85	35 -92
2	30 -68	23 -77
0.425	18 -44	14 -50
0.75	12 -32	10 - 40
Grading Coefficient (Gc)	16 – 34	16 – 34
Maximum oversize (% > 37.5 mm)	5	5
Shrinkage Product (Sp)	100 - 365	100 - 365

Gc - (Grading coefficient) = (P26.5 – P2) x P4.75/100 (percentage passing 26.5 mm sieve minus percentage passing 2.00 mm sieve multiplied by percentage passing 4.75 mm sieve)/100

Sp - Shrinkage Product = Product of linear shrinkage (GHA S6) and percentage passing 0.425 mm sieve

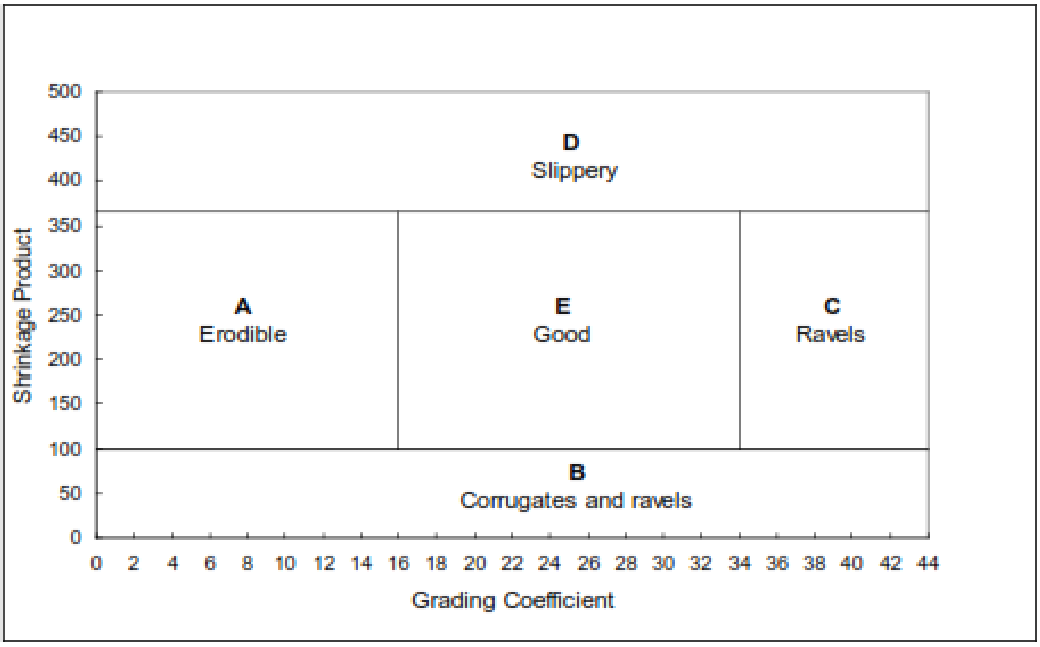
All particle size analyses used to determine these parameters must be normalised for 100% passing the 37.5 mm sieve.

The material shall have a minimum CBR of 20 at 95% MDD (GHA S1) after 4 days' soaking.

The material after placing shall have shrinkage product (Sp) (weighted linear shrinkage) and Grading Coefficient (Gc) properties that plot within the "Good" Zone (Zone E) of Figure 10 (see below), unless approved otherwise by the Engineer.

The use of material Class 1 or Class 2 (which relates to the maximum particle size) will be specified in the special specification.

Figure 10.1: Gravel Wearing Course Material Classification



Clearly, the specification for use of gravel surfacing is unsustainable, especially on high-risk areas such as steep slopes (gradient > 12%), and under intense and considerable long raining seasons which tend to wash away the gravel wearing course.

The need of sealing or alternative surfacing to protect the gravel material is vital. The cost-effectiveness of alternative surfacing methods with the extensive use of available local construction materials should be vigorously explored during Phase II of the study.

5.3.3 GSSRB Section 12 – natural material sub-base and base

This section covers the provision, laying and compacting of natural gravel material for sub-base and base in the pavement.

Sub-section 12.2.1 defines natural material as follows:

The term "natural material" includes lateritic gravel, quartzitic gravel, calcareous gravel, soft stone, conglomerate, sand or clayey sand or a combination of any of these materials. A natural material that can be processed using bulldozers and shovels without the need for blasting or crushing plant is also referred to as "gravel".

Natural material shall be material that can be extracted from a borrow area or a road cutting by ripping to a depth of 300 mm with a single tine hydraulic ripper acceptable to the Engineer drawn by a track type crawler tractor in good order complete with all equipment and accessories as supplied and rated at 220 kW flywheel power and over with an operating mass of not less than 35 tonne and being operated in accordance with the manufacturer's recommendations.

The material may require the use of either a grid or sheepsfoot roller with more than 8 000 kg mass per metre width of roll to break it down and/or screening to achieve the specified grading.

Further, sub-section 12.3.1 classifies material used for the nominal road pavement layers as follows:

Material class	***Typical use***
G80	*Base course*
G60	*Base course for low traffic roads*
G40	*Base course for sealed rural access roads*
G30	*Subbase*

Table 12.1: Requirements for natural gravel materials for base and subbase

Material properties	Material Class			
	G80	G60	G40	G30
CBR (%)	80	60	40	30
CBR Swell (%)	0.25	0.5	0.5	1.0
Grading				
% Passing Sieve Size (mm)				
75	100	100		
37.5	80 - 100	80 - 100		
20	60 - 85	75 - 100		
10	45 - 70	45 - 90		
5.0	30 - 55	30 - 75		
2.0	20 - 45	20 - 50		
0.425	8 - 26	8 - 33		
0.075	5 – 15	5 – 22		
Grading Modulus (min)	2.15	1.95	1.5	1.25
Maximum size (mm)	53.0	63.0	75.0	2/3rd layer thickness
Atterberg Limits				
Liquid Limit (%) (max)	25	30	30	35
Plasticity Index (%) (max)	10	12	14	16
Linear Shrinkage (%) (max)	5	6	7	8
Plasticity modulus (max)	200	250	250	250
Other properties				
10%Fines (kN) (min)	80	50	-	-
Ratio dry/soaked 10%Fines (min)	0.6	0.6		

Notes:
All CBR's will be determined at the field density specified for the layer in which the material is used.
All Atterberg limits will be determined using GHA S6) (Section 2)
All grading specifications are applicable after placing and compaction. Grading curves shall be smooth curves within the specified envelopes and approximately parallel to the envelopes.
Grading Modulus (GM) = 300 – (percentage passing 2.0 + 0.425 + 0.075 mm sieves) x 100
Plasticity modulus = Plasticity Index x percentage passing 0.425 mm sieve

A study by Addison (2008) evaluated some material properties (CBR, grading and Atterberg limits) of natural gravel samples from 454 borrow pits distributed throughout the country for their suitability or otherwise for road construction as a sub-base, base and Otta seal. The results showed that it is difficult getting natural gravel to meet the specification for G80 base material. However, there are significant improvements when a relaxed specification of G60 is used. It was recommended that research should be conducted on the use of natural gravels meeting the specifications for G60 and G30 as base and sub-base respectively by constructing trial pavement sections and monitoring their performance. This is due to the fact that appreciable numbers of gravel pits met the requirements for G60 and hence the widespread utilisation of the gravel materials in the country. Natural gravel should be blended with other materials (stabilised) or crushed stone to improve its engineering properties as layer material for sub-base and base.

An AfCAP report by Netterberg (2014) indicated that there is irrefutable evidence that lateritic materials that do not comply with standard specifications can perform particularly well when used in road construction, even as base course. In order to construct cost-effective roads, particularly those classified as low-volume roads, it is essential that maximum use is made of these local materials. This will require a standardised method for their testing and the development of appropriate specifications for their selection. Extensive research on lateritic materials has been carried out in a number of countries including Ghana (Gidigasu, 1976) and the science of their use is fairly well advanced. However, it is necessary to assess the test and specification limits that are currently being applied internationally and optimise these for use in sub-Saharan Africa. The use of in situ strength instead of the wide range of other material requirements certainly simplifies the material selection and specification process.

The above should guide the selection of the lateritic gravel material for the base/sub-base layers for the demonstration phase.

For construction purposes during the demostration stage, Sub-section 12.4 on Compaction Requirements stipulates as follows:

The minimum required compacted density for pavement layers made of natural gravel shall be as given in Table 12.2 (below).

Table 12.2: Compaction requirements for pavement layers of natural gravel

Layer and typical material class specified	Average dry density (% MDD) (GHA S1)	Minimum dry density (%MDD) (GHA S1)
Base course (G80, G60 or G40)	98	97
Subbase (G40 or G30)	95	94
Note: Compaction to refusal measured by Compaction Meters fitted to the compaction plant should be carried out where possible. However, refusal density shall always exceed the density specified above.		

The maximum thickness of any layer compacted in one lift shall not exceed 200 mm after compaction.

Most likely, as proposed in the road pavement options, some form of blending (stabilisations) of the natural gravel materials would be carried out for the project demonstrations. Sub-section 12.7 of GSSRB on mechanical stabilisation states the following:

Mechanical stabilization of natural gravel subbase and base material, if required by the Special Specification or at the request of the Engineer, shall be defined as the admixture of stabilizing fines or aggregates so as to modify the grading characteristics of the material in accordance with Table 12.1. It can also be carried out by screening into two or more fractions, and recombining. It shall be carried out at the quarry or other site before placing and spreading the materials on the road. Mixing shall be carried out using a mixing plant with measuring hoppers so that a homogeneous mix in the proportions required can be obtained. If necessary, the moisture content of the materials to be mixed shall be adjusted before mixing so that the specified grading can be achieved.

Additives for the stabilisation of lateritic natural gravel for use as base/sub-base pament layers would include natural sand, quarry dust, cement, lime and clay pozzolana. For other tried additives such as fly ash, steel slag (in powder form), sugarcane straw and bamboo leaf would have been interesting for experimentation. However, these may be limited due to location of sources, quantities availabe, preparation methods and sustainabilty analysis.

For instance, Amu et al. (2011) showed that sugarcane straw ash was an effective stabilser for lateritic soils with the following results: optimum moisture content increased from 19.0 to 20.5%, 13.3 to 15.7% and 11.7 to 17.0%, CBR increased from 6.31 to 23.3%, 6.24 to 14.88% and 6.24 to 24.88% and unconfined compression strength increased from 79.64 to 284.66kN/m^2, 204.86 to 350.10kN/m^2 and 240.4 to 564.6kN/m^2 for three samples.

In the study of optimising the pozzolana-lime concentration to maximise geotechnical properties of natural gravel for road construction, Ampadu et al. (2015) show that an optimum lime and pozzolana content for stabilisation of the quartzitic laterite studied was a combination of 4% pozzolana and 6% lime.

5.3.4 GSSRB Section 13 – graded crushed stone sub-base and base

This section covers the procuring, furnishing and placing of approved graded crushed stone on top of a completed selected layer or sub-base and constructing a crushed stone sub-base or base, as the case may be, in accordance with the requirements of these Specifications.

By definition, "Graded crushed stone" shall mean crushed stone with a smooth grading curve, which is within a specified envelope. The stone class and nominal size selected shall be specified in the Special Specification. The range of nominal sizes and gradings of crushed stone are defined in Clause 13.3 (c) below for Stone Classes A, B, C and D. The aggregate shall be produced entirely by the crushing of rock. Single stage crushing shall not be allowed and the crusher installation shall be capable of producing material complying with the specified requirements.

Sub-section 13.3 on material requirement states the following:

The material shall comply with the following requirements:-

(a) It shall consist of crushed stone, free from clay, organic or other deleterious matter, derived from hard, sound, durable and unweathered parent rock.

(b) It shall comply with the physical characteristics given below (Table 13.1).

Material failing to satisfy the requirements of stone Class D shall be rejected.

(i) Stone Classes A, B and C

(ii) Stone Class D

Table 13.1 - Physical Characteristics of Crushed Stone (Classes A, B and C)

	Base			Subbase		
Stone Class	A	B	C	.A	B	C
LAA (%) (max).	30	40	45	40	45	50
Water absorption (%) (max)	1.5	2.0	2.0	2.0	2.5	2.5
FI (%) (max). (-28+20 & -20+14 mm)	25	30	30	35	35	35
10% Fines (kN) (min)	110 (dry)	110 (dry)	110 (dry)	50 (wet)	50 (wet)	50 (wet)
Wet/Dry % (min)	75	75	75	60	60	60

Base

CBR at 98% MDD (GHA S1) and 4 days soak min 80%

Los Angeles Abrasion max 50%

Plasticity Index max 6%

10% Fines Dry min 100 kN

Wet/dry min 75%

Subbase

The plasticity of the material shall be specified in the Special Specification.

CBR at 95% MDD (GHA S1) and 4 days soak min 40%

10% Fines Wet min 50 kN

(c) It shall comply with the following gradings:

(i) Stone Classes A, B and C

(ii) Stone Class D

The grading of the material, after processing, placing and compaction in the pavement shall be a smooth curve without any marked gaps within, and approximately parallel to one of the following envelopes (Table 13.2). The class and nominal size shall be specified in the Special Specification.

Table 13.2 - Grading of Crushed Stone (Classes A, B and C)

Sieve Size (mm)	Percentage by mass passing			
	Base		Subbase	
	0/30	0/40	0/40	0/60
75				100
37.5	100	90- 100	90- 100	75 -95
20	65-95	60 -90	60 -90	50 -80
10	40-70	40 -75	35 -75	30 -67
5	26-50	26 -52	22 -59	20 -54
2	20-40	20 -45	15 -45	13 -40
0.425	10-24	15 -31	4 -23	4 -20
0.075	4 - 10	5 - 15	4 - 12	4 - 10

Cleanliness and plasticity: Material passing the 0.425 mm sieve shall have a Plasticity Index not exceeding 6%. The arithmetic mean of the PIs for a lot (minimum 6 tests) shall not exceed 4.5%.

Base

Table 13.3 - Grading of Crushed Stone (Class D) for Base

Sieve (mm)	% by mass passing
50	100
37.5	90 - 100
20	60 - 100
10	35 - 90
5	20 - 75
2	12 - 50
0.425	7 - 33
0.075	4 - 20

Subbase

Maximum particle size *2/3 layer thickness or 80 mm, whichever is the lesser.*

Uniformity Coefficient *minimum of 5*

(d) The grading and physical requirements of the material for use in treated material in accordance with Section 14 of the Specification shall be specified in the Special Specification.

5.3.5 GSSRB Section 14 – cementitious and bituminous treated materials

This section deals with the addition of cement, lime, bitumen or any other approved additive as a stabiliser to improve soils in the upper layers of earthworks, natural gravels and/or crushed materials. Following the addition and mixing in of the stabiliser, the material is referred to as "treated material".

Sub-section 14.3 of GSSRB on material requirements follows below:

Soils

Natural materials as described in Sections 5 and 12. Soils with a sulphate content (SO_3) greater than 0.5%, by mass, shall not be used for cement or lime stabilization.

(a) Natural material for treated upper surface of formation

The materials to be treated shall conform to the following requirements:

Sands, silty and clayey sands:

maximum size (mm) *10*

% passing 0.075 mm sieve *max 50*

All materials:

Plasticity Index for lime stabilization (%) *max 30*

Plasticity Index for cement stabilization (%) *max 20*

Plasticity Modulus	*max 2500*
Organic matter (%)	*max 3*

Additional requirements for lime treated materials:

% passing 0.425 mm sieve	*min 15*
Plasticity Index (%)	*min 10*

After treatment the material shall have a CBR of at least 15% measured after 7 days curing and 4 days soaking on the site mix compacted to 95% MDD (GHA S1) and the treated material shall have a Plasticity Index not exceeding 15% and a Plasticity Modulus less than 250

(b) Natural material for cement or lime treated subbase

The materials to be treated shall conform to the following requirements:

Gravels:

maximum size (mm)	*50*
% passing 0.075 mm sieve	*max 40*

Sands, silty and clayey sands:

maximum size (mm)	*10*
% passing 0.075 mm sieve	*max 50*

All materials:

Plasticity Index for lime stabilization (%)	*max 30*
Plasticity Index for cement stabilization (%)	*max 20*
Plasticity Modulus	*max 2500*
Organic matter (%)	*max 2*
Methylene Blue Value	*min 2*

Additional requirements for lime treated materials:

% passing 0.425 mm sieve	*min 15*
Plasticity Index (%)	*min 10*

After treatment the material shall have a CBR of at least 60% measured after a 7 day curing and 4 day soaking period on the site mix compacted to 95% MDD (GHA S1) and the treated material shall have a Plasticity Index not exceeding 10% and a Plasticity Modulus less than 250.

Material for a stabilized subbase in an inverted pavement structure shall have a UCS of between 3 and 6 N/mm^2.

(c) Natural materials for cement stabilised base

The materials to be treated shall conform to the following requirements:

Gravels and coarse clayey sands:

maximum size (mm)	*40*
% passing 0.075 mm sieve	*max 35*
Uniformity Coefficient	*min 10*
Plasticity Index (%)	*max 20*
Plasticity Modulus	
mix-in-place method	*max 1500*
stationary plant method	*max 700*
CBR at 95% MDD (GHA S1) and 4 day soak	*min 30%*

After treatment the material shall have a UCS of between 1.5 and 3.0 N/mm^2 measured after 7 days curing and 4 days soaking on the site mix compacted at 97% MDD (GHA S1) and the treated material shall have a Plasticity Index of less than 6 and a Plasticity Modulus of less than 250.

