Alternative Surfacing for Steep Hill Sections in Ghana – Phase 2

Final Design Report

Labour-intensive construction of a low-volume road

Council for Scientific and Industrial Research (CSIR), South Africa

Building and Road Research Institute (BRRI), Ghana

ReCAP Reference number: GHA2065B

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Cover photo: Construction of project road alignment and foundation.

Quality assurance and review table

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ReCAP Database Details: Alternative Surfacing for Steep Hill Sections in Ghana – Phase 2

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Abstract

The AfCAP project on steep hill road sections is investigating the suitability of alternative surfacing on steep gradients of low-volume (feeder) roads in Ghana. This is the final design report, which provides details of the research activities undertaken during the final design stage of the project. The main objective of this report was to finalise the research matrix of alternative surfacings, and to present the final designs, drawings, construction procedures and initial construction costs of all road pavement options to be constructed and monitored on demonstrations sections with steep hill gradients ranging from 12% to 22%. A total of 12 pavement types with five alternative surfacing (stones of approximately 150 mm in size, interlocking block paving, cold mix asphalt, thin mesh-reinforced concrete and roller-compacted concrete) were designed for demonstration purposes. The various data sets and all relevant information established from the final design activities are documented and kept as primary source of information for current and potential future ReCAP projects. Specifically, the database established from the final designs will complement the ReCAP on-going regional project on development of a road material database for use at national levels.

Key words

Low-volume roads, steep gradients, modular paving units, roller-compacted concrete, thin mesh-reinforced concrete, cold mix asphalt.

Acknowledgements

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Research for Community Access Partnership (ReCAP)

Safe and sustainable transport for rural communities

ReCAP is a research programme, funded by UK Aid, with the aim of promoting safe and sustainable transport for rural communities in Africa and Asia. ReCAP comprises the Africa Community Access Partnership (AfCAP) and the Asia Community Access Partnership (AsCAP). These partnerships support 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. The ReCAP programme is managed by Cardno Emerging Markets (UK) Ltd.

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Acronyms, Units and Currencies

AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transport Officials
ACI	American Concrete Institute
ADT	Average Daily Traffic
AfCAP	African Community Access Programme
AIV	Aggregate Impact Value
BRRI	Building and Road Research Institute, Ghana
CBR	California Bearing Ratio
CESA	Cumulative Equivalent Single Axles
CMA	Cold-Mix Asphalt
CML	Central Materials Laboratory
CPS	Concrete Stone Pitching
CSIR	Council for Scientific and Industrial Research
DCP	Dynamic Cone Penetrometer
DESA	Daily Equivalent Single Axles
DFID	Department for International Development (UK)
DFR	Department of Feeder Roads
DN	DCP Number (rate of penetration in mm/blow)
ERA	Ethiopian Road Authority
ESA	Equivalent Single Axles
GHA	Ghana Highways Authority
Ghacem	Ghana Cement Company
GSA	Ghana Standards Authority
GSSRB	Ghana Standard Specifications for Road and Bridge Works
HMA	Hot-Mix Asphalt
HPS	Hand Packed Stones
HVR(s)	High-Volume Road(s)
ICBP	Interlocking Concrete Block Paving
LVR	Low-Volume Roads
LVSRs	Low-Volume Surfaced Roads
MC	Moisture Content
MDD	Maximum Dry Density
MESA	Million Equivalent Single Axles
MoT	Ministry of Transport
MRH	Ministry of Roads and Highways
OMC	Optimum Moisture Content
OPC	Ordinary Portland Cement
PMU	Project Management Unit
PPC	Pozzolanic Portland Cement
RCC	Roller-Compacted Concrete
ReCAP	Research for Community Access Partnership
SEACAP	South East Asia Community Access Programme
TLC	Traffic Loading Class
TMRC	Thin Mesh-Reinforced Concrete
TOR	Terms of Reference
TRL	Transportation Research Laboratory
vpd	Vehicles per day

Executive summary

This is a final design report on the work carried out under Phase 2 of the project on alternative surfacings for steep hill sections on low-volume (feeder) roads in Ghana. The project is investigating the suitability of modular paving (stones and concrete block paving), cold mix asphalt, thin mesh-reinforced concrete, and roller-compacted concrete on hilly gradients that range from 12 to 20%.

The main body of the report presents details of the final materials and road pavement designs for five demonstration and one control sections. The full test matrices and variables of the demonstration sections are presented in the report. These matrices are composed of three variables in terms of mix designs (different combinations of materials and additives) and modular paving types. The report also discusses the pavement and drainage structural designs of the demonstration sections and provides a detailed analysis of their structural layers.

Following the completion of the project draft design report, the first stakeholder workshop of the project was held at the offices of the DFR in Accra. The aim of the workshop was to discuss the proposed research matrix, materials and pavement designs, and debate the initial construction costs of the pavement options. A summary of the key deliberations during the workshop, and the outcomes of all follow-up meetings with the AfCAP Project Management Unit (PMU) and the DFR, are presented in this report. Furthermore, during ReCAP's Inter-Regional Implementation Conference an ad hoc project meeting was held in Uganda (November 2017) to finalise all outstanding issues related to the research matrix and final designs. Discussions dealt with acceptable gradients, geometric characteristics of the carriageway and the use of conventional pavement design methods (e.g. AASHTO design guide) in lieu of the AfCAP DCP-DN design method – because estimated traffic characteristics far exceeded threshold DCP Traffic Load Class (TLC) design values of low-volume roads. A CBR test was therefore included in the laboratory testing programme for the pavement design and analysis. However, the laboratory DCP-DN tests were continued in order to establish a database of materials for the DFR and to complement the AfCAP regional project database.

Materials design

The materials design involved the laboratory assessment of naturally occurring and quarry materials. Mix designs for cold-mix asphalt and concrete were conducted to determine the optimal construction materials for the demonstration sections. To optimise the use of naturally occurring materials, attention was paid to the compatibility between the pavement structure, the materials used, the type of surfacing, construction processes and, above all, control of moisture through effective drainage. A summary of materials testing and design activities are provided below:

- As part of the materials assessment, the project catchment area was scouted for natural gravels with the intent of using these materials in the pavement layers (i.e. base, subbase and subgrade) of the demonstration sections. Three existing borrow pits along the route corridor and two naturally occurring gravels on the road alignment were investigated. The quartz sandstone encountered at chainage 3+057 area is predominantly made of quartz grains and lithic material. This stone is to be used in the hand-packed stone pavement, as well as the lined trapezoidal drains and scour checks. It was established that the existing and operational quarries close to the project road can be the main source of materials for the project.
- The natural gravel materials of the three existing borrow pits were estimated to be approximately 41 500 m³, whereas those of two new borrow pit materials were 40 000 m³. Apart from one of the new borrow pits that is 11 km from the project road, the maximum distance of the other four borrow pits from the project site is 1.4 km. Samples from the three borrow pits were found to be predominantly sand, with varying proportions of clay, silt and gravel. They did not meet the strength criteria for subbase and base layer materials. Therefore, materials from two borrow pits were blended (mechanically stabilised in the laboratory) with quarry product to improve their properties. The CBR values (soaked conditions) of blend materials ranged from 26 to 41 percent; hence they met the subbase/base materials requirements for pavement construction. The natural gravels with a CBR value (soaked conditions) of between 10 and 16 percent met the strength requirements of typical subgrade materials.

- Generally, there is little experience in the design and construction of cold-mix asphalt worldwide, and limited information and universal specifications are available for cold-mix asphalt design. The DFR and Ghana Ministry of Roads and Highways (MRH) have almost no specifications for cold-mix asphalt design, except for when it comes to the engineering properties of aggregates and binders suitable for the mix. Two of the three cold asphalt mixes designed were promising. These two mixes had additives (cement/lime) in the mix composition, which is believed to enhance their engineering properties. The third mix would need modifications to meet design requirements during construction. The three mixes selected for demonstration had optimum emulsion contents of 10.2%, 10.7% and 11.2%, and they had corresponding air void contents of 8.1%, 15.5% and 10.4%, respectively.
- A total of 21 concrete mix derivatives were designed in this project. Out of these, seven mixes would be constructed for the demonstration of thin mesh-reinforced concrete (TMRC) (3), roller-compacted concrete (RCC) (3) and interlocking concrete block paving (ICBP) (1). The compressive strength test results for the various concrete mixes were above the recommended characteristic 28-day compressive strength of 30N/mm² for this project. The average values for the TMRC, ICBP and RCC were 30.2N/mm², 34.6N/mm², and 29.9N/mm², respectively. The incorporation of the in-situ crushed stones in the respective concrete mixes did not affect the overall strength when compared to the mixes with 100% quarry stones. However, the laterite gravels had relatively low strength values. As expected, concrete derivatives with only ordinary Portland cement gave better results when compared to those with modified cement (i.e. Pozzolana Portland Cement)
- Crushed stones and quarry dust materials for surfacing, drainage, stabilisation and concrete works are available at commercial sources in Kumasi (100 km from the project site) and the surrounding areas (e.g. Nkawkaw, 5 km from project site). Additionally, stabilisation materials (cementitious) and emulsions can be sourced from Kumasi and the surrounding areas. It is envisaged that CEM II 32.5 (Cement) will be utilised as the stabilising agent for the base/subbase materials.

Pavement and drainage design

A total of 12 pavement options were derived from five alternative surfacing techniques (stones, interlocking block paving, cold-mix asphalt, thin mesh-reinforced concrete and roller-compacted concrete) for demonstration.

Current low-volume road design tools and manuals do not adequately cover analysis and design of the pavement surfacing types. The available software are sophisticated, expensive and have been developed mostly for high-volume roads. The AASHTO Pavement Design Guide 1993 (commonly used in Ghana for road designs) was used for the design of all pavement options. A 30-day trial version of the StreetPave software (product of American Concrete Pavement Association) was used to verify concrete slab thickness of the rigid pavements.

The pavement design considerations assumed the following parameters:

- The suggested analysis period for rural roads is 20 years and that of medium to lightly trafficked rural roads is 30 years. Based on these numbers of years, the analysis period proposed for the project road is 25 years (average value) and starts from 2018. Based on the performance of similar pavement structures in Ghana, a design life of 15 years was assumed for the pavement structures.
- A base-year traffic characteristic determined from the total Average Daily Traffic (ADT) on the project road was estimated to be 433 vehicles (one direction). Traffic was projected to consist of 70% small vehicles (taxis and private cars); 27% medium vehicles (light and medium trucks – 20% and buses – 7%), and heavy vehicles (heavy trucks, semi-trailers and truck trailers) made up about 3% of the traffic streams.
- Based on the uncertainty about the traffic volume and axles expected on the project road, a reasonable growth rate of 4% (correspond to 2.3 million Equivalent Single Axle Loads, or 2.3 MESA) was used for the pavement design. The growth rate was determined from a sensitivity analysis that considered increasing the growth rate from 2% to 6% by 1 percentage increments. Only commercial vehicles were used to estimate the total ESALs (relative damage exponent of 4 was assumed).
- Traffic speed was assumed to be 30km/h (based on Ghana's road design guide for feeder roads). The vertical longitudinal gradients for the demonstration sections vary between 8% and 20%.

- Geometric design parameters followed the general requirements of AfCAP LVR manuals (cross-fall of 3%, for instance). Since the project site is characterised by significant cuts and fills, a carriageway width of 7.5 m and a paved shoulder width of 1 m were chosen (roadway width of 9.5 m). Demonstration sections usually have two lanes – each 3.75 m wide – thus, a roadway width of 7.5 m, and a 1 m wide shoulder, paved with single chip seal.
- The flexural strength and elastic modulus of concrete mixes were estimated using well-established American Concrete Institute (ACI) correlations with compressive strength.
- To keep the drainage system working efficiently, a lined trapezoidal drain was the preferred choice for the project road. This was particularly apt since the project is in mountainous terrain, with gradients between 8% and 20%, that experiences prolonged high annual rainfall. It was therefore necessary to consider lining the side drains in the steep sections to avoid severe erosion. All outfalls / mitre drains are also to be lined to ensure resistant to severe erosion.
- A rainfall intensity of 125 mm/hour with a frequency of occurrence of 10 years return period was used for the design of side drains. The flow capacity of the proposed drains was calculated to be 1.697 m^3/second, which is in excess of the expected discharges for all three respective drainage sections of the project road.
- A detailed bill of quantities (BoQs) was prepared for all pavement options. Since the contractor for the project was selected by the DFR, the BoQs will only serve as a guideline to monitor the contractor's activities and expenses during construction.

Final pavement designs

The final pavement designs can be summarised in the table below.

<table>
<tr><th>Pavement surfacing</th><th>Description of section</th><th>Structural design details</th></tr>
<tr><td>Concrete stone pitching (CSP)</td><td>Chainage 2+225 to 2+310. Total length of section is 85 m, constructed on an average gradient of 16.0%</td><td>Materials and properties:
– 100-150 mm cube stone pitched in a lean concrete (C15)
– 25mm river sand or quarry dust
– 150mm layer stabilised with cement (4-4.5%); PI <10; CBR = 100 (soaked)
– 150mm drainage layer 19 to 37mm stone
– Subgrade/formation: Natural gravel, min CBR = 15 (soaked)
<table>
<tr><th>Layer</th><th>Material</th><th>Thickness</th><th>Strength</th></tr>
<tr><td>Surfacing</td><td>CSP</td><td>150 mm</td><td>C15</td></tr>
<tr><td>Bedding</td><td>SBL</td><td>25 mm</td><td>-</td></tr>
<tr><td>Base</td><td>Cement stabilised</td><td>150 mm</td><td>CBR = 100</td></tr>
<tr><td>Subgrade</td><td>Natural gravel</td><td>150 mm</td><td>CBR = 15</td></tr>
</table></td></tr>
<tr><td>Hand packed stones (HPS)</td><td>Chainage 2+310 to 2+395. Total length of section is 85 m, constructed on an average gradient of 14.4%</td><td>Materials and properties:
– 100-150 mm cube stone
– SBL: 25mm river sand or quarry dust
– 150mm layer stabilised with cement (4-4.5%); PI <10; CBR = 100 (soaked)
– 150mm drainage layer 19 to 37mm stone
– Subgrade/formation: Natural gravel, min CBR = 15 (soaked)
<table>
<tr><th>Layer</th><th>Material</th><th>Thickness</th><th>Strength</th></tr>
<tr><td>Surfacing</td><td>CSP</td><td>150 mm</td><td>-</td></tr>
<tr><td>Bedding</td><td>SBL</td><td>25 mm</td><td>-</td></tr>
<tr><td>Base</td><td>Cement stabilised</td><td>150 mm</td><td>CBR = 100</td></tr>
<tr><td>Subgrade</td><td>Natural gravel</td><td>150 mm</td><td>CBR = 15</td></tr>
</table></td></tr>
<tr><td>Interlocking concrete block paving (ICBP)</td><td>Chainage 2+395 to 2+480. Total length of section is 85 m, constructed on an average gradient of 12.9%</td><td>Materials and properties:
– 75mm interlocking concrete block paving
– Concrete made from OPC, sand and quarry stones. Minimum 28-day characteristic compressive strength of 30 MPa
– Approximate size; 300 x 220 x 75 mm (H x W x T)
– 150mm layer stabilised with cement (4-4.5%); PI <10; CBR = 100 (soaked)
– 150mm drainage layer 19 to 37mm stone</td></tr>
</table>

<table>
<tr><td></td><td></td><td>– Subgrade/formation: Natural gravel, min CBR = 15 (soaked)
<table>
<tr><th>Layer</th><th>Material</th><th>Thickness</th><th>Strength</th></tr>
<tr><td>Surfacing</td><td>ICBP</td><td>75 mm</td><td>C30</td></tr>
<tr><td>Bedding</td><td>SBL</td><td>25 mm</td><td>-</td></tr>
<tr><td>Base</td><td>Cement stabilised</td><td>150 mm</td><td>CBR = 100</td></tr>
<tr><td>Subgrade</td><td>Natural gravel</td><td>150 mm</td><td>CBR = 15</td></tr>
</table></td></tr>
<tr><td>Roller-compacted concrete (RCC)</td><td>Chainage 2+480 to 2+735. Total length of section is 255 m; three different surfacing mixes (85 m long each, average gradient of 17.2%).</td><td>Materials and properties:
– Concrete made from OPC, pozzolana, sand, quarry stones, and screened natural. Minimum 28-day characteristic compressive strength of 30 MPa
– 150mm layer stabilised with cement (4-4.5%); PI <10; CBR = 100 (soaked)
– 150mm drainage layer 19 to 37mm stone
– Subgrade/formation: Natural gravel, min CBR = 15 (soaked)
<table>
<tr><th>Layer</th><th>Material</th><th>Thickness</th><th>Strength</th></tr>
<tr><td>Surfacing</td><td>RCC</td><td>110 mm</td><td>C30</td></tr>
<tr><td>Base</td><td>Cement stabilised</td><td>150 mm</td><td>CBR = 100</td></tr>
<tr><td>Subgrade</td><td>Natural gravel</td><td>150 mm</td><td>CBR = 15</td></tr>
</table></td></tr>
<tr><td>Thin mesh-reinforced concrete (TMRC)</td><td>Chainage 2+735 to 2+990. Total length of section is 255 m; three different surfacing mixes (85 m long each, average gradient of 17.9%).</td><td>Materials and properties:
– Concrete made from OPC, pozzolana, sand, quarry stones, and screened natural. Minimum 28-day characteristic compressive strength of 30 MPa
– High yield strength steel reinforcement bars > 400 MPa, 6 mm diameter @ 150mm c/c in longitudinal and transverse directions.
– 150mm layer stabilised with cement (4-4.5%); PI <10; CBR = 100 (soaked)
– 150mm drainage layer 19 to 37mm stone
– Subgrade/formation: Natural gravel, min CBR = 15 (soaked)
<table>
<tr><th>Layer</th><th>Material</th><th>Thickness</th><th>Strength</th></tr>
<tr><td>Surfacing</td><td>TMRC</td><td>75 mm</td><td>C30</td></tr>
<tr><td>Base</td><td>Cement stabilised</td><td>150 mm</td><td>CBR = 100</td></tr>
<tr><td>Subgrade</td><td>Natural gravel</td><td>150 mm</td><td>CBR = 15</td></tr>
</table></td></tr>
<tr><td>Cold mix asphalt (CMA)</td><td>Chainage 3+245 to 3+500. Total length of section is 255 m; three different surfacing mixes (85 m long each, average gradient of 13.7%).</td><td>Materials and properties:
– Cold mix asphalt with base emulsion (k1-70 cationic type) made from cement /lime additives, sand, quarry stones, and screened lateritic gravels
– 150mm layer stabilised with cement (4-4.5%); PI <10; CBR = 100 (soaked)
– 150mm drainage layer 19 to 37mm stone
– Subgrade/formation: Natural gravel, min CBR = 15 (soaked)
<table>
<tr><th>Layer</th><th>Material</th><th>Thickness</th><th>Strength</th></tr>
<tr><td>Surfacing</td><td>CMA</td><td>50 mm</td><td>ITS /NA</td></tr>
<tr><td>Base</td><td>Cement stabilised</td><td>150 mm</td><td>CBR = 100</td></tr>
<tr><td>Subgrade</td><td>Natural gravel</td><td>150 mm</td><td>CBR = 15</td></tr>
</table></td></tr>
</table>

Construction and initial cost

Procurement for the works did not go through a separate tender process as DFR had already awarded a contract for the project prior to the start of this research project. As the latter involves new pavement types and construction techniques, the project team and identified experts will provide technical guidance to the contractor’s team during construction and implementation of the research.

A one-day pre-construction training workshop is planned to assist the DFR and the contractor with any technical aspects involved in the construction of the pavements options. The workshop will outline the construction method of the different pavements to the DFR regional and district engineers who are involved in the project. Following the workshop there will be an on-site demonstration of the construction of thin mesh-reinforced concrete (budgeted for in this project), and roller-compacted concrete (not budgeted for in this project). It is assumed that the knowledge gained by engineers from the DFR in the cold-mix asphalt demonstration project in Koforidua will be applied in the construction of the cold-mix asphalt surfacing of this project. However, the project team will also provide guidelines on the construction of cold-mix asphalt during the training workshop.

Prior to the commencement of construction works for the demonstration sections, five trial sections are to be constructed to determine the behaviour of the alternative surfacing types during placing and compaction, as well as to verify the various construction techniques and the contractor's equipment. This activity would also serve as training for the contractor and the construction team.

Comparison of initial construction costs

Construction work activities and current rates of local labour and equipment in Ghana were used for the costing. Construction cost data for each of the different pavement options including, the control section was obtained based on the final designs. Costs were prepared for each variable within a demonstration section matrix. In comparison, the 50 mm cold-mix asphalt surfacing option designed with emulsion and quarry stones has the highest cost, whereas the 100 mm roller-compacted concrete with processed lateritic gravel and quarry stones has the lowest cost. The costs of all three variables of the 75 mm thin mesh-reinforced concrete pavement are comparable to the three variables of the roller-compacted pavement.

Erosion and slope stability protection

Erosion measures

The project catchment area is characterised by steep hills, high rainfall and high temperature and the project road will need to function under these differential conditions. For this reason, adequate erosion and drainage measures need to be implemented for the demonstration sections.

- Single-chip seal shoulders (1 m in length) are provided along the entire demonstration section to provide moisture protection for the pavement layers and also to reduce erosion of the shoulders.
- Thin mesh-reinforced and roller-compacted concrete surfacings are to be placed directly on a lean concrete base to increase the resistance to erosion, as well as the strength and load-bearing capacity.
- The provision of a granular base/subbase layer in the pavement structure would also minimise the potential for erosion and loss of support beneath the lean concrete.
- The width of the base course for all pavements is to be extended beyond the roadway to provide increased edge support and reduce erosion potential.
- At least one layer of all pavements to be demonstrated is stabilised (with cement /lime stabilisation or mechanical modification).

Slope stability

The project site has many steep cut surfaces or fills embankments (average slope of more than 45%). However, the Terms of Reference (ToR) did not include design and construction of slope stability on the project. Hence this activity is the responsibility of the DFR. In spite of this, the project team has provided technical recommendations in this report.

Bio-engineering techniques (e.g. the use of trees, shrubs and other grasses to stabilise slopes, protect embankments, and to provide live check structures in drains) is recommended for this project. This technique is known to employ a more cost-effective approach to reduce erosion and slope instability. In addition, bio-engineering techniques embody both slope stabilisation and slope protection.

The following significant observations were made during the project site investigation:

- From chainage 2+425 to 2+700, several landslides occurred on the cut slope surfaces due to heavy rains. The slides occurred in the conglomeration of silty sandstone rock fragments.
- Visual examination of the cut slope surface at chainage 2+780 suggests an unstable slope with trees at the top of the slope.
- From chainage 2+840 to 2+975, water was seen dripping from the cut slope surface of the moderately weathered sandstone formation.

- At chainage 2+900, sub-surface water was seen to drain from the cut (exposed) surface of the side slopes of the rock.

Conclusions and recommendations

Conclusions

The conclusions made during the project final design phase are summarised as follows:

- Successful utilisation of naturally occurring and locally produced materials such as calcined clay pozzolana or screened lateritic gravels in cold-mix asphalt and concrete (both thin mesh-reinforced and roller-compacted) mix designs for the project will reduce construction costs for the DFR when these surfacing techniques are fully implemented on steep sections of feeder roads.
- All five surfacing options proposed for the project constitute new knowledge that will be transferred to the DFR and MRH engineers, consultants, and contractors who will take part in the training and capacity-building activities of the project. Specifically, the use of thin mesh-reinforced concrete, roller-compacted concrete and cold-mix asphalt on steep gradients is new to the DFR. The use of labour intensive-based construction is the primary and guiding philosophy of the selection and design of these alternative surfacing materials.
- Procedures/guidelines have been established for the design of materials and pavement purposes. A summary of material properties and the test methods used in their evaluation are to be documented and included in future specifications for the DFR and Ghana MRH. The designs and proposed guidelines need to be understood by the contractors and the DFR. The process includes visits and meetings with staff in the DFR, MRH, consultants and the contractors.
- The production of the asphalt and concrete mixes will require control over quantities, mix proportions and construction tolerances, as well as strict supervision to achieve a mix with good performance. Adequate on-site training of the contractor, supervisory staff and the labour force on the project is required. Specifically, the use of thin mesh-reinforced concrete, roller-compacted concrete and cold-mix asphalt will be new to the DFR.
- Mechanical stabilisation of the base/subbase materials is proposed, although a separate cost comparison is needed to compare it with a cement/lime-treated base before the final decision is made for construction.
- Relevant sections of the Ghana Standard Specifications for Road and Bridge Works (GSSRB) section on concrete works are inadequate to assist in mix designs; hence the procedures in the ACI manual were followed for the concrete mix designs. A mix concrete design workbook/spreadsheet has subsequently been established for this project.
- The CSIR and ReCAP PMU have agreed to include non-reinforced concrete surfacing to compare performance with the roller-compacted and thin meshed-reinforced concrete surfacings. This surfacing was proposed during a meeting between the AfCAP PMU (represented by Deputy Team Leader – Infrastructure), and two AfCAP Consultants (Aurecon and the CSIR) on 6 March 2018 in South Africa
- The construction guidelines presented for the alternative surfacings are interim. These guidelines will be further developed into a separate Guideline document for construction of alternative surfacing for steep sections on low-volume roads. The Guideline will form part of the final project deliverable (i.e. Final Report).
- Similarly, the initial construction cost presented in this report is interim, and will be updated after construction of all five alternative surfacings is completed. It should be mentioned that the initial cost is based on the current USD exchange rate and may vary at the time of construction.

Recommendations

Based on the findings of the final design stage of the project, the following recommendations are made:

- The slope stability works for demonstration sections should be top priority, and preferably should be completed before construction of demonstration sections.
- The construction of demonstration sections must be of the highest quality, conforming fully to the standards prepared for the project. Conventional quality control measures based on the DFR requirements should be implemented during construction.

- DFR should clarify deviations from current norms and standard approach of feeder roads construction to the contractor, and highlight research as key component in this project.
- The project has already experienced a challenge of delays, and that has impacted some deliverables. The DFR in consultation with the project team should enforce all obligations of the contractor, such as
  - detailed construction works programme, and
  - making available the list of key project staff (Resident engineer, materials technician/ supervisor, foreman, and surveyor) and equipment holding for capability assessment. This would also guide the project team in the development of training materials for the project.
- As it is critical to establish base line data for monitoring, it is important that the contractor does not execute any activity without the consent of the project team.
- The contractor should strictly adhere to the drainage system and erosion control measures to minimise the life-cycle costs of the pavement options.
- The AfCAP project on RCC (previously not on steep slopes) will be demonstrated on the project road, although material sources and the design approach appear different from those in the steep gradient project. However, the compressive strength results do not significantly differ. The establishment of a demonstration section for the RCC project on the steep gradient project road will have the following benefits:
  - Performance monitoring will be done in a similar environment under the same supervision
  - Construction services will be provided by the same contractor
  - Opportunity to experiment different RCC mix designs and construction methods
    - The steep gradient project will demonstrate three RCC mixes with varying materials including naturally occurring gravels and quarry materials with water/cement ratio of 0.33 for all mixes.
    - The AfCAP RCC project recommended four mixes with water/cement ratios of 0.46 and 0.48 and all used stones from commercial quarries only.
  - On-site training opportunity – whereas training is a main component in the contract for the RCC project, the steep gradient project does not have such an activity in the contract. This is so because the demonstration of RCC was not part of the original contract on steep gradients. Thus, it is possible to have only one training programme organised for the two projects.
  - The pavement foundation of the steep gradient project road is already prepared, so there will be no need for further site investigations prior to the construction of the RCC sections. In addition, the steep gradient project team has already evaluated materials (gravels) for the construction of base and subbase layers for the demonstration sections. The RCC project can utilise these materials.
  - Crushed stones and quarry materials for surfacing, drainage, stabilisation and concrete works are available at commercial sources in Kumasi (100 km from project site) and the surrounding areas (Nkawkaw, 5 km from project site). Thus, the RCC project can source locally available materials from the same quarry that will supply materials to the steep gradient project.
- Pavement construction should not commence without at least two project team members present on site.
- The contractor should be well resourced to procure /source enough materials and equipment/tools before commencement of the works.
- The project team will establish a database of complete and accurate records of the construction process (including photographs and videos where appropriate), material sources and properties, construction procedures/guidelines, quality control procedures and results. This will form a baseline data for performance monitoring activities of the demonstration sections.

1 Background

1.1 Background to this report

This is a final design report on the work carried out in Phase 2 of the project on alternative surfacing for steep hill sections on low-volume (feeder) roads in Ghana. The project investigated the suitability of five alternative surfacing types (modular paving stones, interlocking concrete paving, cold mix asphalt, thin mesh-reinforced concrete and roller-compacted concrete) on steep gradients of low-volume roads in Ghana. A detailed background of the current project was provided in the Inception Report and Draft Design Report. These reports are available on the ReCAP website (www.research4cap.org).

