LIFE-CYCLE COST COMPARISON OF ALTERNATIVE SURFACING FOR STEEP SLOPES ON LOW-VOLUME ROADS IN GHANA

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ABSTRACT

Steep hill sections of low-volume (i.e. feeder) roads in Ghana are at high risk of slope failure, erosion, and drainage-related problems that ultimately affect the rural communities in respect of traffic delays, safety, damage to natural resources, and economic activities. These problems have been mainly attributed to prolonged rainy seasons, coupled with weak natural (lateritic) soils that are commonly used as wearing course on the feeder roads. A study was recently conducted to identify alternative surfacing options to gravel wearing courses used on steep gradients (in excess of 12%) of feeder roads in Ghana. A major outcome was three surfacing options (i.e. concrete, bituminous and stone setts/cobbles) that would be more effective to address drainage and erosion problems on the steep section than gravel wearing courses currently used by the Department of Feeder Roads (DFR). The objective of this paper is to present a life-cycle cost comparison of six pavement options proposed for steep hilly sections of feeder roads in Ghana. The economic evaluation methodology adopted is the present worth of cost. Although not very decisively, the life-cycle cost analysis of the six pavements indicated that with a real discount rate of 12%, 70 mm ultra-thin reinforced concrete surfacing has the lowest cost (GBP 69.7/m²), whereas 50 mm hot-mix asphalt emerged as the option with the highest cost (GBP 91.7/m²). Based on the analysis results, it is concluded that all six pavement options remain cost-effective structures compared with a gravel wearing course. However, the current policies of the DFR may influence the decision on particular surfacings to be adopted for feeder roads in Ghana.

Key words

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

INTRODUCTION

Over the past two decades, the African Community Access Programme (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.

Asphalt or concrete surfacings are reported to be the most suitable surfacings for low-volume road sections with gradients in excess of 12%. Cook et al. (2013) noted that in the past, bituminous surfacings

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were used in most tropical countries. 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. 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.
Stone setts /cobbles 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. The choice between bituminous and concrete surfacings as well as stone setts /cobbles should, however, be made based on the life-cycle cost of the pavement, as well as the effect on road user costs.

This paper compares the life cycle costs of six pavement options with concrete, bituminous and stone setts /cobblestone surfacings for steep sections (i.e. gradients in excess of 12%) of low-volume (feeder) roads in Ghana. The results of the cost analysis are considered as an aid to the Department of Feeder Roads (DFR) of Ghana in decision-making.

BACKGROUND

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). These roads 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). A prolonged rainy seasons (especially in southern Ghana), coupled with weak natural (lateritic) soils, exacerbate the problems facing the hilly sections with gradients in excess of 12% 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 the DFR’s strategy for ensuring sustainable all-season rural access in Ghana.

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 1 of a two-phase study on alternative surfacing for steep slopes in Ghana. The objective of the 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 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 was 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 (Anochie-Boateng and Debrah, 2016). 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 surfacing types and the two different base layer materials provided the matrix of 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 demonstration sections to be designed, constructed and monitored under the Phase 2 of the study.

One of the main outcomes of the site investigations was a severe road surface erosion on unsealed gravel roads. It was noticed that the steep gradients aid the flow of runoffs, thereby rapidly washing the surface material away (i.e. erosion), as shown Figure 1 for one of the sites visited. It was also observed by the project team 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, as shown Figure 2. Where some form of side drain was present, the construction of a low standard and poor workmanship was apparent.

Figure 1: Lack of Roadside Drains Leading to Severe Sheet Erosion

Figure 2: Poor Kerb Drainage Structures Leading to Severe Erosion

PAVEMENT DESIGN

The 18 pavement options were categorised into three groups: concrete, bituminous, and stone pavement structures. Out of these, six pavement options were proposed for the Phase 2 study. Ghana has traditionally used the American Association of State Highway and Transportation Officials (AASHTO) guide for design of pavement structures (AASHTO 1993/1996). Thus, the AASHTO 1993 guide was used for the structural design of the six pavement options. The pavement design considerations assumed the following parameters:

- A design life of 15 years was used for the pavement structures. This is based on the performance of similar pavement structures in Ghana. It is expected that the identified surfacing options (i.e. concrete, asphalt, stone setts/cobbles) should be able to carry the expected traffic loading and withstand the environmental conditions (rainfall and temperature) over this design period with minimal 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.

For this study, environmental rather than traffic loading factors would determine the ultimate 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 mechanical stabilisation. This is important especially for the local lateritic soils with marginal (i.e. substandard) properties that would require improvement in strength and plasticity.