(d) Natural materials for bitumen stabilized base

The materials to be treated shall conform to the following requirements:

maximum size (mm)	*50*
% passing 0.075 mm sieve	*2 - 20*
Plasticity Index (%)	*max 7**
Sand equivalent	*min 30*

CBR at 95% MDD (GHA S1) and 4 day soak min 30%

** If PI > 7% it can be reduced by the addition of an appropriate quantity of lime*

After treatment the material should have the following properties:

Table 14.1: Requirements for Bitumen Treated Material

Parameter		Minimum Strength (N/mm^2)
Unconfined Compressive Strength (UCS), in accordance with B.S. 1881, part 116. 7-day strength, moist curing @ 25ºC, height/width 1:1	Minimum 97% of GHA S1 density*	0.7
Indirect tensile strength (ITS) on 100 mm diameter briquette cured at 40ºC for 72 hours, in accordance with AASHTO T 198	Marshall compaction (75 blows per side)	0.2
Indirect tensile test (ITS) on cured briquettes, soaked for 24 hours as above	Marshall compaction (75 blows per side)	0.15
Maximum added cement content by weight		2%

5.3.6 GSSRB section 18 – concrete works

This section covers the materials, design of mixes, mixing, transport, placing, compaction and curing of concrete and mortar required in the Permanent Works.

The key materials for concrete are specified under sub-section 18.3 which follows below:

General

The Contractor shall submit to the Engineer full details of all materials that he proposes to use for making concrete. No concrete shall be placed in the Works until the Engineer has approved the materials of which it is composed. Approved materials shall not thereafter be altered or substituted by other materials without the consent of the Engineer.

Cement

Cement shall be Portland or Rapid-hardening cement, and shall comply with the requirements of GS 22 and/or BS EN 197 cement standard. Cement shall be classified according to strength class and constituents and the cement classification shall be clearly indicated when delivered to site.

The following cement compositions can be used in structural concrete (all percentages are by mass):

Portland cement:

CEM I (contains more than 95% Portland cement clinker)

Portland composite-cement:

CEM II / A (contains between 6 and 20% cement extender and between 80 and 94% Portland cement clinker)

The following cement compositions can be used in mass concrete if required by the Engineer (all percentages are by mass):

Portland composite-cement:

CEM II / B (contains between 21 and 35% cement extender and between 65 and 79% Portland cement clinker).

Blastfurnace cement:

CEM III / A (contains between 36 and 65% Blastfurnace slag and between 35 and 64% Portland cement clinker.

Cement extenders (with the notation used in BS EN 197) that can be used in cement are:

- *Ground Granulated Blastfurnace Slag (S) conforming to BS 6699 or BS EN 15167*
- *Siliceous Fly Ash (V) conforming to BS EN 450*
- *Calcareous Fly Ash (W) conforming to BS EN 450*
- *Limestone (L or LL) that meets the requirements of BS EN 197*

Sulphate resistant cement shall only be used if specified by the Engineer and all details of the cement shall be submitted to the Engineer before use.

Where a CEM I cement is used, cement extenders can be added to the concrete mix on condition that the percentages added do not exceed the percentages indicated above. The extenders shall meet the requirements as set in the standards listed. Extenders used in a concrete mixture are taken into account as part of the cement content for calculating the minimum cement content or the water/cement ratio: the properties of this blended cement shall be established according to the requirements of EN196.

The strength class of all cement is determined according to BS EN 196-1. The standard strength of cement is the compressive strength at 28 days. The standard and early cement strength requirements of BS EN 197 are listed in Table 18.1. The early strength of cement is determined after either 2 days or 7 days and the early strength can be normal (indicated by N) or high (indicated by R).

Table 18.1: BS EN 197 Cement strength requirements

Strength Class	Compressive strength requirement (MPa)				Initial setting time	Lower level limit values for single results			
	Early strength		Standard strength			Early strength		Standard strength	Initial setting time
	2 days	7 days	28 days		(min)	7 days	28 days	(min)	
32.5 N		≥ 16.0	≥ 32.5	≤ 52.5	≥ 75		14.0	30.0	60
32.5 R	≥ 10.0					8.0		30.0	
42.5 N	≥ 10.0		≥ 42.5	≤ 62.5	≥ 60	8.0		40.0	50
42.5 R	≥ 20.0					18.0		40.0	
52.5 N	≥ 20.0		≥ 52.5	-	≥ 45	18.0		50.0	40
52.5 R	≥ 30.0					28.0		50.0	

Aggregate

Both coarse aggregate (stone) and fine aggregate (sand) shall be clean, hard and durable and shall be natural sand, crushed gravel sand or crushed rock sand complying with BS EN 12620. The aggregate shall not contain iron pyrites or iron oxides. It shall not contain mica, shale, coal or other laminar, soft or porous materials or organic matter unless the Contractor can show by comparative tests, on finished concrete that the presence of such materials does not adversely affect the properties of the concrete.

Where there is a danger of a particular combination of aggregate (particularly those containing amorphous and fine grained silica such as opal, tridymite, cristobalite and volcanic glasses in some quartzites, strain quartz, granites and metasediments) and cement giving rise to a harmful alkali-aggregate reaction, the particular combination shall be tested. When tested for potential alkali-silica reactivity in accordance with ASTM C 1260, C 227, C 295 and C 289, the aggregate shall be non-reactive.

All the material used as fine aggregate shall pass through a 4 mm sieve. In order to achieve an acceptable grading, it may be necessary to blend materials from more than one source.

The grading used in the initial mix designs shall be submitted to the Engineer and the grading of the fine aggregate used subsequently shall not deviate by more than the percentages indicated in Table 18.2 from the grading submitted. If the grading of the fine aggregate changes significantly, new mixes will have to be tested and approved for all classes of concrete.

For the aggregates, it is specified that they *shall not contain iron pyrites or iron oxides*, which are usually igneous aggregates (granites in nature). Laterites and Lateritic Stones abound in the tropical and semi-tropical areas of the world, more than the igneous and other standard rocks that are used as concrete aggregates and road chippings. This lateritic stones, also known as fused laterites, contain considerable iron and aluminium oxides contrary to the specifications. Consequently, a study by Madu (1980) on the performance of lateritic stones as concrete aggregates and road chippings show that *"lateritic aggregates are good materials for road chippings and concrete aggregates although they give results slightly inferior to those obtained from igneous aggregates. There does not appear to be any simple relation between the iron and aluminium oxide contents or the sesquioxide contents of lateritic aggregates and the properties of the resulting concrete, although the sesquioxide contents of the lateritic stones are very broad indications of their quality."*

Granitic (Igneous) coarse aggregates from quarry sites (processed)

Marginal lateritic coarse sggregates with high contents of sesquioxides (do not meet GSSRB specifications)

Figure 5-1: Granitic coarse aggregates for road construction in Ghana

5.4 Brief of the road design guide (RDG) of GHA

The purpose of this document was to serve as design standards on any particular class of road with the following objectives:

- Ensure minimum levels of safety and comfort of road users
- Arrive at an economic design
- Maintain uniformity in alignments, drainage and other road facilities

The GHA was the government agency that put together a team of professionals who developed the document that was adopted in March 1991. The document consists of eight chapters that deal with relevant aspects for the geometric design of primary classes of roads.

The following are assessments of relevant portions of this document that are pertinent to this study:

5.4.1 RDG Chapter 2 – classification of roads and design speed

Extractions of Table 2.1.1 - Functional and Terrain type classification and Table 2.2.1 – Design Speeds of the document gives the basic classification and design speed for feeder roads as shown in the table below:

RDG Table 2.1.1

Road Type	Classification	Design Speed [km/h]	Absolute Values [km/h]
Feeder	Flat	60	40
	Hilly	50	30
	Mountainous	40	20

The functional classification of a feeder road defines it as connecting villages or farming centres to primary or secondary roads. Section 2.3 of RDG stipulates the following:

A route may have different sections which differ in their characters. These characters may be terrain, traffic volume and importance. It is recommended the designer adopts the same design speed for sections with similar characters to ensure a more harmonious alignment.

Geometric design of a route has to be as continuous as possible, therefore selection of lengths and change points have to be considered wisely in sectional designs (see Table 2.3.1).

RDG Table 2.2.1

Road Type	Desirable	Unavoidable Case
Motorway, Primary, Secondary	20 – 30 km	5 km
Feeder	10 – 15 km	2 km
Town, Residential, or Service road in town	From principal intersection to the next principal intersection	

General comment: The above information is not adequate for Phase II of the study.

5.4.2 RDG chapter 6 – road drainage

Section 6.5 of RDG (Chapter 6 deals with gutters) emphasises the importance of lining the side gutters and not leaving them as earth gutters, especially in steep sections, as a result of erosion.

Conventional methods such as stone pitching, block masonry and cement concrete gutters have been proposed as measures for checking road side drainage. These measures come at a cost due to the construction components.

In the course of site visits, an unconventional and innovative way of preventing or reducing excessive erosion/scouring was noticed in a peri-urban settlement in Ejisu, Ashanti region, Ghana. Worn-out tyre was partially cut and filled with stones and placed in a high water flow course of a channel to check scouring. (See photos in Figure 5-2.) It may be interesting to explore this innovative technique as the worn-out tyres are abundantly available all over the country as waste material that is detrimental to the environment.

Figure 5-2: Photos showing innovative use of worn-out tyre (a waste material) for erosion check

5.5 Approach to material selection and utilisation

The concept of Environmentally Optimised Design (EOD) will be adopted in the selection and utilisation of material for Phase II of this study. Mike *et al*. (2009) defined EOD methodology as a design approach that utilises the available resources of budget, manpower and materials to meet the challenges of the road environment and provide appropriate access in the most cost-effective and sustainable manner. In this approach, attempts are made to ensure that each section of road is provided with the most suitable pavement material type for the specific physical factors, including gradient, subgrade type and climate. This approach offers various options and solutions for providing low-volume rural road access.

The key property of the EOD concept is its flexibility in design approach, which is based on the need to support road tasks as well as to consider the road environment (see Figure 5-3).

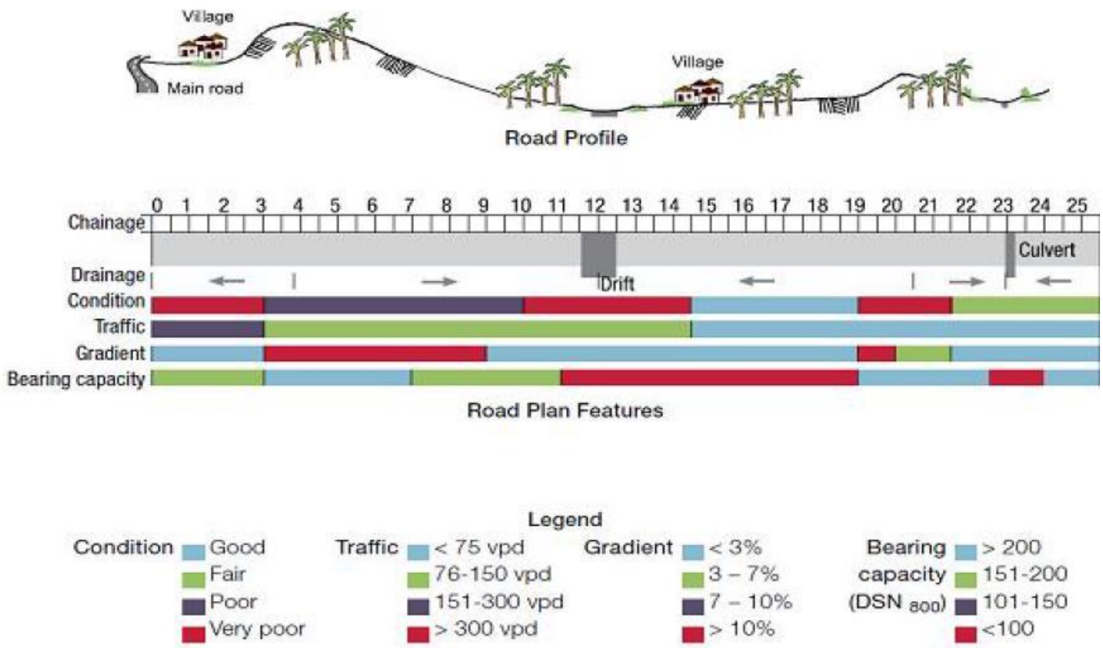


Figure 5-3: Application of the principle of environmentally optimised design (Source: AfCAP, 2009).

5.6 Inventory of available construction materials

5.6.1 Key construction materials

The following are key construction materials that have been identified for the evaluation and adoption of pavement options (surfacing and base/sub-base layers) proposed for this project:

- **Natural gravel (lateritic material)** constitutes a core component of both the bituminous surfacing options and the base/sub-base road pavement structure. In the case of stabilisation of the marginal natural gravel that may require mechanical stabilisation, experiments may be conducted with additives such as lime, pozzolana and quarry dust, fly ash, steel slag (in powder form), sugarcane straw and bamboo leaf, etc. guided by referenced works and standards.

- **Coarse aggregates** in the form of conventional quarry stones (as stipulated in the applied specifications) will serve as source. This is especially important for use in conventional control methods as against the proposed alternative surfacing options.
- **Sands** are to be obtained from natural land deposits/river beds. Sands serve as core construction materials, both as key concrete components and/or stabilising agents of lateritic composites for surfacing options and road base/sub-base layers.
- **Quarry dust** could be used for stabilisation of marginal lateritic material. Quarry dust is also a key material ingredient for the production of interlocking concrete paving blocks of specified compressive strength that will be investigated as a surfacing option.
- **Bitumens (regular or modified)** are critical binding agents for one of the broad surfacing alternatives proposed. Bituminous emulsions and available modified bituminous products would be explored in the experimental project
- **Lime** as a stabilising agent is another material for consideration.
- **Clay pozzolana** would (can) be a composite additive material for stabilisation, both for the proposed surfacing options and for improving the engineering properties of marginal natural gravel (lateritic material).
- **Burnt clay bricks** are construction units that are tried and tested and have been proven to be alternatives for surfacing options. Though not captured as a contending candidate in the inception stage, this surfacing material component will be considered due to the abundance of the core raw material (clay) all over Ghana.
- **Reinforcement** will serve as the conventional material component for the concrete-based alternative options. In this study, mild steel reinforcement will be used if needed.

5.6.2 Materials sources and characteristics

Table 5-1 gives a summary of characteristics and sources of construction materials identified for Phase II of the project. Relevant notes are referred to where applicable.

Table 5-1: Core materials' characteristics and source

Material	Description	Sources	Notes
Lateritic soils (natural gravel)	• Residual deposits formed under tropical climatic conditions. Laterite consists of iron aluminium oxides.	• Borrow pits (*Deposits, Eastern Region)*	Note 1
Course aggregates	• Aggregate for construction in Ghana is mainly from quarry sites (crushed rock).	<u>Quarry Sites</u> ▪ Mansco Quarry Ltd ▪ Kofi Asante Quarry ▪ I & A Quarries	Note 2
Fine aggregates (sand, quarry dust)	• Natural sand from land deposits may contain significant amounts of vegetative mater thereby requiring screening. River sand is usually better. • Quarry dust are usually free of foreign matter and usually has maximum particle sizes of 7mm.	▪ Sand winning Sites ▪ River beds ▪ Quarry Sites	Note 3
Cement	Ordinary Portland Cement: Class N32, etc.	▪ Supplier Dealers	---

Material	Description	Sources	Notes
Bitumen (Penetration grade and modified derivatives)	• 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.	• Supplier Dealers • Core Construction Ltd	Note 4
Stone setts/cobbles (Pavé)	• Cubic pieces of stone larger than setts, usually shaped by hand and built into a road surface layer or surface protection. • A small piece of hard stone trimmed by hand to a size of about 10cm cube used as a paving unit.	• Quarry Sites	---
Clay pozzolana	• Clay pozzolana produced by BRRI serves as cementitious additives to enhance masonry and concrete products. • For masonry- replace one-third portions of cement with pozzolana and mix thoroughly. • For concrete- replace one-quarter portions of cement with pozzolana and mix thoroughly.	• BRRI Factory, Fumesua near Kumasi • Supplier Dealers	Note 5
Paving blocks	• Interlocking concrete paving blocks		Note 6
Mild steel reinforcement	• Commonly of yield strength 250MPa.	• Supplier Dealers	---
Worn-out tyres (waste)	• Unconventional waste material to be explored for scour checks in road side drains.	All over the country	Note 7

Note 1:

Laterite – a type of residual soil that occurs extensively in the humid tropical and sub-tropical zones of the world, including much of central, southern and western Africa.

Unfortunately, laterites have not been used to their fullest extent in the base and sub-base layers of low volume surfaced roads (LVSRs) in sub-Saharan African region for the following reasons:

- The variability in their engineering properties and failure to meet traditional specifications. For example, these materials commonly exhibit gaps in the grading curve (e.g. coarse sand fraction); high plasticity indices (PIs, 15-20) and soaked CBR values lower than the minimum of 80 per cent normally specified.
- Lack of awareness of the more appropriate specifications that were first developed by the Portuguese in the 1950s and 1960s in countries such as Angola and Mozambique and subsequently adapted for use in other countries, notably Brazil and Australia.

The geotechnical properties of lateritic soils considered to be the most relevant to their performance include:

- Particle size distribution
- Atterberg Limits
- Strength of the coarse particles
- Compaction and bearing strength

It was established in this project that material maps showing specific (geo) locations, engineering properties, quantities, and so forth are not available. Interviews conducted with personnel from the DFR, Eastern region, indicated that an unorthodox way of identifying lateritic deposits is where cocoa plantations grow well.

Note 2:

Mansco Stone Quarry Ltd., produces granite chippings for various road and building construction projects. The Quarry is located behind Blueskies factory, about 4.5km west of Doboro on the Accra-Nsawam Road in the Akuapim South District of the Eastern Region and can be accessed through the Doboro-Chinto feeder road. The quarry size is about 47 acres (19 hectares). The massive rock deposit consists mainly of biotite granites and granodiorite of the Cape Coast Granitic Complex. They are light-grey to dark-grey in colour, fine to medium grained and compact. Their characteristics make them suitable especially as road and building construction materials as well as concrete aggregates for other construction works. The various aggregate sizes produced include quarry dust, 6mm, 10mm, 14mm, 19mm, 25mm, and 38mm.

