ENVIRONMENTALLY OPTIMISED DESIGN OF ROAD SURFACING ALTERNATIVES FOR STEEP SLOPE SECTIONS ON RURAL ROADS

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ABSTRACT

Like other sub-Saharan African countries in the tropics, the middle-belt of Ghana has rolling and mountainous landscapes with road problems usually associated with drainage and erosion control. Undulating terrains characterised by steep slopes pose road access challenges. Conventional rural roads wearing course materials such as gravel or single bituminous seals have proven inadequate to address the issues, especially on steep hill sections. To address the problem, the Environmentally Optimized Design (EOD) concept was employed to select resources, including construction materials, to determine the suitability of optimum road surfacing alternatives for steep slope sections (gradients of 12% or more) of rural roads in Ghana. Subsequently, based on assumptions of nominal subgrade (CBR=10%) and low traffic volume (<300 vehicles per day), three alternative derivatives of concrete, bituminous and stone setts/cobbles surfacing were proposed. Further, a tentative pavement structure design based on Transport Research Laboratory's (TRL) estimator for gravel surface design was used to present different road layer combinations. For construction demonstration and monitoring, the three surfacing alternatives are to be placed over different road base materials; i.e., lateritic gravel stabilised with cement, pozzolana, and quarry dust as additives. This paper focuses on three surfacings on stabilised lateritic base/subbase layer materials. The outcomes of the study will contribute to the development of construction guidelines and specifications for rural roads in Ghana, which could serve as a model for other sub-African countries.

Keywords: Environmentally optimised design, rural roads, steep slopes, concrete surfacing, bituminous surfacing, stone setts/cobbles surfacing.

1. INTRODUCTION

More than 70% of Ghana's feeder (rural) roads, managed by the Department of Feeder Roads (DFR), are built on mountainous or rolling terrains. Feeder roads constitute approximately 62% of the entire 68,124 km road network. Still, only five per cent of Ghana's total feeder road network is reported to have bituminous surfacings, with the remaining 95% is either earth or gravel surfacings. Steep sections of feeder roads in Ghana are at high risk of failure due to the high rainfall (annual rainfall ranges from 780 mm to 2160 mm). They are adversely affected by slope failure, erosion, and drainage-related problems that ultimately affect the rural communities regarding traffic delays, safety, damage to natural resources, and economic activities (market days, for example). Prolonged rainy seasons and weak natural (lateritic) soils exacerbate the problems facing the hilly sections of the feeder roads in Ghana. Hence, identifying appropriate surfacing options for higher-risk sections on feeder roads is an essential component of Ghana's strategy for ensuring sustainable all-season rural access.

Notwithstanding the road pavement structure, particularly for this study on steep slopes, the road surface should provide adequate traction for vehicles when wet and should withstand common surface distresses. Natural gravel as the 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 standard material specifications, testing methods, design and construction of low volume roads (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 crucial.

Consultations with the relevant road agencies (i.e. Department of Feeder Roads, Department of Urban Roads and Ghana Highway Authority) revealed a lack of adequate data to address the behaviour and field performance of marginal road materials in Ghana. Research on LVRs in Ghana is relatively limited compared to research on high-volume roads (HVRs). The standard specifications for low-volume roads embrace material specifications for HVRs, which leads to the rejection of local 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. The immediate alternative is to opt for high standard materials, which are scarce and often more expensive. Therefore, the impact of the rejection of marginal materials on the cost of a LVR project becomes severe. The high construction costs may also frustrate LVR projects and can lead to backlog mobility and sustainability problems.

Cook et al. (2013) highlight the importance of developing rural road networks by the sustainable utilisation of local resources to provide cost-effective transport infrastructure. Also, extensive research has been conducted to investigate the performance of marginal materials and the behaviour of LVRs. In Africa, studies conducted by Richards (1978); Overby (1982); Gourley and Greening (1999); Ethiopian Guidelines (2011) and Malawi Guidelines (2013) for LVRs show that many local materials do not meet traditional standards for road construction materials, especially on roads with relatively low predicted traffic flows over their design life. However, all these studies indicate that the performance of marginal materials is mainly affected by moisture, density, and terrain (road environmental factors).