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

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

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. Figure 3 shows the cross-sections proposed for each of the six pavement options.

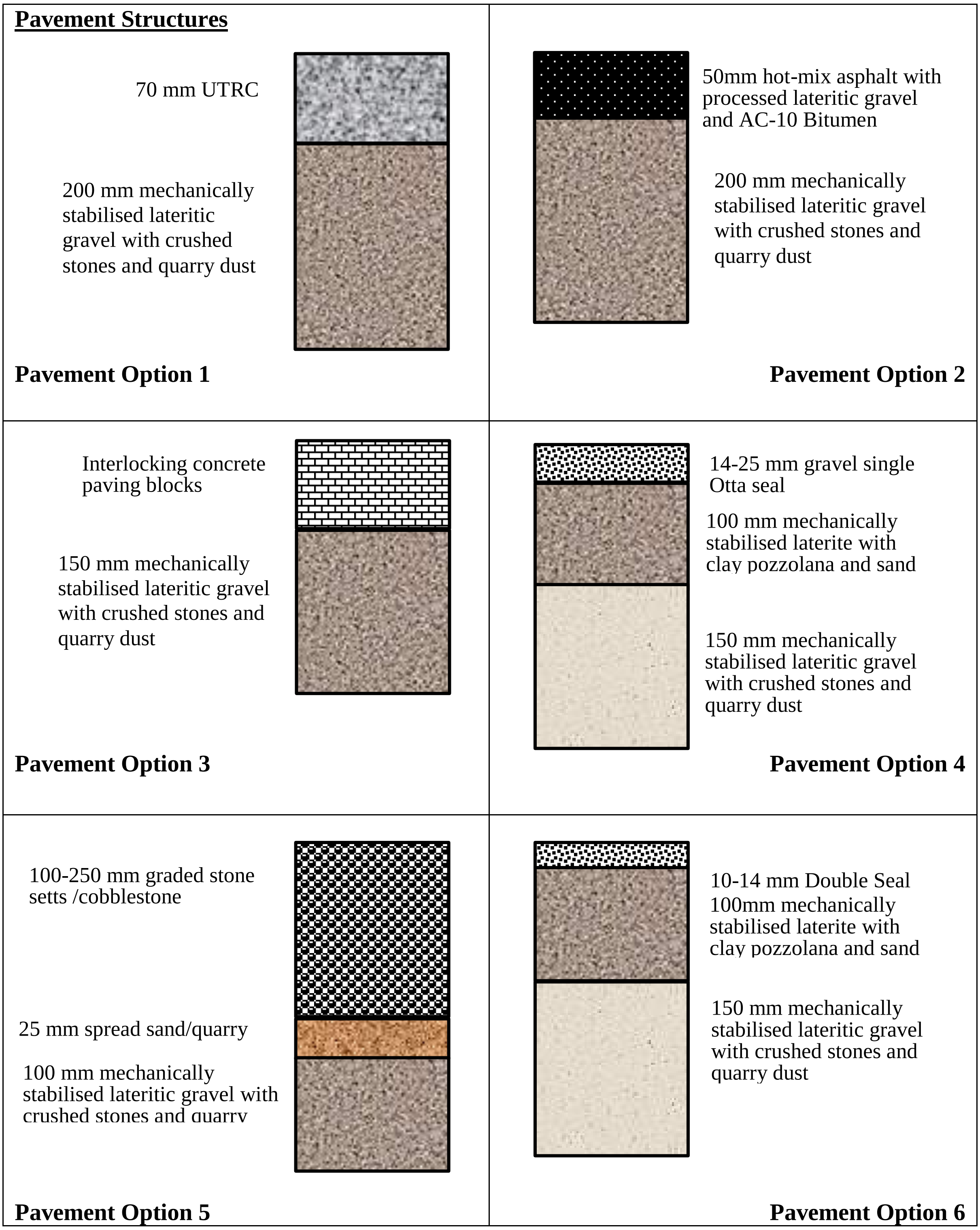

Figure 3: Cross Sections of Proposed Structures for Different Surfacing Options

INITIAL CONSTRUCTION COSTS

In order to arrive at the most cost-effective pavement option, an initial cost assessment was made of the six pavement design alternatives (options) and associated drainage structures capable of providing the required performance over the design life. The initial construction costs were computed based on the current construction rates used in Ghana. A typical steep road section was 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. Costing was mainly based on the pavement structures, as well as on variables such as materials, production, haulage distance, labour, construction and equipment. In addition, a “do-nothing” option was proposed to compare the construction cost with the six pavement 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.