Kofi Asante Quarry: Located at Akwadu, a town about 10km from Koforidua, the capital of Eastern region.

I & A Quarry: Located at Asuboi a town in the Suhum/Kraboa/Coaltar district in the Eastern Region of Ghana. It is along the Acrra Kumasi N6 highway.

Note 3:

Natural sand has been the commonly used fine aggregates for construction. However, in recent times quarry dust is being used in lieu sand, since the quarry dust are usually free from vegetative matter and other 'foreign matter' that could affect the basic engineering properties of the natural sand. In cases where natural sand is used, screening may be required. The cost of all these compared with the quarry dust make it more appropriate as fine aggregate.

Note 4:

Besides the regular bitumen as a binder, other modified derivatives may be explored.

Note 5:

There other supplier dealers at strategic locations in Ghana. Quantities are readily available

Note 6:

The rectangular shaped – 75mm x 200mm x 75mm thick are the most common ones in the open market with compressive strengths ranging 25N/mm^2 to 35N/mm^2. In special cases, higher compressive strengths and other shaped ones are produced for the intended purposes.

Interlocking of the block units plays a key role in the overall functionality when used for paving. The proposed shape is innovative for this purpose.

Note 7:

Worn-out tyre is a waste material that could be detrimental to the environment. In Ghana, they are readily available almost everywhere, though some are used for various purposes. There are always excesses that could explored for use as scour checks (the tyres partially cut and filled with stone setts/cobbles, arranged and anchored to serve improvised rock pile scour checks (see Figure 5-4 below). In that way, there would be savings on the mortar binder while utilising waste materials-worn-out tyres. Other materials identified are shown in Figure 5-5 and Figure 5-6.

	
Conventional rock pile scour check which should be at points maximum 6m intervals for steep slopes greater than 10%	Partially cut out tyre to hold stone setts/cobbles and placed for scour check.

Figure 5-4: Traditional vs. use of waste tyres for scour check

	
Granitic course aggregates, usually 10mm to 25mm	Quarry dust
	
Stone setts/cobbles maximum size 40cm	Mild steel reinforcement

Figure 5-5: Identified traditional materials for the study

Lateritic gravel – marginal (waste material)

Worn tyres (Waste Material)

Traditional Portland Cement

Clay Pozzolana (Cement Additive) by BRRI (Local)

Locally manufactured concrete paving blocks with improved interlocking

Conventional rectangular interlocking concrete paving blocks

Figure 5-6: Innovative and cost-effective materials for the study

5.7 Material-testing laboratories

Testing of materials plays a vital role in the successful execution of materials selection and design, road design and construction. Three main laboratory facilities that have the basic capacity to render the expected services for Phase II of this study were visited as part of materials sourcing for this project. These are:

1. Laboratories at the Building and Road Research Institute (BRRI)

2. Laboratories at the College of Engineering at the Kwame Nkrumah University of Science and Technology (KNUST)

3. Laboratories at the Ghana Highway Authority (GHA)

The project team verified that the appropriate testing protocols and equipment for the constituent materials are available for all surfacings and base/sub-base materials proposed for this study.

All the laboratory facilities have the capacity to undertake the fundamental tests, using acceptable protocols and appropriate equipment. Whereas the facility at the BRRI has the advantage of adequately conducting the chemical analyses of test samples, especially as ‘marginal’ materials have been proposed for this study, it is handicapped at carrying out tests on bituminous surfacing materials. The laboratory facility at KNUST has similar capacity as at the BRRI. Besides rendering training services to students, the facility is also open for consultancy services to the public. The facility at the GHA has the capability to handle bituminous material testing as well as aggregates.

Although they did not visit it, the project team found that the material testing division of the Ghana Standards Authority (GSA; www.gsa.gov.gh) has the capacity to undertake the requisite physical and chemical tests of all the identified construction materials. Their state-of-the-art laboratories position themselves for verification purposes for all tests that may be conducted elsewhere in the three afore mentioned facilities.

Brief descriptions of these laboratories are presented below, and the relevant testing equipment available in these labs is included in this report as Appendix B.

5.7.1 BRRI laboratories

The BRRI has two different laboratories, namely a geotechnical laboratory and a materials engineering laboratory which could be of service to this study. The laboratories are located at the main premises of BRRI at Fumesua in Ashanti Region of Ghana and have the capacity to conduct all basic tests for soils, water, and fine and coarse aggregates. In addition, analyses of the chemical compositions of test samples as well as the possible effects of reactions between constituents of composite samples are carried out at the laboratories. Table 5-2 shows the relevant tests and the standard protocols used.

Table 5-2: Materials testing at BRRI laboratories

Item	Test parameter / description	Standard protocol
Soil testing		
1.	Moisture Content	BS 1377, P1:1990
2.	Atterberg Limits	BS 1377, P2:1990
3.	Specific Gravity	BS 1377, P2:1990
4.	Grading including Hydrometer	BS 1377, P2:1990
5.	Particle Density	BS812- 02
6.	Proctor Compaction	BS 1377, P4:1990
7.	AASHTO Compaction	BS 1377, P4:1990
8.	California Bearing Ratio (CBR)	BS 1377, P4:1990
9.	Field Density Tests	BS 1377 P 9: 1990
10.	Falling and Constant Head Permeability	BS 1377, P5:1990
11.	One-Dimension Consolidation	BS 1377, P6:1990
12.	Unconsolidated and Undrained Triaxial Tests (UU)	BS 1377, P7:1990

Item	Test parameter / description	Standard protocol
13.	Consolidated Drained Triaxial Tests (CD)	BS 1377, P7:1990
14.	Consolidated Undrained Triaxial Tests (CU)	BS 1377, P7:1990
15.	Direct Shear Undisturbed or Remoulded circular specimens	BS 1377, P7:1990
16.	Uniaxial Compressive Strength (UCS)	BS 1377, P7:1990
17.	Organic Matter	ASTM C 421
Stone and coarse aggregates testing		
1.	Specific Gravity	BS 1377, P2:1990
2.	Water Absorption	BS 812 - 02
3.	Elongation	BS 812- 105.2
4.	Flakiness Index	BS 812- 105.1:1990
5.	Grading	BS 1377, P2:1990
6.	Clay, silt and dust in aggregate	BS 812- 103.2
9.	Los Angeles Abrasion (LAA)	BS 812 - P113:1990
10.	10% Fines	BS 812 - P 111:1990
11.	Aggregates Impact Value (AIV)	BS 812 - P 112:1990
12.	Aggregates Crushing Value (ACV)	BS 812 - P 110:1990
13.	Sodium Sulphate Soundness	ASTM C 88
14.	Alkali Silica Reactivity	BS 812 - 123
15.	Compressive Strength on Cubes	BS EN 12390-3
16.	pH	BS 1377-3:1990
17.	Sulphate	BS 812 - 118
18.	Chloride	BS 812 - 117
19.	Organic Matter	ASTM C40

5.7.2 KNUST laboratories

The Civil Engineering department of the College of Engineering, KNUST, Kumasi, has a geotechnical laboratory that handles conventional tests of soils and aggregates; and a chemical laboratory that analyses water and chemical samples under the environmental engineering section. The standard protocols of testing are very similar to those of the BRRI. For instance, the BS 1377 standard protocols are used for basic soil testing. Their facilities primarily render students training yet are open for consultancy services for the general public. There are no functional laboratory services for asphalts and bituminous materials.

5.7.3 GHA laboratories

The GHA central laboratories are based at the Head Office in Accra and they are equipped to perform tests on the following materials:

- Soils and fine aggregates
- Stones and coarse aggregates
- Sand-stone concretes
- Bituminous materials

The protocols make reference to GHA standards which are mainly based on BS, ASTM and AASHTO standards. Table 5-3 lists the key materials parameters and the protocols for the tests that are carried out at the GHA laboratories.

Table 5-3: Materials testing at GHA laboratories

Test parameter	Test Protocol
Soil testing	
Moisture content	BS 1377: Part 2: Clause 3.2, Oven drying method
Liquid limit	GHA S6
Plastic limit	GHA S6
Plasticity index	GHA S6
Linear shrinkage	GHA S6
Density of particles	GHA S1
Particle size distribution	GHA S7 : Clause 3.3, Wet sieving
Organic matter content	BS1377: Part 3: Clause 3
Reference density for compaction	GHA S1
	GHA S3: Cohesive soils and gravels
	GHA S4 : Graded crushed stone sub base and base
Reference density for compaction	GHA S2 : Cohesion less sands and fine gravels
California Bearing Ratio (vibrating hammer)	AASHTO T 176 : Mechanical shaker or manual shaker
Sand equivalent	AASHTO T 176 : Mechanical shaker or manual shaker
Field dry density	GHA S5
	BS 1377
10% Fines aggregate crushing test	AASHTO T: 238 : Part 9: Clause 2.5
	BS 812-111 : Clause 9.4.6, Moisture determination
Stone and coarse aggregates testing	
Particle size distribution	BS EN 933-1
Clay, silt and dust in aggregate	BS 812-103.2
Flakiness index	BS EN 933-3
Relative density- water absorption bulk density	BS EN 1097-6
Voids and bulking moisture content	BS EN 1097-3
Aggregate crushing value	BS 812-109 (Standard method – oven drying) BS 812-110
Organic impurities in sands	AASHTO T 21
Los Angeles abrasion	AASHTO T 96 (ASTM C 131) (coarse aggregate)
	ASTM C 535 (Large size coarse aggregate)
Sand equivalent	AASHTO T 176 (Mechanical shaker or manual shaker method)
10% Fines aggregate crushing value	BS 812-111
Asphalt material testing	
Mix design (Marshall method)	AASHTO T 245, Asphalt Institute mix design methods
Mix design (Superpave method)	AASHTO T 312, Superpave mix design manual SP-2
Moisture sensitivity test (TSR)	ASTM D 4867
Saybolt/universal furol viscosity	AASHTO T 59 (ASTM D 244)
Specific gravity of bitumen	AASHTO T 228 (ASTM D 70)
Flash and fire point test	ASTM D92
Penetration test	ASTM D5
Distillation test (Cutback /emulsified bitumen)	ASTM D 402/ASTM D6997
Extraction test	ASTM D2172
Maximum theoretical specific gravity (G_{mm})	ASTM D 2041 /AASHTO T209
Softening point	ASTM D36
Rolling thin film oven test	AASHTO T 240/ASTM D 2872
Kinematic viscosity	ASTM D2170 / D2170M
Viscosity	ASTM D4402
Bulk specific gravity of asphaltic concrete cores	ASTM D 2726 /AASHTO T166

Test parameter	Test Protocol
Concrete cores	
Marshall Stability and flow of asphaltic concrete mixes	ASTM D6927
Sand-Stone Concrete	**Test Procedure**
Mix Design	D6927 / Superpave
Compressive strength test on cubes or cylinders	BS EN 12390 / ASTM C39 / C39M
Compressive strength test of sandcrete blocks	---
Schmidt hammer	ASTM C 805
Flexural strength on concrete	ASTM C78 / C78M

6. DRAINAGE SYSTEMS AND EROSION CONTROL

6.1 Introduction

Keller and Sherar (2003) attest that water becomes very difficult to control on steep road hills where gradients are greater than 12%. In this section the major drainage and erosion challenges that were observed during the site investigations are highlighted and discussed. Mitigation measures are considered for each of the predominant drainage and erosion problems. The advantages and disadvantages of each remedial measure are assessed to assist in the selection of cost-effective options. The use of available local materials and easy-to-construct drainage systems are key factors for the cost-effectiveness assessment of considered options.

Drainage systems are a critical component that affects the functionality, safety and overall performance of roads. Drainage issues that must be addressed in road design and construction include roadway surface drainage; control of water in ditches and at inlets/outlets; crossings of natural channels and streams; wet area crossings; subsurface construction areas and other areas. These activities are the most significant factors that can promote erosion and increase road costs.

Erosion is the process of separating and transporting sediment by water, wind, gravity or other geologic processes (Atkins et al., 2001). It is a natural process that can be accelerated by vegetation removal, top-soil disturbance or compaction, or the creation of steep slopes (Hyman and Vary, 1999). It has been reported that there is a linear relationship between sediment yield and runoff depth (in mm), based on a field study of embankment slopes along the Qinghai-Tibet highway in China (Xu et al., 2005). The study also confirmed that there is a linear relationship between the runoff depth and the product of rain intensity (mm/hour) and precipitation (mm). These causative factors are important to this project due to terrain and climatic conditions of the identified sites (Eastern region of Ghana) for the Phase II study. In summary, the erosion can be classified as follows:

- **Surface or sheet erosion**: Occurs when rainfall dislodges soil on the surface of material, and the water and soil flow down a slope in sheets.
- **Rill erosion:** Occurs when the velocity of the water flow is great enough to dislodge soil in addition to that dislodged by rainfall. Typical rill erosion has small, narrow channels that form in banks and on slopes not protected from erosion. When unchecked, this type of erosion usually also results in the third type of erosion, namely gullies.
- **Gully erosion:** Occurs when rill erosion combines and concentrates the flow of runoff into gullies. Although soils erode differently, for most road materials it can be assumed that exposed soils will erode and cause sedimentation.

For unsealed gravel/earth roads in steep terrains (gradients > 12%), the three types of erosion listed above could occur and manifest to different extents. Typical drainage and erosion problems associated with the steep hilly sections of the feeder roads visited for this study are discussed in the remainder of this chapter.

Poorly drained pavements and slopes adjacent to roads can cause premature deterioration and lead to costly repairs and replacements (Cedergren, 1989). According to McCuen et al. (2002), before surface and subsurface drainage measures are installed, drainage conditions and patterns should be studied carefully. Specific observations should be made during rainy periods to monitor flow patterns, identify areas where ponding occurs, assess potential damage, and determine preventive measures that can be used to minimise damage and keep the drainage system functioning properly.

For this project, the site visits were conducted in March and April. Historically, these are the early months of the rainy season in Ghana and particularly in the Eastern region, where the project demonstration sites will be constructed. This assisted the project team to identify the type, intensity and extensiveness of drainage structures and erosion problems common to the project sites.

6.2 Surface drainage and erosions

6.2.1 Road surface drainage and erosions

Site investigations showed severe road surface erosion on unsealed gravel/earth roads. As mentioned earlier, the steep gradients (in excess of 12%) aid the flow of runoffs, thereby rapidly washing the surface material away (i.e. erosion), as shown Figure 6-1.

Lack of roadside drains leading to severe road surface sheet erosion

Lack of roadside drains leading to severe road surface sheet erosion

Figure 6-1: Severe road surface (sheet) erosion on gravel roads

6.2.2 Stabilisation of cut or embankments

Cut surfaces or fill embankments need to be protected. Cut or embankment slope stability largely depends on the natural material, which dictates the type of protective measure. The site investigation showed that most of the cut surfaces adjoining the roads on the steep hilly sections were unprotected. This has led to erosion of the cuts surfaces onto the roadway. Figure 6-2 shows eroded cut surfaces of some of the road sites visited.

	
Unprotected cut surface that has been severely eroded, Teiwanya – Sekesua road	Eroded cut surface on the Klo Agogo - Oluahai road

Figure 6-2: Serious road surface (sheet) erosion on gravel roads

6.2.3 Roadside drainage

A roadside drain provides catchment of road surface runoffs and the adjoining sides of the road, and it channels the water to outfalls.

During the site reconnaissance surveys, the project team observed that that majority of the road sections had no proper side drains to channel away runoff from the road surface. In some cases kerbs had been used without success. Where some form of side drain was present, the construction was of a low standard and poor workmanship was apparent. Figure 6-3 shows a lack of or inadequate side drainage structures.

Scouring is a typical problem that occurs on the steep hilly sections of roads. As road surface runoff is adequately channelled to a side drain, it is important to ensure proper erosion control in the side drains, including scour checks. Usually concrete U drains have been successfully used to solve drainage problems of surfaced roads. This drainage system can be adopted for steep sections of the feeder roads. Various options for controlling drainage and erosion problems are discussed in Section 6.3.

	
No side drains to intercept runoffs from the roadside cut surface lead to erosion and sediment deposits on the road surface	Kerb drain has proven unsuccessful, exposing the extent of erosion of the road

	
No side drains to protect the road pavement beneath a 200 mm thick reinforced concrete surfaced section	Broken 450 mm U-side drain on a bituminous surfaced road section

Figure 6-3: Different types or absence of road side drainage structures

6.2.4 Drainage at base of slopes

The trough (base) of the vertical alignment slope section is a relatively low point that receives the runoffs from uphill. These are described as wet area crossings. They become the collection point of the runoffs, thus rendering those sections weak. It makes traversing such points very difficult due to the slippery nature of the road. At times the ground becomes so saturated that ponds are formed, which could lead to impassability or road cut-outs. These sections are also very susceptible to underground water action, especially due to their topographical nature.

Drainage treatments at such sections are critical to the overall functionality of the road. Such treatment includes the provision of culverts and concrete side drains that have enough capacity to collect all the water from the road surface. Figure 6-4 shows typical drainage problems at such sections.

	
Ponding of a low-lying point that results in road cut-off (impassability)	A localised wet crossing point that requires proper drainage intervention

Figure 6-4: Drainage problems at the trough (base) of slope sections

6.2.5 Drainage at inlets and outlets

Inlets and outlet structures play an important role in the overall performance of the drainage system. Water should be controlled and directed, or should have its energy dissipated at the inlet and outlet of culverts, rolling dips or other cross-drainage structures. This can ensure that water and debris enter the cross-drain efficiently without plugging, and exit the cross-drain without damaging the structure or causing erosion at the outlet. As shown in Figure 6-5, the site investigation revealed that sub-standard inlet drainage structures are used on some sections on feeder roads in the Eastern region of Ghana.