This is the final design report on the work carried out after the draft design stage, the first stakeholder workshop and all follow-up meetings on the project. The report provides details of how the final designs of materials and pavement options for the demonstration and control sections were carried out. Five demonstration and one control sections will be constructed using cost-effective machinery and labour-based methods, and all sections will be monitored to collect the data needed to develop best practice guidelines and specifications for steep hill sections on feeder roads in Ghana. It is anticipated that the final guideline/specification will draw on the outputs of the laboratory and field works carried out in the project, and ultimately aligned with the AfCAP West African sub-regional project on the development of low-volume roads manual for Ghana, Sierra Leone and Liberia. Data collected at this stage include field and laboratory testing data, materials and pavement designs data and bill of quantities for construction.

1.2 Objective of this report

The main objective of this report is to finalise the research matrix, and to present the final designs, drawings, construction procedures and initial construction costs of all pavement options for the demonstration sections.

1.3 Surfacing and pavement types

The test matrices of the demonstration sections and the variables of the alternative surfacing are as follows:

- Modular paving units –concrete stone pitching, interlocking block paving, and hand-packed stone
- Cold-mix asphalt – three mix types (combination of different aggregates and additives)
- Thin mesh-reinforced concrete – three mix types (combination of different aggregates and additives)
- Roller-compacted concrete – three mix types (combination of different aggregates and additives)

These surfacings will be placed over road base materials that comprise lime/cement stabilisation, mechanical modification of lateritic gravel or screened lateritic gravels that are blended to meet the base/subbase materials requirement of the GSSRB (2007). Three main pavement types (flexible, rigid and semi-rigid) are to be demonstrated in this project.

1.4 Scope of work

The scope of work for final design stage of the project involves three main tasks, namely materials design, pavement and drainage design, and construction methodology. The approach and main activities carried out for this report are summarised below:

- Field and laboratory testing to finalise appropriate engineering properties for material types and design procedures/guidelines for various pavement options. The aim was to determine whether sufficient material of the required quality is available for the construction of the works.
- Detailed qualitative assessment of the capabilities of BRRI and GHA laboratories. The aim was to conduct critical assessment in terms of laboratory facilities and background of laboratory staff in relevant test methods for construction and monitoring activities of the project.
- Development of construction guidelines and specifications for the pavement surfacing options
- Development of material design and pavement design guidelines and specifications for the pavement surfacing options
- Finalisation of research matrix with the DFR and AfCAP PMU for the project
- Finalise the materials and pavement designs of demonstration sections. This includes final designs of asphalt and concrete materials as well as pavement structural and drainage designs. The design activities include a bill of quantities for the various demonstration matrices.
- Revision of geometric designs for the demonstration sections.
- Supervise the laboratories (BRRI and GHA CML) on materials testing and data analysis of engineering properties of the construction materials.
- Complete materials investigation and hold discussions with the DFR and the contractor during which modifications to the draft designs are anticipated to be made.
- Produce Final Design Report of the project, incorporating final pavement and drainage designs, materials designs, technical drawings, BoQs, construction costs and schedules.

1.5 Final design activities

The activities undertaken for the final design can be summarised as follows:

- Materials designs and characterisation
  - Design of four cold mix asphalt variables for the asphalt pavement
  - Design of seven concrete mix variables for thin mesh-reinforced concrete pavement
  - Design of seven concrete mix variables for roller-compacted concrete pavement
  - Design of seven concrete mix for interlocking concrete block paving
  - Filed and laboratory characterisation of stiffness and strength properties of naturally occurring gravels and blended materials for the pavement base and subbase layers
- Geometric design of the demonstration section (mainly, review of an existing DFR designs)
- Design of side drains
- Pavement design
  - Structural design of flexible pavements with cold mix asphalt surfacing
  - Structural design of rigid pavement with thin mesh-reinforced concrete surfacing
  - Structural design of rigid pavement with roller-compacted concrete surfacing
  - Structural design of modular paving surfacing (interlocking block paving, concrete stone pitching and stone)
  - Structural design of double chip seal for control section
- Detailed drawings for all pavement options, side drains, geometric cross-sections and shoulders.
- Detailed guidelines for the construction of cold mix, thin mesh-reinforced and roller-compacted concrete pavements

- BoQs for initial construction costs and schedules for all pavement types

1.6 Research data

The various laboratory and field testing design data established during the final design stage are documented and kept as the primary source of information for current and AfCAP projects. These data are available on DVDs (attached to this report; too voluminous to be included in the appendix). The data and information include the following:

- Natural gravels and blend materials properties (DVD)
- Laboratory DCP-DN test data and results (DVD)
- Filed DCP survey results (DVD)
- Cold-mix asphalt mix design results and data (DVD)
- Thin mesh-reinforced and roller-compacted Concrete mix design results and data (DVD)
- Mix design worksheets (DVD)
- Detailed pavement structural design drawings (DVD)
- Geometric design drawings (DVD)
- Bill of quantities including "Taking Off" sheets (DVD)

1.7 Report organisation

The main content of this report is divided into the seven section presented here in Table 1.

Table 1 Content of this report

Section	Title	Description
Section 1	Executive Summary	Presents overall summary and findings from the final design stage of the project.
Section 2	Introduction	Gives background, objectives, scope of work and design activities of the project.
Section 3	Construction Materials Assessment	Presents detailed evaluation of naturally occurring gravels on the road corridor, materials blending techniques, and laboratory properties.
Section 4	Asphalt and Concrete Mix Design	Presents materials mix design approaches and test results for cold-mix asphalt, conventional and roller-compacted concrete mix designs
Section 5	Demonstration Sections and Research Matrix	Provides the research matrix and layout of the demonstration sections; including gradients, planned view of the experiment and construction of trial sections.
Section 6	Pavement and Drainage Design	Presents detailed pavement designs for the flexible surfacings (cold-mix asphalt, double-chip seal), semi-rigid modular paving surfacings (concrete-stone pitching, hand-packed stones and interlocking concrete block paving), and rigid surfacings (thin mesh-reinforced and roller-compacted concrete). Detailed design procedures are provided for all paving types. In addition, detailed drawings for cross sections and materials schedules are provided in this section. Design of side drains forms part of this section.

Section 7	Construction Methods and Cost	Construction guidelines for cold-mix asphalt, thin mesh-reinforced concrete and roller-compacted concrete were developed in this section. In addition, erosion measures and slope stability interventions are discussed here. The initial construction costs of the alternative surfacing are presented and briefly.
Section 8	Conclusions and Recommendations	Conclusions, findings, and recommendations for subsequent activities of the project are presented in this section.

2 Assessment of Natural Gravel/Soil Materials

2.1 Natural soils and granular materials

The project road is a new construction that requires fresh pavement layer materials. As part of the materials investigation, the project area was scouted for natural gravels for possible use in the underlying layers of the pavement (i.e. base, subbase and subgrade). Three existing borrow pits along the route corridor (ATR-BP1, ATR-BP2 and ATR-BP3) and two new borrow sites (ATR-BS1 and ATR-BS2) were investigated. Bulk samples were taken from each borrow pit and their characteristics were determined in the laboratory. In-situ materials such as the natural gravel with ferruginous stones and the shale rock pieces and other naturally occurring materials from the project alignment were also investigated for use in the underlying layers of the pavement.

Table 2 presents details of the various borrow pits including their distances from the project site, and capacities. Figure 1 shows two borrow pit sites visited by the project team.

Table 2 Natural gravels and their location

Borrow pit ID	Location	Distance from project site (km)	Estimated quantity (m^3)	Estimated percentage Available (%)
ATR-BP 1	Akwesiho	1.2	15,000	45
ATR-BP 2	Akwesiho	0.8	6,500	15
ATR-BP 3	Akwesiho	0.4	20,000	30
ATR-BS 1	Asuoyaa	11.4	15,000	100
ATR-BS 2	Twenedurase	1.4	25,000	100

Figure 1 Borrow pits for the project

2.2 Physical properties of the natural gravels

2.2.1 Borrow pit materials

Natural gravel material sampled from each borrow pit were tested per the schedule in Table 3, and in accordance with British Standard Test Codes, ASTM Standards, Ghana Highway Authority, and AfCAP protocols where applicable.

The summary results of classification tests conducted on the borrow pit samples are presented in Table 4. Samples from the ATR-BP1, ATR-BP2 and ATR-BP3 borrow pits were found to be predominantly sand with varying proportions of clay, silt and gravel. The grading modulus (GM) and plasticity modulus (PM) of these borrow pit materials (derived from equation 1 and equation 2) ranged from 1.03 to 1.45 and 650 to 1740, respectively. These values did not meet specifications of a G40 materials (natural gravel with CBR of 40% under soaked conditions) provided in the Ghana Standard Specifications for Road and Bridge Works (GSSRB). Although GM of 1.45 for ATR-BP2 borrow pit materials exceeds the minimum specification for a G30 material (natural gravel with CBR of 30% under soaked conditions), its PM value of 650 is above the limiting value of 250. Thus, materials from these borrow pits are less suitable for base or subbase layer materials of a pavement.

The test results on samples from the ATR-BS1 and ATR-BS2 borrow pits showed that the samples tested have a grading modulus above the minimum specification of 1.25 for G30 and 1.5 for G40 gravels. However, their plasticity moduli were above the maximum of 250, and hence did not meet requirements of G80, G60, G40 and G30 materials. Thus, the samples from the two new borrow sites are less suitable, and would require improvement. Consequently, there was the need to blend material from the two borrow pits, and mechanically stabilised it with quarry product to improve material properties. Table 5 shows the grading results of all five borrow pit materials, whereas Figure 2 presents grading curves for the materials on the GSSRB grading envelope for a G60 material.

Table 3 Schedule of test on borrow pit samples

Sample ID	Laboratory test carried out on samples						
	Moisture content	Specific gravity	Grading	Atterberg limit	Compaction	Lab DCP	CBR
ATR-BP 1	√	√	√	√	√	√	√
ATR-BP 2	√	√	√	√	√	√	√
ATR-BP 3	√	√	√	√	√	√	√
ATR-BS 1	√	√	√	√	√	√	√
ATR-BS 2	√	√	√	√	√	√	√

Table 4 Results of physical properties and classification of borrow pit materials

Sample ID	Depth (m)	N.M.C (%)	Density kg/m³	LL (%)	PI (%)	GM	PM	BS 5930 Classification
ATR BP 1	0.0 - 2.5	20.24	2,300	51.5	24.3	1.03	1703	Clayey, gravelly, sand with silt
ATR BP 2	0.0 - 2.5	14.84	2,560	32.1	12.3	1.45	650	Silty, sandy, gravel with clay
ATR BP 3	0.0 - 2.5	21.02	2,560	48.5	24.6	1.03	1740	Gravelly, clayey, sand with silt
ATR-BS 1	0.3 - 0.65	14.44	2,630	55.9	22.9	1.77	806	Clayey, sandy gravel with some silt
ATR-BS2	0.3 – 0.7	13.38	2,680	54.3	17.2	2.42	323	Silty, sandy gravel with trace of clay

$$GM = 300 - (\%\,passing\ 2.0\,mm + \%\,passing\ 0.425\,mm + \%\,passing\ 0.075\,mm\ sieves) \times 100 \quad \text{Eq. 1}$$

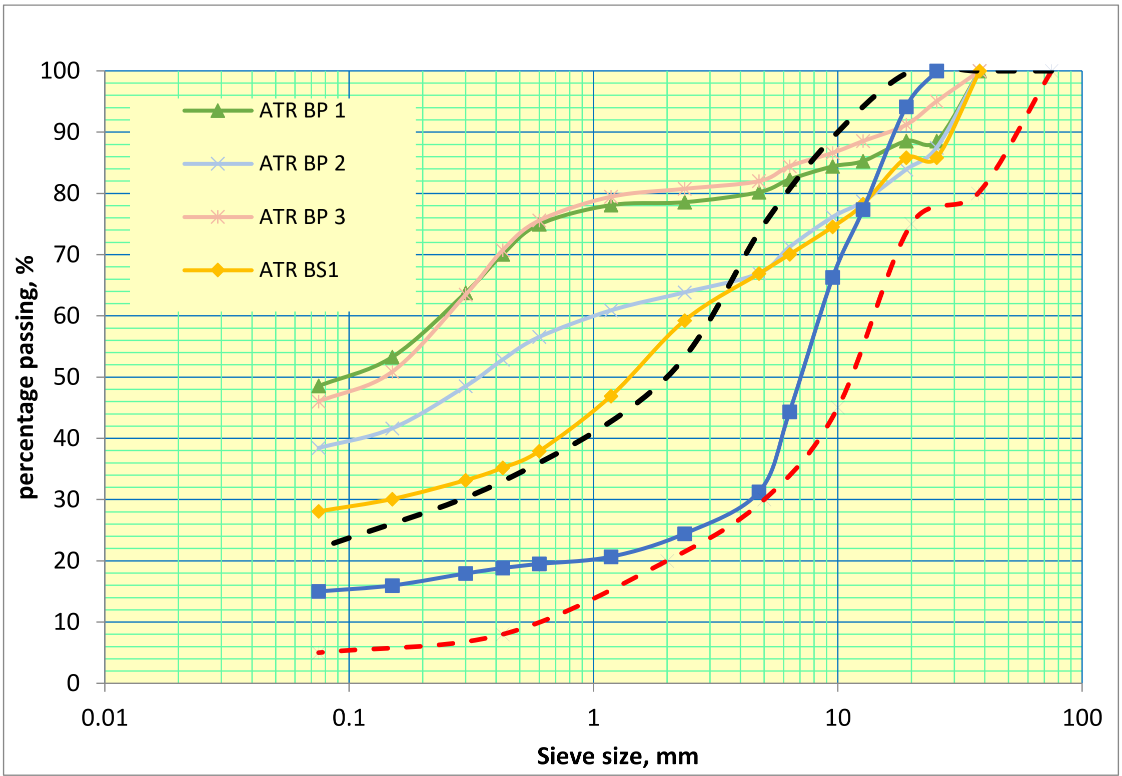
$$PM = PI \times \%\,passing\ 0.425\,mm\ sieve \quad \text{Eq. 2}$$

Table 5 Grading results of borrow pit materials

Borrow pit					
Sample ID	ATR BP 1	ATR BP 2	ATR BP 3	ATR BS1	ATR BS2
Sieve size (mm)	% Passing	% Passing	% Passing	% Passing	% Passing
50.80	100	100	100	100	100
38.10	100	100	100	100	100
25.40	89	87	95	86	100
19.05	89	84	91	86	94
12.70	85	79	89	78	77
9.53	84	76	87	75	66

6.35	82	71	84	70	44
4.76	80	67	82	67	31
2.36	79	64	81	59	24
1.18	78	61	79	47	21
0.60	75	57	76	38	20
0.43	70	53	71	35	19
0.30	64	49	63	33	18
0.15	53	42	51	30	16
0.075	48.5	38.4	46.0	28.1	15.0

Figure 2 Grading curve for borrow pit materials with G60 grading envelope



2.2.2 Existing road surface materials

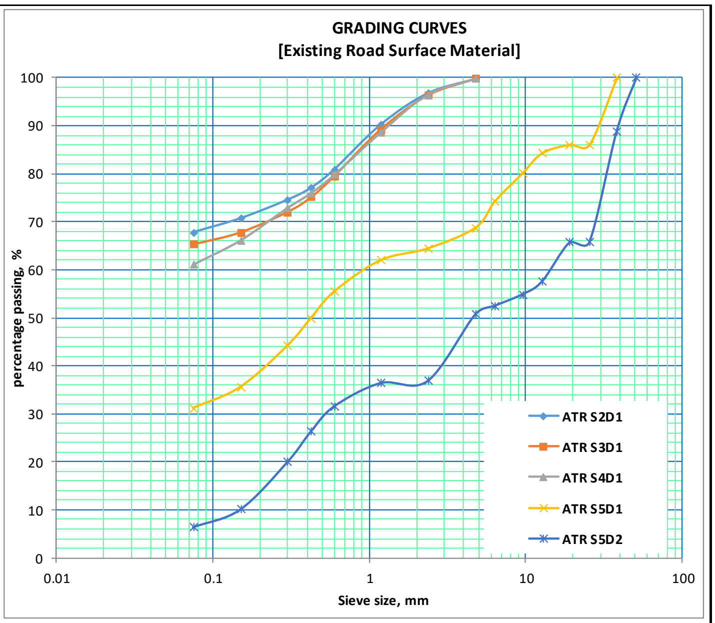
Gravel materials were also sampled from the existing road alignment (mainly from the cut slopes) and tested in the laboratory. The summary results of the tests conducted on these samples are presented in Table 6. The classification test results indicate that the road surface material is characterised predominantly by sandy silt (chainage1+825 to 2+365) with traces of clay and gravel. Materials from chainage2+365 to 2+875 also showed soils with predominantly gravelly sand and sandy gravel, with traces of clay and silt. Figure 3 presents the grading curve for these samples.

Table 6 Summary of classification test results for existing road surface material

Sample ID	Depth (m)	N.M.C (%)	Density, kg/m³	LL (%)	PI (%)	GM	Plasticity modulus
ATR BP 1	0.0 - 2.5	20.24	2,300	51.5	24.3	1.03	1703
ATR BP 2	0.0 - 2.5	14.84	2,560	32.1	12.3	1.45	650
ATR BP 3	0.0 - 2.5	21.02	2,560	48.5	24.6	1.03	1740
ATR-BS 1	0.3 - 0.65	14.44	2,630	55.9	22.9	1.77	806
ATR-BS2	0.3 – 0.7	13.38	2,680	54.3	17.2	2.42	323

Figure 3 Grading curve for existing road surface material

BLENDED MATERIALS					
SAMPLE ID	ATR S2D1	ATR S3D1	ATR S4D1	ATR S5D1	ATR S5D2
SIEVE SIZE, mm	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING
76.20	100	100	100	100	100
63.50	100	100	100	100	100
50.80	100	100	100	100	100
38.10	100	100	100	100	89
25.40	100	100	100	86	66
19.05	100	100	100	86	66
12.70	100	100	100	84	58
9.53	100	100	100	80	55
6.35	100	100	100	74	53
4.76	100	100	100	69	51
2.36	97	96	96	64	37
1.18	90	89	89	62	36
0.60	81	80	80	56	32
0.425	77	75	76	50	26
0.30	75	72	73	44	20
0.15	71	68	66	36	10
0.075	67.8	65.3	61.1	31.2	6



2.2.3 Blend materials

As mentioned previously, there was the need to blend material from the borrow pits, and mechanically stabilised (in the laboratory) it with quarry product to provide improved properties.

The blend proportions were informed by the individual properties of the borrow materials, the proximity of the borrow pit to the project site, and the economics in hauling these materials. Table 7presents the blend options for materials optimisation. Subsequently, the blend options were characterised to enable the best optimised blend to be selected for further assessment. Table 8 presents the testing programme for the blend materials.

Table 7 Proposed blend options for base/subbase material

Blend Option	Blend composition (%)			Expected GM of blend	GSSRB Grading modulus (GM), Min			
	ATR-BS1	ATR-BS2	Quarry Dust	LL (%)	G80	G60	G40	G30
BLEND A	20	70	10	2.23	2.15	1.95	1.5	1.25
BLEND B	25	65	10	2.20				
BLEND C	35	55	10	2.14				
BLEND D	40	50	10	2.11				
BLEND E	0	85	15	2.34				

Table 8 Schedule of laboratory testing on blend materials

Blend option	Grading	Specific gravity	Atterberg limit	Compaction	Laboratory DCP	Resilient modulus
BLEND A	√	√	√	√	√	√
BLEND B	√	√	√	√	√	√
BLEND C	√	√	√	√	√	√
BLEND D	√	√	√	√	√	√
BLEND E	√	√	√	√	√	√

The summary of physical properties of the blend materials are presented in Table 9. The grading moduli ranged from 2.03 to 2.30, indicating that all five blend materials meet the minimum grading modulus specification value of 1.95 for a G60 material (GSSRB, 2007). However, the plasticity modulus values of all five blends (302 to 450) did not meet the GSSRB criteria.

Table 10 shows the grading results of all five borrow pit materials, whereas Figure 4 presents grading curves for the blend materials on the GSSRB grading envelope for a G60 material.

Table 9 Results of physical properties and classification of blend materials

Bl end option	Density, kg/m³	Liquid Limit (%)	Plasticity Index (%)	Grading modulus	Plasticity modulus	BS 5930 classification
BLEND A	2,300	44.8	16.0	2.21	387	Sandy gravel with traces of clay and silt
BLEND B	2,340	43.2	14.4	2.30	302	Sandy gravel with traces of clay and silt
BLEND C	2,480	43.4	15.3	2.30	324	Sandy gravel with traces of clay and silt
BLEND D	2,410	42.0	15.1	2.07	443	Sandy gravel with traces of clay and silt
BLEND E	2,430	44.7	14.7	2.03	450	Sandy gravel with traces of silt and clay

BLENDED MATERIALS					
SAMPLE ID	ATR BLEND A	ATR BLEND B	ATR BLEND C	ATR BLEND D	ATR BLEND E
SIEVE SIZE, mm	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING
76.20	100	100	100	100	100
63.50	100	100	100	100	100
50.80	100	100	100	100	100
38.10	100	100	100	100	100
25.40	100	100	100	100	100
19.05	100	100	98	100	100
12.70	87	83	82	83	94
9.53	76	74	69	74	87
6.35	61	57	54	60	71
4.76	45	41	40	50	54
2.36	36	32	33	42	44
1.18	30	26	26	36	36
0.60	26	22	23	31	32
0.425	24	21	21	29	31
0.30	23	20	20	27	29
0.15	20	18	18	24	25
0.075	19.1	16.4	16.6	22.5	22.7

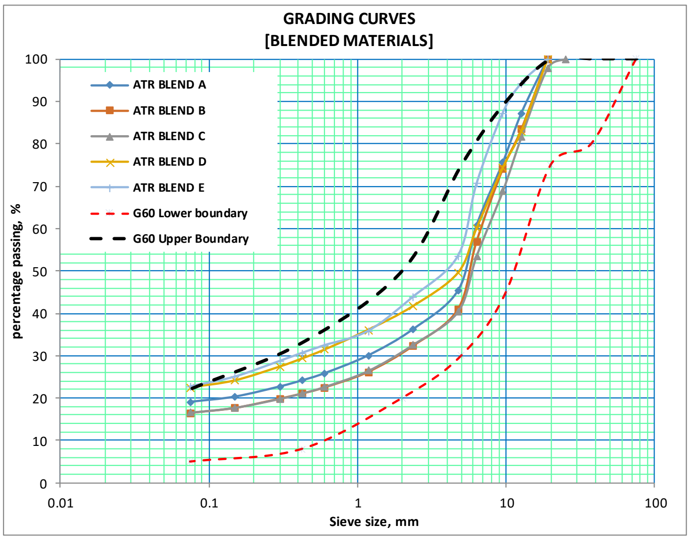
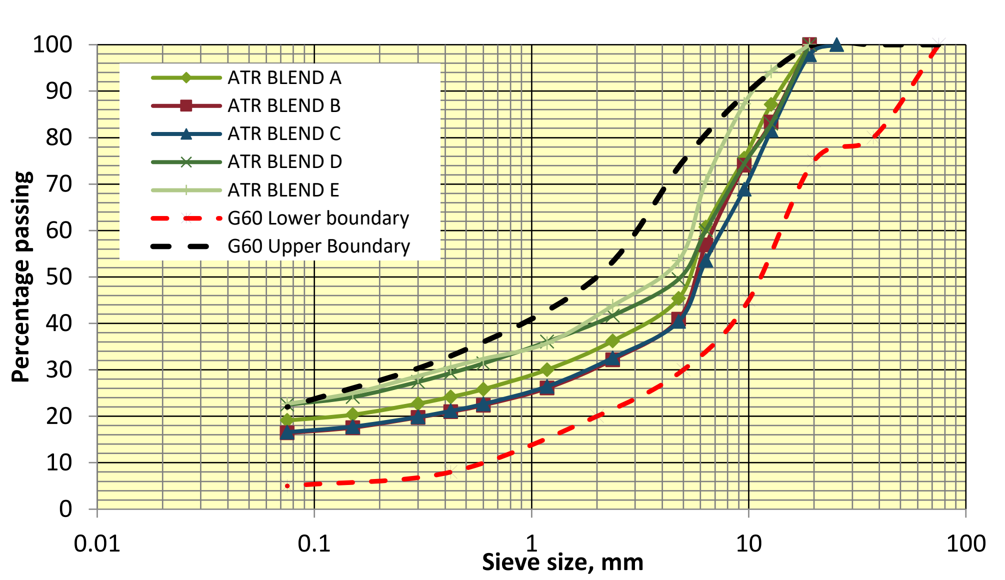


Table 10 Grading results of blend materials

Blend materials					
Sample ID	ATR Blend A	ATR Blend B	ATR Blend C	ATR Blend D	ATR Blend E
Sieve size, mm	% Passing	% Passing	% Passing	% Passing	% Passing
50.80	100	100	100	100	100
38.10	100	100	100	100	100
25.40	100	100	100	100	100
19.05	100	100	98	100	100
12.70	87	83	82	83	94
9.53	76	74	69	74	87
6.35	61	57	54	60	71
4.76	45	41	40	50	54
2.36	36	32	33	42	44
1.18	30	26	26	36	36
0.60	26	22	23	31	32
0.43	24	21	21	29	31
0.30	23	20	20	27	29
0.15	20	18	18	24	25
0.075	19.1	16.4	16.6	22.5	22.7

Figure 4 Grading curve for blended materials with G60 grading envelope



2.2.4 Moisture-density relationships (compaction test)

Moisture-density relationships for the borrow pit and blend materials were determined in accordance with BS 1377-4:1990. The summary of compaction test results of the borrow pit materials are presented in Table 11, and the compaction properties are plotted in Figure 5.The results show that the material from ATR-BS2 has a relatively high maximum dry density, and corresponding lower optimum moisture content. The ATR-BS2 material is expected to have better strength properties when compared with the remaining borrow pit materials. Consequently, the properties of the blend materials could be heavily influenced by the proportion of ATR-BS2 material used.

A summary of compaction test results for the five blends are presented in Table 12. The compaction curves are presented in Figure 6. The maximum dry density and optimum moisture content of the blends ranged from 2, 204 kg/m³ to 2.246 kg/m³, and 10.2% to 11.6%, respectively.

Table 11 Compaction test results on borrow pit materials

Sample ID	Depth (m)	Compactions characteristics	
		MDD (kg/m³)	OMC (%)
ATR BP 1	0.0 - 2.5 0	1,786	18.5
ATR BP 2	0.0 - 2.50	1,960	12.0
ATR BP 3	0.0 - 2.50	1,979	9.8
ATR BS 1	0.3 - 0.65	1,947	13.6
ATR BS 2	0.3 – 0.70	2,285	8.0

Table 12 Summary of compaction test results on blended materials

Sample ID	Compactions characteristics	
	MDD (kg/m³)	OMC (%)
BLEND A	2,208	10.2
BLEND B	2,204	10.8
BLEND C	2,246	11.5
BLEND D	2,127	11.6
BLEND E	2,183	11.4

Figure 5 Compaction curves for the borrow pit samples

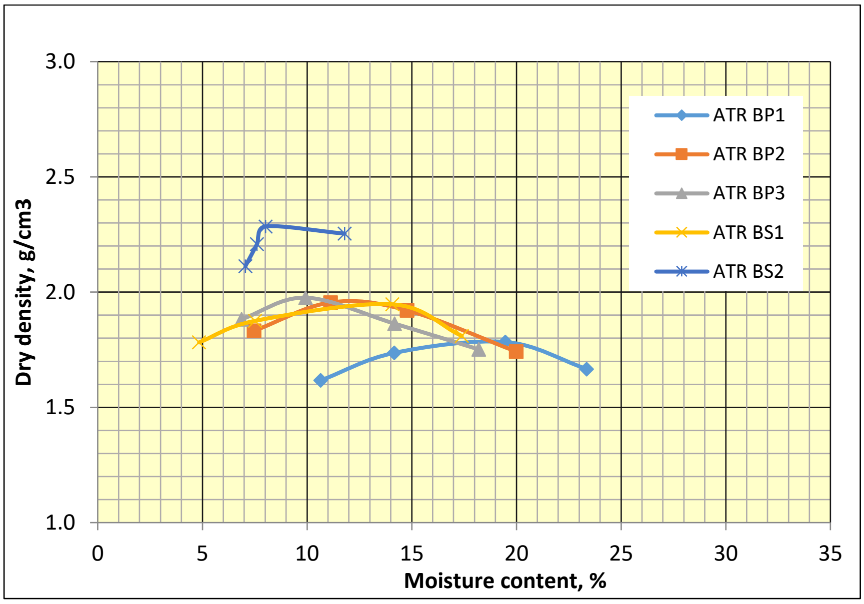
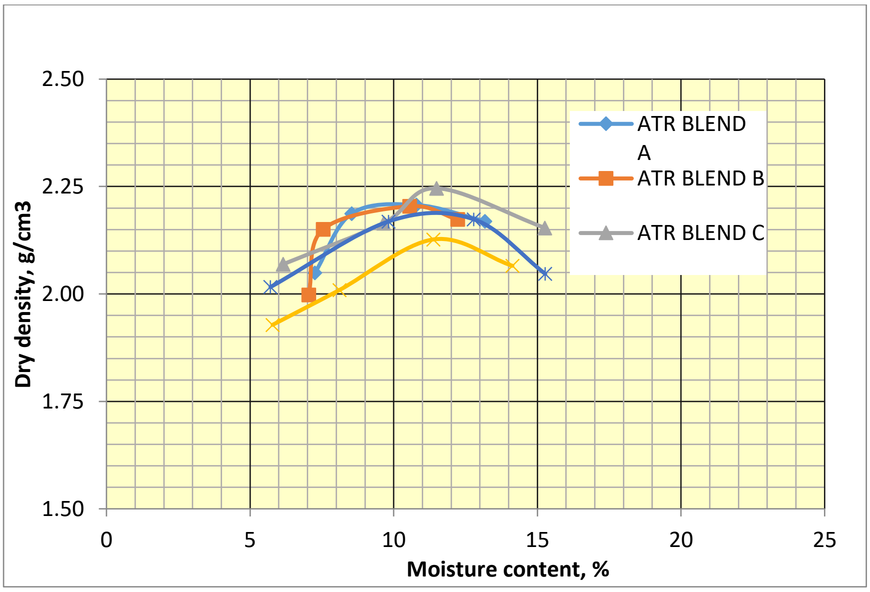


Figure 6 Compaction curve for blend materials



2.3 Material characterisation

The following characterisation tests were conducted on the gravels and bend materials to determine their strength and stiffness properties:

- CBR,
- Resilient modulus, and
- DN value (laboratory DCP test).