The concept of EOD was adopted and adapted within the context and conditions of Ghana to deal with the problem of steep hill sections of the Ghana feeder roads. Ahead of the use of EOD, field surveys of the existing state of feeder roads and the associated problems, as well as local materials with potential for pavement use, were undertaken (Anochie-Boateng and Debrah, 2016). Also, the best practices used in similar jurisdictions and documented were reviewed to develop road surfacing alternatives that suit the Ghanaian conditions, especially using the available local resources as much as practicable. Further, an appropriate pavement design method was used to design pavement structures of different combinations using the Transport Research Laboratory's approach that typifies the underlying pavement layers.

The outcome of this study presents an essential initial step in dealing with the problems identified with the road surfacing on LVRs and feeder roads in Ghana, especially for sections in hilly areas. The following sections describe the study approach, materials selection processes, and pavement designs and finally present the resulting surfacing alternatives with the entire pavement structures.

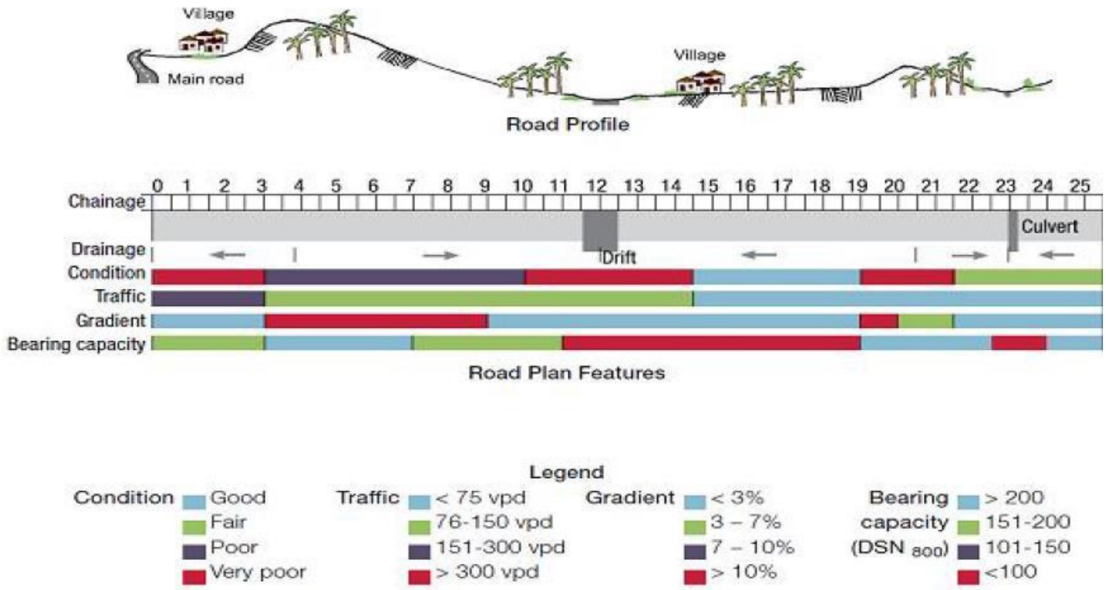
2. STUDY APPROACH

2.1 Overview of Study Activities

The study was carried out in stepwise phases comprising specific activities. These include a detailed review of all available data and an evaluation of existing guidelines and standards for low-volume roads in Ghana. Essential engineering and related technical documents used in Ghana and elsewhere were reviewed. Interviews, meetings and consultations with key officials of the DFR and other stakeholders were conducted to obtain technical information (Anochie-Boateng and Debrah, 2016-a, 2016-b, 2016-c). There were seminars and workshops organised. Visits to material sources in two regions in Ghana, assess their potential use for the design and construction of demonstration sites and appraise information on naturally occurring local construction materials. Finally, the concept of environmentally optimised design (EOD), briefly explained in the following section, was used to design alternative surfacing types that could be demonstrated for real-life performance assessments.