Poorly constructed inlet structure that has not been protected and maintained

Figure 6-5: Drainage problems at the trough (base) of slope sections

6.3 Drainage systems and erosions control measures

Good water drainage begins in the design and construction phases of road building. Road surfaces should be shaped appropriately to keep water from accumulating on the road surface. Standing water should be avoided, as it often creates or worsens potholes, ruts and sags (Keller and Sherar, 2003). Drainage ditches should be constructed only when necessary. For example, a road graded away from a cut slope without ditches disturbs less ground and is less expensive to construct than an in-sloped or crowned road with drainage ditches, although the fill slope may require explicit erosion control measures (Moll et al., 1997). Some of the effective measures for drainage and erosion control are discussed below.

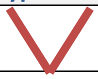
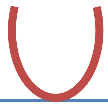
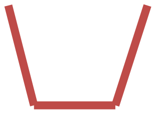
6.3.1 Road surface drainage and erosion control

The better way of addressing road surface drainage and erosion control is by proper shaping of the cross section of the road surface to the required camber (slopes) or the use of proper drainage structures to channel water away from the road surface in a manner that minimises effects to adjacent areas. As the sections are on steep slopes, a proper camber by blading would be essential, since anything less or leaving the surface unsealed will create erosion problems.

6.3.2 Roadside drains and erosion control

The identified roadside drainage structures and erosion control systems that were assessed for cost-effective options include drains, berm drains, toe drains, drainage channels, and cascades, as well as U-shaped gutters, reinforced concrete, and corrugated half-pipe drains (GSPW, 2003). These options would be dictated by site-specific conditions for optimum design and construction techniques. Armor roadway ditches and leadoff ditches with rock riprap masonry, concrete lining, geotextiles, and/or grasses have also been used successfully to protect highly erosive soils (Keller and Sherar, 2003). Ditch structures can furthermore be used to dissipate energy and control ditch erosion. If ditch erosion occurs, the best solution may be to place additional cross-drains to disperse and reduce the amount of water that is causing the erosion. There are three main ditch shapes: V, U, and trapezoidal. Each can be filled or lined (Orr, 1998). Table 6-1 lists the three main drain types with their advantages and disadvantages.

Table 6-1: Ditch types by shape with advantages and disadvantages

Ditch Type	Typical Shape	Advantages	Disadvantages
V-type		Easiest to construct	Difficult to maintain
U-type or rounded bottom		More efficient hydraulically than V-type Ease to maintain Desirable for erosion control	Relatively difficult to construct
Trapezoidal, or flat-bottomed		Most efficient hydraulically Can handle heavier flows Reduce erosion problems Spread water flow	Relatively difficult to construct

The DFR draft design standards specify the provision of lined drains or scour checks in terrains with a gradient of more than 5% (see Table 6-2). These standards provide a guideline to address drainage and erosion problems on the steep sections of the feeder roads.

Table 6-2: Extraction from DFR design standards on drainage (Table 6.1 of DFR Standards)

Type of drainage	Function	Design consideration
Surface drainage	Remove rain water from road surface	Provide camber or cross fall: - unpaved- 5%-7% - paved-max of 3% For longitudinal slope a minimum of 0.5% is preferred.
Side drainage (unlined and lined drains)	Remove runoff from the road pavement, shoulders and cut and fill slopes	Drain size shall be designed to adequate hydrological and hydraulic capacity For unlined drains:- min gradient of 1.5% max gradient of 5% Above 5% gradient, provide lined drains or scour checks. In flat terrain min. of 0.3% is allowed *Design flow*: 1 in 2 years (side drain) *Minimum freeboard*: 100mm (all side drains) *Minimum sizes*: 0.3m2 (unlined side drain cross-section) *Minimum velocity*: 0.75 m/s (all side drains) Maximum velocity: 1.2 m/s (unlined side drains) 3.0 m/s (lined side drains)
Cross drainage (culverts, vented fords, drifts, bridges)	It offers a safe passage of runoff from one side of the road to the other, and is also used at water crossing points to allow for passage of stream across the road	The size of the catchment, rainfall intensity, topography land use, soil type freeboard and return period *Minimum gradients*: 1.0% (culverts) *Maximum velocity*: 1.2 m/s (discharge to existing unlined watercourse) *Minimum sizes*: 700mm X 900mm U
Scour checks	Erosion control	Refer to Table 6.2 of DFR design standards

6.3.3 Erosion control of cut/embankment surfaces

Steep slope road sections running in cut surfaces have erosion problems. The cut surface has to be protected against erosion. The nature of protection is largely dependent on the material characteristics of the cut surface. For instance, a solid rocky cut surface may only require cutting to a specific slope for stability. However, weathered materials in cuts or fill embankments require checks against erosion. Measures for consideration include the following:

- Use of vegetation cover
- Appropriate geotextiles, which could be improvised with ‘chicken wire mesh’ anchored in place
- Concrete lining; stone pitching; block walling the cut/embankment surface

6.3.4 Wet crossings drainage systems

The DFR standards are silent on interventions such as the trench or French drains which could be used at weak (soft) sections of the road such as the trough (base) (as discussed earlier). These drains are relatively cheaper than the traditional culverts (concrete pipes) or box culverts which are the practice commonly used by the DFR. Culverts are generally used as cross drains for ditch relief and to pass water under a road along a natural drainage (Orr, 1998; Keller and Sherar, 2003). Culverts need to be properly sized, installed and protected from erosion and scour. Culverts are most usually made of concrete or corrugated metal, plastic pipe, and occasionally wood or masonry (Keller and Sherar, 2003). It is important that culverts have adequate flow capacity for the site, that the culvert size and shape match the needs of the site (e.g. fish passage), and that installation be cost-effective.

Rolling dip cross-drains, or broad-base dips, are designed for dispersing surface water on roads with slower traffic (Keller and Sherar, 2003) Relative to culvert pipes, rolling dips usually cost less, require less maintenance, and are less likely to plug and fail. Rolling dips are ideal for low-volume roads with low to moderate traffic speeds (less 50 kph) and low average daily traffic (Copstead et al., 1989; Keller and Sherar, 2003). It is important that rolling dips be deep enough to provide adequate drainage, perpendicular to the road or angled at 25 degrees or less, outsloped (3 to 5%), and long enough (15 to 60 m) to allow vehicles and equipment to pass. In soft soils, it is important to armour the mound and dip with gravel or rock. The ideal spacing of rolling dip cross-drains is a function of the road grade and soil type (Keller and Sherar, 2003).

6.3.5 Flow controls at inlets and outlets

Culvert inlet structures (drop inlets) are usually placed in the inside ditch line at the location of a culvert cross-drain. They are commonly constructed of concrete masonry, as shown in Figure 4-5. In some cases, round metal pipes are typically used at where the ditch is eroding and down-cutting, so that the structure controls the ditch elevation. Inlet structures are also useful to change the direction of water flowing in the ditch, particularly on steep grades, and they can help stabilise the cut bank behind the pipe inlet.

There is a need to dissipate the energy of surface runoff as it is concentrated in natural and man-made channels. Drain outlets can be armoured to dissipate energy and prevent erosion by using rock, brush, logging slash, non-erosive soils and/or vegetation (Keller and Sherar, 2003). For steep slopes in heavier water discharge situations, check dams, interceptor drains, benches and contour terracing can be effective countermeasures. It must be noted that the mitigating measures mentioned above are not specified in the DFR standards.

7. ALTERNATIVE SURFACING TYPES

7.1 Introduction

Significant research has focused primarily on deriving local specifications, designs and techniques for improving the cost-effective provision of low-volume roads sealed with alternative surfacings such as concrete, bituminous, and stone setts/cobbles. AfCAP projects have advanced the application of innovative paving techniques and methods that optimise the use of local labour and materials, and thus they increase opportunities for the local community to participate in low-volume road construction and maintenance. The choice of road construction materials for sealed (paved) surfacings can have an impact on the environment. Often, gravel is used as a low-cost resource. While this keeps construction costs low, maintenance costs can be significant, particularly in regions or countries with heavy rainfall. In some situations, gravel may be sourced from outside the locality, thus increasing both construction and maintenance costs and carbon footprint or emission (due to long-haul transportation of the material). There is also a growing concern about the possible depletion of gravel in many countries, and research is needed to determine appropriate and affordable solutions for pavement surfacing.

7.2 Sealed surfacing

Cook et al. (2013) noted that in the past bituminous surfacings were used in most tropical countries. However, there are wide differences in the relative price of bitumen and cement and so the cost of concrete surfacings can sometimes be favourable, particularly in those countries that import bitumen but manufacture their own cement. The choice between bituminous and concrete surfacings should, however, be made based on the life-cycle cost of the pavement, as well as the effect on road user costs. Asphalt or concrete surfacings are reported to be the most suitable surfacings for low-volume road sections with gradients in excess of 12%. For these steep sections, it is generally believed that thin bituminous surfacing seals are unlikely to perform well. They are usually affected by the flow of surface-running water and are prone to deterioration or shoving under wheel loads, which leads to a loss of bond with the base and stripping. A coarse and stable base to “anchor” the surfacing seals is usually provided to overcome the above shortcomings and, most importantly, adequate drainage systems are provided to protect the pavement structure.

In comparison, concrete surfacings could provide a viable solution for steep sections of low-volume roads as they offer very good resistance to wheel loads and generally require less maintenance, compared to bituminous surfacings. There is also a reduced risk of major deterioration in the form of slippage cracks, permanent deformation and potholes that could impair the safety of road users, especially motorcycle and bicycle users.

Cobblestone and stone setts obtained from local areas or within the vicinity of the road sections have also been found to be viable surfacing options for the steep sections. According to Leta and Langa (2010) these stones have only been used on a limited basis for road paving in Mozambique.

7.2.1 Concrete surfacing

Non-reinforced concrete surfacings have been reported to be the common option for low-volume roads that are constructed in regions with an aggressive natural environment, such as steep slopes (Cook, 2013). Concrete possesses little tensile strength; hence the success of a concrete slab is dependent on preventing tensile cracking. Concrete must be well constructed with sufficient cross fall for drainage and with sufficient skidding resistance to provide safe passage. Reinforced concrete paving is normally considered too expensive for general application in low-volume rural roads.

According to Cook et al. (2013), the results from SEACAP and other trials have indicated that good performance of non-reinforced concrete surfacings is dependent on a sound uniform base/sub-base that prevents brittle failure at slab corners. It was recommended that appropriate quality control measures be exercised in the mixing of the concrete and the placement of the inter-slab dowels as well as joint filling. The rigidity of concrete slab would not protect against poor bases. Therefore, ensuring that the underlying support for the concrete is always adequate and not damaged through erosion, for example, is vital for the successful application of concrete surfacings.

In a study conducted by Leta and Langa (2010), concrete slabs were used as intervention for steep sections on low-volume roads in Mozambique. The purpose of the study was to provide details of the experimental sections constructed on low-volume rural roads in Mozambique by using locally available or produced materials for paving. The materials used for the study were fired clay brick, cobblestone and concrete slabs constructed by small-scale local contractors with active participation of the local communities. The preliminary finding reported by these researchers stipulates that two years after completion (< 100 vpd), no tensile cracking was observed on the concrete section.

Research on the use of an ultra-thin continuously reinforced concrete pavement (UTCRCP) was done to see whether it could be a solution for building long-life roads (CSIR Built Environment, 2010). The UTCRCP technology was developed in Denmark and imported by the South African National Road Agency Ltd (SANRAL). The CSIR in association with the University of Pretoria and consultants customised the product for South African conditions. Following the successful research results, the Gauteng Department of Roads and Transport decided to use the ultra-thin concrete technology for its roads upgrading programme. Some roads in the suburbs of Gauteng province in South Africa have already been constructed with this technology. Road construction involved the use of labour-intensive technology that required only light construction equipment and led to the creation of job opportunities for the local communities and small contractors. Such road provides an all-weather surface and improves the lives of communities along the roads by curbing dust and reducing damage to vehicles. Research has established that roads built with the ultra-thin concrete technology would require minimal maintenance. The indications are that they have a life span of more than 20 years, resulting in reduced life cycle costs and disruptions to roads users.

Roller-Compacted Concrete (RCC) is reported to be an appropriate pavement construction solution (more durable than bituminous surfacing) for local streets and roads. RCC construction and maintenance costs have been speculated to be 30% lower than those of asphalt (https://www.youtube.com/watch?v=CP8zjaT35X8). RCC could therefore be a viable alternative for low-volume roads, and specifically for use on steep gradients. A key advantage of RCC is that it allows for roads to be reopened to traffic soon after construction. It should be mentioned that a separate project is being undertaken in Ghana to conduct a desk study of the international practice related to RCC. To avoid duplication of effort, the outcomes on the RCC project will be used for this study.

In Malawi, both unreinforced and reinforced concrete slab pavements of varying thickness (minimum of 50 mm, i.e. UTCRCP) with minimum strength of 20 MPa have been proposed for low-volume roads (Ministry of Transport and Public Works, 2013). Given the fact that Malawi and Mozambique have similar geographic and socio-economic conditions as Ghana, the probability of successfully using reinforced and unreinforced concrete slab pavements on steep sections of feeder roads in Ghana is high.

7.2.2 Bituminous surfacing

Bituminous surfacings have been widely used for both high-volume and low-volume roads. Hence significant knowledge is available for material selection and designs, as well as construction techniques and associated costs. Bituminous surfacings are a common upgrade option for low-volume roads at relatively lower cost, with moderate to low maintenance cost. These surfacings are, however, dependent on the availability of locally suitable materials for both surfacing and base layers of the pavement. Examples of bituminous surfacings that have been commonly used on low-volume roads are chip seal, sand seal, slurry seal, cape seal, Otta seal, cold pre-mix and penetration macadam. These surfacings are constructed on base/sub-base layers made of natural gravels, graded crushed stone, dry-bound macadam, water-bound macadam, chemically stabilised soils, and mechanically stabilised soils.

A detailed guideline for the selection of bituminous surfacing types and their appropriateness in specific situations for low-volume roads in South Africa is presented in Sabita Manual 10 (2011). A similar guideline was recently adopted by the Ministry of Transport and Public Works of Malawi (2013). In these guidelines, the specific situations for bituminous surfacings including the ease of construction and design, suitability for labour-intensive construction, sensitivity to material quality, sensitivity to gradient, high skid resistance requirement and risk of poor maintenance are taken into account when selecting bituminous surfacings for low-volume roads. The surfacings include thin seal, double or combination seal, and micro-surfacing/asphalt.

A study by TRL (2008) found that either a double seal surface with crushed aggregates or a double Otta seal with graded aggregates could be used as surfacing option for low-volume roads. The choice, however, depends on the availability and cost of suitable aggregates. When constructed as a double layer, a surface dressing would provide a durable impermeable seal for the road for about eight years, whereas the Otta seal could provide 12 years' protection (TRL, 2008). Both of these surfacing types have been found to exhibit minor distresses over their design life if constructed properly. In Ghana, double seal surfacings have been used successfully on the Kwahu and Akuapem mountains roads for several years under Ghana Highways Authority.

A recent study by Ampadu and Addison (2015) showed that under Ghanaian conditions, bituminous surfacing involving single chip seals were the least cost effective. It should however be noted that this study was very limited in the sense that bituminous surfacing currently constitutes only 5% of the total length of feeder roads in Ghana and distinctions were not made between roads located in steep sections and non-steep sections.

7.2.3 Interlocking block paving surfacings

Interlocking block paving is a relatively simple skill that can be learned and transferred easily and it is especially relevant to Ghana, where labour costs are relatively low, high-tech equipment is expensive and the practice is highly sustainable. Paving blocks made of either natural stones, Portland cement concrete or fired clay may be a cost-effective solution for feeder roads on steep terrains. For example, in areas where stone such as limestone or granite may be won and shaped easily by local entrepreneurs, predominantly with hand tools, stone paving blocks may be an attractive option. On the other hand, in areas of abundant clay deposits where local skills for producing burnt clay products (e.g. in certain Eastern regions where local pots -"Coolers," "Asanka," etc. are made), fired clay blocks could be an innovative approach. There are significant opportunities for this project to continue the work of the original AfCAP and SEACAP in building the evidence on alternative and locally suitable materials. One such example is the Rural Road Surfacing Research (RRSR) report on rice husk fired clay bricks as road pavements in Vietnam (supported by SEACAP). The report illustrates the potential for the introduction of fired clay brick road paving using rice husk as a brick-making energy source, thus reducing emissions associated with the production of the material (and therefore the embedded carbon within the material itself).

Cook et al. (2013) reported that block surfacing options require moderate to low maintenance. For instance, rapid and effective repairs of localised failed areas can be carried out by re-using the blocks already in the road. Block surfacing is also resistant to erosion or high axle loads, provided that the surfacing materials are sufficiently strong and durable and they are constructed on adequate base/sub-bases. In addition, it requires light equipment, which creates job opportunities for the local communities and has the advantage of promoting and utilising local small-scale contractors. Examples of these surfacings include fired clay brick, mortared and non-mortared joints, concrete brick, cobblestone, stone setts or pave, and dressed stone.

However, the problem of weeds that grow between the joints of paving should be given careful thought before this option is adopted, as Ghana is a tropical country with lots of rain and therefore rapid vegetation growth.