2.3.1 Determination of CBR values for borrow pit and blend materials

CBR tests were conducted on the borrow pit and blend materials in accordance with the BS 1377-4:1990 test procedures. The tests were conducted at three compaction levels (100% MDD, 98 % MDD and 95% MDD) and three different moisture conditions (96 hrs soaked, OMC and 0.75OMC). The test results of the materials at different compaction levels are presented in Table 13. The results show that soaked CBR of the borrow pit materials ranged from 10 to 34 % (except ATR BP1, with CBR of 4 %) at 100% Mod AASHTO density, whereas the CBR values of the blends ranged from 26 to 47%. The maximum swell values were negligible for all samples (< 0.8 %). The CBR of both borrow pit and blend samples were not significantly influenced by compaction energy as the values obtained at 98 and 95% were all close to the values at 100% MDD.

Based on the CBR values, the blend materials were classified as G40 and G30. Only one borrow pit material could be classified as G30 in accordance with GSSRB specifications. Blend C and Blend D with CBR values of 26% and 28%, respectively marginally meet the specification for G30 materials.

Based on the properties and experience, the four borrow pit materials that could not be classified by the GSSRB qualify as subgrade materials for pavements.

Table 13 CBR Test results at different compaction levels

Sample ID	Depth (m)	96 hrs soaked CBR values						GSSRB Classification	Pavement material type
		CBR @ 100%MDD		CBR @ 98%MDD		CBR @ 95%MDD			
		CBR, %	Swell, %	CBR, %	Swell, %	CBR, %	Swell, %		
ATR BP 1	0.0 - 2.50	4	0.73	4	0.83	3	0.83	N/A	Subgrade
ATR BP 2	0.0 - 2.50	10	0.45	10	0.51	9	0.50	N/A	Subgrade
ATR BP 3	0.0 - 2.50	11	0.39	11	0.44	10	0.42	N/A	Subgrade
ATR-BS 1	0.3 - 0.65	16	0.21	16	0.24	13	0.23	N/A	Subgrade
ATR-BS2	0.3 - 0.70	34	0.47	33	0.54	30	0.51	G30	Subbase
BLEND A	-	47	0.13	46	0	42	0	G40	subbase
BLEND B	-	36	0	35	0	32	0	G30	subbase
BLEND C	-	26	0	25	0	23	0	N/A	Subgrade
BLEND D	-	28	0	28	0	25	0	N/A	Subgrade
BLEND E	-	41	0	40	0	37	0	G30	Subbase

Table 14 shows the CBR results of the samples at different moisture conditions. Based on the results, Blend A, Blend B and Blend E could be classified as G40, G30 and G40, respectively in accordance with GSSRB (2007). Blend C and Blend D with CBR values of 26% and 28% marginally meet the GSSRB CBR specification for G30 materials. The penetration data and graphs for the CBR test are available on the DVDs that contain the final design data and information.

Table 14 CBR Test results at different moisture conditions

Sample ID	CBR @96hr Soaked		CBR @ OMC		CBR @ 0.75OMC		GSSRB Natural Gravel Specifications
	CBR, %	Swell,%	CBR, %	Swell,%	CBR, %	Swell,%	
BLEND A	47	0.13	57	-	85	-	G40
BLEND B	36	0	41	-	75	-	G40
BLEND C	26	0	34	-	71	-	G30
BLEND D	28	0	33	-	67	-	G30
BLEND E	41	0	73	-	95	-	G40

2.3.2 GHA Laboratory test results on blend materials

Various index and CBR tests were conducted on the blend materials at the GHA laboratories in Takoradi to verify the results of the main testing programme conducted at the BRRI laboratories. The summary results of tests conducted on the blends are presented in Table 15. Based on the results, the blend materials were classified as G60 and G80 (at 100% compaction) in accordance with the GSSRB specification. The notable difference in the results between the two laboratories is attributed to the sampling of the natural gravel for the blend. The verification test results at 100% MDD however, correlated well with the CBR tests at 0.75 of OMC, and support the finding that the blend materials attained improved strength properties.

It should be mentioned that the results from the GHA laboratories were not used in the pavement design as the purpose of testing was for verification only.

Table 15 Summary of Laboratory test Results on Blended Materials obtained from GHA Laboratory

Sample ID	MDD (kg/m³)	OMC %	LL, %	PI %	CBR 96 Hrs Soaked				GSSRB Classification (100% MDD)
					100 % MDD	98 % MDD	95 % MDD	93 % MDD	
BLEND A	2,220	10.0	49	23	76	65	50	39	G80
BLEND B	2,188	9.6	51	24	76	65	49	39	G80
BLEND C	2,150	10.4	52	25	56	48	37	29	G60
BLEND D	2,130	10.8	53	25	67	59	58	41	G40
BLEND E	2,286	9.8	46	21	95	84	67	56	G80

2.3.3 Determination of resilient modulus

The resilient modulus test was conducted on one natural and four blend materials in accordance with the AASHTO standard test procedures (AASHTO T 307-99). The test was conducted to determine the variation of the modulus properties of the materials at different applied stress levels. Samples were prepared at maximum density and optimum moisture content for testing at the GHA Central Materials Laboratory in Accra. Table 16 shows the summarised results for the materials tested. In comparison, Blend A had higher resilient modulus values whereas Blend D had the lowest values at all stress levels.

Table 16 Summary of resilient modulus test results

Test sequence	ATR-BS2		Blend A		Blend B		Blend C		Blend D	
	Applied Stress (kPa)	MR (MPa)	Applied Stress (kPa)	MR (MPa)	Applied Stress (kPa)	MR (MPa)	Applied Stress (kPa)	MR (MPa)	Applied Stress (kPa)	MR (MPa)
0	109.3	134.6	106.2	140.2	109.5	111.4	101.9	106.2	110.0	103.6
1	63.2	90.9	62.9	89.5	63.5	99.1	60.8	84.0	63.3	89.5
2	75.6	94.6	74.5	117.2	76.0	101.5	71.5	97.7	75.7	92.5
3	87.8	109.3	86.3	137.8	88.5	104.0	82.5	109.3	88.2	96.6
4	71.6	101.5	69.7	115.1	71.6	102.9	67.1	115.4	71.8	103.3
5	91.8	107.6	89.4	140.5	92.4	108.7	85.3	116.7	92.3	94.4
6	111.9	121.7	109.4	150.7	113.2	113.0	103.2	120.3	113.4	101.4
7	90.2	104.2	87.3	133.1	90.7	113.4	82.4	121.4	91.0	102.5
8	130.7	135.2	127.3	175.2	132.4	116.4	119.1	124.0	132.8	108.3
9	171.3	152.8	167.6	190.5	172.8	123.8	159.2	142.0	174.5	114.2
10	87.9	106.3	85.0	145.0	88.9	116.1	78.8	143.6	89.0	112.4
11	108.0	117.1	104.8	165.6	109.6	123.7	97.3	143.8	110.1	110.9
12	168.5	155.1	165.3	196.8	170.8	131.4	155.3	159.4	172.7	122.0
13	105.1	114.4	101.8	175.9	107.8	126.6	92.6	165.0	107.9	116.2
14	125.1	130.4	121.2	184.5	128.5	129.9	110.9	164.0	128.9	121.7
15	205.1	165.2	197.6	210.2	204.1	135.2	180.6	170.2	205.4	118.4

2.3.4 Determination of laboratory DN-values for borrow pit and blend materials

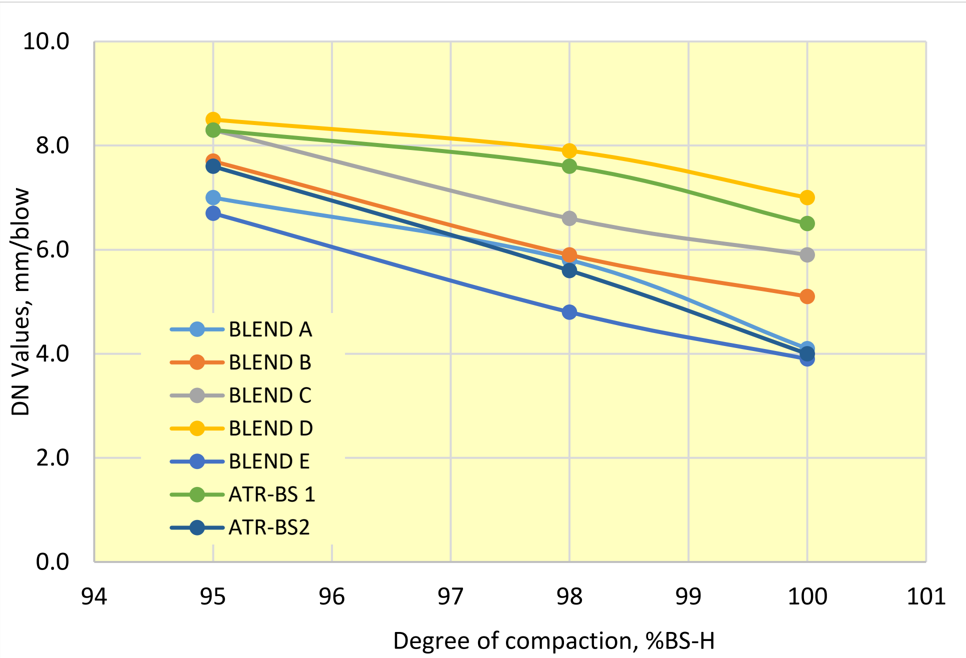
The Lab DCP test was conducted on the borrow pit and blend materials in accordance with AfCAP protocols (ETA, 2016).Samples were prepared and tested at different moisture and compaction conditions. The DN-values were determined at 96hrs (4 days) soaked, optimum moisture content (OMC) and 0.75 of OMC, and at 100%, 98% and 95% MDD.

Table 17 presents the DN results at the various testing conditions, and Figure 7resents the variation of DN-values with degree of compaction for the materials tested. Blend D has the highest DN values (lower strength) and Blend E has the lowest DN-values (i.e. higher strength). The DCP penetration data for the various samples are available on a DVD that is attached to this report.

Table 17 Summary of laboratory DN-value test results for blended materials

Sample ID	Depth (m)	Average Weighted DN Values (mm/Blow)					
		DN Values at different moisture conditions (mm/blow)			Values at different compactive energies [compacted at OMC]		
		DN @ 96hr Soaked	DN @ OMC	DN @ 0.75 OMC	100% MDD	98% MDD	95% MDD
ATR BP 1	0.0 - 2.50	33.4	12.5	11.7	---	---	---
ATR BP 2	0.0 - 2.50	13.2	10.8	5.1	---	---	---
ATR BP 3	0.0 - 2.50	12.5	8.7	6.8	---	---	---
ATR-BS 1	0.3 - 0.65	12.8	6.5	5.0	6.5	7.6	8.3
ATR-BS2	0.3 - 0.70	4.9	4.0	3.7	4.0	5.6	7.6
BLEND A	-	5.0	4.1	3.7	4.1	5.8	7.0
BLEND B	-	7.2	5.1	5.0	5.1	5.9	7.7
BLEND C	-	10.9	5.9	5.9	5.9	6.6	8.3
BLEND D	-	10.6	7.0	3.8	7.0	7.9	8.5
BLEND E	-	5.2	3.9	3.9	3.9	4.8	6.7

Figure 7 Variation of DN-value with degree of compaction for materials tested



2.4 DCP survey along the construction trial and demonstration sections

Field DCP tests were conducted on the centreline of the road alignment of the construction trial sections and the demonstration sections. The AfCAP DCP test protocols (Ethiopia, Tanzania, Malawi, etc.) were followed for testing. The objective was to assess variations in strength of the road alignment for proper recommendation of pavement foundations layers of the demonstration sections. DCP tests were not conducted at chainage3+095 (roller-compacted concrete section), owing to the exposed underlying rock formation that was difficult to penetrate with the apparatus.

Within the construction trial sections (Chainage 1+825 to 2+025), the DCP test was conducted at intervals of 100 m, whereas intervals of 50 m were used for the demonstration sections (Chainage 2+025 to 2+875). Figure 8 shows photographs of the DCP field testing on some of the road sections.

Figure 8 DCP Test being carried out at the Experimental Sections

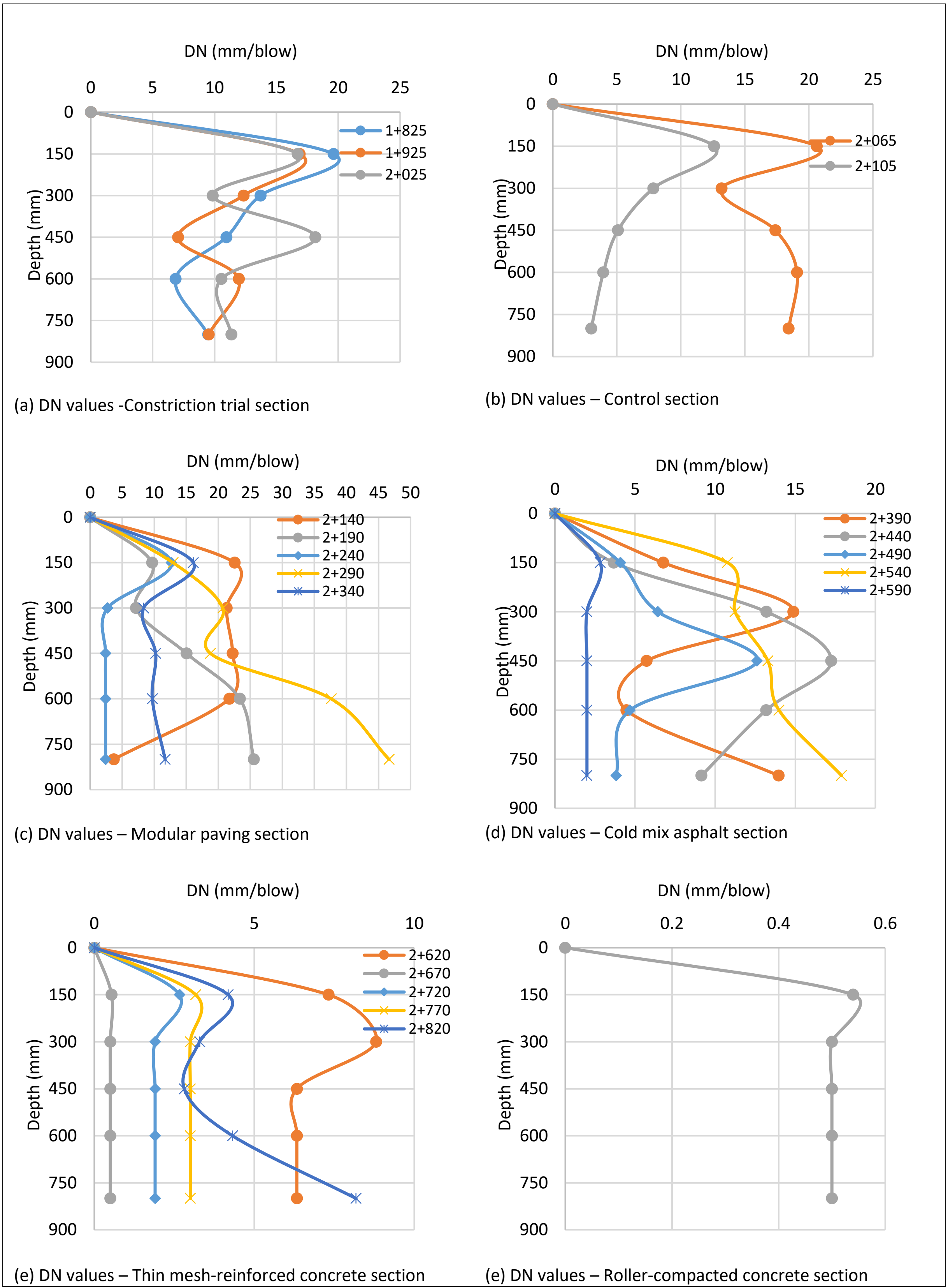
Figure 9 Portions of Exposed Sedimentary Rocks at CH 2+875 to CH 3+130

2.4.1 Field DCP test results

Analysis results of the DCP tests at various chainages are presented in Figure 10. The DN values for each 150 mm layer were plotted against the depth of the alignment to depict changes in strengths of the foundation materials of the demonstration sections.

It can be seen that the mesh-reinforced and roller-compacted concrete sections have very low DN values, implying that the pavement structure may not require subgrade layers. On the other hand, the DN values for majority of the chainages where the modular paving and cold mix asphalt surfacings will be demonstrated would require engineered foundation/subgrade materials. Generally, one or two layers of subgrade materials would be required for the construction of the pavements with modular paving and cold mix asphalt surfacings.

Figure 10 DCP-DN values against depth of road alignment



3 Asphalt and Concrete Mix Design

3.1 Cold mix asphalt design

3.1.1 Mix types

Four mix types were designed based on cold graded aggregates in combination with the emulsion and additive options. As part of the mix design, laboratory tests to determine the physical properties of component materials (i.e. aggregates and emulsions) were carried out. The proposed cold-mix asphalt (CMA) variables for the project are presented below:

Mix options	Description
CMA-Mix1	Base emulsion (K1-70 Cation type) with all quarry stones
CMA-Mix 2	Base emulsion (K1-70 cation type) with blended quarry stones (70%) and Screened Laterite (30%).
CMA-Mix 3	Base emulsion K1-70 cationic type (with optimum cement/lime additives) with quarry stones
CMA-Mix 4	Base emulsion (with optimum lime/cement additives) with blended stones (70%) and screened laterite (30%)

3.1.2 Materials

The aggregates were procured from the ESM Quarry, Buoho-Kumasi. The required emulsion K1-70 that conformed to specifications after a distillation test was carried out, was procured from Platinum Seal Ltd. As far as additives are concerned, Ordinary Portland Cement (Ghacem 32.5R) was opted for because of its availability on the Ghanaian open market, and lime from Carmeuse Ltd was chosen.

3.1.3 Test methods

The Marshall method of mix design is popularly used to design asphalt mixes. No universally accepted mix design procedures for cold mix asphalt was available to the project team, hence the procedures in the Marshall Method were followed for the design of the four CMA variables.

The grading envelope recommended by the AfCAP Manual for Ethiopian Roads Agency (ERA, 2016) was used as a guideline to design grading of the CMA variables. All four CMA variables were designed with nominal maximum size of 14 mm.

3.1.4 Design procedure

The mix design procedure involved a number of sequential steps, which are described below:

Step 1: Aggregates selection

Aggregates were tested to ascertain whether their engineering properties met the requirements set by MRH specifications (1991). Testing of aggregates comprises the following: Aggregate Impact Value (AIV); Los Angeles Abrasion Test (LAA); Ten Percent Fines; Water Absorption; Specific Gravity; stripping test. These tests results of two aggregate materials are presented in Table 18 Summary of aggregate test results on the ESM quarry samplesbelow. All results meet the MRH aggregate requirements.

Table 18 Summary of aggregate test results on the ESM quarry samples

Sample ID	Nominal size (mm)	FI	EI	W_abs	G_s	AIV	LAA	TFV		
								Dry	Wet	W/D Ratio
		%	%	%	g/cm³	%	%	kN	kN	(%)
BQ-A3	14	31	23	0.19	2.61	15	32	150	128	85
BQ-A4	10	27	25	0.62	2.64	---	---	---	---	---

Step 2: Design of aggregate grading

Sieve analysis was initially conducted on individual aggregate fractions (BINS) to establish their grading properties. Next, the aggregate fractions were combined and adjusted by multipliers in order to achieve the desired target, i.e. the combined aggregates were optimised to attain the designed grading for the asphalt mixes. The sieve analysis results and designed aggregate gradings for the four mixes are presented in Figures 11 to 14.

Figure 11 Design grading - CMA-Mix1 (K1-70) cation emulsion with all quarry stones

Multipliers (%)	Sieve Size (mm)	BIN 1	BIN 2	BIN 3	Min	Max	Design grading	AFCAP Specification
		14mm	10mm	Quarry dust				
		5.0	35.0	60.0				
% Passing	25	100	100	100	100	100	100	100
	20	100	100	100	100	100	100	100
	14	28	100	100	100	100	96	100-100
	10	3	100	100	85	100	95	85-100
	6.3	1	34	98	62	78	71	62 - 78
	5	1	2	85	46	60	52	46-60
	2	0	1	54	28	40	33	28-40
	1.18	0	1	39	16	26	24	16-26
	0.425	0	1	19	7	13	12	7-13
	0.3	0	1	13	5	10	8	5-10
	0.15	0	0	6	2	6	4	2-6
	0.075	0	0	3	1	3	2	1-3

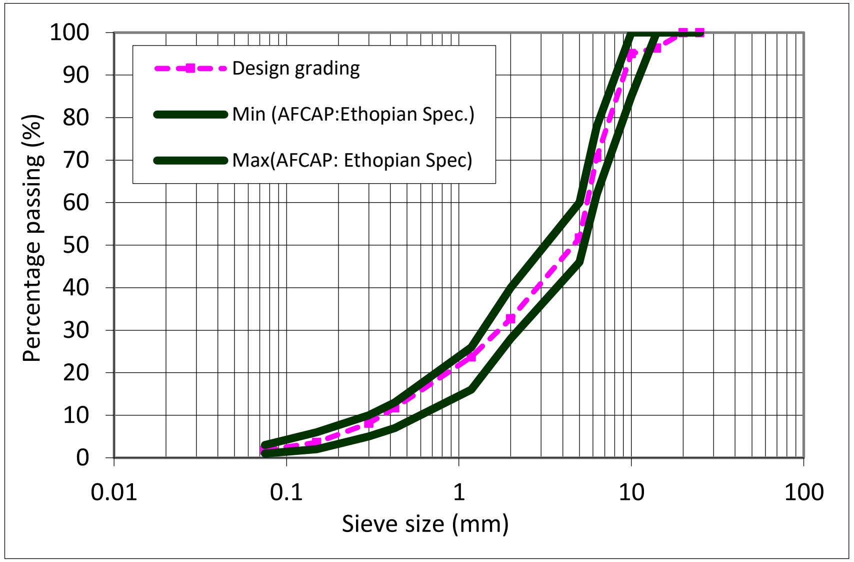


Figure 12 CMA-Mix 2: Base emulsion (K1-70 cationic type) with blended quarry stones (70%) and screened laterite (30%).

Multipliers (%)	Sieve Size (mm)	BIN 1	BIN 1	BIN 2	BIN 3	Min	Max	Design grading	AFCAP Specification
		Screen Latrine	14 mm	10 mm	Quarry dust				
		30.0	7.0	8.0	55.0				
% Passing	25	100	100	100	100	100	100	100	100
	20	100	100	100	100	100	100	100	100
	14	100	28	100	100	100	100	95	100-100
	10	100	3	100	100	85	100	93.2	85-100
	6.3	64	1	34	98	62	78	75.9	62 - 78
	5	43	1	2	85	46	60	59.9	46-60
	2	1	0	1	54	28	40	30.1	28-40
	1.18	0	0	1	39	16	26	21.5	16-26
	0.425	0	0	1	19	7	13	10.5	7-13
	0.3	0	0	1	13	5	10	7.2	5-10
	0.15	0	0	0	6	2	6	3.4	2-6
	0.075	0	0	0	3	1	3	1.7	1-3

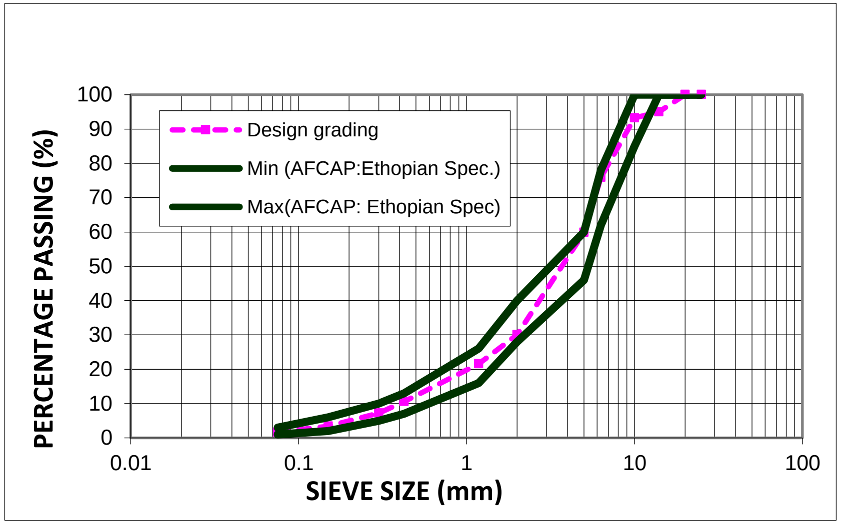


Figure 13 CMA-Mix 3: Base Emulsion K1-70 Cationic Type (with optimum cement/lime additives) with quarry stones

Multipliers (%)	Sieve Size (mm)	Bin 1 14 mm	BIN 2 10 mm	BIN 3 Quarry dust	Cement	Lime	Min	Max	Design grading	AFCAP Specification
		4.0	43.0	50.0	2.0	1.0				
% Passing	25	100	100	100	100	100	100	100	100	100
	20	100	100	100	100	100	100	100	100	100
	14	28	100	100	100	100	100	100	97	100-100
	10	3	100	100	100	100	85	100	96	85-100
	6.3	1	34	98	100	100	62	78	66.3	62 - 78
	5	1	2	85	100	100	46	60	45.9	46-60
	2	0	1	54	100	100	28	40	29.9	28-40
	1.18	0	1	39	100	100	16	26	22.4	16-26
	0.425	0	1	19	100	99	7	13	12.4	7-13
	0.3	0	1	13	98	98	5	10	9.4	5-10
	0.15	0	0	6	87	95	2	6	5.7	2-6
	0.075	0	0	3	71	91	1	3	3.5	1-3

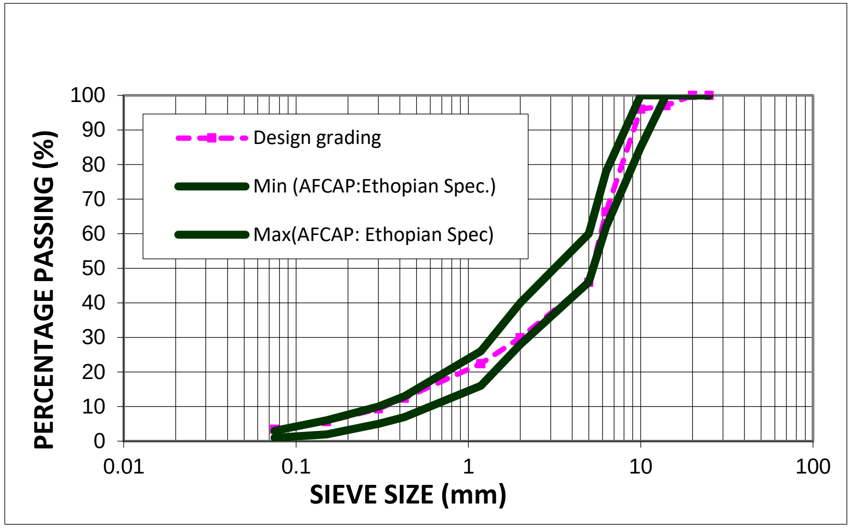
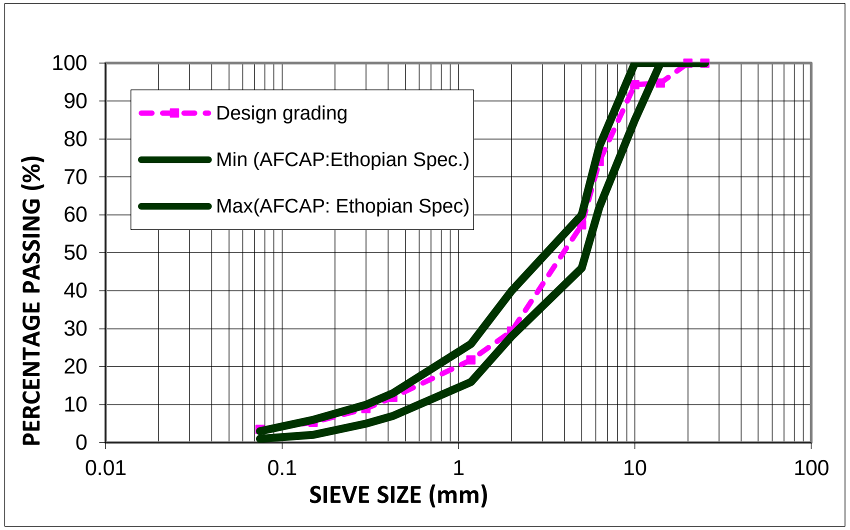


Figure 14 CMA-Mix 4: Base Emulsion (with optimum lime/cement additives) with blended Stones (70%) and Screened Laterite (30%)

Multipliers (%)	Sieve Size (mm)	Bin 1 Screen Latrine	BIN 2 14 mm	BIN 3 10 mm	Bin 4 Quarry Dust	Cement	Lime	Min	Max	Design grading	AFCAP Specification
		30	6.0	13.0	48.0	2.0	1.0				
% Passing	25	100	100	100	100	100	100	100	100	100	100
	20	100	100	100	100	100	100	100	100	100	100
	14	100	28	100	100	100	100	100	100	95	100-100
	10	100	3	100	100	100	100	85	100	94	85-100
	6.3	64	1	34	98	100	100	62	78	74	62 - 78
	5	43	1	2	85	100	100	46	60	57	46-60
	2	1	0	1	54	100	100	28	40	29	28-40
	1.18	0	0	1	39	100	100	16	26	22	16-26
	0.425	0	0	1	19	100	99	7	13	12	7-13
	0.3	0	0	1	13	98	98	5	10	9	5-10
	0.15	0	0	0	6	87	95	2	6	5	2-6
	0.075	0	0	0	3	71	91	1	3	3	1-3



Step 3: Determination of initial emulsion content

The Centrifuge Kerosene Equivalent (CKE) test is conventionally used to estimate the initial residual bitumen content. However, in the absence of CKE equipment, the emulsified bitumen content could be estimated using the Asphalt Institute empirical formula given in equation 3.

$$P = (0.05A + 0.1B + 0.5C) \times 0.7 \qquad \text{Eq. 3}$$

where

P = % Initial residual bitumen content by mass of total mixture,

A = % of aggregate retained on sieve 2.36 mm

B = % of aggregate passing sieve 2.36 mm and retained on 0.075 mm

C = % of aggregate passing 0.075 mm

The initial emulsion content value was obtained through dividing P by the percentage of bitumen content in the emulsion. The bitumen content in the emulsion, as determined by the distillation test, was 71.9%.Therefore, the following initial emulsion contents (Table 19) were obtained for the four cold mix types.