2.2 Environmental Optimized Design Concept

Mike et al. (2009) defined the EOD concept as a design approach that uses the available budget, human resources and materials to meet the challenges of the road environment and provide appropriate access in the most cost-effectively and sustainable way. The concept of EOD was adopted to select and utilise construction materials for the alternative surfacings for this study. In this approach, attempts are made to ensure that each section of the road is equipped with the most suitable road 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. Figure 1 shows the critical property of the EOD concept and its flexibility in the design approach, which is based on the need to support road tasks and consider the road environment.



Source: Research in Community Access Partnership (ReCAP), 2009.

Figure 1: Application of the principle of environmentally optimised design

3. OUTCOMES FROM THE DESK AND FIELD STUDIES

3.1 Review of Available Standards and Documents

A desk study involving reviews of relevant reference materials was carried out. Firstly, key engineering documents used by the Ghana road agencies were assessed. Two documents; a) the Ghana Standard Specifications for Road and Bridge Works (Ministry of Transport, 2007), which is the primary reference for road-related works carried out in Ghana and b) the Ghana Highway Authority's Design Guide (1991) were reviewed. In addition, Standards and Guidelines used in other countries were assessed to supplement vital information gathered from the Ghana documents. These include; 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). Further, other publications, including Addison (2008), Ampadu et al. (2016), Ampadu and Addison (2015), and many others, were reviewed for valuable information for the study.

From the desk study, field surveys were undertaken to identify available resources (construction materials, local human resources, construction equipment) in the framework of the EOD concept and the ground conditions of the project site. A future demonstration of the study outcomes would be possibly demonstrated. The identified potential materials from the field survey are as follows.

3.2 Available Construction Materials

The following are essential construction materials identified while considering the guidelines of the EOD concept 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 many cases, stabilising marginal natural gravel require mechanical stabilisation. Such stabilisation could be achieved by introducing additives such as lime, pozzolana and quarry dust, fly ash, steel slag (in powder form), sugarcane straw and bamboo leaf, and others.

- **Coarse aggregates** in the form of conventional quarry stones (as stipulated in the applied specifications) served as a critical source, which is especially important for traditional control methods against the proposed alternative surfacing options.

- **Sands** were obtained from natural land deposits/river beds. Sands serve as core construction materials, key concrete components and stabilising agents of lateritic composites for surfacing options and road base/sub-base layers.

- **Quarry dust** was considered for the stabilisation of marginal lateritic material. Quarry dust is also a key material ingredient for producing interlocking concrete paving blocks of specified compressive strength that will be investigated as a surfacing option.

- **Bitumen (regular or modified)** was the critical binding agent for proposed bituminous road surfacing alternatives.

- **Lime** as a stabilising agent is another material for consideration.

- **Clay pozzolana,** an additive material for stabilisation, was a composite for the proposed surfacing options and improved the engineering properties of marginal natural gravel (lateritic material).

- **Burnt clay bricks** are construction units that are tested and 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** served as the conventional material component for the concrete-based alternative options. In this study, mild steel reinforcement will be used if needed.

4. ALTERNATIVE SURFACING TYPES

4.1 General Factors Affecting the Choice of Surfacings

Factors that influence the choice of appropriate surfacing types for low-volume roads include traffic (volume and type), pavement type, materials type and quality, environment (climate; temperature, rainfall), operational characteristics (speed, geometry, gradient, curvature), skid resistance, surface texture, construction techniques and contractor experience, maintenance capacity and reliability, economic and financial factors (available funding, life-cycle costs, and others).

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 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 assist in making a final choice concerning surfacing options for the steep road sections in Ghana. With these factors considered in the context of this study, a selection process was developed to select the appropriate surfacing alternatives, described following.