7.2.4 Stone setts and cobbles

Cobblestone surfacing is a historical technique that has been adopted successfully as a robust low-maintenance alternative to gravel on low-volume rural roads where there is good supply of suitable stone. This technique is reported to be suitable for small-scale community-based quarrying and production, especially where local skills in stone excavation and production are well established. A pilot study was done recently in Mozambique (Leta and Langa, 2010) in areas where suitable stones were found in abundance and skilled local artisans are encouraged to set up small companies and carry out this work. Three different approaches to cobblestone paving were implemented during the study:

1. Injoint filling with fine sand, on relatively flat surfaces
2. Jointing with cement mortar
3. Jointing with cement mortar plus application of 50-75mm concrete screed on top to avoid the "disintegration" of exposed stone by heavy vehicles

The researchers found that the section with cement-grouted stone + 50 mm cement mortar screed was constructed five years before their study (i.e. 2005) and in good condition, with no major cracking or deformation observed. A probable explanation for this observation was the low traffic levels on that section which is located just off the main road, and passing through the District Administration offices.

The Project Team found that stone setts/cobbles are rarely if ever used on feeder roads in Ghana, but they are included in the list of alternative surfacings because they have wide range of advantages, including the following:

- Properly constructed cobblestone /stone setts are almost completely impermeable
- No major maintenance is required, other than the removing of dust and weeds growing in the joints, especially in very low traffic areas
- Suitable for construction by small and medium-scale contractors and unskilled labour
- Erosion resistant
- Relatively inexpensive; equipment, materials, labour, low maintenance, etc.
- The coursed pattern is simple to lay
- Visually appealing (different patterns, for example)
- Will improve friction or traction on the steep slopes
- Structural advantage of flexing rather than cracking
- Labour intensive – local employment

7.3 Surfacings for steep sections

Steep gradients on low-volume roads can significantly alter the course of water runoff and lead to soil erosion. In developing countries, soil erosion can lead to intensification of agricultural practices and deforestation. In addition, runoff from roads can have a negative impact on water quality, carrying substances from both the road surface itself and discharges (oil, tyres) from vehicles using the road. These adverse impacts can be reduced through effective design, construction and maintenance of roads with proper drainage and erosion measures. Given that this project focuses on steep sections, there is an opportunity to contribute further research on what works and what does not in terms of the proposed surfacing options. Other factors to take into account when dealing with steep sections are construction techniques and material types.

For the purposes of this project, only surfacing options suitable for steep sections of low-volume roads are the main focus. Significant information has been published in the past about the service life of different surfacing types for low-volume roads. However, very little information is provided regarding the surfacing options for steep sections of low-volume rural roads with high gradients. Providing a surfacing for steep sections of low-volume rural roads calls for the innovative use of locally available materials and construction techniques that may often be of non-standard nature, in situations where the cost of conventional materials would be prohibitive.

Steep gradients influence both the constructability and the performance of the low-volume road surfacings. For instance, spraying of binders on steep gradients could be difficult, both from operating the equipment and the safety of the worker. Although it would be expensive to use concrete surfacing on low-volume roads, this may be necessary on very steep gradients, particularly in high rainfall areas (e.g. Ashanti, Brong Ahafo and Western regions of Ghana) where some types of bituminous surfacings (for example) may not be feasible. In South Africa, polymer modified binders are recommended for sections with gradients more than 12% (Sabita Manual 10, 2011). In addition, due to the traction of heavy vehicle tyres, thin surfacings and single seals often do not perform well. Steep gradients also require special attention to skid resistance in dry and wet weather.

The inception report of this project provided details of the most extensively used surfacings for steep sections on low-volume rural roads with slopes more than 12%. The surfacing options were classified into concrete surfacings, bituminous surfacings, and stone setts/cobbles.

Although the available information indicates that conventional concrete or bituminous surfacings are the most extensively used surfacings for grades in excess of 12%, the application of cost-effective locally available materials is paramount for this project.

If necessary, the conventional surfacings will serve as control to be compared with three identified groups of candidate cost-effective alternative surfacings. The selection of any option will be motivated mainly by economic viability, social reasons and environmental considerations.

7.4 Proposed surfacing solutions

Figures 7-1 to 7-4 present the viable pavement options or surfacing techniques identified to mitigate problems associated with steep sections of low-volume roads.

As was mentioned previously, for concrete or bituminous surfacings to perform well, the base/sub-base should be properly prepared and well compacted to act as a level platform for the surfacing. For this reason, two base layer options are proposed for this project. It is projected that the selected cost-effective surfacings will be constructed on a base (or sub-base) layer made of naturally occurring lateritic gravels that are mechanically modified or mixed with sand or pozzolana. It is suggested that a cost analysis of the surfacings should include the base layers as well.

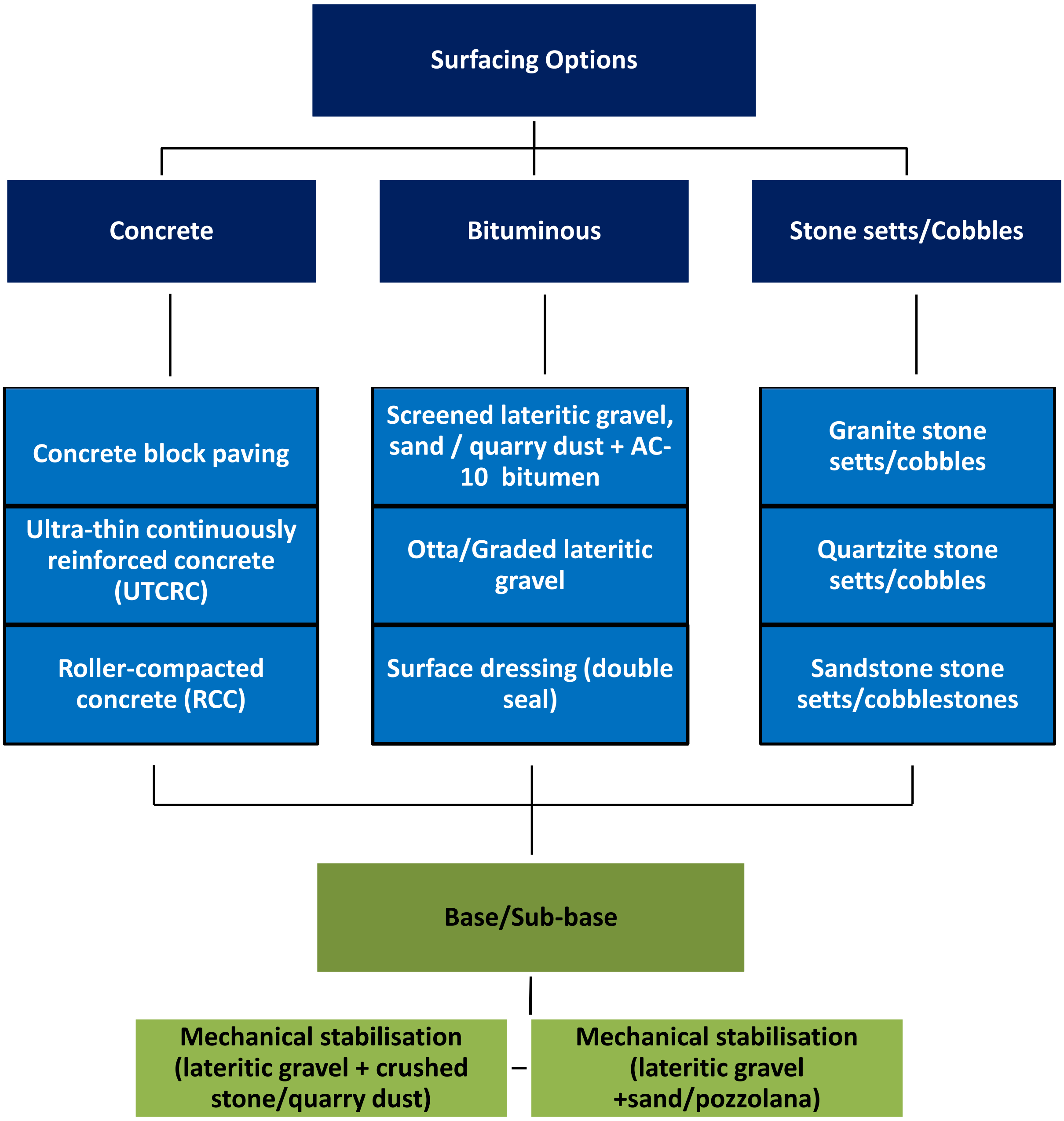


Figure 7-1: Illustration of surfacing and base layer options

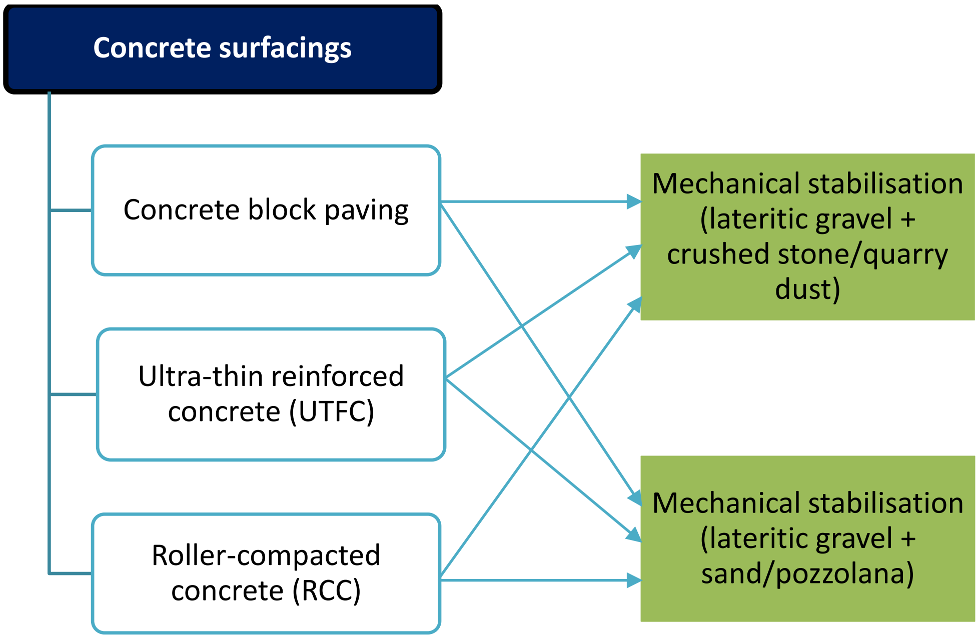


Figure 7-2: Concrete surfacings with possible base layers

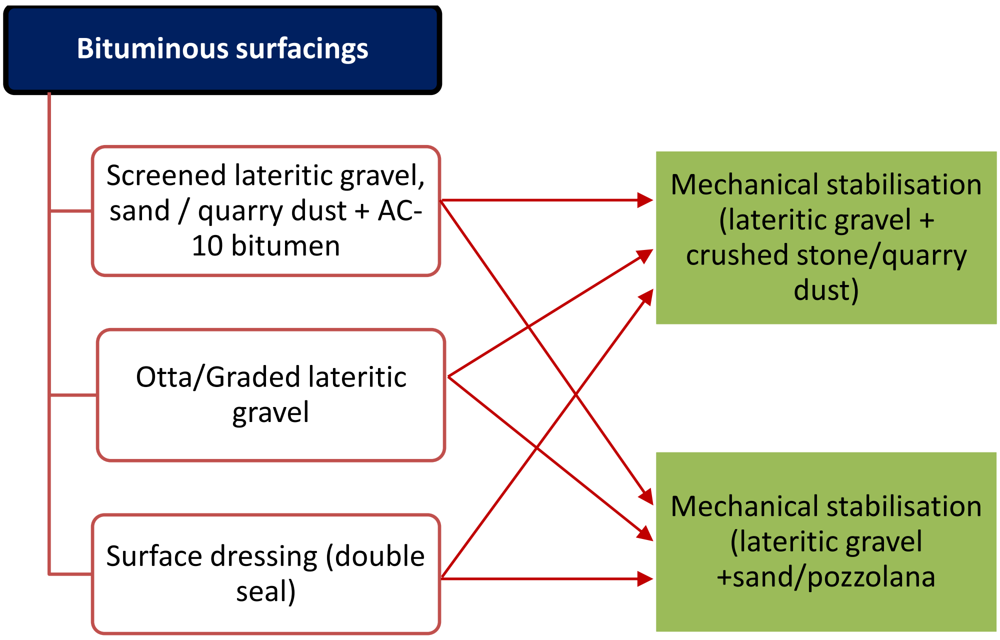


Figure 7-3: Bituminous surfacings with possible base layers

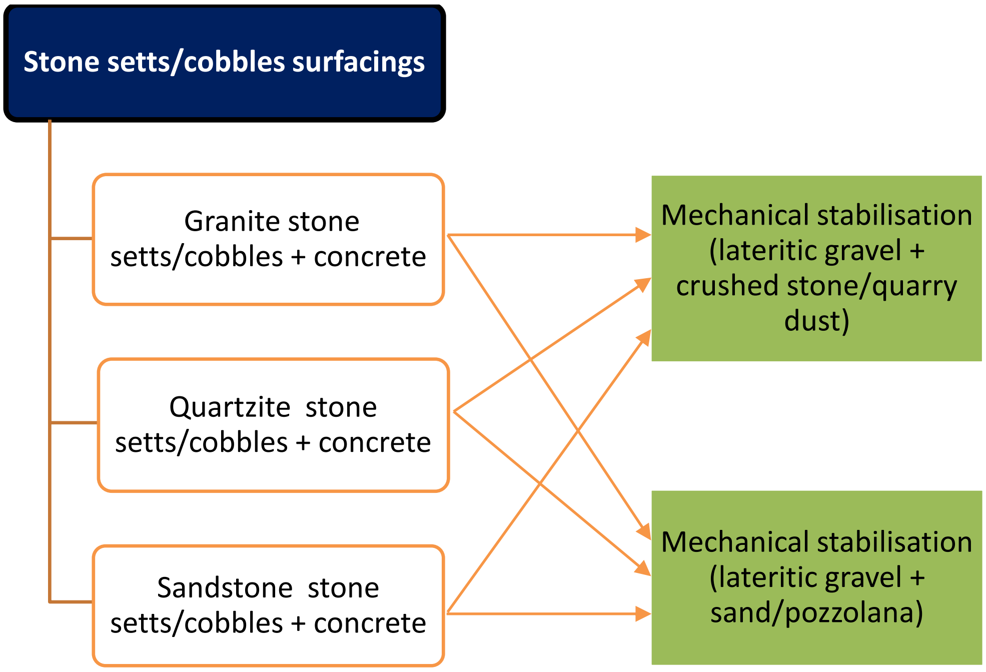


Figure 7-4: Cobblestone and stone setts surfacings with possible base layers

7.5 General factors affecting choice of surfacings

The major factors that usually affect the choice of the appropriate surfacing type for low-volume roads in a given situation include the following:

- Traffic (volume and type)
- Pavement type
- Materials type and quality
- Environment (climate; temperature, rainfall)
- Operational characteristics (speed, geometry, e.g. gradient, curvature)
- Skid resistance
- Surface texture
- Construction techniques and contractor experience
- Maintenance capacity and reliability
- Economic and financial factors (available funding, life-cycle costs, etc.)

The suitability of various surfacings options for low-volume surfaced roads, in terms of their efficiency and effectiveness in relation to the operational factors outlined above, is summarised in the Sabita Manual 10 (2011), and in the Ministry of Transport and Public Works (2013) documents. Although the list may not be exhaustive, the factors listed can be adapted or developed to suit local conditions. They can subsequently be used to assist in making a final choice with regard to surfacing options for the steep road sections in Ghana.

7.6 Methodologies for selection of surfacing

Based on Figures 7-1 to 7-4, a total of 18 surfacing options are proposed for this project. Achieving consensus on the use of a particular surfacing (pavement) option could be a long and protracted process, and may potentially lead to substantial project delays. It is noted that 18 surfacing options are too many for a single project. It is possible that different surfacing types could be adopted by regional or district feeder road authorities, thus, many surfacing options may be beneficial to the DFR later on. However, for this project, it is proposed to limit the options to a maximum of six. However, the selection of a particular surfacing will be based chiefly on locally available materials and initial cost. Other factors that will play a significant role in the selection include climate, topography, equipment and contractors' experience, local construction practices, maintenance practices, labour and material costs and, to a lesser extent, traffic volume and axle loads.

Usually, the optimum surfacing for such a large number of alternative surfacings proposed for this study should be selected based on a well-structured methodology or procedure. Nevertheless, cost is the most essential criterion for the ultimate decision in this case. A number of low-volume rural roads and surfacing selection procedures or tools developed for the "screening" process for the South East Asia Community Access Programme (SEACAP) and South Sudan (Cook and Meksavanh 2009; UNOPS, 2012) have been identified for this project. There are other optional tools to consider for the selection of surfacing options. An alternative and potentially useful tool is the points system used by the Word Bank (Henning et al., 2005) as well as the Sabita "SuperSurf" package developed by using Excel spreadsheets, a simple mechanism for carrying out cost comparisons in respect of the maintenance of an existing unpaved road (Sabita, 2004).

7.7 Life-cycle cost analysis

In order to determine the most cost-effective type of surfacing to use on low-volume surfaced roads, it is necessary to undertake a life-cycle cost (LCC) analysis of the feasible options. Such an analysis focuses on the cost of the various surfacing options by comparing the construction and maintenance costs during the life of the road according to the criterion of total (life cycle) costs.

A detailed comparison between the life-cycle cost of gravel and of bituminous surfacing options for feeder roads in Ghana was presented by Ampadu et al. (2015). The objective of their study was to compare the life-cycle cost of gravel surfacing with that of bituminous seal surfacing options for engineered feeder roads in Ghana using actual cost data. Data was collected from eight feeder road projects with gravel surfacing and a similar number with bituminous surfacing. The projects were carried out in six regions of Ghana and were completed between 2010 and 2013. The life-cycle cost for each road was computed using a discount rate of 12% and an inflation rate of 15% over an analysis period of 21 years.