Table 19 Initial emulsion content

Cold-mix asphalt types	Initial emulsion content (%)
CMA-Mix 1	7.2
CMA-Mix 2	7.0
CMA-Mix 3	7.7
CMA-Mix 4	7.6

Step 4: Trial mix or the use of additives

The initial emulsion content for each mix type was increased by one per cent to prepare samples for five different emulsion contents, with four replicates per emulsion content. Therefore, twenty briquettes for each mix were prepared, totalling 80 briquettes in all.

The trial design was carried out for each mix composition of the four cold mix types (**Error! Reference source not found.** to Table 23 Mix composition CMA 4). Partly as a guide with regard to mix procedure, reference was made to the Marshall Method, where each specimen with a mass of 1300 g was mixed thoroughly for 60 seconds at room temperature with the required emulsion content. It was then air dried in the sun for at most five minutes, to enable the emulsion to break before compaction.

Oruc et al. (2006) studied the effect of cement on emulsified asphalt mixtures. They substituted ordinary Portland cement (OPC for mineral filler with an increasing percentile, from 0% to 6%, in their study, and concluded that mix properties such as resilient modulus, temperature susceptibility, resistance to water damage, creep and permanent deformation resistance were all improved through the addition of OPC. The use of lime as an additive in the trial mix could not be ignored, because it serves as an anti-stripping agent in the mix; thus enhancing bonding and moisture resistance. A composite mix of 2% OPC and 1% lime (by mass of the total mix) was consequently added. The inclusion of the additives (lime and OPC) was however carried out for only CMA-Mix 3 and CMA-Mix 4 respectively. Below are the mix compositions for the four cold mix types.

Table 20 Mix composition CMA 1

Sieve size	Mix composition (g) (Batching of Mix by 1% Emulsion increment)				
14mm	60.3	59.7	59.0	58.4	57.7
10mm	422.2	417.7	413.1	408.6	404.0
Quarry Dust	723.8	716.0	708.2	700.4	692.6
	Emulsion contents and aggregates proportions				
Emulsion %	7.2	8.2	9.2	10.2	11.2
Emulsion (g)	93.6	106.6	119.6	132.6	145.6
Aggregates (g)	1206	1193	1180	1167	1154

Table 21 Mix composition CMA 2

Sieve size	Mix composition (g) (Batching of Mix by 1% Emulsion increment)				
Laterites	362.7	358.8	354.9	351	347.1
14mm	84.6	83.7	82.8	81.9	81.0
10mm	96.7	95.7	94.6	93.6	92.6
Quarry Dust	665.0	657.8	650.7	643.5	636.4
	Emulsion contents and aggregates proportions				
Emulsion %	7	8	9	10	11
Emulsion (g)	91	104	117	130	143
Aggregates (g)	1209	1196	1183	1170	1157

Table 22 Mix composition CMA 3

Sieve size	Mix composition (g) (Batching of Mix by 1% Emulsion increment)				
14mm	48.0	47.5	47.0	46.4	45.9
10mm	516.0	510.4	504.8	499.2	493.6
Quarry Dust	600.0	593.5	587.0	580.5	574.0
Cement	24.0	24.0	23.5	23.2	23.0
Lime	12.0	11.9	11.7	11.6	11.5
	Emulsion contents and aggregates proportions				
Emulsion %	7.7	8.7	9.7	10.7	11.7
Emulsion (g)	100.1	113.1	126.1	139.1	152.1
Aggregates (g)	1199.9	1186.9	1173.9	1160.9	1147.9

Table 23 Mix composition CMA 4

Sieve size	Mix composition (g) (Batching of Mix by 1% Emulsion increment)				
Laterites	360.4	356.5	352.6	348.7	344.8
14mm	72.1	71.3	70.5	69.7	69.0
10mm	156.2	154.5	152.8	151.1	149.4
Quarry Dust	588.6	582.2	575.8	569.5	563.1
Cement	24.0	23.8	23.5	23.2	23.0
Lime	12.0	11.9	11.8	11.6	11.5
	Emulsion contents and aggregates proportions				
Emulsion %	7.6	8.6	9.6	10.6	11.6
Emulsion (g)	98.8	111.8	124.8	137.8	150.8
Aggregates (g)	1201.2	1188.2	1175.2	1162.2	1149.2

Step 5: Determination of stability and flow properties

Each briquette was compacted with 75 blows from a 4.54 kg compaction hammer falling through 457 mm onto the top and bottom. The briquettes were later extruded, and for easy identification they were labelled in readiness for performance tests.

The specimens were subjected to two laboratory performance tests: a stripping test, and a resilient modulus test.

Four briquettes were selected for the resilient modulus (MR) test, and twenty briquettes were selected for the stability-loss-on-soaking test. Ten briquettes were used for the Marshal stability and flow tests, to determine the maximum load that the briquettes can sustain, and the deformation at failure in millimetres. The test results of the trial specimens of the four mixes are presented in Tables 24 to 27, and the summary of volumetric properties of the optimum mixes are presented in Table 28.

Table 24 Summary results of trial mixes for CMA-1

Sample Ref	Bulk S G)	Lab. Max S G (loose mix) G_{mm}	% Air Voids	Stability (N)	Flow (mm)
7.2M_1A	2.125	2.430	12.54	1,600	2.70
7.2M_1B	2.156	2.430	11.26	2,900	5.20
8.2M_1A	2.106	2.428	13.26	224	1.80
8.2M_1D	2.093	2.428	13.78	224	2.20
9.2M_1B	2.029	2.368	14.30	224	1.70
9.2M_1E	2.124	2.368	10.29	collapsed	-
10.2M_1B	2.110	2.383	11.48	224	1.70
10.2M_1E	2.111	2.383	11.43	400	0.60
11.2M1A	2.125	2.261	6.01	700	5.10
11.2M_1C	2.140	2.261	5.33	1300	4.30

Table 25 Summary results of trial mixes for CMA-2

Sample Ref	Bulk S G (0.99654)	Lab. Max S G (loose mix) G_{mm}	% Air Voids	Stability (N)	Flow (mm)
7M_2A	2.200	2.513	12.45	200	2.00
7M_2B	2.219	2.513	11.71	200	1.90
8M_2A	2.220	2.567	13.51	2600	6.00
8M_2C	2.210	2.567	13.90	collapsed	-
9M_2B	2.141	2.447	12.49	200	1.40
9M_2D	2.213	2.447	9.58	200	1.10
10M_2B	2.067	2.479	16.60	collapsed	-
10M_2C	2.124	2.479	14.31	collapsed	-
11M_2D	2.147	2.514	14.58	3100	7.60
11M_2C	2.150	2.514	14.49	1800	5.10

Table 26 Summary results of trial mixes for CMA-3

Sample Ref	Bulk S G (0.99654)	Max S G (loose mix) G_{mm}	% Air Voids	Stability (N)	Flow (mm)
$10.7M_3C$	2.035	2.430	16.27	3100	6.40
$10.7M_3D$	2.020	2.430	16.88	3600	6.40
$11.7M_3C$	2.068	2.428	14.83	4000	5.10
$11.7M_3D$	2.033	2.368	14.16	4000	7.60

Table 27 Summary results of trial mixes for CMA-4

Sample Ref	Bulk S G (0.99654)	Lab. Max S G (loose mix) G_{mm}	% Air Voids	Stability (N)	Flow (mm)
$9.6M_4B$	2.088	2.368	11.83	2200	5.00
$9.6M_4D$	2.081	2.368	12.12	2700	3.80
$10.6M_4A$	2.104	2.383	11.72	3100	6.40
$10.6M_4B$	2.088	2.383	12.38	2700	5.10
$11.6M_4A$	2.126	2.261	5.98	2700	6.40
$11.6M_4D$	2.072	2.261	8.36	2200	6.40

Table 28 Summary of mix design properties for optimum mixes

Mix property	Analysis at optimum binder content			
	CMA-1	CMA-2	CMA-3	CMA-4
Emulsion content	10.2%	9.40%	11.20%	10.70%
Marshall Stability	100 N	1,400 N	3,480 N	3,000 N
Flow value	2.1mm	1.8 mm	6.35 mm	5.9 mm
Voids in total mix	8.1%	8.6 %	15.5%	10.4%
Voids filled with emulsion	73.0%	82.0%	49.2 %	66.5%
Void in mineral aggregate	28.0%	47.5%	28.0 %	30.5%

3.1.5 Discussion of test results

Air voids

Inadequate voids in an asphalt mix cause bleeding and excessive voids enhance spalling and ingress of water. This reduces the life span of the pavement. With the four cold mix types, the air voids values were found to be quite high. Most of the briquettes therefore collapsed during extrusion and this attributed to poor bonding within the asphalt matrix, which implies inadequate emulsion content.

The results show that the briquettes of Mix 3 and Mix 4 (with an emulsion content of between 9% and 11%) were stable enough for Marshall testing. Briquettes with emulsion contents ranging from 7% to 9% all collapsed because workability was poor, due to the introduction of the additives. The presence of the additives (cement and lime) in Mix 3 and Mix 4 increased the percentage of the mix passing through a sieve of 75 µm. The mix specimens were seemingly dry and this meant that bonding was poor. The mix with the lowest air voids value of 4.95 was CMA-Mix 1 at an emulsion content of 11.2%, and the highest was 16.71 for CMA-Mix 3 at an emulsion content of 10.2%.

Briquettes of CMA-Mix 3 with emulsion contents ranging from 7.2% to 9.2% collapsed because the emulsion contents apparently did not enhance good bonding in the aggregates mix.

Stability and flow

Marshall stability and flow tests were carried out in accordance with ASTM D1559 (ASTM, 2004). However, because of high void values and the collapse of briquettes, readings were taken straight away, without the placement of briquettes in a bath. The highest stability value attained by the briquettes was 4 kN for CMA-Mix 3 with a flow value of 6.35 mm at 11.7% emulsion content. The lowest stability value attained was 224 N, which was common for all mix variables of the four mixes, with emulsion contents lower than 10%.

Stability loss on soaking or swell test

A swell test was conducted on the compacted specimens to determine the mixture's resistance to water. Basically, a swell test measures the swelling of a compacted specimen after it has been submerged in water for 24 hours. A detailed description of the swell test can be found in The Asphalt Institute Manual (Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types, 1997).

A high swell value indicates that the asphalt mixture has a low water resistance. However, this test could not be carried out because the briquettes collapsed in the water.

Stripping test

A stripping test was carried out on the aggregates by employing the AASHTO T182-84 test method to ascertain the adhesive property, or the bond between the aggregates and the emulsion. During testing, 100 g of the sample was placed in a jar of distilled water at 60°C for 16 to 18 hours. The percentage of mix that remained coated was visually estimated.

All mixes appeared to have good binding between the aggregates and the emulsion.

Resilient modulus test

The indirect tensile test was used for determining the resilient modulus of cold mix samples. The test was conducted on cold mix samples in accordance with BS EN 12697-26 using the GHA universal testing machine system. Testing was conducted on the specimens at a test temperature of 25 °C.

The mean values of the resilient modulus, achieved by carrying out the indirect tensile test on the four selected briquettes comprising of all the mixes are shown below and it could be inferred that Mix 3 and Mix 4 are more resilient than Mix 1 and Mix 2.These values are extremely low and do not appear as true representation of the materials tested. Efforts were made to conduct a verification test in a different Lab. However, no accredited Lab was available to conduct the tests.

Table 29 Summary of resilient modulus test

Mix Options	Emulsion Content (%)	Resilient Modulus (MPa)
CMA-Mix 1	10.2	94.96
CMA-Mix 2	11.0	93.81
CMA-Mix 3	10.7	109.8
CMA-Mix 4	10.6	637.1

3.1.6 Remarks on mixes

Three mixes will be demonstrated in this project. CMA-Mix 3 and CMA-Mix 4 were superior in terms of the outcomes from the laboratory mix design, hence they will constitute two mixes for demonstration. In comparison, CMA- Mix 1 was a better mix than CMA-Mix 2. Additives can be added to enhance the performance of the two mixes. For field trials, efforts will be made to improve CMA-Mix 1 and CMA-Mix 2 in order to select one of them as the third mix for demonstration.

3.2 Concrete mix design and testing

3.2.1 Concrete mix variables

As indicated earlier, the three concrete surfacing options demonstrated in this study are (1) interlocking concrete block paving (ICBP), (2) thin mesh-reinforced concrete (TMRC), and (3) roller-compacted concrete (RCC). For ease of construction and performance comparison, a common materials design was adopted for all three surfacing options. A first round of four different trial blends/mixes was made with varying proportions of the constituents for the proposed surfacing options (see Table 30).

The concrete mix design aimed to determine the proportions of the concrete mix constituents (cement1, coarse aggregate, fine aggregate and water), and was carried out in accordance with British Standards, as applicable in the specific tests. Additionally, guidelines from the Design of Normal Concrete Mixes of the Building Research Establishment, 2nd edition, BRE (1997) and the Standard practice for selecting proportions for normal, heavyweight, and mass concrete of the American Concrete Institute - ACI 211.191 (2009) were followed during the design.

Table 30 Concrete derivatives and their constituents for initial trial mixes

Concrete derivative	Trial mix	Constituent
Thin Mesh Reinforced Concrete	TMRC - Mix 1	– Ordinary Portland Cement (OPC) – Natural Sand – Quarry Aggregates
	TMRC - Mix 2	– PPC (30% Pozzolana + 70% OPC) – Natural Sand – Quarry Aggregate
	TMRC - Mix 3	– OPC – Natural Sand – 70% Quarry Aggregate + 30% In-situ aggregate
	TMRC - Mix 4	– OPC – Natural Sand – 70% Quarry Aggregate + 30% Screened lateritic gravel
Roller Compacted Concrete	RCC - Mix 1	– OPC – Quarry Dust – Quarry Aggregates
	RCC - Mix 2	– PPC (30% Pozzolana + 70% OPC) – Quarry Dust – Quarry Aggregate
	RCC - Mix 3	– OPC – Quarry Dust – 70% Quarry Aggregate + 30% In-situ aggregate
	RCC - Mix 4	– OPC – Quarry Dust – 70% Quarry Aggregate + 30% Screened lateritic gravel
Interlocking Concrete Paving Block	ICPB - Mix 1	– OPC – Quarry Dust – Quarry Aggregates

[1]Cement for the mix design was used in a generic sense in this study. This is because, in some cases, the cement is a composite cementitious material consisting of a mixture of raw Ordinary Portland Cement (OPC) and clay pozzolana, to form Pozzolana Portland Cement (PPC).

	ICPB - Mix 2	– PPC – Quarry Dust – Quarry Aggregate
	ICPB - Mix 3	– OPC – Quarry Dust – Quarry Aggregate (70%) – In-situ aggregate (30%)
	ICPB - Mix 4	– 0PC – Quarry Dust – 70% Quarry Aggregate + 30% Screened laterite

3.2.2 Materials for the concrete derivatives

Cement and cementitious additives

Ordinary Portland cement (OPC)

In view of the target minimum characteristic strengths of 30 N/mm²fortheconcrete, cement classCEM42.5Nwas used for the derivatives of the concrete surfacing options. Testsweremainlyconductedtodeterminethephysicalandchemicalpropertiesand these results are presented in Table 31. Based on the preliminary results and availability, Ghacem cement grade 42.5N was selected for this project. On the other hand, Ghacem32.5Rwouldbeusedforallancillary concrete works of structural strengths under 30N /mm² (e.g. lean concrete layer), as well as an additive for cold-mix asphalt.

Table 31 Results of cement samples investigated

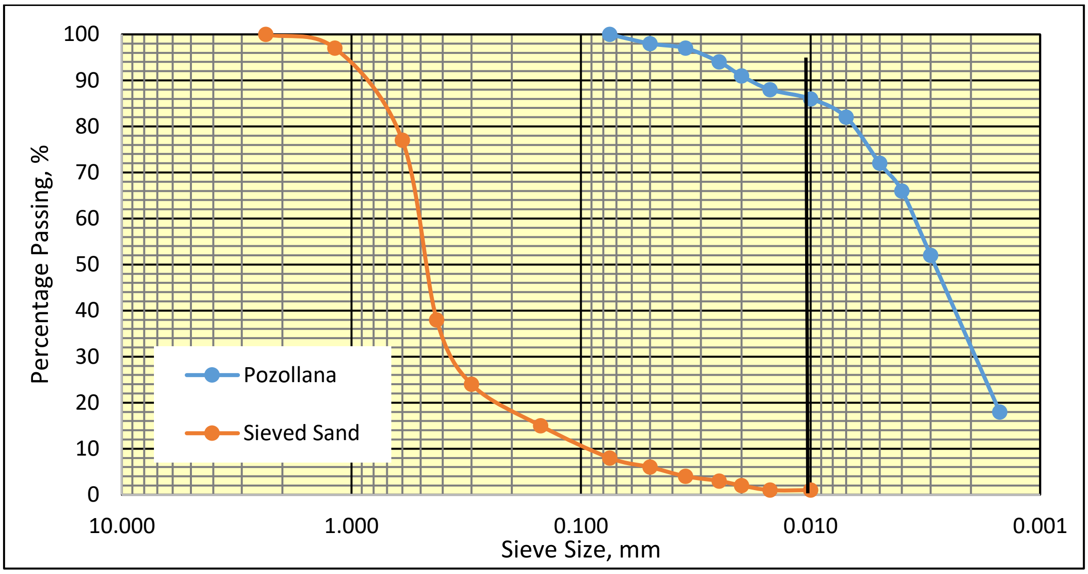
Test conducted	Unit	Results		Specification GS1118:2016
		Ghacem 42.5N	Diamond Cement42.5N	
Sulphate (SO^{2-}_3)content	%m/m	2.23	2.11	4.00(max)
Chloride(Cl^-)content	%m/m	0.01	0.01	0.10(max)
Loss of ignition	%m/m	2.97	2.93	5.00(max)
Insoluble residue	%m/m	1.81	0.63	5.00(max)
Initial setting time	min	225	219	60(min)
2-day compressive strength	N/mm²	26	25	20 (min)
7-day compressive strength	N/mm²	32	31	N/A
28-daycompressivestrength	N/mm²	43	43	42.5-62.5

Clay pozzolana

Clay pozzolana is an innovative product developed by the Building and Road Research Institute (BRRI) after more than 30 years of research. It can replace up to 35% of Ordinary Portland Cement (OPC) to obtain Portland Pozzolana Cement (PPC), which can then be used for both concrete and general construction. Work done with clay pozzolana in Ghana shows that the replacement of OPC by up to 30% by mass of pozzolana to produce PPC exhibits compressive strengths of values fit for both load-bearing and non-load-bearing structural applications (Atiemo, 1998; 2005). PPC used for mortar and concrete applications improves the strength characteristics and durability of concrete and it reduces materials costs significantly (Aldemir, 2006). The cost of PPC per 50 kg bag is about 15% cheaper than OPC and PPC has relatively greater plasticity and workability than OPC. Clay pozzolana cements have been used for construction applications across the length and breadth of Ghana.

The typical particle size distribution of clay pozzolana materials is mostly finer than 100 µm. For instance, in analysing a sample of clay pozzolana, it was established that over 85% of the nominal particles of the clay pozzolana are finer than 100 µm. The pozzolana samples were further compared with sieved natural sand and the distribution curves are presented in Figure 15. The finer particle sizes of clay pozzolana were very similar to those of OPC results in a PPC material that usually meets the Blaine fine test protocols.

Figure 15 Comparison of particle size distribution of clay pozzolana and sieved natural sand



Portland Pozzolana Cement

For this project, Portland Pozzolana Cement (PPC) was a composite cementitious material of OPC grade 42.5 and a percentage replacement of calcine clay pozzolana. The choice of the 42.5 class grade of cement is based on the proposed concrete characteristic strength of 30 N/mm². It should be noted that because clay pozzolana has a negligible binding property and is only introduced to the cement as an additive that enhances the other properties of the concrete (such as durability), the concrete derivatives of PPC are expected to be slightly lower in characteristic compressive strengths when compared to their corresponding derivatives from OPC. The PPC concrete products are nonetheless also expected to be of a higher durability (ability of concrete to resist weathering action, chemical attack and abrasion) than those obtained from raw OPC, because the gain of compressive strengths is expected to go beyond the characteristic 28-day strength to a 60-day strength (Atiemo, 1998; Helmuth, 1987).

A chemical analysis of OPC, clay pozzolana and 20% and 30% replacement of the OPC to form composite cementitious materials denoted PPC20 and PPC30 samples was carried out using X-ray fluorescence (XRF) to determine the chemical constituents (see Table 31). The chemical composition of the raw OPC involved mainly major oxides (CaO, SiO2, Al2O3, SO3 and Fe2O3) constituting about 90%, with the rest of the compound being the minor oxides (MgO, Na2O, K2O, MnO, etc). The 20 and 30% replacement of the OPC results in the composite portions of slightly altered cementitious material having better hydration.

The specific gravities of samples of clay pozzolana and OPC were 2.67 and 3.18, respectively. Thus, for a given PPC, the resulting composite cement becomes lighter than the raw OPC. This property enhances the workability of PPC applications in terms of mixing concrete constituents. Pozzolana cements are noted for their slow strength development, resulting in low early (28-day) strength characteristics and slow setting times. Yet they produce enhanced durability in the long term with relatively significant economic benefits, since the unit cost of PPC is cheaper than that of raw OPC applications (Boakye et al., 2014).

The above findings formed the basis for experimentation within the proposed research matrices for concrete alternatives using the PPC applications (i.e. percentage replacement of OPC with pozzolana).

Table 32 Summary Chemical composition clay pozzolana, OPC and PPC samples

Item	Constituents	Chemical Formula	Percentage (%)			
			Pozzolana	OPC	PPC_{20}	PPC_{30}
1	Silicon dioxide	SiO_2	62.77	18.86	16.53	15.07
2	Aluminium oxide	Al_2O_3	18.71	3.57	4.93	4.58
3	Iron (III) oxide	Fe_2O_3	11.68	3.39	3.07	2.66
4	Calcium oxide	CaO	0.25	59.83	58.44	58.82
5	Magnesium oxide	MgO	1.46	1.89	2.64	3.98
6	Manganese (II) oxide	MnO	0.46	0.14	0.06	0.04
7	Titanium dioxide	TiO_2	0.41	0.19	0.11	0.26
8	Sulfur trioxide	SO_3	0.19	4.93	3.06	3.23
9	Sodium oxide	Na_2O	0.21	4.71	0.12	0.22
10	Phosphorus pentoxide	P_2O_5	0.03	0.22	0.01	0.02
11	Chlorine	Cl	0.00	0.01	0.00	0.00
12	Potassium oxide	K_2O	1.08	2.12	0.65	0.62
13	Loss on ignition	*L.O.I*	2.75	3.04	10.5	11.0

3.2.3 Aggregates

Coarse Aggregates

The following different types of coarse aggregates were identified and sourced for laboratory tests to be used in the proposed surfacing matrix:

- Three in-situ sedimentary rock samples (sample IDs: ATR-RS1, ATR-RS2 and ATR-RS3).
- Coarse quarry aggregate samples (BQ-A) obtained from Buoho (near Kumasi), supplied by the ESM Company (Kumasi) about 140 km from the project site. These samples were used for the trial mixes and mix designs for the concrete derivatives, as well as for the cold-mix asphalt.
- Screened lateritic gravels (sample IDs: ATR-SA1 and ATR-SA2) were obtained from identified borrow pits at two sources (borrow sites at Asuoyaa and Twenedurase).

Table 33 shows the nature and sources or locations of the coarse aggregates. A list of test properties with appropriate test methods/protocols and a schedule of the laboratory tests that were carried out on the coarse aggregates are given in Table 34 and Table 35. It is noteworthy that not all tests are applicable to all coarse aggregate samples. For instance, the screened ferruginous lateritic gravels were not tested for the shape indices because the particles were nodular in shape.

Table 33 Nature and source/location of coarse aggregates

Sample ID	Source	Location	Distance to project site	Sample type	Geo-locations	
					Northings	Eastings
ATR-RS1	Along project road corridor	Ch.3+072	Project site	Sedimentary Rock	6.622794	-0.798142
ATR-RS2	Along project road corridor	Ch.3+222	Project site	Sedimentary Rock	6.622250	-0.799324
ATR-RS3	Along project road corridor	Ch.3+230	Project site	Sedimentary Rock	6.622291	-0.799252
BQ-A	ESM Company Limited	Buoho, Kumasi	142km	Granitic Rock	6.784952	-1.648585
MQ-A	Mansco Stone Quarry Limited	Nsawam, Accra	127km	Granitic Rock	5.7857681	-0.358317
ATR-SA1	Asuoyaa Village (BorrowSite1)	Asuoyaa village	11km	Screened Lateritic Gravel (Quarzitic)	6.672974	-0.876897
ATR-SA2	Twenedurase Village (BorrowSite2)	Twenedurase village(close toch.3+500)	1km	Screened Lateritic Gravel (Ferruginous)	6.614513	-0.791101

Table 34 Test property and method / protocol conducted on the coarse aggregates

Number	Test property	Test method/Protocol
1	Sieve Analysis	BSEN933-1:2012–Tests for geometrical properties of aggregates–Part1:Determinationofparticlesizedistribution–Sieving method
2	Flakiness Index	BSEN933-3:2012– Tests for geometrical properties of aggregates –Part3:Determinationofparticleshape –Flakiness Index
3	Impact Value	BS812-112:1990–Part112:Methodsfordeterminationofaggregate impact value(AIV)
4	Crushing Value	BS812-110:1990–Part110:Methodfordeterminationofaggregate crushing value(ACV)
5	Water Absorption	BS812:Part2:1995–Part2.Methodsfordeterminationofdensity/ ASTMC127C-Standardtest method for relative density and absorption of coarse aggregate
7	Specific Gravity	BS812:Part2:1995–Testing aggregates–Part2.Methodsfor Determination of density
8	Elongation Index	BS812-105.2:1990–Testing aggregates–Part105:Methodfor determination of particle shape–Elongation index of coarse aggregate
9	Los Angeles Abrasion	ASTMC131/C131M–Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
10	Bulk density(loose and compacted)	BS812:Part2:1995–Test in aggregates–Part2.Methodsfor Determination of density
11	Aggregate Soundness Test(Na_2SO_4)	BS812-121:1989–Testing aggregates–Part121:Methodfor determination of soundness

Table 35 Schedule of test carried on the various sources of coarse aggregate

No.	Test Property	In-Situ Rock Aggregates			ESM Quarry Aggregates			Screened Laterite			Test Method / Protocol
		ATR-RS1	ATR-RS2	ATR-RS3	BQ-A1	BQ-A2	BQ-A3	BQ-A4	ATR-SA1	ATR-SA2	
1	Sieve Analysis	X	X	X	X	X	X	X	X		BS EN 933-1:2012 –Part 1
2	Flakiness Index	X	X	X	X	X	X	X			BS EN 933-3:2012 –Part 3
3	Impact Value	X	X	X	X	X	X	X			BS 812-112:1990– Part 112
4	Ten percent Fine Value	X	X	X	X	X	X	X	X		BS 812-111:1990 –Part 111
5	Water Absorption	X	X	X	X	X	X	X	X		BS 812: Part 2:1995 – Part 2. / ASTM C127C
7	Specific Gravity	X	X	X	X	X	X	X	X		BS 812: Part 2:1995 –Part 2.
8	Elongation Index	X	X	X	X	X	X	X			BS 812-105.2:1990– Part 105
9	Los Angeles Abrasion	X	X	X	X	X	X	X			ASTM C131/C131M
10	Bulk density (loose and compacted)	X	X	X	X	X	X	X			BS 812: Part 2:1995 –Part 2.
11	Aggregate Soundness Test (Na_2SO_4)	X	X	X	X	X	X	X			BS 812-121:1989 Part 121

X = tests conducted

In-situ rocks

The three sedimentary rock types (ATR-RS1, ATR-RS2 and ATR-RS3) sampled at the project site were manually crushed into three nominal sizes (37.5 mm, 25 mm and 14 mm) and tests were conducted on the samples.