Table 1 indicates the total construction costs of the pavement structures. The costing was done based on the initial cost estimates, and cost per square metre for the six pavement options. It can be seen that the 70 mm ultra-thin reinforced concrete pavement (6 mm diameter mild steel), placed on mechanically stabilised lateritic base has the lowest construction cost, whereas a 50 mm hot-mix asphalt surfacing with processed lateritic gravel and AC-10 bitumen placed on 200 mm stabilised base has the highest construction cost. 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.

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. It should also be mentioned that the hot-mix asphalt surfacing with screened lateritic gravels 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.

Table 1: Initial Construction Cost for Pavement Options

Option #	Pavement structure	Provisional Sum GBP	Lined Side Drains Cost GBP	Pavement Layers Cost GBP	Culvert Cost GBP	Estimated Total Cost GBP	Cost Per Sq. Metre GBP
1	70 mm ultra-thin reinforced concrete on 200 mm mechanically stabilised laterite base	12 450.00	28 636.00	53 340.00	6000.00	100 426.00	66.95
2	Screened gravel single Otta seal [14mm-25mm aggregates] on 100mm mechanically stabilised base and 150mm mechanically stabilised subbase	12 450.00	28 636.00	55 200.00	6000.00	102 286.00	68.19
3	Stone setts / cobbles [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	Interlocking concrete 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 hot-mix asphalt with processed lateritic gravel and AC-10 bitumen on 200 mm mechanically stabilised base	12 450.00	28 636.00	89 100.00	6000.00	136 186.00	90.79

Note: 1GBP = GHS 5.3

LIFE-CYCLE COST AND DISCUSSION

It is a common practice to use the life-cycle cost to determine the most cost-effective options for road construction projects. A basic method utilised by many transportation agencies, and selected for this paper, is the present worth of cost. This method discounts all future sums to the present using an appropriate discount rate. The six alternative pavement designs were compared on the basis of the present worth of the life-cycle costs. The main economic factors known to determine the cost of a road include the analysis period, the construction cost, the maintenance costs and the real discount rate. The empirical relationship to determine the present worth of cost is solved by using Equation 2.

$$PWOC = C + M_1(1+r)^{-x_1} + \cdots + M_j(1+r)^{-x_j}) - S(1+r)^{-z} \qquad (2)$$

where, PWOC = present worth of costs; C = present cost of initial construction; M_j = cost of the j^{th} maintenance measure expressed in terms of current costs; r = real discount rate; x_j = number of years from the present to the j^{th} maintenance measure, within the analysis period (where x_j = 1 to z); z = analysis period; S = salvage value of pavement at the end of the analysis period expressed in terms of present values.

The following assumptions were made:

- The pavement structures selected for this study are in the same road category (i.e. low-volume roads). Road user costs for the six pavement alternatives were considered to be negligible.
- The suggested analysis period for rural access roads is 20 years and that of lightly trafficked rural roads is 30 years (Technical Recommendations for Highways—TRH4, 1996). Based on these number of years, the analysis period used in this paper is 25 years (average value) and starts from 2017.
- The salvage values were assumed to be zero for all pavement options, even though there would still be some value regained in most pavements and especially more regained in the ultra-thin concrete and the interlocking concrete block pavements.
- All pavements options are subject to similar traffic and climate, and are assumed to have the same equivalent standard axle loads.
- The discount rate of 12% used by Ampadu et al. (2015) for the life-cycle cost analyses of eight gravel roads in Ghana were adopted for this study. The value of 12% was also used for the economic cost analysis of the World Bank/ Department for International Development (DFID) projects from six countries (Tsunokawa 2010).
- Typical maintenance measures are based on known performance of similar pavement structures/ materials to the six pavement structures for this study.

Future Maintenance

When different pavement types are compared on the basis of cost, the future maintenance costs should be included in the analysis to ensure that a reasonable comparison is made TRH4 (1996). For this study, typical maintenance schedules for the six pavement options were used in the analysis. The analysis model assumed that a double surfacing seal would be maintained with fog sprays at 3 and 10 years at the cost of GBP 0.52/m², and reseal at 12 years at the cost of GBP 1.05/m². It was further assumed that the maintenance schedule and cost for screened gravel single Otta seal would be two times the double surfacing seal as the total surfacing life is assumed to be 5-8 years. The asphalt surfacing would be maintained with a thin asphalt (<30 mm) at 15 years, and would cost GBP 5.24/m². Detailed technical information obtained from Hans Brink & Associates (South Africa, 2016) indicated that the ultra-thin reinforced concrete would be repaired (shrinkage and thermal cracks) in less than one year intervals, but after 10 years, no repairs will be expected because of very low traffic. It is estimated that the cost of these repairs would be 1% of initial construction cost of the pavement structure. The pavement with an interlocking concrete paving block would be maintained (removal and replacement of damaged blocks) at 10 years and thereafter every five years at the cost of 5% of initial construction cost at GBP 4.4/m². With respect to stone setts /cobble stones, the major maintenance strategy would be removal of weeds, and in an unlikely case, minimal repairs of damaged stones after 20 years at the cost of GBP 1.05/m².