4.2 Selection Process of Surfacing Options

A range of experimental factors was considered above to simplify the selection process. Subsequently, the general procedure for selecting appropriate surfacing options for the steep sections is presented in an eight-step selection process shown in Figure 2.

Following selecting the appropriate surfacing alternatives, a tentative design for the pavement structures capturing the underlying road layers was presented.

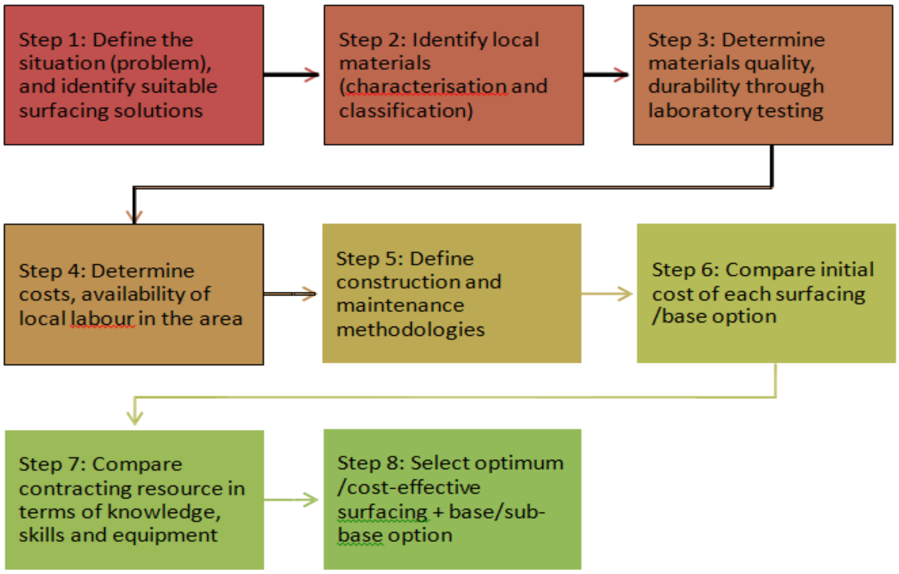


Figure 2: Systematic stepwise process for selecting optimum pavement layers

4.3 Tentative Pavement Design

The tentative pavement design considerations assumed the following parameters:

- A design life of 15 years, based on the performance of similar pavement structures in Ghana, was adopted. In addition, it was expected that the proposed surfacing alternatives would be able to carry the expected traffic loading and withstand the environmental conditions (rainfall and temperature) over the 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.

- 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. Annual traffic growth of 2% encompassing generated traffic after surfacing was considered for the vehicle types over the design life was applied to determine the cumulative Equivalent Standard Axle Loads (ESALs). Traffic growth on these feeder roads is not expected to exceed 3%.

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

The selection of pavement materials for the layers considered the respective strengths and the fact that they are placed on high/steep sections subject to traction as the vehicle descends a hill. There is a need to stabilise the base/sub-base material, which naturally occurs in lateritic soils. The stabilisation is essential, especially for the ‘marginal’ lateritic soils that would require improvement in strength and plasticity.