The results for gravel surfacing were then compared with those for single bituminous seal surfacing and for double bituminous seal surfacing. The results were further compared with those from experimental sections of Otta seal surfacing using natural gravel and crushed rock as aggregates. Based on the high initial construction costs of bituminous seal surfacing and the low maintenance intervention practices, the study concluded that gravel surfacing remains the least cost-effective option.

Although the common practice is to undertake a life-cycle cost analysis to determine the most cost-effective options for road construction projects, such an analysis may not suit the annual budget of the available funds for a project like this, where only the steep hill sections are considered. Therefore, only initial cost assessment is conducted to rank selected pavement options from the 18 options presented in Section 7.4.

7.8 Selection process of surfacing options

A detailed cost analysis is not required at this stage of the project. The management and maintenance strategies used by the DFR over the life of low-volume roads will play a role in the final selection of the surfacing option. The selection process proposed is intended to facilitate discussion and an understanding of critical concerns and their relative importance to the overall project. To this end, the project team should hold discussions with the DFR during the project initiation stage of the Phase II study to decide on the pavement options for demonstration. It is expected that consultation will be made to reach a consensus that adequately balances competing project needs that are not improperly skewed toward one particular surfacing type. This process is necessary to maximise the effectiveness of the selection process as a tool for identifying the most suitable surfacings option for the project sites.

To assist in facilitating the selection process, a range of practical factors that were listed in Section 7.5 should be considered. The general process recommended for selecting appropriate surfacing options for the steep sections in this study is presented in Figure 7-5.

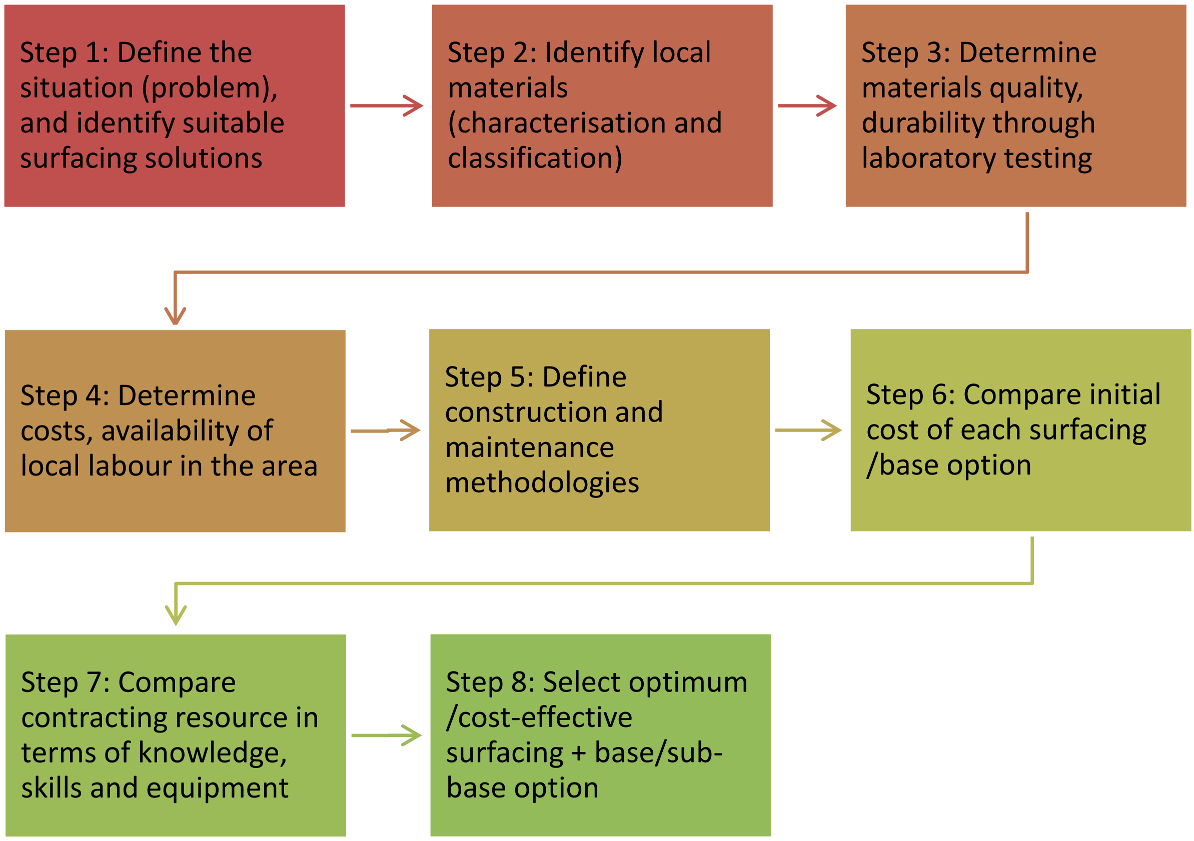


Figure 7-5: Selection process for optimum surfacing type

8. SCOPING OF PHASE II

8.1 Introduction

Ghana consists of ten regions, from which the Eastern and Volta regions are considered mountainous with more roads located in hilly and rolling terrain (Source: DFR, Ghana). The climate of Ghana is tropical, with an average temperatures ranging from 21°C to 28°C, and a relative humidity of between 77 and 85%, while rainfall ranges from 780 mm to 2160 mm per year. A prolonged rainy season (especially in the south-west), coupled with poor natural soils, has led to poor performance of low-volume (i.e. feeder) roads and low durability of paved roads in the country. The Western, Eastern and Ashanti regions experience the highest annual rainfall. The main problems associated with feeder roads (gravel wearing course) in these regions are erosion and drainage related.

Addison, (2008) evaluated the properties of natural gravels in Ghana, and recommended that they could be blended with other materials (stabilised) or crushed stone to improve their engineering properties for use as base/sub-base materials. A detailed characteristics and sources of construction materials identified for Phase II of the project is provided in the Inception Report (Anochie-Boateng and Debrah, 2016). After deliberations, and having taken cognisance of costs and logistical implications, it was agreed at the stakeholder workshop that demonstration sites for Phase II of the study will be located in the Eastern region (high rainfall, mountainous area). This was based on the fact that about 30% of feeder roads in the Eastern region are located in hilly and rolling terrain, and are characterised by significant gradients in excess of 10%. Although traffic is not expected to exceed 80 vpd, it tends to be very high (100 to 200 vpd) during market days.

This section outlines the objectives and the frame work for phase II of the study. The framework is designed to link closely with the Phase I study. Although the sources of funding for the two phases are different, activities of Phase I will not be repeated in Phase II. For instance, document review, selection of demonstration sites, sources of available/potential future materials, etc. are completed and included in the Inception Report (Anochie-Boateng and Debrah, 2016). The proposed methodology, the recommended pavement options for demonstration sites as well as indicative cost for Phase II are the key elements of this section.

8.2 Project objectives

The main goal is to establish optimal pavement solutions that provide all-weather access to communities who would at some time during the year be cut off due to erosion and drainage problems on steep sections of gravel roads. This would be achieved in the following ways:

- Development of cost-effective and sustainable pavement options.
- Development of sustainable solutions to mitigate erosion and drainage problems.
- Use of locally available materials and skills (labour, contractors, supervisors, etc.).
- Implementation of solutions through construction of demonstration sections for monitoring.

- Re-evaluating the designs and construction methods and data for the development of guidelines and specifications.
- Training and capacity building as well as knowledge and technology transfer to the DFR staff, local consultants, and contractors.

8.3 Expected benefits

A number of benefits are anticipated based on the overall outcomes and deliverables of the entire study (Phases I and II). These include:

- Economic justification for surfacing when compared to gravel roads.
- Appropriate surfacings that will provide good performance under the prevailing gradient, traffic, climatic, road maintenance capability, etc.
- A more cost-effective paved road network (or sections thereof), reducing the length of environmentally unsustainable unpaved roads.
- Generation of more semi-skilled workers and small-contractors, thus employment creation.
- Ability to carry out rapid and effective maintenance of localised failures on roads by re-using the local materials with minimum skill requirements.
- Greater use of local materials and a reduced reliance on conventional materials such as reinforcement steel, bitumen, cement, crushed stones.
- Simplified site investigations and material testing procedures for steep slope sections.
- Analysis of the collected data will assist the DFR to establish correlations between construction quality and performance, as well as to assess the cost effectiveness of specific construction methods and materials.
- Availability of quality data will also assist the DFR to undertake similar studies, enabling them to home in on specific issues in order to develop sustainable solutions.
- Capacity building and improved knowledge amongst Ghanaian practitioners, researchers at BRRI and the DFR staff, regarding improved solutions to problems with steep slopes in Ghana.

8.4 Methodology

It is proposed that the Phase II study be undertaken in three stages with some activities carried out concurrently.

8.4.1 Stage I: Design and construction

The pavement options proposed for the study are an engineering undertaking and therefore appropriate designs have to be carried out. Adequate documentation defining the works are required and this includes working drawings and all sketches as may be necessary, bills of quantities (BoQs) and the procedures and specifications that should be followed in the design process.

This stage will involve the supervision of design and construction to ensure that activities pertaining to the demonstration sites are carried out properly. The design comprises structural and materials (concrete and asphalt) designs. Selected pavement options will be designed and constructed at the demonstration sites for a variety of surfacings techniques and bases/sub-base materials presented in Section 7. As observed during the Phase I study, drainage would have a great impact on the designs, as most of the in-situ gravel materials are considered marginal. The ultimate aim of this stage is to utilize the available tools and methodologies that provide appropriate designs taken into consideration the environment and the low levels of traffic normally found on the low-volume rural roads. There are prospects to use the current AfCAP DCP design tool and local or overseas monograms for the pavement design and analysis.

8.4.2 Stage II: Monitoring of demonstration sites

This stage will involve monitoring of the performance of the appropriate alternative surfacing solutions proposed for the study. The performance of the surfacings should be monitored over a period of time and findings should be documented for future developments (specifications/manuals). The selection criteria for potential or candidate demonstration sites were provided in Section 7. This was guided by several factors such as traffic, rainfall pattern, gradient in excess of 12%, and socio-economic factors of the area. Based on these factors, ten road sections were deemed appropriate for the study. Depending on availability of funding, a maximum of six pavement options are proposed for the demonstration study. The project team determined that the following points must be considered when DFR is making the final decision on the demonstration sites:

- The demonstration sections must have a reasonable supply of naturally occurring construction materials, especially those that need to be blended for final products.
- To minimise cost, demonstration sections should be done in conjunction with ongoing or proposed DFR construction projects where there are hilly short (250 m to 500 m) sections. It is proposed that the demonstration sections should be built alongside control sections using the normal materials being used on the feeder roads, with all construction and other characteristics being identical. Only one surfacing type (variable) should be included in each demonstration section. Main parameters to be captured include functional, structural and the operational data of the sections.
- The pavement designs should take cognisance of small contractors and applicable construction methods.
- The successful material and pavement designs should be selected on the basis of life-cycle cost rather than on construction cost only.
- The pavement designs should preferably be suitable to labour-based methods.
- There must be capacity at the DFR to issue tenders and to supervise the construction.

8.4.3 Stage III: Capacity building / skills development

The goal is to capacitate the DFR so that they can play a leading role in the implementation of the identified surfacing options and techniques for improving all-weather passability on steep sections of the feeder roads network in Ghana. This stage would require training and mentorship of engineers and technicians from DFR, local consultants and contractors in the first six months of the project. In addition, this project would also be used to build capacity for BRRI researchers and technicians. A skills/knowledge gap analysis of all staff (DFR, contractors, local consultants) on the project will be required to ensure that they are well equipped with the right skills, knowledge and capabilities to meet the design, construction and monitoring needs of the project. It is envisaged that the major challenge of capacity building/skill development will be the technology transfer of asphalt and concrete (e.g. ultra-thin continuously reinforced concrete design and construction). Adapting these technologies to satisfy local conditions will be the main focus.

8.4.4 Cost-benefit analysis

The present value of future benefits and costs must be calculated and compared to the present value of investment costs. If the costs and benefits of each alternative surfacing have been identified and properly quantified, then the selection of the surfacing option (s) can take place. A final decision will be made on which surfacing option is the most beneficial from an economic perspective. For project analysis, all related costs and benefits should be identified and justified in terms of their relevance to the project and for the respective surfacing options.

8.4.5 Workshop

Two workshops are proposed for Phase II of the study; the first after the construction phase, and the second after the draft report is submitted. The aims of the workshops are to demonstrate the surfacing technologies to stakeholders, and to disseminate the findings and recommendations of the study. This will give the DFR and other stakeholders an opportunity to contribute to the study and enhance the final project report. The project team will assist the DFR in organising the workshops to ensure their success. The workshops will be held at the DFR facilities. The outcome and discussion points will be incorporated into a workshop report that will be one of the project’s technical deliverables.

8.4.6 Reporting and preparation of guidelines and specifications

In this activity, all data captured during Phase II (e.g. design data, construction data, etc.) will be incorporated into a final project report proposing cost-effective and sustainable options for demonstration sections. These data will form the basis to develop a technical guideline document or specifications for the recommended surfacings. As a long-term plan, the DFR should be able to develop a low-volume roads manual for steep sections based on these guidelines or specifications.

8.5 Recommended pavement options

All 18 pavement options identified for consideration are presented in Section 7. These 18 options were categorised into three groups: concrete, bituminous, and stone pavement structures. Out of these, six pavement options are proposed for the Phase II study. In addition, a “do-nothing” option is proposed for cost comparison with the six options. The do-nothing option would entail the continuation of routine maintenance activities of the existing gravel wearing course and kerb drainage structures on the hilly road sections, and does not include any upgrading that would change the current road operation or extend its service life.

The cost assessment and ranking of the six pavement options are provided in the following sub-sections.

8.5.1 Initial cost assessment of surfacing options

In order to arrive at the most cost-effective pavement option, an initial cost assessment was made of potential pavement design alternatives and associated drainage structures capable of providing the required performance over the design life. These cost assessments are provided in the following sub-sections. The initial cost assessment was based on a tentative design for six pavement options.

The tentative pavement design considerations assumed the following parameters:

- Design life of 15 years. This is based on the performance of similar pavement structures in Ghana. In addition, it is expected that the identified surfacing options (e.g. concrete, lateritic asphalt, stone setts/cobbles) should be to able to carry the expected traffic loading and withstand the environmental conditions (rainfall and temperature) over this design period with no or minimum maintenance interventions.

- A base-year traffic characteristic was determined from a weighting average of a typical market day traffic volume [200 vpd; one day/week] and a non-market day traffic volume [50 vpd; six days/week] which results in slightly over 70 vpd. Thus, an annual average daily traffic of 80 vpd with distribution (heavy trucks = 10%; light trucks/buses = 50%; small cars/taxi cabs/motorcycles, etc. = 40%) for the base year was adopted.

- An annual traffic growth of 2% (generated traffic after surfacing is taken into consideration) for the vehicle types over the design life was applied to determine the cumulative Equivalent Standard Axle Loads (ESALs). Although it is anticipated that traffic volume will increase when the proposed surfacings are successfully implemented, it is difficult to estimate how much the traffic volume will change. Traffic growth on these feeder roads is not expected to exceed 3%.

In the estimation of the total ESALs, the damaging effect from the small cars group was assumed negligible. It should be mentioned that for this study, environmental rather than traffic loading factors would determine the performance of the road sections under consideration. Thus, materials and drainage systems, as well as construction techniques are vital to the initial costing of the selected pavement options.

The selection of pavement materials for the layers took into consideration the respective strengths and the fact that they are to be placed on high/steep sections which would be subject to traction as the vehicle descends a hill. For the base/sub-base material, which is naturally occurring lateritic soils, there is a need for stabilisation. This is important especially for the 'marginal' lateritic soils that would require improvement in strength and plasticity.

The Transport Research Laboratory's (TRL) proposed gravel thickness estimator (Equation 1) for low-volume roads for a residual rut depth of 40 mm was used to determine the layer thicknesses for the base/sub-base materials (Toole et al., 2002).

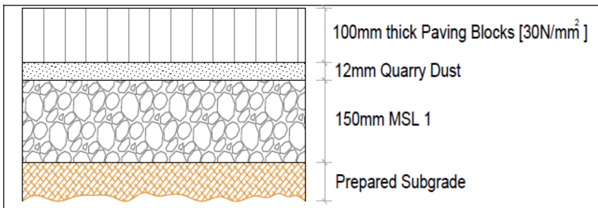
$$LogN_{40} = \frac{h[CBR]^{0.63}}{190} - 0.2 \qquad \text{Equation 1}$$

where N – number of standard 80kN axles

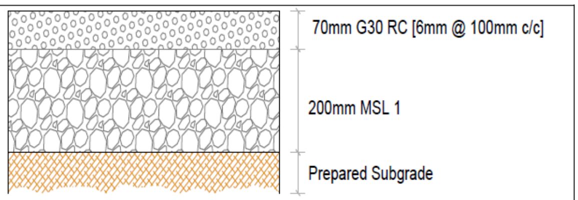
h – thickness of granular (gravel) material required in mm

CBR – subgrade CBR (%)

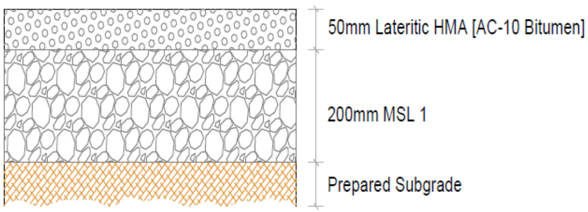
In-situ subgrade CBR of 10% was assumed in the estimations based on field assessment of the ground conditions. The pavement layer thicknesses for each option are shown in Figure 8-1.