Total Life Cycle Cost

The result of the present worth of cost analysis with the initial construction and future maintenance is presented in Table 2 for the six pavement options. It shows that all alternative surfacings with concrete, bituminous and stones pavements, are economically feasible with an average life-cycle cost of GBP 80/m² at a real discount rate of 12%. The 70 mm ultra-thin reinforced concrete placed on 200 mm mechanically stabilised laterite base is significantly less costly than the others, whereas the 50 mm hot-mix asphalt with processed lateritic gravel and AC-10 bitumen, placed on 200 mm mechanically stabilised base emerged as the option with the highest life-cycle cost. Usually, if the difference in present worth of costs between two alternatives is 10% or less, then the present worth of costs of the two alternatives is taken to be the same (TRH4, 1996). For instance, the life-cycle cost for the 70 mm ultra-thin reinforced concrete and the gravel single Otta seal surfacings can be taken as the same (i.e. cost difference is 1.2%). The life-cycle cost of the 50 mm hot-mix asphalt, interlocking paving block, and double seal is comparable (i.e. 3% between the asphalt and double seal; 2% between paving block and double seal and 0.7% between the asphalt and paving block). The difference between the life-cycle costs for the stone setts/cobbles and the double seal surfacings is also comparable (i.e. cost difference is 8.6%). Generally, the cost difference between the initial construction, and total life-cycle was insignificant for all six pavement options selected for this study.

A sensitivity analysis was conducted on the life-cycle costs at discount rates of 8%, 10% and 12%. The results are included in Table 2, and presented graphically in Figure 4. The sensitivity analysis shows that the discount rate can vary from 8% to 12 % with no significant influence on the present worth of costs for the six pavement options. The costs are slightly high at a discount rate of 8% for all the pavement options.

Table 2: Total life-cycle cost of paving options

Surfacing	**Surfacing Life (Years)**	**Structural Maintenance**		**Maintenance Cost /m² (GBP)**	**Initial Cost / m² (GBP)**	**Life-Cycle Cost / m² (GBP¹)**		
		Strategy	**After x years**			**r = 8%**	**r = 10%**	**r = 12%**
70 mm UTRC	30-50	Repairs	20	0.37	66.95	70.58	70.10	69.71
50 mm HMA	15-20	overlay	15	5.24	90.79	92.44	92.05	91.75
Paving Blocks	30-50	Repairs	10	4.40	87.85	94.03	92.26	91.11
Gravel Single Otta Seal	5-8	Reseal	3	4.20	68.19	71.05	70.79	70.57
Stone Setts /Cobbles	20-30	Repairs	20	9.44	81.15	81.38	81.31	81.26
Double Seal	10-15	Fog spray	3	0.52	88.19	89.27	89.12	89.00
		Fog spray	10	0.52				
		Reseal	12	1.05				