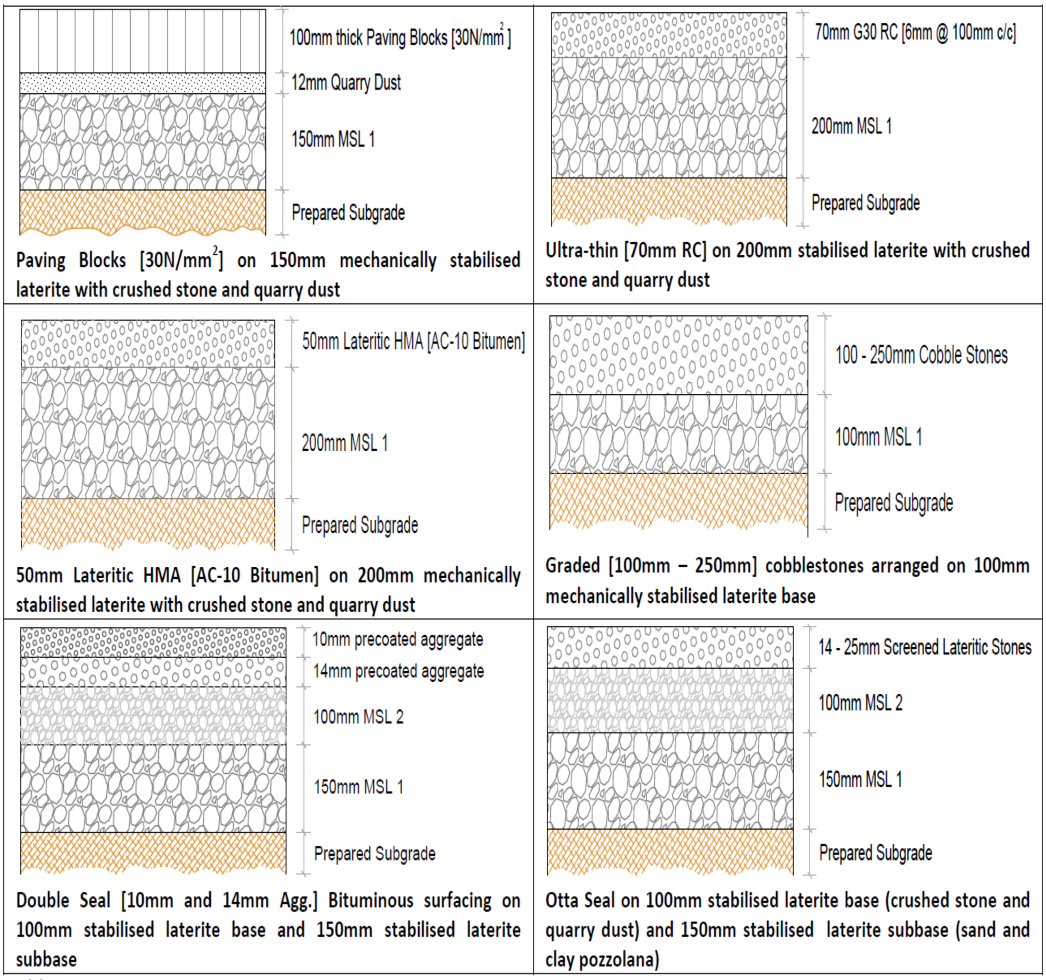
The study used Transport Research Laboratory's (TRL) proposed gravel thickness estimator as in (1) for low-volume roads for a residual rut depth of 40 mm to determine the layer thicknesses for the base/sub-base materials (Toole et al., 2002). In-situ subgrade CBR of 10% was assumed in the estimations based on field assessment of the ground conditions.

$$\text{Log}\, N = \frac{h[CBR]^{0.63}}{190} - 0.24 \tag{1}$$

where N number of standard 80kN axles
h thickness of granular (gravel) material required in mm
CBR subgrade CBR (%)

4.4 Proposed Surfacing Solutions

From the study, surfacing alternatives identified and proposed to mitigate problems associated with steep sections of low-volume roads are presented schematically over the underlying pavement layer structure with designed thicknesses for each option, as shown in Figure 3.



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

Figure 3: Cross-sectional scheme of the proposed pavement layer thicknesses

5. CONCLUSIONS

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

- The standards and specification documents used by the DFR require a 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) served valuable inputs for developing the surfacing alternatives while adopting and adapting the concept of EOD in the local context and conditions in Ghana.

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

- Gravel surfacing was inappropriate for steep sections of the feeder roads, especially on steep hill sections susceptible to erosions and slope failures.

- Notwithstanding the nationwide availability of naturally occurring gravel materials, it is challenging to get natural gravel to meet the G80 (material with a 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 to provide feeder roads in Ghana.

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