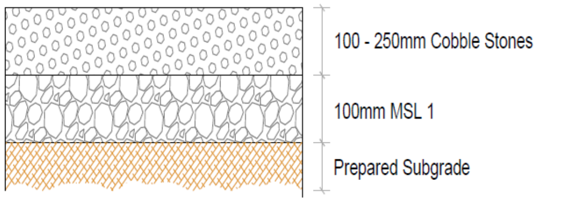
Paving Blocks [30N/mm²] on 150mm mechanically stabilised laterite with crushed stone and quarry dust



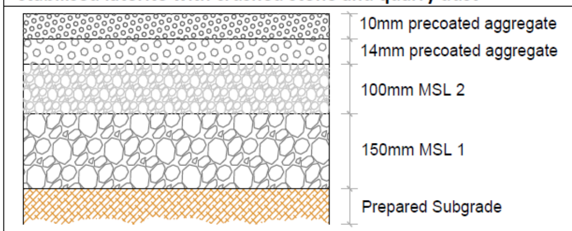
Ultra-thin [70mm RC] on 200mm stabilised laterite with crushed stone and quarry dust



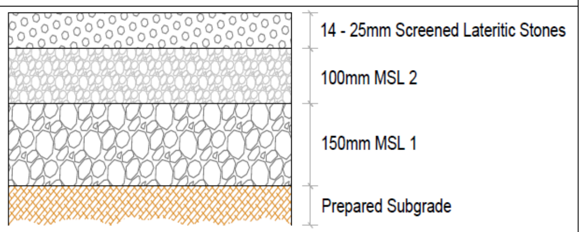
50mm Lateritic HMA [AC-10 Bitumen] on 200mm mechanically stabilised laterite with crushed stone and quarry dust



Graded [100mm – 250mm] cobblestones arranged on 100mm mechanically stabilised laterite base



Double Seal [10mm and 14mm Agg.] Bituminous surfacing on 100mm stabilised laterite base and 150mm stabilised laterite subbase



Otta Seal on 100mm stabilised laterite base (crushed stone and quarry dust) and 150mm stabilised laterite subbase (sand and clay pozzolana)

Figure 8-1: Cross sections of proposed pavement options from tentative designs

Notes:

1. MSL 1 represents mechanically stabilised lateritic gravel with crushed stones and quarry dust while MSL 2 denotes mechanically stabilised laterite with clay pozzolana and sand.

2. MSL 1 has a mix proportion of 60% lateritic gravel with 40% stabiliser being 1:1 ratio mix of crushed stones and quarry dust.

3. MSL 2 has a mix proportion of 80% lateritic gravel stabilised with 20% of clay pozzolana and quarry dust/sand.

8.5.2 Approach to the initial cost assessment

The cost assessment for each pavement option took into consideration the current practices in Ghana, and was based on the following:

- General items such as contractual requirements, specific construction requirements, and earth works for the preparation of existing ground
- Trapezoidal concrete side drains on both sides of the road section
- Pavement layer materials and construction
- The work-method principle guided by Civil Engineering Standard Method of Measurement, 3rd edition (CESSM3) was used to prepare the bill of quantities (BOQs) for each option. The rates for this estimation were based on the prevailing local market determinants, i.e.:
- Material costs including handling, haulage, placement and compaction
- Actual construction charges that also depend on the following:
    - Labour (skilled and unskilled) and equipment costs
    - Overhead costs, i.e. preliminary charges, inspections and meetings
    - Quality assurance charges for materials testing – field and laboratory
    - Profit margins for contractors

In establishing the rates, BOQs of previous road projects were used as a guide, together with trends of the monthly cost indices that are released by the Ministry of Roads and Highways (MRH) (http://www.mrh.gov.gh/5/8/monthly-cost-indices). Appropriate use of local labour and equipment is factored into the bill of quantiles. . In these estimations, quotations were initially based on the local currency (GHS), and converted to GBP at the current exchange rate of 1GBP to 5.52GHS, (www.xe.com; 4 May, 2016).

8.5.3 Cost of preliminaries and initial preparation of road formation

Provisional sums are normally allowed in all road construction works. For this study, provisional sums were used for the cost components of the preliminary general items and earthworks leading to road formation at the steep sections. This provision is assumed to be the same for all selected pavement (surfacing) options. Details of the preliminary cost are presented in Table A-1 (Appendix A).

8.5.4 Cost estimate for drainage options

V-drains are often used for gravel roads, especially for hard ground conditions where moisture is not expected to have a significant effect on the pavement structure. For steep slopes and especially under the prescribed rainfall conditions in many parts of Ghana, the ground condition would require the provision of lined drains to protect the pavement layers against erosion and moisture ingress. In the design considerations, the edges of the drains could also provide lateral brazing for the cobblestone and paving block surfacing options.

The total estimated cost for V, U and trapezoidal drains were GBP 8 400, GPB 29 300 and GBP 28 636 respectively. Detailed costing for these drainage systems is presented in Table A-2 (Appendix A). For the purpose of this study, concrete-lined drains provide a better option than the V-drains that are traditionally not lined. A trapezoidal-shaped drain, typically of minimum effective depth 600 mm was found to be more cost effective than a corresponding U-shaped drain. Therefore, the cost of the trapezoidal-shaped drain is used in the summary costs to rank the various pavement options (see Table 8-1).

Figure 8-2 shows the proposed side drains of 150 mm thick grade 25N/mm^2 concrete all round at minimum inner depth of 0.6 m for trapezoidal and U-shaped drainage structures for this project.

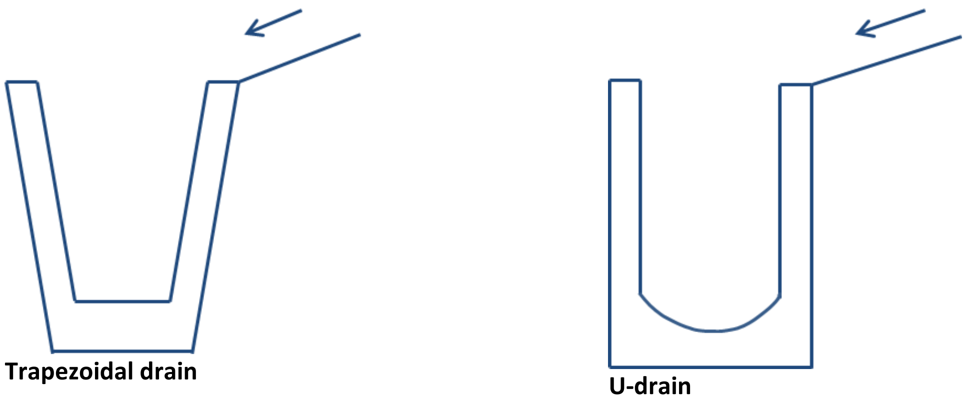


Figure 8-2: Schematic cross-sections of concrete-lined trapezoidal and U-shaped drains

8.5.5 Cost of pavement options

A typical steep road section is assumed to be 250 m in length and 6 m in width. Construction work activities and current rates of local labour and equipment have been considered in the cost. Figure 8-2 shows the cross-sections proposed for each of the six pavement options. Costing was mainly based on the pavement structures, as well as on variables such as materials, production, haulage distance, labour, construction and equipment. Detailed costing for the six pavement options is presented in Table A-3 (Appendix A).

8.5.6 Ranking of pavement options

Table 8-1 indicates the ranking of the six selected pavement options for the study. The ranking was done based on the initial cost estimates, and cost per square metre for the six pavement options. The 70 mm ultra-thin continuously reinforced concrete pavement (6 mm diameter mild steel), placed on mechanically stabilised lateritic base is ranked number 1, whereas a 50 mm hot-mix asphalt surfacing with processed lateritic gravel with AC-10 bitumen on 200 mm stabilised base [laterite with crushed stone and quarry dust] is ranked number 6.

The total cost per square metre of "do-nothing," option i.e. unsealed gravel surfacing is GBP 106.07. This includes the cost of all maintenance strategies (i.e. re-shaping, re-gravel earth drains clearing

/cleaning, etc.) over the 15 years period. The detailed cost for this option is provided in Table A-4 (Appendix A).

It is assumed that maintenance cost for the six pavement options would be insignificant during the 15 years analysis period. For instance, it is expected that there will be no maintenance cost for the ultra-thin concrete surfacing over the 15 years period. The total number of options to be constructed under phase II study would depend on DFR, as they will provide funding for this aspect of the project. An indicative budget for the construction of these pavements is provided under sub-section 8.9. All costs were based on the current practices of the DFR in Ghana.

Table 8-1: Ranking of pavement options in terms of initial cost

Rank No.	Pavement Option	Preliminary cost GBP	Lined side drains cost GBP	Pavement layers cost GBP	Culvert[1] cost GBP	Total estimated cost GBP	Cost per square metre GBP
1	Ultra-thin [70 mm RC] on 200 mm stabilised laterite base [crushed stone and quarry dust]	12 450.00	28 636.00	53 340.00	6000.00	100 426.00	66.95
2	Otta seal [14mm-25mm aggregates] on 100mm stabilised base and 150mm stabilised subbase	12 450.00	28 636.00	55 200.00	6000.00	102 286.00	68.19
3	Graded cobblestone [100 mm-250 mm] arranged on spread sand/quarry dust blinding of average depth 25 mm on 100 mm stabilised laterite	12 450.00	28 636.00	74 646.00	6000.00	121 732.00	81.15
4	Paving blocks on 150 mm stabilised laterite [crushed stone and quarry dust]	12 450.00	28 636.00	84 696.00	6000.00	131 782.00	87.85
5	Double seal [10 mm and 14 mm] on 100 mm stabilised base and 150 mm stabilised sub-base	12 450.00	28 636.00	85 200.00	6000.00	132 286.00	88.19
6	50 mm HMA with processed lateritic gravel with AC-10 bitumen on 200 mm stabilised base [laterite with crushed stone and quarry dust]	12 450.00	28 636.00	89 100.00	6000.00	136 186.00	90.79

[1]: Interim (provided by local engineer), will be revised as a more detailed cost is provided by DFR

Notes:

1. In case of a limited budget, it is proposed that four options be considered for the demonstration sites. These are (a) ultra-thin [70 mm RC] on 200 mm stabilised laterite base [crushed stone and quarry dust]; (b) 50 mm HMA with processed lateritic gravel with AC-10 bitumen on 200 mm stabilised base [laterite with crushed stone and quarry dust], and (c) interlocking paving blocks on 150 mm stabilised laterite [crushed stone and quarry dust], and (d) Otta seal [14mm-25mm aggregates] on 100mm stabilised base and 150mm stabilised subbase.

2. The HMA surfacing with screened lateritic gravels (option 6) has significant haulage cost component due to distance (approximately 100-200 km) between asphalt processing plants and the natural material sources /construction sites. Also, the construction method could require relatively expensive equipment, thus increasing the initial cost of this pavement option.

3. Both Otta seal and double seal pavement structures require a sub-base due to the near zero structural strength of the surfacing material.

4. It is assumed that provisional sums for general items and initial preparation of road formation, as well as drainage systems will be the same for all pavement options. This may not be necessarily true. However, it is expected that cost variations would be minimal.

8.6 Deliverables

The main deliverables for this phase of the project should include the following:

1. Inception report
2. Construction report
3. Draft project report
4. Workshop reports
5. Final project report

8.7 Project team/personnel

It is recommended that the project team should consist of two key researchers and two technicians. One of the researchers (preferably senior, with in-depth knowledge of road and road materials engineering) will be the team leader, whereas the other researcher will be the local civil engineer on the project. The two technicians will assist in monitoring of field performance, laboratory testing and data entry.

8.8 Project time

It is anticipated that the project can be completed in 24 months including six (6) months for design and construction of sections, and procurement of contractors. This will enable the AfCAP consultants to have a minimum of two rainfall cycles to supervise monitoring, testing and data collection from the demonstration sections.

8.9 Project budget

Only indicative costs are provided in this report. The costs for Phase II will be shared between AfCAP and DFR.

8.9.1 AfCAP budget

The estimated manpower input is as follows:

Team leader (principal researcher): 200 man-days

Researcher: 120 man-days

Technicians (2): 220 man-days

The estimated budget (AfCAP) for consultant’s fees and running cost is £350,000.

8.9.2 DFR budget

It is proposed that the DFR carries the costs for the design and construction of the selected pavement options. Indicative costs are presented in Table 8-1, which can assist the DFR in preparing a budget for the project. As an example, the total budget required to construct all six proposed pavement options is £725,000, whereas the total budget required for the recommended four key pavement options (i.e. 70 mm ultra-thin concrete, 50 mm HMA, Otta seal and the interlocking block paving surfacings) is £471,000. Note that these costs take into consideration the current practice, as well as cost for road construction and supervision in Ghana.

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

The following conclusions are made based on the outcomes of the study:

- The current standards and specification documents used by the DFR require considerable update to bring them to address steep slope problems. Similar documents developed for low-volume rural roads (e.g. Low Volume Rural Roads Surfacing and Pavements - A Guide to Good Practice, Cook et al., 2013; Guideline: Low Volume Sealed Roads; SATCC, 2003; Design Manual for Low Volume Sealed Roads in Malawi, 2013; Rural Roads in Sub-Saharan Africa - Lessons from World Bank Experience; and Design Manual for Low Volume Roads (Part B) in Ethiopia 2011) can be used as a starting point to develop standards for the DFR.

- Currently, there is no accepted method of prospecting for materials in Ghana for low-volume roads. This remains an issue that needs to be resolved in future projects. It is believed that equally good or better materials exist than those that are currently used, but there is no systematic approach to prospecting and mapping their sources.

- Significant quantities of naturally occurring materials exist in Ghana for utilisation in the construction of steep sections of feeder roads. Although they do not meet the conventional requirements and specifications for road construction, it is possible to mechanically stabilise them to improve their properties.

- Gravel surfacing is inappropriate for steep sections of the feeder roads visited. Gravel loss was common to these sections, and thus a gravel wearing course was found to be unsustainable. Some road sections had suffered extensive forms of erosion due to intensive rainfall.

- Although bituminous seals and reinforced concrete surfacings have been used on some sections of the roads visited, they are plagued with poor workmanship, over-designs (concrete), under-designs (bituminous surfacing), as well as premature failures.

- All 18 pavement options identified through this project are feasible for the current and future studies, but the ultra-thin continuously reinforced concrete pavement option was found to be the most cost effective (based on initial cost assessment) and to involve labour-intensive technologies that can be explored for steep sections on feeder roads. However, extensive consultations would be required to determine the appropriate pavement options that will meet the needs and budget of the DFR.

- Notwithstanding, the nationwide availability of naturally occurring gravel materials, it is difficult to get natural gravel to meet the G80 (material with minimum CBR of 80%) for base materials.

- The various surfacing techniques identified in this project provide the necessary opportunity to advance the application of innovative engineering solutions or technologies for the provision of feeder roads in Ghana.

- The DFR would need technical assistance in mix designs for the selected bituminous and concrete surfacing options for Phase II. This is obvious as many of the proposed surfacings are new, and the technologies are not locally available at the moment.

9.2 Recommendations

The following recommendations are made for Phase II of the study:

- There should be a conscious effort to incorporate the outcomes and outputs of the study in hand into the current DFR standards as guidelines for and specifications of steep sections. In this regard, there will be a need to address all identified gaps of the current DFR technical documents.

- Further investigation is needed into the use of lateritic gravels on steep sections of feeder roads in Ghana. It appears that limited investigations have been undertaken to develop specifications for their use in such terrains. The DFR should seriously consider using Phase II of this study for further investigation of these natural materials.

- The pavement design for cost-effective pavement options should be done in a holistic manner, i.e. attention should be paid to the compatibility between the pavement structure, the materials used, type of surfacing, construction processes and maintenance or rehabilitation techniques.

- Based on the inputs from stakeholders at the workshop, it is recommended that the mapping of locally available materials should be considered as a separate project.

- The DFR should strictly adopt the following drainage system and erosion control measures:

    - Road surface: Surfacing (sealing) the road surface with up to 5% camber is the best way to provide adequate channelling of surface runoff.

    - Proper side drains, preferably lined with concrete, must be provided at steep road sections. This should be based on the characteristics of the natural material of the side drains. Where the in-situ material of the side drains is rocky, only scour checks placed at intervals of less than 6 m may be required. The DFR should experiment with the use of worn-out tyres (waste material) with stone setts/cobbles for scour checks.

- For a project of this nature, where research is a significant and important component of the process, it is recommended that the current DFR process or criteria for the selection of contractors should be reviewed.

    - Selected supervisors and contractors should be adequately trained to execute the demonstration projects.

    - Training will focus on the transfer of new road-building technologies and the use of marginal materials contrary to the conventional practices they are used to.

- There is a need to review the capacity of the potential road material laboratories that will be utilised in this study. Equipment, personnel, historical test data and any previous reports should be reviewed to determine whether or not these laboratories are capable of conducting all the tests that will be included in Phase II. The laboratories should be accredited by the National Standards Board. It is recommended that, where feasible, test samples should be selected for comparative and verification tests in the selected laboratories.

- Based on the fact that sourcing for data and information was a challenge in Phase I, it is recommended that the DFR initiates a study to establish Technical Data Management Systems (TDMS) for low-volume roads.
- The prospective communities should be sensitised from the start of the project to express their opinions, especially in any decisions that may have an impact on their economic and social activities during the construction stage.
- Innovative maintenance strategies should be invented for hilly sections on the feeder roads in Ghana.

REFERENCES

1. Addison G.K. (2008). Availability of natural gravel material for road construction in Ghana, MSc thesis. KNUST, Kumasi Ghana.

2. Ampadu S.I.K., Akayuli, C.F.A., and Opuni K.O. (2016). Optimizing the pozzolana-lime concentration to maximize geotechnical properties of natural gravel for rural road construction, International Journal of Pavement Engineering, In Press.

3. Ampadu, S.I.K. and Addison, F.K. (2015). A comparison between the life cycle cost of gravel and of bituminous surfacing options for feeder roads in Ghana. International Journal of Pavement Engineering. DOI:10.1080/10298436.2015.1065990.