¹: 1GBP = GHS 5.52

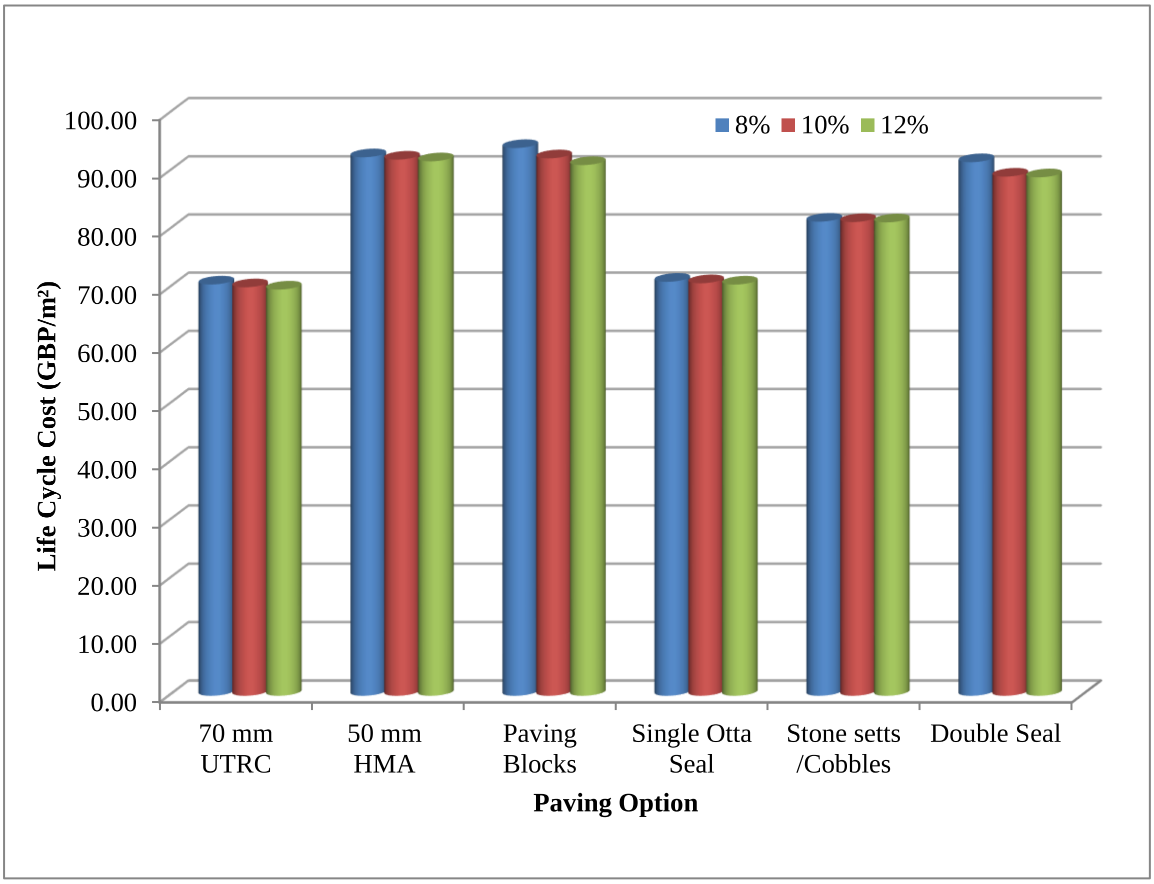

Figure 4: Comparison of life-cycle cost at three discount rates

CONCLUSIONS

The following conclusions are drawn from the economic cost analysis of the six pavement options presented in this paper:

- 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 a project like this, where only the steep hill sections are considered. This has been clearly demonstrated as the cost difference between the initial construction and the total life-cycle was found to be insignificant for all six pavement options selected for this study. However, it is noted that the expected low rate of maintenance schedules and the negligible adverse effect of traffic loading (80 vpd) on these pavements (attributes of low-volume roads) contributed to the negligible difference in the costs.
- Based on the economic cost analysis, all six pavement options are feasible for steep sections on feeder roads, but the ultra-thin reinforced concrete pavement was found to be the most cost-effective option. The relatively high initial cost of the hot-mix asphalt pavement option, and hence, higher life-cycle cost is attributed to the assumed high haulage cost component due to long distances between asphalt processing plants and the construction sites, and the use of more expensive construction equipment.
- It is not cost-effective to use gravel wearing course on the steep hilly sections of the feeder roads in Ghana (i.e. total cost is GBP 106.07 per square metre) compared with the most expensive pavement option, i.e. the hot-mix asphalt that would cost GBP 92 per square metre. Although all six surfacing options would be beneficial from an economic viewpoint, the current policies of the

DFR may influence the final decision on which particular pavement options to adopt for addressing the problems associated with the steep gradients on feeder roads in Ghana.

RECOMMENDATIONS

Based on this study, the following recommendations are made:

- The 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 structures, the materials used, type of surfacing, construction processes and maintenance or rehabilitation techniques.
- Innovative and comprehensive maintenance strategies that include cost-effective measures to improve surfacing condition and structural maintenance should be identified and evaluated for the proposed pavement options. This would assist in the life-cycle cost analysis and pragmatic decision-making.
- As mechanically stabilised lateritic soils constitute the common materials for the base layers of all pavement options, further economic analysis of their utilisation is needed for 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 consider using the outcomes of this study for further investigation of these natural materials.
- The DFR should strictly adopt effective drainage system and erosion control measures to minimise the life-cycle costs of the pavement options. For instance, the camber for hilly sections should be up to 5% to provide adequate channelling of surface runoff. In addition, proper side drains, preferably lined with concrete, must be provided at steep road sections to reduce maintenance costs.

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