A summary of results obtained for the various tests conducted on these samples is presented in Table 36. Test results on the crushed in-situ rock samples indicate aggregates with a specific gravity ranging between 2.60 and 2.68. With reference to the limits provided in the GSSRB, the maximum water absorption test result of 2.34% is less than the maximum specified limit of 2.5%. Also, the maximum flakiness index of 28.5% is less than the maximum specified limit of 35% for crushed aggregates. However, Los Angeles Abrasion (LAA) test results on the in-situ samples yielded a minimum value of 51.37%, which is higher than the specified limit of 40%. Thus, it was very promising to experiment with the in-situ sedimentary rock samples as aggregates for concrete products have been marginalised over the years.

Table 36 Summary results on in-situ sedimentary rock samples

Sample ID	Nominal Size, mm	Test property								
		Gs (g/cm³)	Water (abs) (%)	EI (%)	FI (%)	AIV (%)	LAA (%)	10% Fines (TFV)		
								Dry (D) (kN)	Wet (W) (kN)	W/D Ratio (%)
ATR-RS 1	37.5	2.66	1.20	0.00	23.15	28	58	37	4	9.90
	25	2.65	1.25	7.31	13.13					
	14	2.63	1.32	26.14	17.98					
ATR-RS 2	37.5	2.65	1.61	29.64	15.29	25	51	33	3	9.91
	25	2.60	1.74	2.49	13.56					
	14	2.63	1.91	7.26	26.64					
ATR-RS 3	37.5	2.64	2.34	0.00	17.23	31	64	41	4	9.88
	25	2.68	2.01	6.58	14.77					
	14	2.64	2.16	30.45	28.55					

Note: Nomenclature for Sample ID (ATR=Akwesiho-Twenedurase Road; RS=Rock Sample)

Conventional quarry stones

On the other hand, aggregates from the ESM Quarry were granitic in nature. Four samples with nominal sizes of 25 mm, 19 mm, 16 mm and 10 mm were tested for their grading and physical properties. The summary of the laboratory test results of these samples is presented in Table 37 and Table 38. Test results of the crushed rock samples from the ESM Quarry indicated aggregates with specific gravity ranging between 2.61 and 2.71 g/cm³. For the four samples tested the maximum values obtained for flakiness index, water absorption, and Los Angeles Abrasion tests were 31%, 0.62% and 36.04% respectively. The test results obtained for these aggregates fall within the specified limit provided in the GSSRB specifications.

Quarry aggregate samples (19 mm; 14 mm; 10 mm and quarry dust) from Mansco Stone Quarry were also subjected to the engineering property testing. The results showed that the products meet the basic specification requirements for use as concrete and road materials. The quarry aggregates from Mansco Stone Quarry, which is situated about 150 km from the project site, could therefore be a standing alternative to the main source from ESM Quarry.

Table 37 Sieve analysis results for aggregate samples from the ESM quarry

Sample ID	Nominal size	Sieve analysis(percentage passing BS Sieves)							
		53.0 mm	37.5 mm	19mm	9.5mm	4.75 mm	2.36 mm	0.425 mm	0.075 mm
BQ-A1	25mm	100	100	10.8	0.39	0.35	0.35	0.28	0.18
BQ-A2	19mm	100	100	78.9	0.37	0.33	0.32	0.23	0.12
BQ-A3	16mm	100	100	100	12.62	0.91	0.81	0.58	0.30
BQ-A4	10mm	100	100	100	98.00	1.58	1.38	1.03	0.66

Table 38 Physical property results of aggregate samples from the ESM quarry

Sample ID	Nominal siz	FI(%)	EI(%)	Absorption	G_s g/cm	AIV(%)	LAA(%)	TFV(kN)		
								Dry, D	Wet, W	W/D ratio
BQ-A1	25mm	27	29	0.09	2.71	-				
BQ-A2	19mm	16	36	0.06	2.67	-	36.04	136	105	77
BQ-A3	16mm	31	23	0.19	2.61	14.74	31.5	150	128	85
BQ-A4	10mm	27	25	0.62	2.64					

Screened laterite

Two types of screened gravels were obtained from the two borrow pits, namely quarzitic gravel (from Asuoyaa borrow pit) and ferruginous gravel (from Twenedurase borrow pit). The quarzitic gravels were more angular compared to the ferruginous gravel, which were rounded.

Fine aggregates

Fine aggregates sourced for this project were mainly natural sand and quarry dust supplied by ESM Company, at Buoho near Kumasi. Table 39 shows the primary characteristics of the fine aggregates.

Table 39 Summary of particle size distribution of fine aggregate samples

SAMPLE ID	Sieve analysis (percentage passing BS sieves), %								Silt/Clay content (%)
	53.0 mm	37.5 mm	19 mm	9.5 mm	4.75 mm	2.36 mm	0.425 mm	0.075 mm	
Quarry dust	100	100	100	100	85	72	31	10.7	8.3
Natural sand	100	100	100	100	99	92	62	22.8	14.8

Chemical tests were also conducted on both in situ and ESM quarry aggregates and the results are presented in Table 40. The tests were conducted in accordance with ASTM C88-05 – *Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate*.

Test results indicated that the average soundness values are below the threshold value of 15%. However, the individual results show that the aggregates with smaller sizes (16 mm) have better soundness properties than the larger ones (19 mm). This suggests that smaller size (limiting size of 16 mm) particles may exhibit better performance; thus they were considered for this study.

Table 40 Summary of sodium sulphate soundness test results

SAMPLE ID	Nominal size, mm	Sodium sulphate soundness test result	
		Loss in mass (%)	Average soundness (%)
ATR-RS 1	19	9.71	7.59
	16	5.47	
ATR-RS 2	19	8.65	6.83
	16	5.0	
ATR-RS 3	19	18.66	12.71
	16	6.76	
BQ-A2	19	16.67	9.33
BQ-A3	16	1.96	

3.2.4 Grading design of aggregates

An optimum grading of the combined coarse and fine aggregates for the concrete mix options was arrived at by iterating aggregate blends and using the BS 882: 1992 recommended aggregates grading envelope for concrete. The iteration process also took into consideration the fineness modulus (FM) of the combined aggregates. The grading of constituent aggregates used to obtain the all-in aggregates for the blends of concrete derivatives is shown in Table 41.

Table 41 Design aggregate grading

Sieve size	25mm	19mm	16mm	10mm	Quarry dust	Sand
50mm	100	100	100	100	100	100
37.5mm	100	100	100	100	100	100
25mm	82	100	100	100	100	100
19mm	10	79	100	100	100	100
12.5mm	0	3	67	100	100	100
9.5mm	0	0	13	98	100	100
4.75mm	0	0	1	2	85	99
2.36mm	0	0	1	1	72	98
1.18mm	0	0	1	1	52	94
0.6mm	0	0	1	1	37	74
0.3mm	0	0	1	1	25	51
0.15mm	0	0	0	1	15	33
0.075mm	0.2	0.2	0.3	0.7	10.7	22.8

The coarse and fine aggregates were blended to give an all-in aggregate with FM values (as determined from Equation 4) of 4.89, 4.80 and 5.1 for TMRC, ICPB and RCC aggregates respectively. The grading characteristics also met the BS 882: 1992 specifications for concrete aggregates from natural sources.

$$FM = \frac{\sum \textit{Cumulative \% retained on each Standard Sieves}}{100} \qquad \text{Eq. 4}$$

Following two rounds of trial mix designs of the concrete derivatives, the final grading results and their corresponding grading curves are presented in Figure 15 to Figure 18. The blended aggregates for only quarry aggregates as well as for both quarry and in-situ crushed stones are shown for TMRC, ICBP and RCC. Table 42 shows the grading values of the individual concrete derivatives.

Figure 16 Grading characteristics of TMRC variables

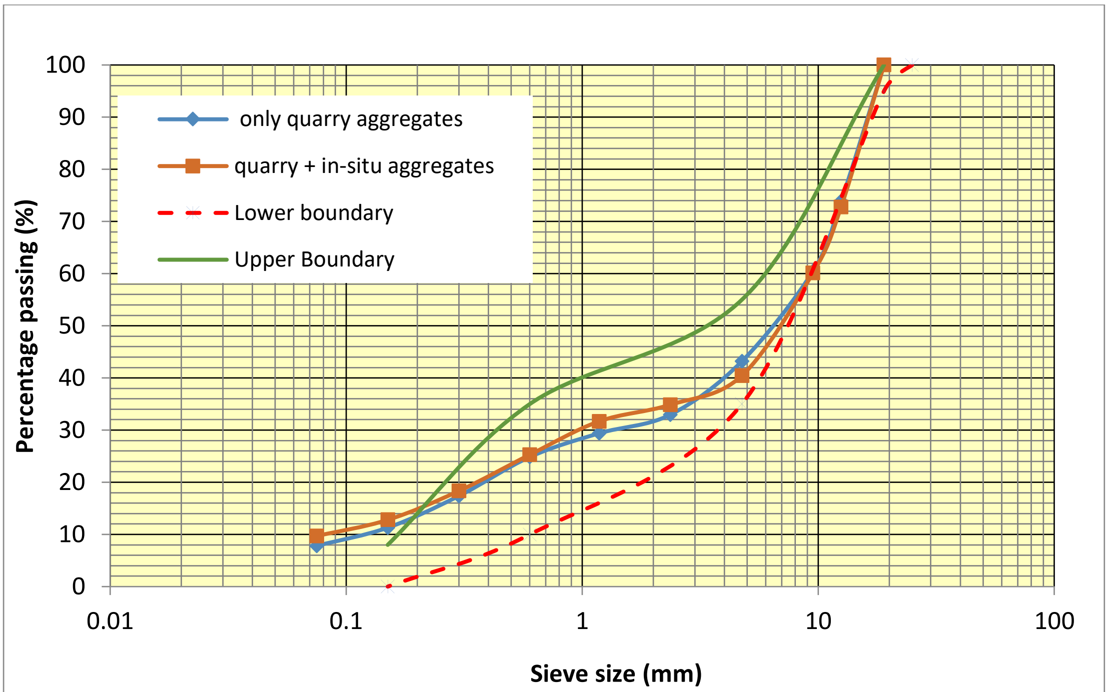


Figure 17 Grading characteristics of ICBP variables

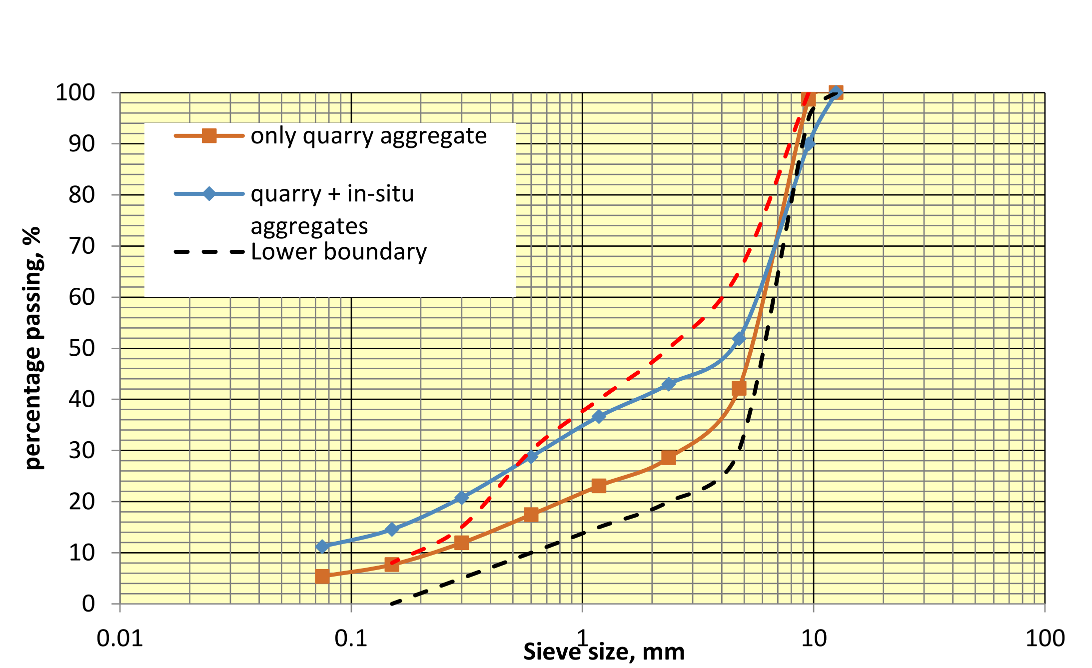


Figure 18 Grading characteristics of RCC variables

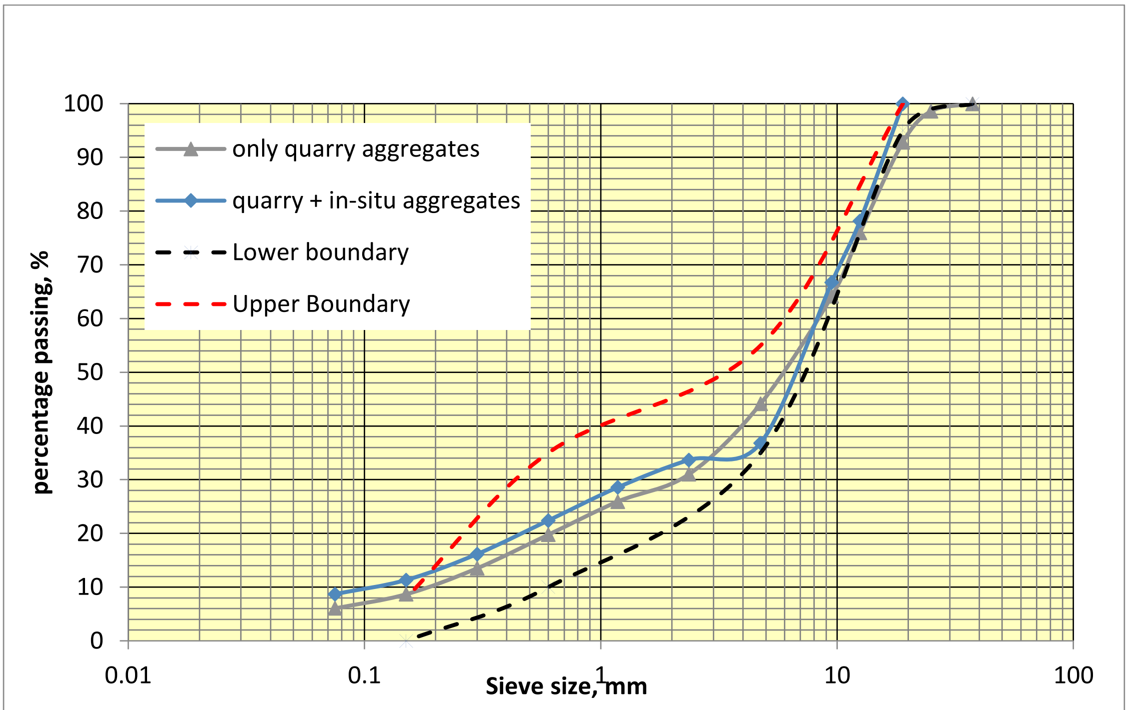


Table 42 Design aggregate grading for TMRC, ICBP and RCC concrete derivatives

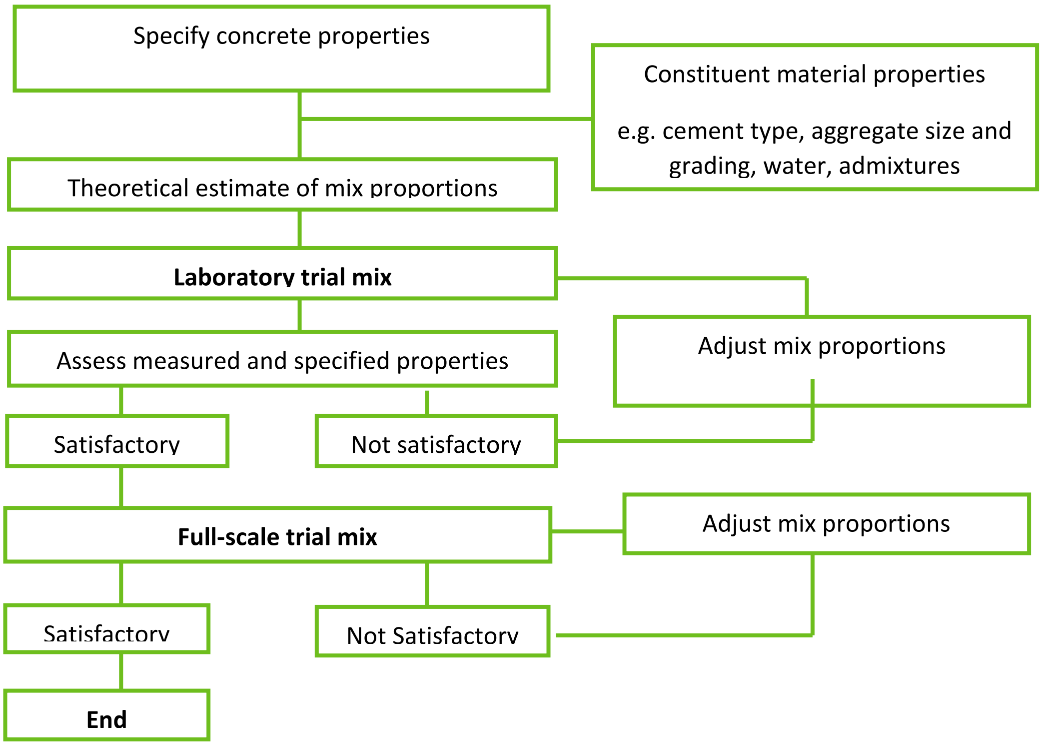
Sieve size (mm)	Thin mesh-reinforced concrete – Maximum size – 20mm				Interlocking concrete block paving – Maximum size – 10mm				Roller-compacted concrete – Maximum size – 20mm			
	Quarry aggregates only	Quarry with in-situ aggregates	BS 882: 1992 grading envelope		Quarry aggregates only	Quarry with in-situ aggregates	BS 882: 1992 grading envelope		Quarry aggregates only	Quarry with in-situ aggregates	BS 882: 1992 grading envelope	
			Lower limit	Upper limit			Lower limit	Upper limit			Lower limit	Upper limit
	%Passing	%Passing	%Passing	%Passing	%Passing	%Passing	%Passing	%Passing	%Passing	%Passing	%Passing	%Passing
50	100	100	100	100	100	100	100	100	100	100	100	100
37.5	100	100	100	100	100	100	100	100	100	100	100	100
25	100	100	100	100	100	100	100	100	99	100	100	100
19	100	100	95	100	100	100	100	100	93	100	95	100
12.5	74	73	-	-	100	100	100	100	76	78	-	-
9.5	60	60	-	-	99	90	95	100	64	67	-	-
4.75	43	40	35	55	42	52	30	65	44	37	35	55
2.36	33	35	-	-	29	43	20	50	31	34	-	-
1.18	29	32	-	-	23	37	15	40	26	29	-	-
0.6	25	25	10	35	17	29	10	30	20	22	10	35
0.3	17	18	-	-	12	21	5	15	14	16	-	-
0.15	11	13	0	8	8	15	0	8	9	11	0	8
0.075	7.8	9.7	-	-	5.4	11.2	-	-	6.0	8.7	-	-

3.2.5 Mix design process

The method of concrete mix design applied here was adopted from the design of normal concrete mixes, Building Research Establishment, BRE (1997) with some guiding inputs from the American Concrete Institute's Standard practice for selecting proportions for normal, heavyweight, and mass concrete ACI 211.191 (2009).

A flow chat adapted from BRE (1997) for the mix design process is presented in Figure 19.

Figure 19 Flow chat developed for the mix design process



Thus, the adapted design process followed for this study was divided into five primary steps:

Step 1 Characteristic strength and determination of target mean strength

A characteristic strength (fc) of 30 N/mm² for this project was determined based on interactions between the project team and the DFR, as well as the expected traffic loading and environmental stresses on the project road. The target mean strength (fm) is further calculated using Equation 5.

$$\boldsymbol{f_m} = \boldsymbol{f_c} + \boldsymbol{M};\ given\ \boldsymbol{M} = \boldsymbol{k} \times \boldsymbol{s} \qquad \text{Eq. 5}$$

where,

fm= the target mean strength of the concrete

fc = the characteristic strength of the concrete and M is the margin

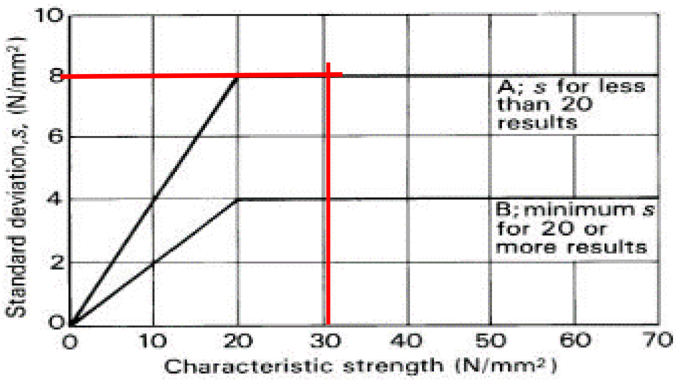
k = a value appropriate to the defect percentage permitted below the characteristic strength, and

s = the standard deviation.

The standard deviation in characteristic strength at 28 days was read from 8 N/mm², and for a defect percentage of 2.5% the value of k was determined to be 1.960.

The margin (M) was then calculated as 15.7 N/mm². The target mean strength is therefore, 45.7 N/mm².

Figure 20 Relationship between standard deviation and characteristic strength



Source: Design of normal concrete mixes, 2nd edition, BRE, 1997

Step 2 Determination of free water/cement ratio

The approximate compressive strength was determined by looking at the target mean strength (i.e. 45.7 N/mm²). Based on the cement class type used in the project (42.5 at 28 days) and the crushed coarse aggregate for the concrete, an approximate compressive strength as indicated in Table 43 was 49 N/mm².

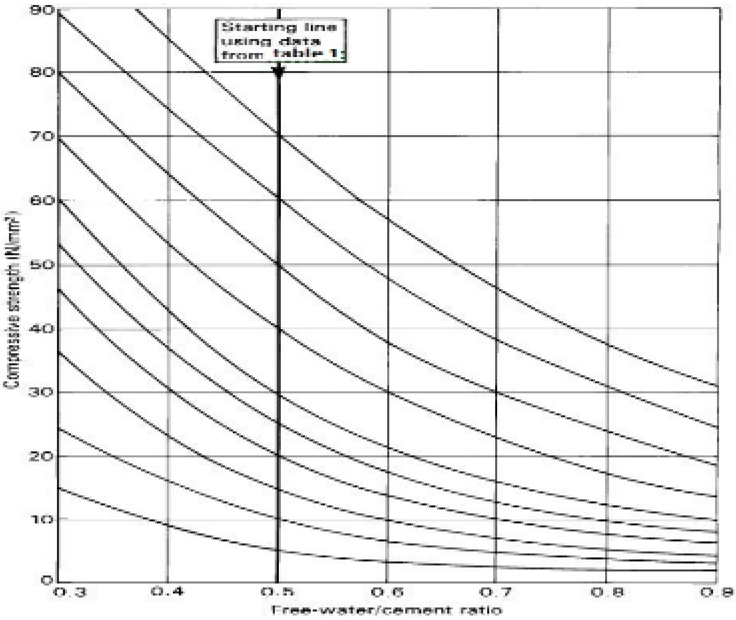
Table 43 Compressive strength (N/mm²) of concrete mixes made with a water/cement ratio of 0.5

Cement strength class	Type of coarse aggregate	Compressive strengths (N/mm²) Age (days)			
		3	7	28	91
42.5	Uncrushed	22	30	42	49
	Crushed	27	36	49	56
52.5	Uncrushed	29	37	48	54
	Crushed	34	43	55	61

Source: Design of normal concrete mixes, 2nd edition, BRE, 1997

In the Figure 21, the 'starting line' was traced to the curve of 49 N/mm² at 0.5 free-water surface. The target mean strength of 45.7N/mm² was plotted in Figure 21 and the free-water ratio for the target was calculated as 0.49, which was adopted as 0.5 for the thin mesh-reinforced concrete mixes. The respective water-cement ratios for the roller-compacted concrete and interlocking concrete block paving were determined as 0.33 (for both).

Figure 21 Relationship between compressive strength and water/cement ratio



Source: Design of normal concrete mixes, 2nd edition, BRE, 1997

Step 3 Determination of free water content

The total water in a concrete mix consists of the water absorbed by the aggregate and the free water available for the hydration of the cement and for the workability of the fresh concrete. In practice, aggregates are often wet and they contain both absorbed water and free surface water.

The free-water content, W, is calculated from equation 6

$$Free - water\ content,\ \boldsymbol{W} = \frac{2}{3}\boldsymbol{W_f} + \frac{1}{3}\boldsymbol{W_c} \qquad \text{Eq. 6}$$

where,

Wf = Free-water content appropriate to a type of fine aggregate
Wc = Free-water content appropriate to a type of coarse aggregate

The approximate free-water content of the crushed aggregates (both coarse and fine aggregates) used for the three different mixes (TMRC, ICBP, and RCC) was obtained from Table 44 for a slump of 10 mm – 30 mm. For instance, for a 20 mm maximum crushed aggregate size of the coarse aggregates used in TMRC, an approximate free-water content of 210 kg per cubic metre of concrete was used for each mix.

Table 44 Approximate free-water content (kg/m³) required to give various levels of workability

Slump (mm)		0 - 10	10 - 30	30 - 60	60 - 180
Vebe time (s)-define !		**>12**	**6 - 12**	**3 - 6**	**0 - 3**
Maximum size of aggregate (mm)	Type of aggregate				
10	Uncrushed	150	180	205	225
	Crushed	180	205	230	250
20	Uncrushed	135	160	180	195
	Crushed	170	190	210	225

40	Uncrushed	115	140	160	175
	Crushed	155	175	190	205

Source: Design of normal concrete mixes, 2nd edition, BRE, 1997

Since the coarse and fine aggregates used are of different types, the free-water content for TMRC was estimated from Equation 8 as 190 kg/m³. The applicable values are 190 kg/m3 for TMRC and RCC, while ICBP has a free-water content of 205 kg/m³.

Step 4 Determination of cement content

Using Equation7, the cement contents for the various concrete derivatives were determined as 388 kg/m3, 444 kg/m3 and 485 kg/m3 for TMRC, RCC and ICPB respectively.

$$Cement\ content, \boldsymbol{C} = \frac{\boldsymbol{Free\ Water\ Content}}{\boldsymbol{Free\ Water{-}Cement\ Ratio}} \quad \text{Eq. 7}$$

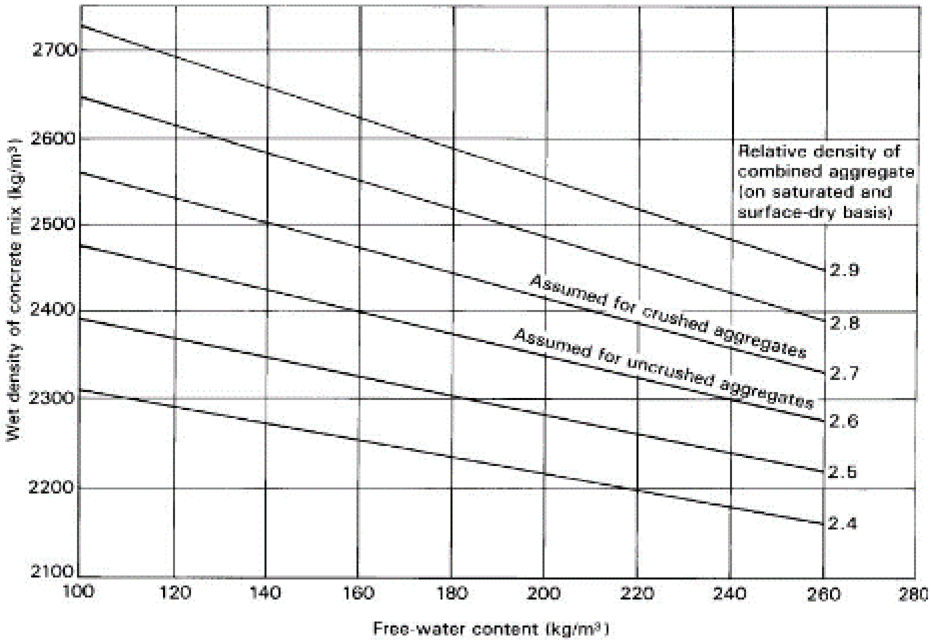
Step 5 Determination of total aggregate content

The various wet densities of the concrete products were determined using a relative aggregate density of 2.7 and the various estimated free-water contents (see Figure 8). The wet densities were determined as 2435 kg/m³, 2471 kg/m³ and 2490 kg/m³ for TMRC, ICPB and RCC, respectively. Subsequently, the total aggregate content for each concrete product was calculated based on Equation 8.

$$Total\ Aggregate\ Content = \rho_{wet} - C - W \quad \text{Eq. 8}$$

Equation 8 states that, where ρwet equals the wet density of the concrete, C is the cement content and W is the free-water content. Thus, the total aggregate contents for the TMRC, ICPB and RCC were determined as 1857 kg/m³, 1826 kg/m³ and 1899 kg/m³, respectively.