4. Amu, O.O., Ogunniyi, S.A. and Oladeji, O.O. (2011). Geotechnical properties of lateritic soil stabilized with sugarcane straw ash, American Journal of Scientific and Industrial Research.

5. Anochie-Boateng, J.K. and Debrah, E.K. (2016). Inception report on Alternative Surfacing for Steep Hill Sections in Ghana-Phase I, ReCAP Project Activity Number: GHA2065A.

6. Anochie-Boateng, J.K. and Debrah, E.K. (2016-a). Alternative surfacing for steep hill sections in Ghana – Phase I, Inception report, ReCAP Project Activity Number: GHA2065A.

7. Anochie-Boateng, J.K. and Debrah, E.K. (2016-b). Alternative surfacing for steep hill sections in Ghana – Phase I, Draft report, ReCAP Project Activity Number: GHA2065A.

8. Anochie-Boateng, J.K. and Debrah, E.K. (2016-c). Alternative surfacing for steep hill sections in Ghana – Phase I, Workshop report, ReCAP Project Activity Number: GHA2065A.

9. Atkins, R. J., Leslie, M. R., Polster, D. F., Wise, M. P. and Wong, R. H. (2001). Best Management Practices Handbook: Hillslope Restoration in British Columbia. Victoria, B. C. Watershed Restoration Program

10. Cedergren, H. (1989). Seepage, Drainage, and Flow Nets. 3rd Edition John Wiley and Sons. New York, USA.

11. Committee of Transport Officials (2013). Draft TMH 9. *Standard visual assessment manual Part E: Unpaved roads*.

12. Cook J.R. & Meksavanh, B. (2009). Performance monitoring of low volume rural roads in Northwest Lao PDR. SEACAP 17.02 DfID for MPWT, 2009.

13. Cook J.R., Petts, R.C. and Rolt, J. (2013). Low volume rural roads-A Guide to Good Practice.

14. Department of Feeder Roads, Ministry of Roads and Highways, Ghana. (2001). New classification of feeder roads in Ghana.

15. Ethiopian Roads Authority (2011). Design manual for low volume roads. Federal Democratic Republic of Ethiopia.

16. Ghana Highway Authority (1991). Road design guide.

17. Gourley, C.S. and Greening, P.A.K.A (1999). Performance of low-volume sealed roads: results and recommendations for studies in southern Africa. TRL Published Report PR/OSC/167/99. Crowthorne.

18. Guide to Slope Protection Works (GSPW). (2003). His Majesty's Government of Nepal. Ganabahal, Kathmandu.

19. Henning, T., Kadar, P. and Bennet, R. (2005). Surfacing alternatives for unsealed roads. World Bank TRN-33, Washington.

20. InfraAfrica (Pty) Ltd, Botswana, Netterberg, F. (2014). Review of specifications for the use of laterite in road pavements (Contract: AFCAP/GEN/124).

21. Keller, G. and Sherar, J. (2003). Low-Volume Roads Engineering: Best Management Practices Field Guide. United States Agency for International Development (USAID).

22. Kenya (1993). Roads 2000, Pilot Project Final Report. Ministry of Public Works and Housing, Kenya.

23. Leta, N.V. and Langa, R. (2010). Use of Locally-produced materials for low-volume road paving, 1st AfCAP Practitioners Conference, 23-25 November 2010.

24. Madu, R.M. (1980). The performance of lateritic stones as concrete aggregates and road chippings. Materiaux et Constructions, Vol 13, 78, pp 403-411.

25. McCuen, R. H., Johnson, P. A. and Ragan, R. M. (2002). Hydraulic Design Series No. 2, Second Edition: Highway Hydrology. USDoT Federal Highway Administration. Publication No. FHWA-NH1-02-001

26. Mike, J., Mike, T. and Simon, G. (2009). Local resource solutions to problematic rural road access in Lao PDR SEACAP 17.

27. Ministry of Transport (2007). Standard specification for road and bridge works for Ghana.

28. Ministry of Transport and Public Works (2013). Design manual for low volume sealed roads in Malawi, January 2013.

29. Moll, J., Copstead, R and Johansen, D. K. (1997). Travelled Way Surface Shape. San Dimas Technology and Development Center, Forest Service, US Department of Agriculture. Washington, D. C. USA.

30. Orr, D. P. (1998). Roadway and Roadside Drainage. CLRP Publication No. 98-5. Cornell Local Roads Program and New York LTAP Centre. New York, USA.

31. Overby, C. (1982). Materials and pavement design for sealed low traffic roads in Botswana. Norwegian Road Research Laboratory. Oslo, Norway.

32. Richards, R.G. (1978). Lightly trafficked roads in southern Africa. A review of practice and recommendations for design. NITRR Rep RP/8/78, Pretoria, South Africa.

33. SABITA (2004). SuperSurf User Manual; SABITA Manual No. 7.

34. SABITA (2011). Appropriate bituminous surfacings for low volume roads and temporary deviations. Manual 10. South African Bitumen Association, May 2011.

35. Southern Africa Transport and Communication Commission (SATCC) (2003). SADC Guideline on low-volume sealed roads. Gaborone. Botswana.

36. The World Bank (2005). Surfacing alternatives for unsealed rural roads, Project Number – Z092780, September 2005.

37. Theuns, H. (2006). Surfacing alternatives for unsealed rural roads. Transport Note No. TRN-33, Roads and Rural Transport Thematic Group, The World Bank, Washington DC.

38. Toole, Morosiuk, Petts and Done (2002) TRL, Management guidelines for unsealed roads. [http://www.transport-links.org/transport_links/filearea/documentstore/Draft Gravel Guidelines.pdf, accessed May 4, 2016]

39. TRL (2008). Mainstreaming appropriate local road standards and developing a strategy for the Lao PDR, SEACAP 3.01.

40. UNOPS (2012). South Sudan low volume roads design manual. DfID for Ministry of Roads and Bridges, S Sudan.

41. Xu, X. L., K. L. Zhang, L. F. Luo., Y. P. Kong and L. Pang. (2005). Relations between Rain Characters and Sediment Yielding and Runoff on Embankment Slope of Qinghai-Tibet Road. Journal of Soil and Water Conservation. Volume 9, Number 1, pp. 23-24, 74.

Appendix A: Detailed cost comparison of pavement and drainage options

Table A-1 Provisional Sums for general items and initial preparation of road to formation

ITEM	DESCRIPTION	UNIT	QTY	RATE GBP	AMOUNT GBP
	CONTRACTUAL REQUIREMENTS				
A 110	Performance Security	sum			
A 120	Insurance of Works	sum			
A 130	Insurance of Constructional Plant	sum			
A 140	Third Party Insurance	sum			
A150	Insurance Against Accident to Workmen	sum			
	SPECIFIC REQUIREMENTS				
A211	Provide office space for Consultant's team and maintain according to the consultant's specification	sum			2 500.00
A250	Provide for material site investigation and testing	sum			1 000.00
A260	Testing of the Works	sum			800.00
A 279.1	Installation of sign post indicating Contract Name, Contractor and Contract Supervisory Agency	nr	2	100.00	200.00
A290.2	Setting out of works	m	250	5.00	1 250.00
	METHOD RELATED CHARGES				
A311.1	Setting up Contractor's compound	sum			1 200.00
A311.2	Maintain Contractor's Compound	Month	3	200.00	600.00
A311.3	Removing Contractor's Compound	sum			500.00
A420.1	Provide safe drinking water for site employees including storage facilities (Polytank, etc.)	p. sum	Item		1 000.00
A420.2	Provide and maintain protective clothing, safety equipment for use by site employees	p. sum	Item		250.00
A420.4	Provide and maintain temporary latrines, relocate as necessary and remove and backfill on completion	p. sum	Item		1 000.00
A420.5	Provide First Aid kit and train First Aider	p. sum	Item		250.00
A420.6	Provide education to workers and local communities on STDs HIV/AIDS awareness and consultation meetings	p. sum	Item		500.00
	PREPARATION OF ROAD FORMATION				
E 230.2	Excavation of hard rock (bulldozer) using rippers and cart away from site.	cu.m	50	7.00	350.00
E625	Fill to road formation with excavated material from borrow pits, haul,and compact	cu.m	100	3.00	300.00
E 592.3	Blading road surface to crossfalls and compaction to form road.	sq.m	1 500	0.50	750.00
	TOTAL BILL - GENERAL ITEMS and ROAD FORMATION CARRIED TO COST OF SURFACING				**12 450.00**

Table A-2 Estimated cost of drainage structures

ITEM	DESCRIPTION	UNIT	QTY	RATE GBP	AMOUNT GBP
UNLINED V-SHAPED DRAIN [EXCAVATION IN HARD GROUND]					
	Excavation of trenches				
E 322	Excavation of trenches for V-drain maximum depth 1.50m in hard material.	cu.m	700	12.00	8 400.00
	TOTAL BILL - UNLINED [EXCAVATION IN HARD GROUND] V-DRAIN				**8 400.00**
CONCRETE LINED TRAPEZOIDAL SHAPED DRAIN [MINIMUM EFFECTIVE DEPTH 0.6M]					
	Excavation of trenches				
E 322	Excavation of trenches for trapezoidal drain, maximum depth 1.00m, backfill and cart away surplus material.	cu.m	900	6.00	5 400.00
	Formwork				
G 144	Rough formwork to vertical surfaces,0.4-1.2m wide	sq.m	680	5.00	3 400.00
	Placing concrete				
F 253	Provide and Place Concrete Grade C25/20	cu.m	171	116.00	19 836.00
	TOTAL BILL - CONCRETE TRAPEZOIDAL DRAIN CARRIED TO COST OF SURFACING				**28 636.00**
CONCRETE LINED U-SHAPED [MINIMUM INNER DEPTH 0.6M]					
	Excavation of trenches				
E 322	Excavation of trenches for 0.6m U-drain, maximum depth 1.50m, backfill and cart away surplus material.	cu.m	750	6.00	4 500.00
	Formwork				
G 144	Rough formwork to vertical surfaces (0.6-1.2m wide) and rounded inner bottom	sq.m	800	5.00	4 000.00
	Placing concrete				
F 253	Provide and Place Concrete Grade C25/20	cu.m	180	116.00	20 880.00
	TOTAL BILL - CONCRETE 0.6m U-DRAIN				**29 380.00**

Table A-3 Detailed cost comparison of pavement and drainage options

ITEM	DESCRIPTION	UNIT	QTY	RATE GBP	AMOUNT GBP
Paving Blocks on 150mm Stabilised Laterite [Crushed Stone and Quarry Dust]					
	Provide, place and compact to specification mechanically stabilised laterite with 40% (1:1 crush stone and quarry dust)	cu.m	225	96.00	21 600.00
R783	Provide and place precast paving block [strength 30N/mm2] over evenly spread Quarry Dust of average depth 12mm	sq.m	1 500	42.00	63 000.00
	Key in at the edges	m	12	8.00	96.00
				Total for Option	**84 696.00**
Ultra-Thin [70mm RC] on 200mm Stabilised Laterite [Crushed Stone and Quarry Dust]					
	Provide, place and compact to specification mechanically stabilised laterite with 40% (1:1 crush stone and quarry dust)	cu.m	300	96.00	28 800.00
F 263	Provide and place concrete Grade C30/20	cu.m	105	180.00	18 900.00
G514	Reinforcement mild steel bars nominal size of 6mm	tonne	6	940.00	5 640.00
				Total for Option	**53 340.00**
Graded Cobblestone [100mm-250mm] Arranged on 100mm Stabilised Laterite, Finished with Concrete					
	Provide, place and compact to specification mechanically stabilised laterite with 40% (1:1 crush stone and quarry dust)	cu.m	150	96.00	14 400.00
	Provide, spread sand/quarry dust blinding of average depth 25mm to receive cobblestones	cu.m	38	12.00	450.00
	Provide and arrange in place	sq.m	1 500	32.00	48 000.00
	Key in at the edges	m	12	8.00	96.00
F 263	Provide and place concrete Grade C30/20 to fill irregular voids in cobblestones	cu.m	65	180.00	11 700.00
				Total for Option	**74 646.00**
Double Seal [10mm and 14mm] on 100mm Stabilised Base and 150mm Stabilised Subbase					
	Provide, place and compact subbase to specification mechanically stabilised laterite with 20% (1:1 sand and clay pozzolana)	cu.m	225	88.00	19 800.00
	Provide, place and compact base to specification mechanically stabilised laterite with 40% (1:1 crush stone and quarry dust)	cu.m	150	96.00	14 400.00
	Provide, Spray Bitumen Primer Coat on Base	sq.m	1 500	4.00	6 000.00
	Provide, spread and roll-over 14mm pre-coated chippings	sq.m	1 500	14.00	21 000.00
	Provide, Spray Bitumen Primer Coat on 14mm layer	sq.m	1 500	4.00	6 000.00
	Provide, spread 10mm pre-coated chippings and roll-over	sq.m	1 500	12.00	18 000.00
				Total for Option	**85 200.00**
Lateritic HMA [AC-10 Bitumen] on 200mm Stabilised Base [Laterite with Crushed Stone and Quarry Dust]					
	Provide, Place and compact base to specification mechanically stabilised laterite with 40% (1:1 crush stone and quarry dust)	cu.m	225	96.00	21 600.00
	Haulage of HMA constituents materials to Asphalt Plant Production Site and back to Construction Site [100-200km]	cu.m-km	11 250	1.20	13 500.00
	Provide, Spray Bitumen Primer Coat on Base	sq.m	1 500	6.00	9 000.00
	Provide, lay and compact to 50mm thick HMA (AC-10) over stabilised Base	sq.m	1 500	30.00	45 000.00
				Total for Option	**89 100.00**
Otta Seal [14mm-25mm aggregates] on 100mm Stabilised Base and 150mm Stabilised Subbase					
	Provide, place and compact subbase to specification mechanically stabilised laterite with 20% (1:1 sand and clay pozzolana)	cu.m	225	88.00	19 800.00
	Provide, place and compact base to specification mechanically stabilised laterite with 40% (1:1 crush stone and quarry dust)	cu.m	150	96.00	14 400.00
	Provide, spray emulsion binder (2.0 litre/m^2) on Stabilised Base	sq.m	1 500	4.00	6 000.00
	Provide screened natural gravel [14mm - 25mm], spread and roll-over sprayed emulsified binder	sq.m	1 500	10.00	15 000.00
				Total for Option	**55 200.00**

Table A-4: Detailed cost for "do-nothing" option

Unsealed gravel surfacing – 300 mm stabilised laterite						
YEAR	**ITEM**	**DESCRIPTION**	**UNIT**	**QTY**	**RATE GBP**	**AMOUNT GBP**
Year 0	Initial Construction Cost	Provide, place and compact to specification mechancally stabilised laterite with 40% (1:1 crushstone and quarry dust)	cu.m	450	96.00	43 200.00
		Excavation of unlined earth drains - both sides	cu.m	600	6.00	3 600.00
Maintenance work schedules						
Year 1	Reshaping	Blade to shape existing gravel surface	sq.m	1 500	3.00	4 500.00
Year 2	Regravel - natural gravel 150mm thick	Provide, replace lost gravel and compact to specification natural gravel 150mm over existing.	cu.m	225	40.00	9 000.00
Year 3	Earth drains clearing	Clear and clean earth side drains	m	500	1.00	500.00
	Regravel with natural gravel- 150 mm thick	Blade to shape existing gravel	sq.m	1 500	3.00	4 500.00
Year 4	Regravel - 150 mm thick	Provide, replace and compact to specification natural gravel	cu.m	225	40.00	9 000.00
Year 5	Earth drains clearing	Clear and clean earth side drains	m	500	1.00	500.00
	Regravel - mechanically stabilised 100 mm thick	Provide, replace lost gravel and compact to specification mechanically stabilised gravel 100mm over existing.	cu.m	150	96.00	14 400.00
Year 6	Reshaping	Blade to shape existing gravel surface	sq.m	1 500	3.00	4 500.00
Year 7	Regravel - natural gravel 150mm thick	Provide, replace lost gravel and compact to specification natural gravel 150mm over existing.	cu.m	225	40.00	9 000.00
Year 8	Earth drains clearing	Clear and clean earth side drains	m	500	1.00	500.00
	Regravel with natural gravel- 150 mm thick	Blade to shape existing gravel	sq.m	1 500	3.00	4 500.00
Year 9	Regravel - 150 mm thick	Provide, replace and compact to specification natural gravel	cu.m	225	40.00	9 000.00
Year 10	Earth drains clearing	Clear and clean earth side drains	m	500	1.00	500.00
	Regravel - mechanically stabilised 100 mm thick	Provide, replace lost gravel and compact to specification mechanically stabilised gravel 100mm over existing.	cu.m	150	96.00	14 400.00
Year 11	Reshaping	Blade to shape existing gravel surface	sq.m	1 500	3.00	4 500.00
Year 12	Regravel - natural gravel 150mm thick	Provide, replace lost gravel and compact to specification natural gravel 150mm over existing.	cu.m	225	40.00	9 000.00
Year 13	Earth drains clearing	Clear and clean earth side drains	m	500	1.00	500.00
	Regravel with natural gravel- 150 mm thick	Blade to shape existing gravel	sq.m	1 500	3.00	4 500.00
Year 14	Regravel - 150 mm thick	Provide, replace and compact to specification natural gravel	cu.m	225	40.00	9 000.00
Year 15	Residual value of road					
		Total for Option				**159 100.00**

Appendix B: Testing equipment for pavement materials


Triaxial and CBR equipment


Direct shear equipment


Consolidation equipment


Scales and oven equipment set-up


Triaxial test equipment


Direct shear equipment


Quant. extraction equipment, penetrometer


Quant. extraction equipment, penetrometer