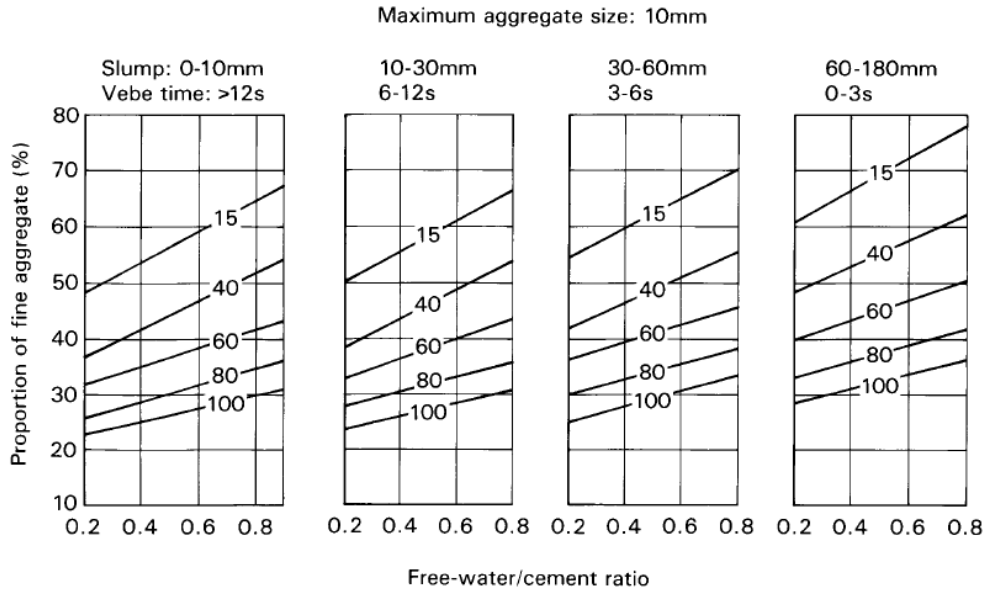
Figure 22 Estimated wet density of fully compacted concrete

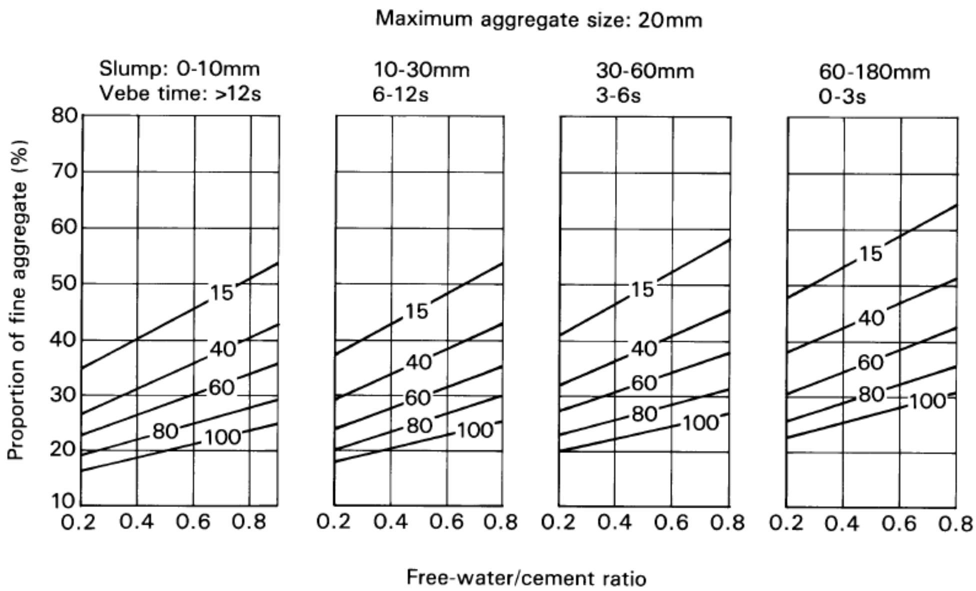


Source: Design of normal concrete mixes, 2nd edition, BRE, 1997

Step 6 Determination of fine and coarse aggregate proportions

In determining the proportions of the fine and coarse aggregates, the grading characteristics of the aggregates for each concrete product were applied. The 10 mm and 20 mm maximum aggregate charts were used to determine the recommended values for the proportion of fine aggregates depending on the maximum size of aggregate, the workability level, the grading of the fine aggregate (defined by the percentage passing a 600 µm sieve) and the free-water/cement ratio





Thus, the fine and coarse aggregate content were determined using equations9 and 10.

$$FA\ Content\ =\ Total\ Aggregate\ Content\ *\ Proportion\ of\ Fines \quad \text{Eq. 9}$$

$$CA\ Content\ =\ Total\ Aggregate\ Content - \ Fine\ Aggregate \quad \text{Eq. 10}$$

Where, FA is Fine Aggregate and CA is Coarse Aggregates.

The fine aggregate content values obtained for TMRC, ICPB and RCC were 650 kg/m3, 858 kg/m3 and 703 kg/m3. The coarse aggregate content values were also found to be 1207, 968 and 1196 kg/m3 for TMRC, ICPB and RCC, respectively. The results were further compared with the recommended proportions of fine and coarse aggregates for the applicable free water-cement ratios, the maximum aggregate sizes and the expected workability level (BRE, 1997).

3.2.6 Production of trial mixes

Using the designed proportions obtained from the concrete mix design process, six concrete specimens were produced for each proposed concrete product. The specimens were produced according to the following procedures.

Firstly, the volume of concrete mix required to make six specimens for each concrete product was computed using the geometry of the various moulds used. An allowance of 25% was made to ensure there was sufficient concrete mix that could also be used for a slump test. Table 45 presents the batching weights used to produce the specimens for the various concrete products.

In producing the trial mix for each concrete derivative the dry constituents (cement, fine and coarse aggregates) were mixed in a concrete mixer for 1 minute, and then the calculated amount of water was added before the whole mixture was mixed for another 1 minute.

Table 45 Concrete constituent proportions for one specimen per trial mix

Concrete constituent	Unit	Proportion of constituent per trial mix		
		TMRC	ICPB	RCC
Cement	Kg	1.64	0.95	0.87
Fine aggregate	Kg	2.74	1.68	1.38
Coarse aggregate	Kg	5.09	1.90	2.35
Water	Kg	0.80	0.31	0.29

3.2.7 Sample preparation and testing

Once the concrete mix was ready, slump tests were conducted to determine the workability of the fresh concrete. The slump tests were done by placing three layers of concrete in a firmly held slump cone and compacting each layer 25 times with a tamping rod. On the removal of the cone, the difference in height between the uppermost part of the slumped concrete and the upturned cone was recorded in millimetre as the slump.

To cast the trial mix specimens, the interior of the mould for making the concrete specimens was thinly coated with oil to prevent adhesion of the concrete. Two types of moulds were used, the 150 mm x 150 mm cube mould (used for the production of the TMRC specimens), and the 100 mm diameter cylindrical mould of 200 mm length (used for the production of ICPB and RCC specimens). The cylindrical moulds were used for the ICPB and RCC specimens because of the relatively drier nature of the mixes with free-water cementitious ratios of 0.33 as opposed to the 0.5 ratio of the TMRC specimens.

For the TMRC each mould was filled with three layers of concrete, and each layer was tamped 25 times with a 25 mm square steel rod. The top surface was finished with a trowel and the date of manufacturing, as well as the concrete mix ID was recorded in the surface of the concrete. The cubes were stored undisturbed for 24 hours at room temperature. After 24 hours the moulds were stripped and the cubes were cured further by immersing them in water at temperatures of 25 to 27°C until the testing date.

For the ICPB and RCC specimens, the concrete was placed in the cylindrical mould in four layers with each layer receiving 25 blows from a 2.5 kg hammer. These specimens were cured with damp cloths that were constantly watered in a controlled ambient temperature environment of about 25 to 27°C.

Compressive strength tests were conducted on each trial mix specimen after 7 days and again after 28 days. The testing on the 7th day in addition to the conventional practice of testing strength on the characteristic 28th day (as stipulated in the GSSRB document) was done for research purposes – in particular to obtain an idea of the early period (7-day) strength gains. The average compressive strength of the three specimens for each trial mix was computed and the results are presented in Table 46.

Table 46 Summary of compressive test results for first trial mix

Trial Mix	Constituent	Specimen Type	Specimen characteristics at 7 days			Specimen characteristics at 28 days		
			Average Density (g/cm³)	Average F'_c (N/mm²)	Stdev (N/mm²)	Average Density (g/cm³)	Average F'_c (N/mm²)	Stdev (N/mm²)
TMRC Mix1A	OPC, Sand, Coarse Aggregate from Quarry	150mm cube	2.553	25.33	0.98	2.466	46.2[1]	2.25
TMRC Mix2A	PPC, Sand, Coarse Aggregate from Quarry	150mm cube	2.512	15.95	0.67	2.473	30.3[1]	1.36
TMRC Mix3A	OPC, Sand, Coarse Aggregate [70%Quarry + 30% In-situ rock]	150mm cube	2.437	22.53	0.04	2.402	40.9[1]	1.44
TMRC Mix4A	OPC, Sand, Coarse Aggregate [70%Quarry + 30% Screened laterite]	150mm cube	2.436	18.2	0.67	2.409	33.5[1]	2.11
ICPB-Mix1A	OPC, Quarry Dust, Coarse Aggregate from Quarry	100mm ϕ Cylinder	2.505	21.6	3.82	2.495	40.1	1.84
ICPB-Mix2A	PPC, Sand, Coarse Aggregate from Quarry	100mm ϕ Cylinder	2.490	17.7	0.16	2.478	32.2	1.29
ICPB-Mix3A	OPC, Quarry Dust, Coarse Aggregate [70%Quarry + 30% In-situ rock]	100mm ϕ Cylinder	2.473	22.0	3.82	2.490	39.2	1.70
ICPB-Mix4A	OPC, Quarry Dust, Coarse Aggregate [70%Quarry + 30% Screened laterite]	100mm ϕ Cylinder	2.485	20.2	2.39	2.499	32.6	1.04
RCC-Mix1A	OPC, Quarry Dust, Coarse Aggregate from Quarry	100mm ϕ Cylinder	2.497	19.6	0.16	2.491	36.0	1.06
RCC-Mix2A	PPC, Sand, Coarse Aggregate from Quarry	100mm ϕ Cylinder	2.489	17.2	0.33	2.478	31.4	2.61
RCC-Mix3A	OPC, Quarry Dust, Coarse Aggregate [70%Quarry + 30% In-situ rock]	100mm ϕ Cylinder	2.477	13.0	3.43	2.494	25.9	1.44
RCC-Mix4A	OPC, Quarry Dust, Coarse Aggregate [70%Quarry + 30% Screened laterite]	100mm ϕ Cylinder	2.483	10.7	1.11	2.497	21.6	1.99

F'_c = Compressive strength at 28 days in N/mm²
[1]A factor of 0.8 is used to convert compressive strength of cube samples to that of cylindrical samples.

In general, the compressive strength test results obtained for the various concrete products in the first trial mix were just above the characteristic compressive strength of 30 N/mm2 for TMRC (30.2 N/mm²) and ICBP (36.0 N/mm²), whereas an overall average 28-day compressive strength of less than 30 N/mm2 was recorded for the RCC (28.7 N/mm², marginally). As expected, concrete derivatives with only raw OPC gave better results. The respective compressive strengths on the 28th day for all three concrete specimens were 37, 40.1 and 36.0 N/mm² for TMRC, ICBP and RCC.

The incorporation of the in-situ crushed stones in the respective concrete products did not perform badly when compared to the use of 100% conventional and granitic quarry stones (from the ESM Quarry). However, the screened laterite components did not seem to improve the strength properties of the specimens. This was seen for almost all the specimens of the three different concrete derivatives (TMRC, ICBP, and RCC).

The mix proportions from the design of the first round of trials for the three concrete surfacings are presented in Table 47 to Table 49.

Table 47 First round trial mix proportions by mass -thin-mesh-reinforced concrete

Material component			Unit	Thin-mesh-reinforced concrete (TMRC)			
				TMRC - Mix 1A	TMRC - Mix 2A	TMRC - Mix 3A	TMRC - Mix 4A
Cement	**Portland Cement Class CEM I 42.5N**	Ghacem 42.5N	kg	400		400	400
	Portland-Pozzolana (70/30) Composite Cement	Ghacem 42.5N	kg		280		
		Calcine Clay Pozzolan	kg		120		
Fine Aggregate		Sieved Natural Sand	kg	742	742	742	742
		Quarry Dust	kg				
Coarse Aggregates	**Quarry Aggregate**	19mm	kg	464	464	325	325
		16mm	kg	649	649	454	454
		10mm	kg				
	In-situ Rock Aggregate	19mm	kg			139	
		16mm	kg			195	
		10mm	kg				
	Screened laterite		kg				334
Water		Clean Water	kg	180	180	180	180
		w/c ratio		0.45	0.45	0.45	0.45

Table 48 First round trial mix proportions by mass - interlocking concrete paving block

Material component			Unit	Interlocking concrete paving block (ICPB)			
				ICPB-Mix 1A	ICPB – Mix 2A	ICPB – Mix 3A	ICPB – Mix 4A
Cement	Portland Cement Class CEM I 42.5N	Ghacem 42.5N	kg	455		455	455
	Portland-Pozzolana (70/30) Composite Cement	Ghacem 42.5N	kg		341		
		Calcine Clay Pozzolana	kg		114		
Fine Aggregate		Sieved Natural Sand	kg	742			
		Quarry Dust	kg		858	858	858
Coarse Aggregates	Quarry Aggregate	19mm	kg				
		16mm	kg				
		10mm	kg	967	967	677	677
	In-situ Rock Aggregate	19mm	kg				
		16mm	kg				
		10mm	kg			290	
	Screened laterite		kg				290
Water		Clean Water	kg	180	150	150	150
		w/c ratio		0.33	0.33	0.33	0.33

Table 49 First round trial mix proportions by mass - roller-compactor concrete

Material component			Unit	Roller compacted-concrete(RCC)			
				RCC–Mix1A	RCC–Mix2A	RCC–Mix3A	RCC–Mix4A
Cement	**Portland Cement ClassCEMI42.5N**	Ghacem42.5N	kg	364		364	364
	Portland-Pozzolana (70/30)Composite Cement	Ghacem42.5N	kg		225		
		Calcine Clay Pozzolana	kg		109		
Fine Aggregate		Sieved natural Sand	kg	742			
		Quarry dust	kg		741	741	741
Coarse Aggregates	**Quarry Aggregate**	19mm	kg	296	296	207	207
		16mm	kg	544	544	381	381
		10mm	kg	395	395	277	277
	In-situ Rock Aggregate	19mm	kg			89	
		16mm	kg			163	
		10mm	kg			119	
	Screened laterite		kg				371
Water		Clean Water	kg	180	120	120	120
		w/c ratio		0.33	0.33	0.33	0.33

3.2.8 Second round of trial mixes

After the results from the first round of trial mixes were perused, a second trial mix was designed with some adjustments in the proportion of the constituents to help achieve better results. The adjustments made included reducing the proportion of clay pozzolana in the PPC from 30% to 20%, while in some derivatives the proportions of coarse aggregates were adjusted to 75% of quarry stones and 25% of in-situ crushed rock stones. The screen laterite component was ignored in the second round of trials, due to its generally poor performance in the first round as well as the laborious nature of the preparations for the screening. Table 50 shows the matrix of concrete mix constituents considered for the second round.

Generally, the compressive strength test results of the second trial mix show an improvement over the first round of trial mixes for both the 7-day and 28-day tests. Table 50 presents compressive test results for the second trial mix.

The best and recommended concrete derivatives from the two rounds of trials according to the revised research matrix for the surfacing demonstration are presented in Table 52. The mix proportions corresponding to the recommended concrete derivatives are also presented in Table 53 to Table 55 for construction demonstration.

Table 50 Concrete variations and their constituent for second trial mixes

Concrete surfacing	Variables	Constituent
TMRC	TMRC - Mix 1B	OPC, sand, quarry aggregates
	TMRC - Mix 2B	PPC (80% OPC + 20% Pozzolana),sand, quarry aggregates
	TMRC - Mix 3B	OPC, sand, quarry aggregate (75%) and In-situ aggregate (25%)
RCC	RCC - Mix 1B	OPC, sand, quarry aggregates
	RCC - Mix 2B	PPC (80% OPC + 20% Pozzolana), sand, quarry aggregates
	RCC - Mix 3B	OPC, sand, quarry aggregate (75%); In-situ aggregate (25%)
ICBP	ICBP - Mix 1B	OPC, sand, quarry aggregates
	ICBP - Mix 2B	PPC (80% OPC + 20% Pozzolana), sand, quarry aggregates
	ICBP - Mix 3B	OPC, sand, quarry aggregate (75%) and In-situ aggregate (25%)

Table 51 Summary of compressive strength test results on second trial mix specimens

Trial Mix	Specimen Type	Specimen Characteristics at 7 days			Specimen Characteristics at 28 days		
		Average Density (g/cm³)	Average Compressive Strength (N/mm²)	Standard Deviation of Strength (N/mm²)	Average Density (g/cm³)	Average Compressive Strength (N/mm²)	Standard Deviation of Strength (N/mm²)
TMRC Mix1B	150mm cube	2.559	26.3	0.53	2.535	45.6[1]	3.06
TMRC Mix2B	150mm cube	2.557	19.2	2.09	2.584	37.3[1]	0.61
TMRC Mix3B	150mm cube	2.510	22.4	1.82	2.497	38.2[1]	0.39
PB-Mix1B	100mm ϕ Cylinder	2.499	30.6	5.93	2.499	43.3	1.60
PB-Mix2B	100mm ϕ Cylinder	2.350	28.2	2.83	2.478	39.2	1.11
PB-Mix3B	100mm ϕ Cylinder	2.347	27.7	0.32	2.489	39.4	0.66
RCC-Mix1B	100mm ϕ Cylinder	2.432	24.0	2.07	2.424	38.8	1.84
RCC-Mix2B	100mm ϕ Cylinder	2.304	21.3	2.53	2.395	33.3	0.96
RCC-Mix3B	100mm ϕ Cylinder	2.410	19.4	1.39	2.396	31.1	1.04

[1] *A factor of 0.8 is used to convert compressive strength of cube samples to that of cylindrical samples*.

Table 52 Recommended constituents for the concrete derivatives to be experimented

Concrete surfacing	Variables	Constituent
TMRC	TMRC - Mix 1B	OPC, Sand, Quarry aggregates
	TMRC - Mix 2B	PPC (80% OPC + 20% Pozzolana),sand, quarry aggregates
	TMRC - Mix 3B	OPC, sand, quarry aggregates (75%) and in-situ aggregate (25%)
RCC	RCC - Mix 1B	OPC, sand, quarry aggregates
	RCC - Mix 2B	PPC (80% OPC + 20% Pozzolana), sand, quarry aggregate
	RCC - Mix 3B	OPC, sand, quarry aggregate (75%) and in-situ aggregate (25%)
ICBP	ICBP - Mix 1B	OPC, sand, quarry aggregate

Table 53 Trial mix proportions by mass -thin-mesh-reinforced concrete for second round

Material Component			Unit	Thin-mesh-reinforced concrete (TMRC)		
				TMRC - Mix 1B	TMRC - Mix 2B	TMRC - Mix 3B
Cement	**Portland Cement Class CEM I 42.5N**	Ghacem 42.5N	kg	420		420
	Portland-Pozzolana (70/30) Composite Cement	Ghacem 42.5N	kg		336	
		Calcine Clay Pozzolana	kg		84	
Fine Aggregate		Sieved Natural Sand	kg	632	632	632
		Quarry Dust	kg			
	Quarry Aggregate	19mm	kg	350	350	263
		16mm	kg	385	385	289
		10mm	kg	439	439	438

Coarse Aggregates	In-situ Rock Aggregate	19mm	kg			88
		16mm	kg			96
		10mm	kg			
	Screened laterite		kg			
Water		Clean Water	kg	210	210	210
		w/c ratio		0.50	0.50	0.50

Table 54 Second round trial mix proportions by mass - roller-compactor concrete

Material component			Unit	Roller compacted-concrete(RCC)		
				RCC–Mix1B	RCC–Mix2B	RCC–Mix3B
Cement	**Portland Cement ClassCEMI42.5N**	Ghacem42.5N	kg	567		567
	Portland-Pozzolana (70/30)Composite	Ghacem42.5N	kg		454	
		Calcine Clay Pozzolana	kg		113	
Fine Aggregate		Sieved Natural Sand	kg	258	258	258
		Quarry Dust	kg	379	379	379
Coarse Aggregates	**Quarry Aggregate**	19mm	kg	138	138	207
		16mm	kg	172	172	381
		10mm	kg	34572	34572	277
	In-situ Rock Aggregate	19mm	kg			89
		16mm	kg			163
		10mm	kg			119
	Screened laterite		kg			
Water		Clean Water	kg	170	170	170
		w/c ratio		0.33	0.33	0.33

Table 55 Second round trial mix proportions by mass - interlocking concrete paving

Material component			Unit	Interlocking concrete paving block
				ICPB-Mix 1B
Cement	**Portland Cement Class CEM I 42.5N**	Ghacem 42.5N	kg	515
	Portland-Pozzolana (70/30) Composite Cement	Ghacem 42.5N	kg	
		Calcine Clay Pozzolana	kg	
Fine Aggregate		Sieved Natural Sand	kg	180
		Quarry Dust	kg	586
Coarse Aggregates	**Quarry Aggregate**	19mm	kg	
		16mm	kg	
		10mm	kg	925
	In-situ Rock Aggregate	19mm	kg	
		16mm	kg	
		10mm	kg	
	Screened laterite		kg	
Water		Clean Water	kg	170
		w/c ratio		0.33

4 Demonstration Sections and Research Matrix

4.1 Research matrix and variables

The proposed demonstration section test matrix and variables are presented in Table 56. Matrix for each demonstration section is made up of three variables in terms of mix designs (different combinations of materials and additives), and modular paving types. The matrices were developed in consultation with the DFR as materials procurement and construction are their responsibility.

The locations of the demonstration sections were agreed by the DFR during the first stakeholder workshop. Part of the road section with gradient of 8% was considered for the construction of one variable each of all five alternative surfacing, This section will serve as the construction trial section to train the contractor in the techniques that would be used in the study, and evaluate the contractor's equipment prior to the main works.

The following were considered for the development of the research matrix:

- Gradient – comparison of performance of the alternative surfacing on the various gradients.
- Construction methods will vary (labour intensive and light equipment techniques).
- Pavement design method for the structural layers will be fixed.
- Similar materials will be used for underlying layers.
- Thicknesses might vary slightly for construction expediency.
- Significant use will be made of local resources—materials, contractors, labour and construction methods.
- Access will be gained to local materials.
- Materials and pavement designs are suitable for labour-based methods.
- Mechanical stabilisation techniques would only be applied to natural gravels that do not meet construction standards of base/subbase layers.
- Main surface drainage structure for the demonstration sections is trapezoidal drains.
- The DFR engineers will supervise the construction the construction works.

4.2 Layout of demonstration sections

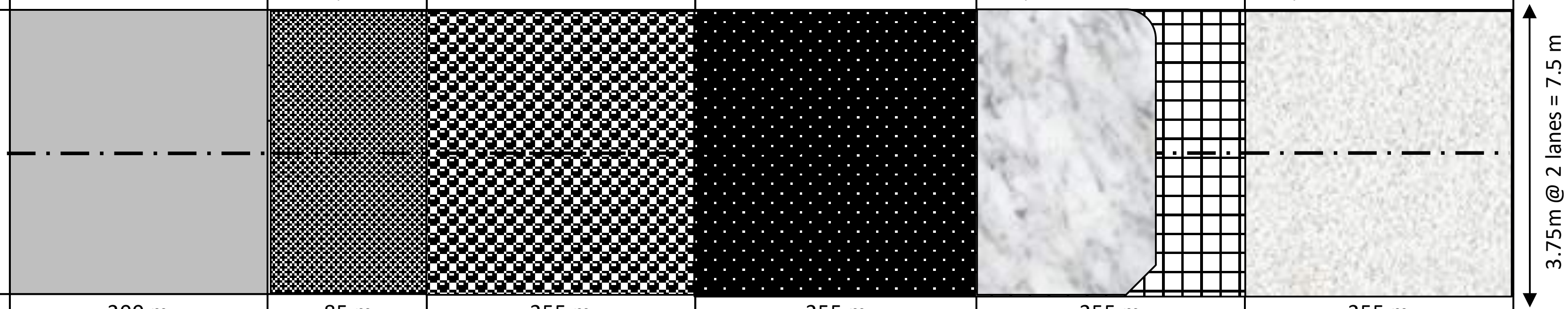
Five demonstration sections comprising twelve pavement options and one control section are to be constructed and monitored in this project. Figure 23 shows the schematic representation of the sections with various lengths. Detailed layouts of individual sections are available on a DVD that is attached with this report. Figure displays the representation of demonstration control sections on elevated gradients. It can be seen that the project site is extremely steep, with gradients of up to 20%.

Table 56 Matrix and variables of alternative surfacing

Section	Section type	Gradient	Subsection Chainage	Length	Description of surfacing variable
1 [Ch1+825 to 2+025]	Construction trial sections [200 m]	8%	1+825 to 1+865	40 m	Concrete stone pitching – dressed stones (150 mm) laid on a bed of base sand with joints filled with sand mortar
			1+865 to 1+905	40 m	80 mm thick interlocking paving blocks made from OPC, natural sand and quarry stones
			1+905 to 1+945	40 m	50 mm thick cold mix asphalt with base emulsion (K1-70 cationic type) with all quarry stones
			1+945 to 1+985	40 m	75 mm thin mesh-reinforced concrete made from OPC, sand, quarry stones
			1+985 to 2+025	40 m	100 mm roller compacted concrete from OPC, sand, quarry stones
2 [Ch. 2+025 to 2+110]	Control section [85 m]	8%	2+025 to 2+110	85 m	Double chip seal with 14 mm /10 mm size aggregates
3 [Ch. 2+110 to 2+365]	Demonstration section: Modular paving [255 m]	13.5%	2+110 to 2+195	85 m	Concrete stone pitching – dressed stones (150 mm) laid on a sand bedding layer (30 mm)
			2+195 to 2+280	85 m	Hand-packed stone - large broken stones (150 mm) laid on a sand bedding layer (50 mm)
			2+280 to 2+365	85m	80 mm thick interlocking paving blocks made from OPC, natural sand and quarry stones on a sand bedding layer (30 mm)
4 [Ch.2+365 to 2+620]	Demonstration section: Cold mix asphalt [255 m]	15%	2+365 to 2+450	85 m	50 mm thick cold mix asphalt with base emulsion (K1-70 cationic type) with all quarry stones
			2+450 to 2+535	85 m	50 mm thick cold mix asphalt/emulsion (K1-70 cationic type) manufactured with optimum lime/cement additives and blended stones (70%) and screened laterite (30%)
			2+535 to 2+620	85m	50 mm thick cold mix asphalt/emulsion (K1-70 cationic type) manufactured with optimum lime/cement additives and 100% quarry stones
5 [Ch. 2+620 to 2+875]	Demonstration section: Thin mesh-reinforced concrete [255 m]	17%	2+620 to 2+705	85 m	75 mm thin mesh-reinforced concrete made from OPC, sand, quarry stones
			2+705 to 2+790	85 m	75 mm thin mesh-reinforced concrete made from PPC (80% OPC + 20% Pozzolana), sand, quarry stones
			2+790 to 2+875	85m	75 mm thin mesh-reinforced concrete from OPC, sand, quarry stones (75%), in-situ aggregate (screened laterite, 25%)
6 [Ch.2+875 to 3+130]	Demonstration section: Roller-compacted concrete [255 m]	20%	2+875 to 2+960	85 m	100 mm roller-compacted concrete made from OPC, sand, quarry stones
			2+960 to 3+045	85 m	100 mm roller-compacted concrete made from PPC (80% OPC + 20% Pozzolana), sand, quarry stones
			3+045to 3+130	85m	100 mm roller-compacted concrete from OPC, sand, quarry stones (75%), in-situ aggregate (screened laterite, 25%)

Figure 23 **Schematic representation of the experimental sections**

	Ch 1+825	Ch 2+025	Ch 2+110	Ch 2+365	Ch 2+620	Ch 2+875 – Ch 3+200
Surfacing type	All surfacing types; trial sections (5@ 40m)	Control section (Double seal @85m)	Modular paving (2 stones+ 1 ICBP @85m)	Cold mix asphalt (3 variables @ 85m)	Thin meshed-reinforced concrete (3 variables @ 85m)	Roller compacted concrete (3 variables @ 85m)
Section						
Length (m)	200 m	85 m	255 m	255 m	255 m	255 m



Notes:

1: Chainages between control and RCC sections only serve as boundaries for the study

2: Trial sections (CSP, ICBP, CMA, TMRC, RCC)

3: Control section (double chip seal)

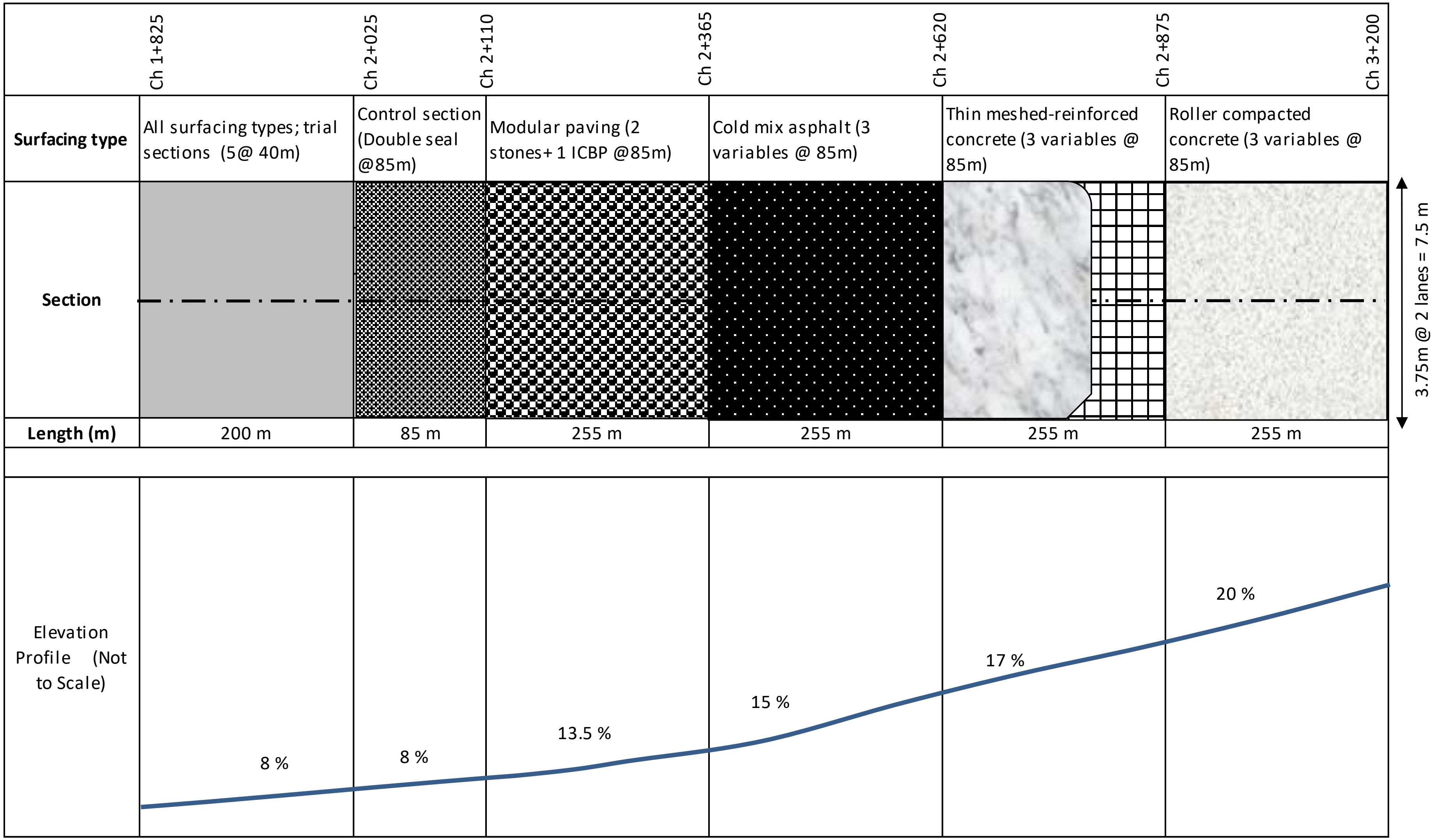
4: Modular surfacing (CSP, HPS, ICBP)

5: CMA (variations in component materials /mix design)

6: TMRC (variations in component materials /mix design)

7: RCC (variations in component materials /mix design)

Figure 24 **Elevated gradients of demonstration and control sections**



5 Pavement Design

5.1 Design approach

The pavement structural design was based on the results of laboratory testing and the materials design programme presented in Sections 3 and 4 of this report, and it was to some extent influenced by available materials characterisation theories. The selection of materials was based on a combination of factors including availability, economic limitations, materials properties, and previous experience. These factors were evaluated during the design process in order to select the materials best suited to the project road conditions.

Originally, it was intended that the pavement design would follow the AfCAP DCP-DN pavement design approach for low-volume roads. However, the estimated traffic volume, and corresponding cumulative equivalent single axles were more than the upper threshold value for low-volume roads, hence conventional pavement design approach instead of AfCAP DCP-DN pavement design method was used in this project.

Several pavement design methods such as C&C Pave, StreetPave, mePAD, or meGAMES were explored for their use in this project. However, the software associated with these methods has restricted use (licensing issues, although some 30-day trial/non-professional versions are available). It was therefore appropriate and convenient to use the AASHTO Guide for Design of Pavement Structures (1993). The AASHTO pavement design method is versatile, readily available to the DFR and easy to follow. Design spreadsheets (AASHFLEX, AASHTO_Rigid) are also available to use the AASHTO design guide.

A 30-day trial version of the StreetPave software was used to verify slab thicknesses of the rigid pavements. Other pavement design standards used in Ghana, and the AfCAP low-volume roads design manuals were consulted during the design.

5.2 Design procedure

The procedures in the AASHTO Guide for Design of Pavement Structures (1993) were followed for the pavement designs.

5.3 Pavement options

A total of 12 pavement types with five alternative surfacing (stones, interlocking block paving, cold mix asphalt, thin mesh-reinforced concrete and roller-compacted concrete) are to be constructed for demonstration. The 12 options are presented in Table 57.

Table 57 Pavement types and options

Pavement type	Pavement option	Description of pavement surfacing[2]
Modular	1	Concrete stone pitching
	2	interlocking block paving
	3	Hand-packed stone
Bituminous	4	Cold mix asphalt with base emulsion and all quarry stones

[2]Structural designs for the different surfacing types of the bituminous and concrete pavement options are same (i.e. designs for pavement options 4 to 5 are same; 7-9 are same and 10-12 are same).

	5	Cold mix asphalt/emulsion manufactured with optimum lime/cement additives and blended stones (70%) and screened laterite (30%)
	6	Cold mix asphalt/emulsion manufactured with optimum lime/cement additives and 100% quarry stones
Concrete	7	Thin mesh-reinforced concrete made from OPC, sand, quarry stones
	8	Thin mesh-reinforced concrete made from PPC (75% OPC + 25% Pozzolana), sand, quarry stones
	9	Thin mesh-reinforced concrete from OPC, sand, quarry stones (70%), in-situ aggregate (screened laterite, 30%)
	10	Roller-compacted concrete made from OPC, sand, quarry stones
	11	Roller-compacted concrete made from PPC (75% OPC + 25% Pozzolana), sand, quarry stones
	12	Roller-compacted concrete from OPC, sand, quarry stones (70%), in-situ aggregate (screened laterite, 30%)

5.4 Pavement design standards and manuals

The following pavement design and materials specifications documents and were referred to during the final design of the demonstration sections.

- The AASHTO Guide for Design of Pavement Structures (1993)
- The Ghana Highway Authority Road Design Guide (1991)
- The Ghana Standard Specifications for Road and Bridge Works (2007)
- Ethiopia Roads Authority. Design Manual For Low-Volume Roads Part D (2016)
- Ministry of Works, Transport and Communication – Tanzania. Low-Volume Roads Manual Part D (2016)
- Ministry of Transport and Public Works – Republic of Malawi. Design Manual For Low-Volume Sealed Roads (2013)
- A Policy on Geometric Design of Highways and Streets (AASHTO, 2001)
- Ministry of Roads and Highways Standard Details, Road Signs and Markings for Urban and Trunk Roads (1991)

5.5 Topography and geology

A detailed topography and geology of the project catchment area was presented in the Draft Design Report. The terrain of the project road is rolling for the first two sections and then changes to a climbing and winding topography with very steep slopes. Beds within the project area are generally composed of a thick sequence of white, highly matured quarzitic sandstones. Predominant structures associated with the project area are bedding and jointing, with joint frequency.

5.6 Climate

5.6.1 Rainfall

The annual average rainfall of the project catchment area over the period 2006-2016 is 1,362 mm, with the maximum annual rainfall of 1,627 mm (2010) and the minimum of 1,209 mm (2009). Over the analysis period, the month of June mostly recorded the maximum rainfall with an average of 209 mm. On the average, the project area receives more than 80% of its total rainfall between the months of March and October. The months of November through February recorded the lowest monthly rainfall ranging from 20 to 55 mm.

5.6.2 Temperature

The temperature records for the period 2009 to 2016 were analysed and the trends that emerged over the period were presented in the Draft Design Report. Annual cyclical patterns show maximum temperatures of 37°C usually occurring in February/March, while the annual minimum occurs in September/October with 25°C. A critical look at the trend shows a very slight longer period of the maximum temperature, January through March. These temperature records have a bearing on the evapotranspiration characteristics of the project area.

5.6.3 Evapotranspiration characteristics

Monthly evapotranspiration is generally high in the dry season (December through February). Typical monthly averages for the analysis period were about 3,000 mm. Thus, adequate measures would have to be put in place to check excessive loss of moisture from construction products during this weather-friendly period. Curing and moisture control would be important to ensure efficient construction deliverables.

5.6.4 Environmental impact

The project area is characterised by steep hills, high rainfall and high temperature differential conditions under which the project roadwill function, and the underlying subgrade conditions.

Because of anticipated moisture from high levels of precipitation, the drainage structures will be constructed with the backdrop that it is capable of removing excess moisture in less than one week. The pavement design process takes into consideration, erosions and slope stability problems identified along the project road.

5.6.5 Existing roadbed

The summary results of the DCP tests conducted on the experimental section are presented in Section 3 of this report. The results indicate that the thin mesh-reinforced concrete, and roller-compacted concrete demonstration sections are to be constructed on a rocky road bed, hence the number of construction layers may be reduced. On the other hand, the cold-mix asphalt and modular paving surfacing options as well as the double chip seal control and construction trial sections are to be constructed on a relatively softer roadbed.

5.6.6 Traffic estimate

Details of traffic count results were discussed in the Draft Design Report of the project. The total Average Daily Traffic (ADT) in the base year of the demonstration sections was estimated to be 433 vehicles (one direction). Traffic was projected to consist of 70% small vehicles (taxis and private cars); 27% medium vehicles (light and medium trucks – 20% and buses – 7%), and heavy vehicles (heavy trucks, semi-trailers and truck trailers) made up about 3% of the traffic streams. Although the actual directional split was about 55% uphill against 45% downhill for the peak period, 50/50 split was assumed for pavement design.

Design equivalent standard axles

A 7-day traffic count summary (ADT of commercial vehicles in one direction) and the corresponding equivalent single axle load (ESAL) are given in Table 58 below.

Table 58 Axle load characteristics

Vehicle type	ADT	(ESA/ Vehicle)[1]	DESA
Buses	30	1.0	30.0
Light and medium trucks	87	2.5	217.5
Heavy trucks and trailers	13	5.0	65.0
Total ESA/day			312.5

[1]ERA, 2016 (Based on relative damage exponent n value of 4).

Cumulative equivalent single axle load over a design life (N) of 15 years and growth rate (r) of 2%:

$$= 365 \times DESA \times \left[\frac{(1+r)^N - 1}{r}\right]$$

$$= 365 \times 312.5 \times \left[\frac{(1+0.02)^{15} - 1}{0.02}\right]$$

$= 1{,}972{,}530$ (Equivalent standard axle load)

A more accurate way to estimate traffic growth is to predict future traffic based on an economic growth indicator model that uses the theory of demand for travel. In the absence of valid economic data (such as income elasticity, demand, growth rate of population, growth rate per capita income, growth of agricultural sector, or growth of industry/mining from the project catchment area), a more simplistic growth factor was used for the design.

An annual growth of 2% in commercial vehicles over the design life of the pavements is approximately 2 million ESALs. Increasing the growth rate from 2% to 6% by 1 percentage increments will increase the ESAL to about 2.7 million (i.e. an increase of 35% – not likely to happen on the project road). Although the 2% growth rate appears low, based on interactions with the DFR as well as with opinion leaders from the community around the project catchment area during the first stakeholder workshop, a 6% growth rate seems exorbitantly high. It is however possible that trucks with three or more axles will use the road within the first five years of the project's implementation.

Although it is anticipated that traffic volume will increase when the proposed surfacings have been successfully implemented, a reasonable growth rate of 4% (corresponding to 2.3 million ESALs) was used for the pavement design. The anticipated future traffic, based on a sensitivity analysis, is presented in Figure 25, indicating that the cumulative traffic volume could range from 1.9 million to 2.7 million ESALs in 15 years from the base year. Thus, the expected traffic on the project road is likely to be in the same traffic loading class (1 to 3 million ESALs, AASHTO).

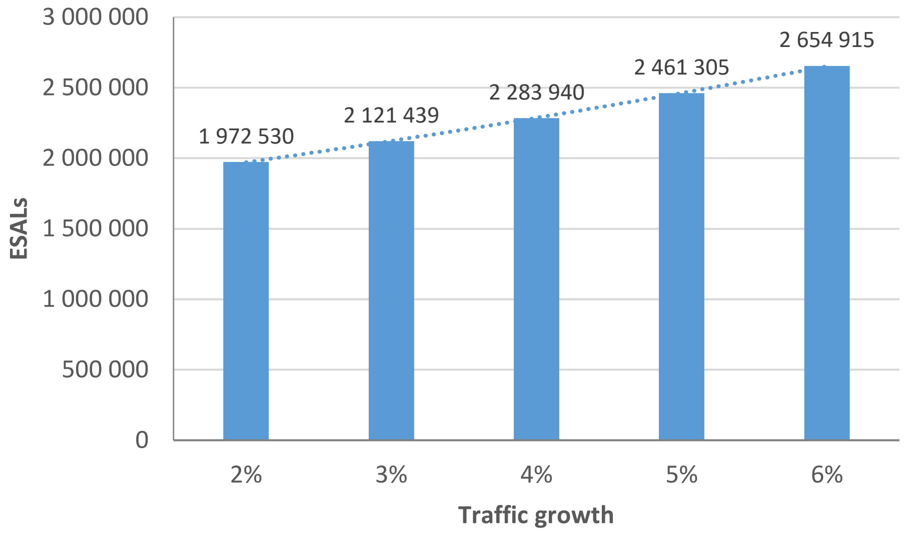


Figure 25 Sensitivity analysis of traffic growth rate

5.6.7 Material properties for structural design

Material properties were based on laboratory test results and on mix design properties obtained from Section 3 (soil/gravel materials) and Section 4 (concrete and asphalt materials).

5.7 Design of flexible pavement options

Apart from the cold-mix asphalt pavement option, all three modular paving options were designed as flexible pavements. In order to make optimum use of the existing layers, the method uses the structural number concept of the AASHTO Design Guide (1993).

5.7.1 Design and analysis periods

The design life is 15 years (i.e. from the time the experimental section is open to traffic), while the analysis period is 25 years.

5.7.2 Design traffic

Based on average daily traffic, ESALs and a growth rate of 4%, the cumulative ESAL over the 15 years' design life to be used for the pavement design was found to be 2.3 million.

5.7.3 Serviceability

The value recommended by AASHTO for the initial design serviceability index of flexible pavements is 4.2. A terminal serviceability value of 2.0 was considered for the design, i.e. a design serviceability loss of 2.2.

5.7.4 Reliability

Suggested levels of reliability for various functional classifications are given in the AASHTO Guide and range from 50% to 99.9% for local roads to interstate and other freeways respectively.

The project road is in a rural location where daily traffic is not expected to exceed half of its capacity. An 80% reliability level was selected for this design.

5.7.5 Overall standard deviation

The value AASHTO recommends for the overall standard deviation of flexible pavements is 0.40 to 0.50. A value of 0.45 was used for this design.

5.7.6 Effective subgrade resilient modulus

Based on the CBR results of the natural materials from the road alignment and borrow pits, a minimum CBR value of 15% (soaked, wet roadbed moisture conditions) was used for the design.

The roadbed resilient modulus (MR) was calculated based on TRL correlation for unbound materials (adopted by AASHTO, 2002).

$M_R = 17.629 \times CBR^{0.64}$ (MPa)

$M_R = 17.629 \times 15^{0.64}$

$M_R = 100$ MPa

The effective subgrade MR for the design was determined based on relative damage (u_f), a concept used by AASHTO for flexible pavement design (1993).

$u_f = 1.18 \times 10^8 \times {M_R}^{-2.32}$ Eq. 10

According to the GHA Pavement Design Manual (1995) areas in Ghana with a minimum annual rainfall of between 1,000 and 1,500 mm generally have four months' wet and eight months' dry season respectively. The minimum annual rainfall for the project catchment area is 1,209 mm. In addition, the GHA Pavement Design Manual recommends a reduction of the calculated $M_R$value by 20% for each of the months of the rainy season.

The project catchment area under consideration experiences four dry and eight wet months (GHA2065B Draft Design Report). Hence, the effective subgrade MR was determined as follows:

Dry season (Nov, Dec, Jan, Feb) = 100 MPa

Wet season (Mar, Apr, May, Jun, Jul, Aug, Sep, Oct) = 80 MPa

With a relative damage of 0.01 for the 12 months, the seasonal subgrade MR for the design was 85 MPa.

5.7.7 Resilient modulus of layer materials

The MR values for each layer of material were determined via a laboratory testing programme. Table 59presents a summary of the materials assessed and their properties for structural design.

Table 59 Resilient modulus for the unbound materials

Materials	CBR (%)-soaked,	M_R (MPa)	Mr (psi)	Pavement material type
ATR BP 1	4	43	6,213	Very weak subgrade
ATR BP 2	10	77	11,169	Subgrade
ATR BP 3	11	82	11,871	Subgrade
ATR-BS 1	16	104	15,089	Subgrade
ATR-BS2	34	168	24,443	Granular subbase
Blend A	47	207	30,044	Granular base
Blend B	36	175	25,354	Granular base
Blend C	26	142	20,587	Granular subbase
Blend D	28	149	21,587	Granular subbase
Blend E	41	190	27,554	Granular base

5.7.8 Flexible pavement thickness

A structural number design approach was used to determine the thickness of the flexible pavements (i.e. cold-mix and modular paving surfacings). The equation for a flexible pavement design given in the AASHTO 1993 design guide was used for this design. The design structural number (SN) is determined by inserting various predetermined parameters into the Equation 11below.

$$\log(W_{18}) = Z_R \times S_o + 9.36\log(SN+1) - 0.20 + \frac{\log\left(\frac{\Delta PSI}{4.2-1.5}\right)}{0.40+\frac{1094}{(SN+1)^{5.19}}} + 2.32\log(M_R) - 8.07 \qquad \text{(Eq. 11)}$$

where:

W18 = predicted number of standard equivalent single axle load (ESAL) applications

ZR = standard normal deviate

So = combined standard error of the traffic prediction and performance prediction

ΔPSI = serviceability loss /difference between the initial design serviceability index, po, and the design terminal serviceability index, pt

MR = resilient modulus (psi)

ai = ith layer coefficient

Di = ith layer thickness (in.)

mi = ith layer drainage coefficient

Since the AASHTO Guide (1993) utilises imperial units, conversions to the metric system were made manually. Table 60 shows the design variables/parameters and the computed SN values for the pavement layers of the project road.

Table 60 Design input parameters for the flexible pavement

Inputs	Parameter
Estimated future traffic	2.3 million ESALs
Design reliability	85%
Overall standard deviation	0.45
Effective subgrade modulus	85 MPa
Serviceability loss	2.2

Equation 12 provides the basis for converting flexible pavement structural number (SN) into actual thickness of surfacing, base and subbase:

$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3 \qquad \text{(Eq. 12)}$$

where

a_1 , a_2, a_3 = coefficients of relative strength of the surfacing, base and subbase materials, respectively.

D_1 , D_2, D_3 = thickness (in inches) of the surfacing, base, and subbase layers, respectively.

m_1 , m_2 = drainage coefficients for base and subbase layers, respectively.

5.7.9 Layer coefficients

Guidelines for the selection of other values for layer coefficients are given in the AASHTO design guide. The coefficients presented in Table 61are based on the best available data for both low- and high-volume roads. These values were used for the flexible pavement designs.

Table 61 Layer coefficients used for the design

Material	Layer coefficient
Asphalt concrete wearing course (Cold-mix asphalt)	0.35
Asphalt stabilised base course	0.23
Cement stabilised base course	0.23
Granular base course of crushed/ natural material	0.14
Granular subbase course of natural gravel	0.10

5.7.10 Drainage coefficients

The following AASHTO definitions of the various drainage levels of the pavement structure were used as a guide to select drainage coefficients (m_i) for the design. It was assumed that the pavement structure will be exposed to moisture levels approaching saturation 5% to 25% of time.

- Excellent drainage – water is removed within two hours
- Good drainage – water is removed within one day
- Fair drainage – water is removed within seven days
- Poor drainage – water is removed within one month
- Very poor drainage – water is not removed

Based on the above drainage guide and taking cognisance of the high annual rainfall in the project catchment area (on average 1,362 mm), a well-designed and well-constructed road with a good drainage system is necessary for this project.

A drainage coefficient of 0.8 to 1.0 was selected for both the base and subbase courses. However, a value of 0.8 should provide a suitable safety factor – especially in the wet environment of the project road.

Trial designs were undertaken to come up with optimise design for the flexible pavement options. Table 62 to Table 65 show the design variables /parameters and the computed SN values for the pavement layers of the project road.

Table 62 Cold Mix Asphalt Trials

Trial	Pavement Layer	Material Coefficient	Drainage Coefficient	Design Thickness (mm)	SN (mm)	SN (mm)
Trial 1	Cold Mix	0.35		50	17.5	
	Granular base	0.14	0.8	150	16.8	
	Subbase	0.10	0.8	150	12	
	Selected[1]	0.09	0.8	150	10.8	
	Selected[2]	0.08	0.8	150	9.6	
					66.7	**< 81.28**
Trial 2 (Selected)	Cold Mix	0.35		50	17.5	
	Stabilised base	0.23	0.8	150	27.6	
	Subbase	0.14	0.8	150	16.8	
	Selected*	0.09	0.8	150	10.8	

	Selected**	0.08	0.8	150	9.6	
					82.3	**> 81.28**
Trail 3	Cold Mix	0.35		50	17.5	
	Granular base	0.14	0.9	150	18.9	
	Subbase	0.10	0.9	150	13.5	
	Selected*	0.09	0.9	150	12.15	
	Selected**	0.08	0.9	150	10.8	
					72.9	**< 81.28**
Trial 4	Cold Mix	0.35		50	17.5	
	Stabilised base	0.23	0.9	150	31.05	
	Subbase	0.10	0.9	150	13.5	
	Selected*	0.09	0.9	150	12.15	
	Selected**	0.08	0.9	150	10.8	
					85.0	**> 81.28**
Trial 5	Cold Mix	0.35		50	17.5	
	Granular base	0.14	1.0	150	21	
	Subbase	0.10	1.0	150	15	
	Selected*	0.09	1.0	150	13.5	
					67.0	**< 81.28**
Trial 6	Cold Mix	0.35		50	17.5	
	Granular base	0.14	1.0	150	21	
	Subbase	0.23	1.0	150	34.5	
	Selected*	0.09	1.0	150	13.5	
					86.5	**> 81.28**

Table 63 Block Paving Trials

Trial	Pavement Layer	Material Coefficient	Drainage Coefficient	Design Thickness (mm)	SN (mm)	SN (mm)
Trail 1	Block Paving	0.4		80	32	
	Granular base	0.14	0.8	150	16.8	
	Subbase	0.10	0.8	150	12	
	Selected*	0.09	0.8	150	10.8	
					71.6	**< 81.28**
Trial 2 (Selected)	Block Paving	0.4		80	32	
	Stabilised base	0.23	0.8	150	27.6	
	Subbase	0.10	0.8	150	12	
	Selected*	0.09	0.8	150	10.8	
					82.4	**> 81.28**
Trail 3	Block Paving	0.4		80	32	
	Granular base	0.14	0.9	150	18.9	
	Subbase	0.10	0.9	150	13.5	
	Selected*	0.09	0.9	150	12.2	
					76.6	**< 81.28**
Trial 4	Block Paving	0.4		80	32	
	Stabilised base	0.23	0.9	150	31	
	Subbase	0.10	0.9	150	13.5	

	Selected*	0.09	0.9	150	12.2	
					88.7	**> 81.28**
Trial 5	Block Paving	0.4		80	32	
	Granular base	0.14	1.0	150	21	
	Subbase	0.10	1.0	150	15	
	Selected*	0.09	1.0	150	13.5	
					81.5	**> 81.28**

Table 64 Stone pitching trials

Trial	Pavement Layer	Material Coefficient	Drainage Coefficient	Design Thickness (mm)	SN (mm)	SN (mm)
Trail 1	Stone pitching	0.3		150	45	
	Granular base	0.14	0.8	150	16.8	
	Subbase	0.10	0.8	150	12	
	Selected*	0.09	0.8	150	10.8	
					84.6	**> 81.28**
Trial 2 (Selected)	Stone pitching	0.3		150	45	
	Stabilised base	0.23	0.8	150	27.6	
	Subbase	0.10	0.8	150	12	
					84.6	**> 81.28**
Trail 3	Stone pitching	0.3		150	45	
	Granular base	0.14	0.9	150	18.9	
	Subbase	0.10	0.9	150	13.5	
					77.4	**< 81.28**
Trial 4	Stone pitching	0.3		150	45	
	Stabilised base	0.23	0.9	150	31.1	
	Subbase	0.1	0.9	150	13.5	
					89.6	**> 81.28**
Trial 5	Stone pitching	0.3		150	45	
	Granular base	0.14	1.0	150	21	
	Subbase	0.1	1.0	150	15	
					81.0	**< 81.28**
Trial 6	Stone pitching	0.3		150	45	
	Stabilised base	0.23	1.0	150	34.5	
	Subbase	0.1	1.0	150	15.0	
					94.5	**> 81.28**

Table 65 Hand packed Stones Trials

Trial	Pavement Layer	Material Coefficient	Drainage Coefficient	Design Thickness (mm)	SN (mm)	SN (mm)
Trail 1	HPS	0.3		150	45	
	Base	0.14	0.8	150	16.8	
					91.8	**> 81.28**
Trial 2 (Selected)	HPS	0.3		150	45	
	Granular base	0.14	0.8	150	16.8	
	Subbase	0.23	0.8	150	27.6	
					89.4	**> 81.28**
Trail 3	HPS	0.3		150	45	
	Granular base	0.14	0.9	150	18.9	
	Selected[1]	0.1	0.9	150	13.5	
	Selected[2]	0.09	0.9	150	12.2	
					89.6	**> 81.28**
Trial 4	HPS	0.3		150	45	
	Granular base	0.14	1.0	0	0	
	Subbase	0.10	1.0	0	0	
	Selected[1]	0.09	1.0	0	0	
	Selected[2]	0.08	1.0	150	12	
					57	**< 81.28**

5.8 Design of rigid pavement options

Two types of rigid pavements (roller compacted concrete and thin mesh-reinforced concrete) were designed for demonstration in the project. Both pavements do not require dowelled joints (i.e. load transfer would be achieved via aggregate interlock).

5.8.1 Traffic

Same as that for flexible pavements (Section6.6.6)

5.8.2 Serviceability

The recommended value of initial design serviceability index by AASHTO for rigid pavements is 4.5. A terminal serviceability value of 2.0 was considered for the design, i.e. design serviceability loss is 2.5.

5.8.3 Reliability

An 85% reliability level was selected for this design (same as that for the flexible pavement design).

5.8.4 Overall standard deviation

The recommended value of overall standard deviation by AASHTO for rigid pavements is 0.30 to 0.40. A value of 0.35 was used for this design.

5.8.5 Effective modulus of subgrade reaction

Using AASHTO 1993 design guide with the following input parameters:

- thickness of subbase: 6 inches (150 mm),
- resilient modulus of subbase: 142 MPa (20,587 psi, Blend C), and

- resilient modulus of subgrade: 85 MPa (12,318 psi.)

A k-value of 600 pci (pounds per cubic inch)was obtained. The effective k-value for the design was 70 pci(adjusted for potential erosion of subbase material, Loss of Support = 1.5)

5.8.6 Concrete slab properties

The average values for the 28-day compressive strength (Section 4) were used to derive the flexural strength and elastic moduli for the three types of concrete mixes that were designed for the roller-compacted and thin mesh-reinforced concrete slabs. The flexural strength and elastic modulus of the mixes were estimated using the well-established American Concrete Institute (ACI) correlations presented below. The correlation results are presented in Table 67.

Table 66 ACI Correlations equations

Code	Country	Flexural strength relationship	Elastic modulus relationship
ACI	**USA**	$\boldsymbol{f_r = 0.62\sqrt{f'_c}}$	$\boldsymbol{E_c = 4734\sqrt{f'_c}}$

E_c = concrete elastic modulus at 28 days in N/mm²
f'_c = cylinder compressive strength at 28 days in N/mm²
f_r = flexural strength (modulus of rupture) at 28 days in N/mm²

Table 67 Concrete strength and stiffness correlations results

Concrete material	Constituent of concrete slab	Compressive strength (MPa)	Flexural strength (MPa)	Elastic modulus (MPa)
Thin mesh-reinforced concrete (TMRC)	Concrete made from OPC, sand, quarry stones	37.0	3.77	28,796
	concrete made from PPC 80% OPC + 20% Pozzolana), sand, quarry stones	30.0	3.40	25,930
	Concrete from OPC, sand, quarry stones (70%), in-situ aggregate, 30%)	32.7	3.55	27,070
Roller compacted concrete (RCC)	Concrete made from OPC, sand, quarry stones	36.0	3.72	28,404
	Concrete made from PPC (80% OPC + 20% Pozzolana), sand, quarry stones	31.5	3.48	26,570
	Concrete made from PPC, sand, coarse aggregate from quarry dust	31.4	3.47	26,527

5.8.7 Slab thickness

Similar to the flexible pavement design, the AASHTO 1993 rigid pavement design guide was used to determine the thickness of the various concrete slabs. The thickness (D) of the slab is determined by inserting various predetermined input parameters into the Equation 13.

$$\log(W_{18}) = Z_R \times S_o + 7.35\log(D+1) - 0.06 + \frac{\log\left(\frac{\Delta PSI}{4.2-1.5}\right)}{1+\frac{1.624\times10^7}{(D+1)^{8.46}}} + (4.22 - 0.32p_t)log\left[\frac{S'_c \times C_d(D^{0.75}-1.132)}{215.63\times J\left(D^{0.75}-\frac{18.42}{\left(\frac{E_c}{k}\right)}\right)}\right] \quad \text{(Eq. 13)}$$

where:

W_{18}	=	predicted number of standard equivalent single axle load applications
Z_R	=	standard normal deviate
S_o	=	combined standard error of the traffic prediction and performance prediction
D	=	thickness of pavement slab (in.)
ΔPSI	=	difference between the initial design serviceability index, p_o, and the design terminal serviceability index, p_t
S'_c	=	concrete modulus of rupture (flexural strength) (psi)
J	=	load transfer coefficient
C_d	=	drainage coefficient
E_c	=	concrete modulus of elasticity (psi)
k	=	modulus of subgrade reaction (pci)

Table 68 Design input parameters for the rigid pavement

Inputs	Parameter
Estimated future traffic	2.3 million ESALs
Design reliability	85%
Overall standard deviation	0.35
k-value	70 pci
Serviceability loss	2.5

Table 69 Designed slab thicknesses

Concrete material	Constituent of concrete slab	Flexural strength (MPa)	Elastic modulus (MPa)	Slab thickness (mm)	
				AASHTO 1993	ACPA[1] StreetPave
Thin mesh-reinforced concrete (TMRC)	Concrete made from OPC, sand, quarry stones	3.77	28,796	109 mm	103 mm
	concrete made from PPC (75% OPC + 25% Pozzolana), sand, quarry stones	3.40	25,930	114 mm	103 mm
	Concrete from OPC, sand, quarry stones (70%), in-situ aggregate (screened laterite, 30%)	3.55	27,070	112 mm	103 mm
Roller compacted concrete (RCC)	Concrete made from OPC, sand, quarry stones	3.72	28,404	109 mm	101 mm
	Concrete made from PPC (75% OPC + 25% Pozzolana), sand, quarry stones	3.48	26,570	113 mm	101 mm
	Concrete made from OPC, sand, quarry stones (75%), in-situ aggregate (screened laterite, 25%)	3.47	26,527	113 mm	101 mm

[1]Available software only does jointed plain concrete pavement analysis, hence slab thickness is believed to be overestimated for continuously mesh-reinforced concrete slab.

5.8.8 Concrete pavement options

Based on the pavement analysis and design results, the proposed pavement options for the various concrete slabs are summarised in Table 70.

Table 70 Summary of concrete pavement structure

Concrete material	Constituent of concrete slab	Base/subbase materials[3]	Slab thickness[4]	Base/subbase thickness
Thin mesh-reinforced concrete (TMRC)	Concrete made from OPC, sand, quarry stones	Blend A,B,E (Table 24)	75 mm	150 mm
	concrete made from PPC 80% OPC + 20% Pozzolana), sand, quarry stones	Blend A,B,E	75 mm	150 mm
	Concrete from OPC, sand, quarry stones (70%), in-situ aggregate, 30%)	Blend A,B,E	75 mm	150 mm
Roller compacted concrete (RCC)	Concrete made from OPC, sand, quarry stones	*Blend A,B,E	100 mm	150 mm
	Concrete made from PPC (80% OPC + 20% Pozzolana), sand, quarry stones	*Blend A,B,E	100 mm	150 mm
	Concrete made from PPC, sand, coarse aggregate from quarry dust	*Blend A,B,E	100 mm	150 mm

*: Preferably blends with relatively low PIs should be used in the base/subbase layer.-

5.8.9 Drainage

As mentioned previously, the quality of drainage is assumed to be “good” (i.e. water is removed within one day) and the percentage of time during which the pavement is exposed to moisture levels approaching saturation is from 5 to 25% of the year. Based on these criteria, a value of 1.05 for drainage coefficient for rigid pavements (Cd) was selected from the AASHTO Design Guide (1993).

5.8.10 Load transfer

The two concrete pavements do not require a load transfer mechanism in the design.

5.8.11 Loss of support

Because of the planned construction of lean concrete beneath the concrete slabs and the good drainage system, there will be less potential for pumping to occur; therefore the minimum value of 1.0 was selected for the design.

[3]Detailed properties presented in Section 3 of the Report

[4] Design does not consider reinforcements; hence recommended slab thickness for the thin mesh-reinforced concrete slab is 75 mm. The roller compacted concrete also constructed 100 mm thick. The reductions in thicknesses will be compensated by placing both the RCC and TMRC slabs will be placed on a 30 to50 mm lean concrete (strength, 15 MPa), and a 150 mm base/subbase support layer of 150 mm thick.

5.8.12 Reinforcement design for the TMRC

The original design consisted of 70 mm thick concrete using normal Portland cement and a minimal amount of reinforced steel (6 mm diameter welded wire mesh placed on a neutral axis with grid size of 200 x 200 mm). The TMRC has only 0.24% steel embedded in the concrete). Due to constructability problems, the minimum thickness suggested has now been increased to 75 mm.

5.9 Design of double chip seal (14 mm /10 mm)for the control section

The design and steps for a double chip seal follow the procedures as prescribed in TRH 3 (2007)[5] , the Ghana Ministry of Roads and Highways (MRH, 2005), and the Ghana standards (GSSRB, 2007).

5.9.1 Design Traffic

The traffic volume is expressed as the number of equivalent light vehicles (ELV) per lane per day:

ELV = L + (40*H)

Where L = Number of light vehicles/lane/day

H = Number of heavy vehicles/lane/day

Table 71 Design traffic distribution of the project road

Vehicle type	ADT	ELV/lane/day
Buses	30	[(30 + 87) + (40 * 13)] **= 637**
Light and medium trucks	87	
Heavy and trailers	13	

5.9.2 Potential embedment

The potential embedment was calculated using the average corrected penetration from at least 10 ball penetration tests (recommendations from TRH3, 2007). The purpose of the testing is to determine the embedment of seal aggregate into the base, which affects the spray rate. As this testing is done on site, an estimated embedment will be used for design purposes. MRH (2005) allows for a maximum Ball Penetration of 2.5 mm. This is, however, at a maximum and a corrected ball penetration of 2.0 mm was used.

5.9.3 Average least dimension (ALD)

The ALD is determined on site using a method recommended by TRH 3 (2007). The purpose is to adjust the stone seal binder application rate for the appropriate seal type.

ALD of 14 mm / 10 mm double chip seal = ALD of first layer + ALD of second layer.

MRH (2005) specifies the minimum ALD for gradings of chippings as 5.0 mm and 7.0 mm for 10 mm and 14 mm aggregates, respectively(total ALD = 12 mm). The 15.0 mm ALD design chart was subsequently used based on experience and the specified minimum criteria from MRH (2005).

5.9.4 Minimum and maximum binder application rates

The minimum and maximum binder application rates (net cold binder) are a function of the following:

[5] Accessible. Available in South Africa and as a free online document

- ELV/lane/day
- Corrected ball penetration
- Average least dimension (ALD) of the aggregate
- Texture depth

Table 72 depicts the binder application rates as per TRH 3(2007). The texture depth testing is done on site as is recommended in TRH 3 (2007). Based on the design traffic of 637, and the corrected ball penetration of 2.0 mm, the embedment is approximately 0.2 mm. Hence, the assumed texture depth was determined based on experience.

Table 72 Binder application rates (TRH 3, 2007)

Average least dimension (ALD)	Corrected ball penetration	ELV / lane / day	Texture depth	Binder application rates (l/m^2)	
				Minimum	Maximum
15 mm	2.0 mm	637	0.7 mm / 1.0 mm	2.60	3.05

5.9.5 Adjustments

- Existing surface texture

Additional binder is required on coarse-textured surfaces to ensure that there is sufficient tack coat on the aggregates in new seals to prevent whip-off. Very coarse-textured surfaces should be pre-treated before the double seal can be constructed.

Adjustment: + 0.37 l/m2 for 0.7 mm texture depth

+ 0.39 l/m2 for 1.0 mm texture depth

- Climate

The design curves presented above are appropriate for moderate conditions only. As the project road is located in a heavy rainfall region in Ghana, it is recommended that up to 10% of net cold binder should be subtracted for wet/humid areas

Adjustment: - 5% of minimum net cold binder

- Slow-moving traffic

Slow-moving heavy vehicles influence the binder application. A reduction of the binder application rate is required when the speeds of heavy vehicles reduce to below 40 km/h. A reduction of up to 10% may be required to prevent bleeding and fattiness (TRH 3, 2007).

Adjustment: - 5% of minimum net cold binder

- Aggregate spread rate

Add up to 10% binder for a medium-dense ‘shoulder-to-shoulder’ matrix or up to 20% for an open ‘shoulder-to-shoulder’ matrix (TRH3, 2007). The adjustment is only valid for aggregates with low flakiness indices (< 10%). The approximate stone spread rate for each ALD can be determined using Appendix D and the flakiness index.

Adjustment: + 5% of minimum net cold binder.

Table 73 Summary of adjustments

ALD	Texture depth (mm)	Binder application rates (l/m^2)		Adjustments			
		Min	Max	Surface texture (l/m^2)	Climate (%)	Slow-moving traffic (%)	Aggregate spread rate
15.0 mm	0.7	2.60	3.05	+ 0.37	- 5 %	- 5 %	+ 5 %
	1.0			+ 0.39			

5.9.6 Practical minimum and maximum binder application rates

The specifications for pavement seals are the MC 3000 cutback bitumen (MRH, 2005). The binder specifications for cutback bitumen are depicted in Table 74.The guideline for construction is presented in Table 75.

Table 74 Grades of cutback bitumen for seals (MRH, 2005)

ASTM grade equivalent	Additional grade[6]	Viscosity (Centistokes)	% Kerosene by volume
MC 3000	AMC 5	5 000 – 12 000	11
	AMC 6	12 000 – 32 000	7
	AMC 7	-	3

Table 75 Factor for converting net cold residual binder to hot spray rate, storage, and spraying temperature

Binder type	Conversion factor [7]	Spray temperature (°C)	Maximum storage temperature (°C)
Cutback bitumen MC 3000	1.19 – 1.27	130 - 155	100

5.9.7 Material requirements and design summary

Table 76 and Table 77 present the parameters and requirements of bitumen and aggregates for chip seal construction in Ghana (MRH, 2005). A summary of the double chip seal design for the project is presented in Table 78.

Table 76 MC 3000 specifications (MRH, 2005)

Parameter	MC 3000	
	Minimum	Maximum
Kinematic viscosity at 60°C (140F) [centistokes]	3 000	6 000
Flash point (Tag open-cup) (°C)	66	-
Water (%)	-	0.2
Distillate (% by volume of total distillate to 360°C) To 225°C To 260°C To 315°C	- 0	- 15

[6]AMC cutbacks are used for priming unbound aggregate bases, promoting adhesion between a seal or asphalt and base or as a sealing binder. The cutbacks are made from bitumen which is diluted with an amount of solvent to reduce the handling temperature/viscosity.

[7]Binders from different sources have different temperature conversion factors. The user should refer to the manufacturer. For design purposes, a conversion factor of 1.25 was used.

	15	75
Residue from distillation to 360°C (Volume percentage of sample difference)	80	-
Absolute viscosity at 60°C [poises]	300	1 200
Ductility (5cm/min.cm)	100	-
Solubility in Trichloroethylene (%)	99.0	-
Spot test with standard naphtha-	Negative for all grades	

Table 77 Material and shape requirements of aggregates (MRH, 2005)

Test	Requirement	Limit
Los Angeles Abrasion (LAA)	Max %	30
Aggregate Crushing Value (ACV)	Max %	25
Sodium Sulphate Soundness (SSS)	Max %	12
Flakiness Index	Max (14mm)	25
	Max (10mm, 7mm)	30
Elongation Indices	Max %	35
10% Fines	Min (dry) kN	210
Wet/Dry Strength Ratio	%	75
Stripping Test (ASTM D1644-80)	Max %	5

Table 78 Summary of single seal design

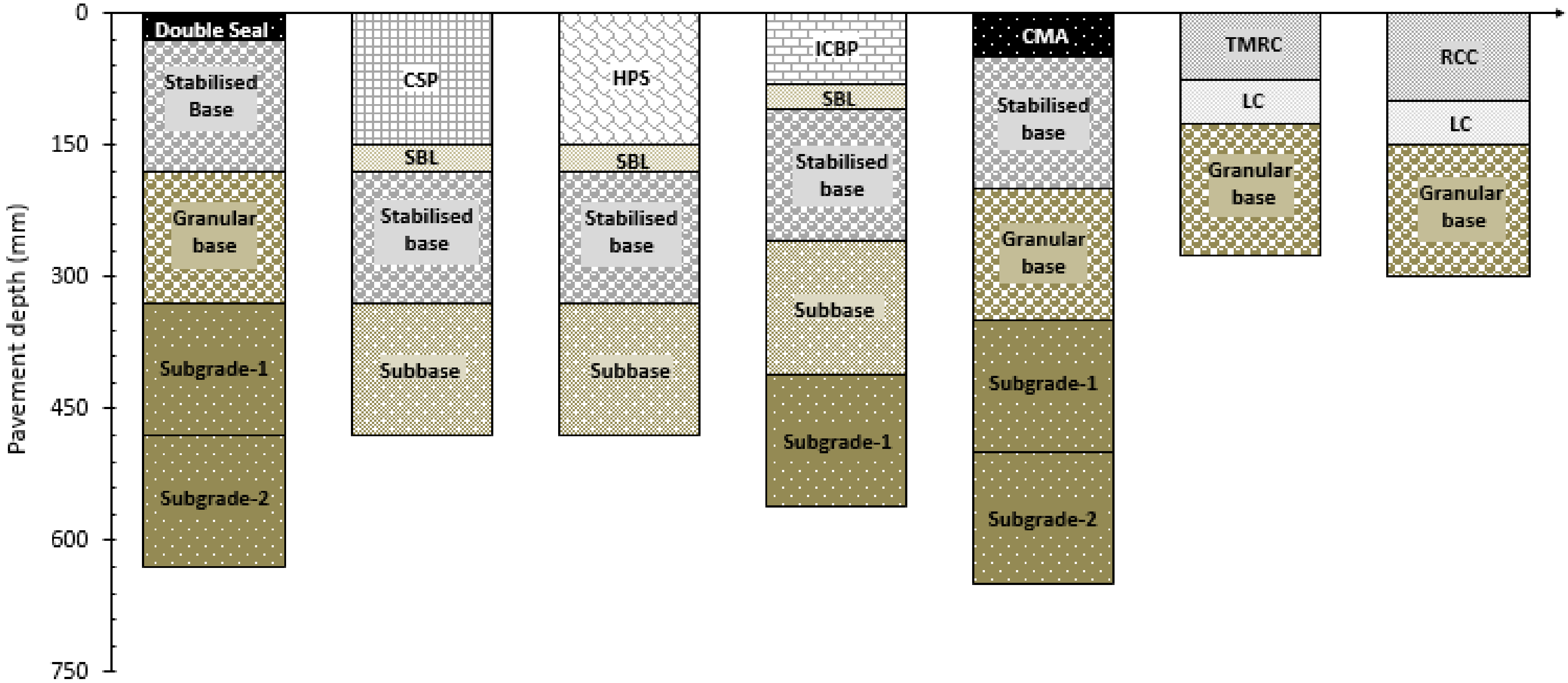
Parameter	Double seal design	
Traffic	637 elv/lane/day	
Aggregate ALD	15.0 mm	
Texture	0.7 mm	1.0 mm
Corrected ball penetration	2.0 mm	
Net cold binder	Min: 2.60 l/m² Max: 3.04 l/m²	
Adjustments: Texture Climate Slow-moving traffic Aggregate spread rate	 + 0.37 l/m² - 0.13 l/m² - 0.13 l/m² + 0.13 l/m²	 + 0.39 l/m² - 0.13 l/m² - 0.13 l/m² + 0.13 l/m²
Minimum net cold design application rate	2.84 l/m²	2.86 l/m²
Binder type	Cutback bitumen MC 3000	
Hot application rate	2.84 * 1.25 = 3.55 l/m² @ (130 – 155) °C	2.86 * 1.25 = 3.58 l/m² @ (130 – 155) °C
Distribution of binder (50/30/20) Tack coat application rate (hot) Penetration coat rate (hot) Fog spray	 1.78 l/m² 1.06 l/m² 0.71 l/m²	 1.79 l/m² 1.07 l/m² 0.72 l/m²

5.10 Pavement structures and cross-sections

Figure 26 present the schematic of the pavement structures for the experimental/demonstration sections.

Examples of cross-sections for each experimental/demonstration section with detailed materials schedules are presented in Figure 27 to Figure 34.

Figure 26 **Schematic pavement experimental/demonstration sections**



Notes: CSP = Concrete stone pitching; SBL = Sand bedding layer; HPS = Hand-packed stones; CMA = Cold mix asphalt; TMRC = Thin mesh-reinforced concrete; LC= Lean concrete; RCC = Roller-compacted concrete

Figure 27 Layout of experimental/ demonstration Sections

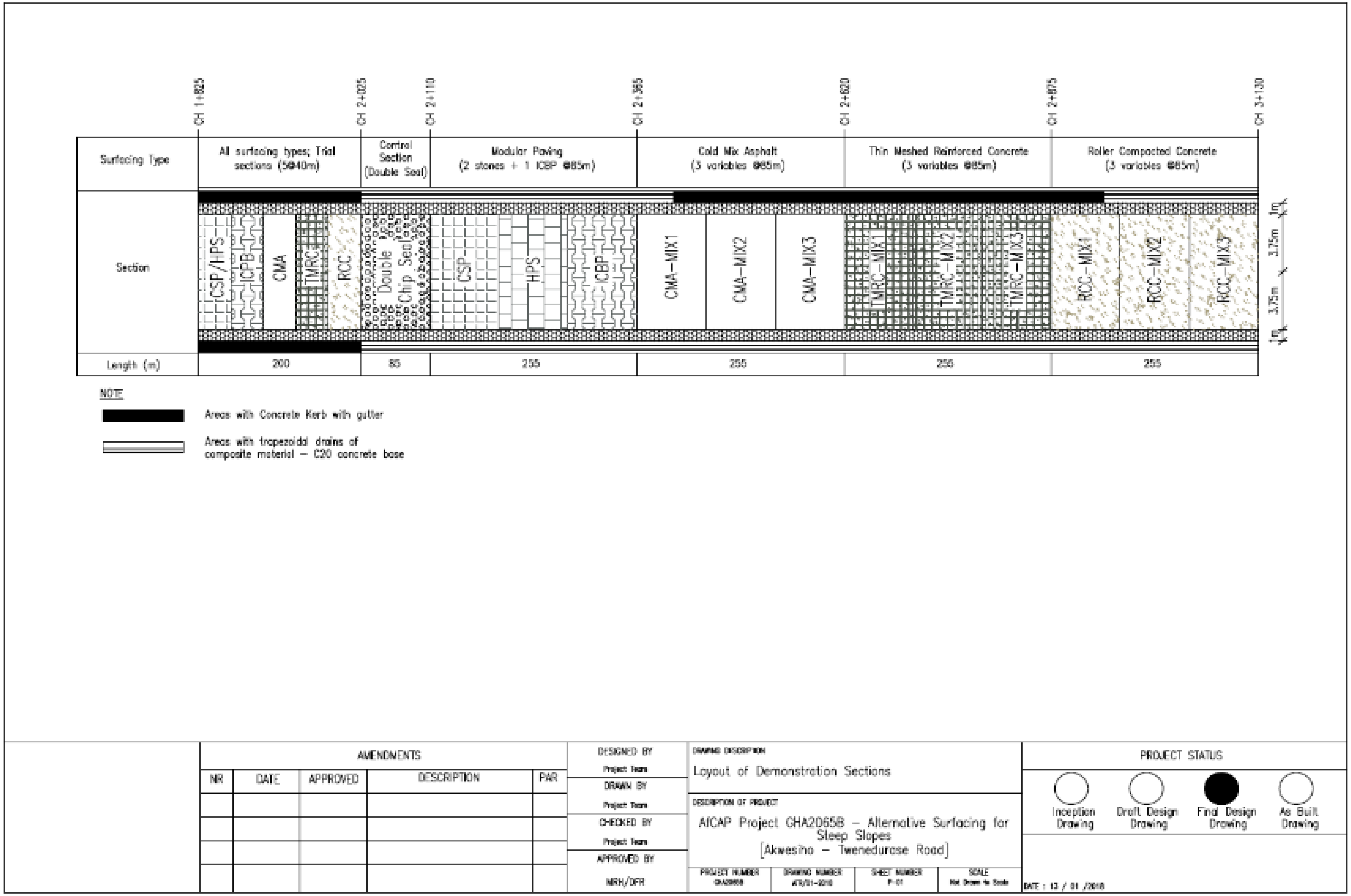
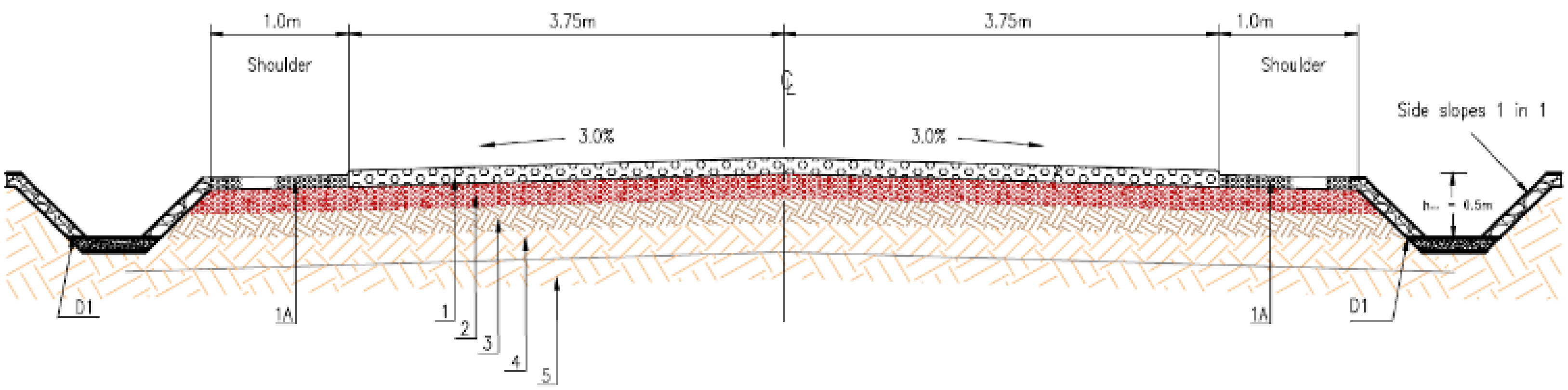


Figure 28 **Typical cross section for double chip seal @Chainage 2 + 065**



MATERIAL SCHEDULE				
LAYER NO.	DESCRIPTION	MATERIAL TYPE	SPECIFICATION	RELATIVE COMPACTION (% OF MOD. AASHTO)
1	30mm Wearing Course	Double Chip Seal of 14mm/10mm precoated aggregate		
2	150mm Stabilized Base	Cement Stabilized base	UCS = 1.5 – 3.0 MPa where UCS is stated at 14 days	
3	150mm Base	Granular Base course of crushed or natural material	G40 : CBR = 40%	
4	150mm Subgrade 1	Unbound granular material	Min CBR = 25% @ 95/97 BS heavy compaction ; Max Swell 1.0%–1.5% @ 100% BS heavy compaction ; Max grain size = 2/3 layer thickness	97%
5	150mm Subgrade 2	Unbound granular material	Min CBR = 15% @ 93/95 BS heavy compaction ; Max Swell 1.5% @ 100% BS heavy compaction ; Max grain size = 2/3 layer thickness	95%
1A	Road Shoulder Surface Material	14mm Single Chip Seal		

AMENDMENTS				
NR	DATE	APPROVED	DESCRIPTION	PAR

DESIGNED BY: Project Team
DRAWN BY: Project Team
CHECKED BY: Project Team
APPROVED BY: MRH/DFR

Typical Cross Sections

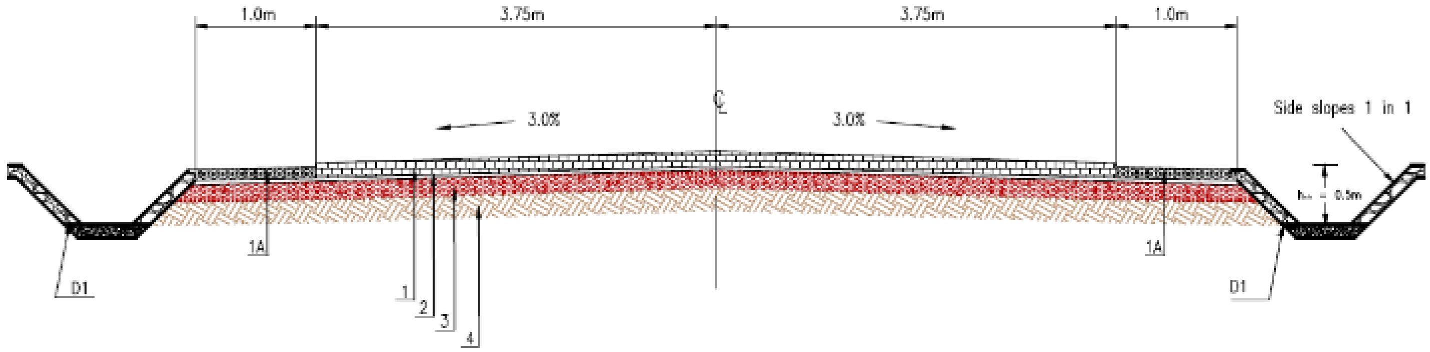
AfCAP Project GHA2065B – Alternative Surfacing for Steep Slopes [Akwesiho – Twenedurase Road]

SCALE: Not Drawn to Scale

PROJECT STATUS: Inception Drawing / Draft Design Drawing / Final Design Drawing / As Built Drawing

DATE : 13 / 01 /2018

Figure 29 Typical cross section for CSP @ Chainage 2 + 150



MATERIAL SCHEDULE				
LAYER NO.	DESCRIPTION	MATERIAL TYPE	SPECIFICATION	RELATIVE COMPACTION (% OF MOD. AASHTO)
1	150mm Wearing Course	Concrete Stone Pitching	150mm cubic Stone laid on a bed of loose sand with the joints filled with sand–mortar.	
2	30mm Sand Bed Layer	Sand		
3	150mm Stabilized Base	Cement Stabilized Base	UCS = 1.5 – 3.0 MPa where UCS is stated at 14 days	
4	150mm Subbase	Granular Subbase course of natural material (G30)	Min CBR = 30%	95%
1A	Road Shoulder Surface Material	14mm Single Chip Seal		
D1	Trapezoidal lined drain	100mm thick concrete base with stone pitched walls	Min. Concrete Strength = C20; 100–150mm shaped stones	

AMENDMENTS				
NR	DATE	APPROVED	DESCRIPTION	PAR

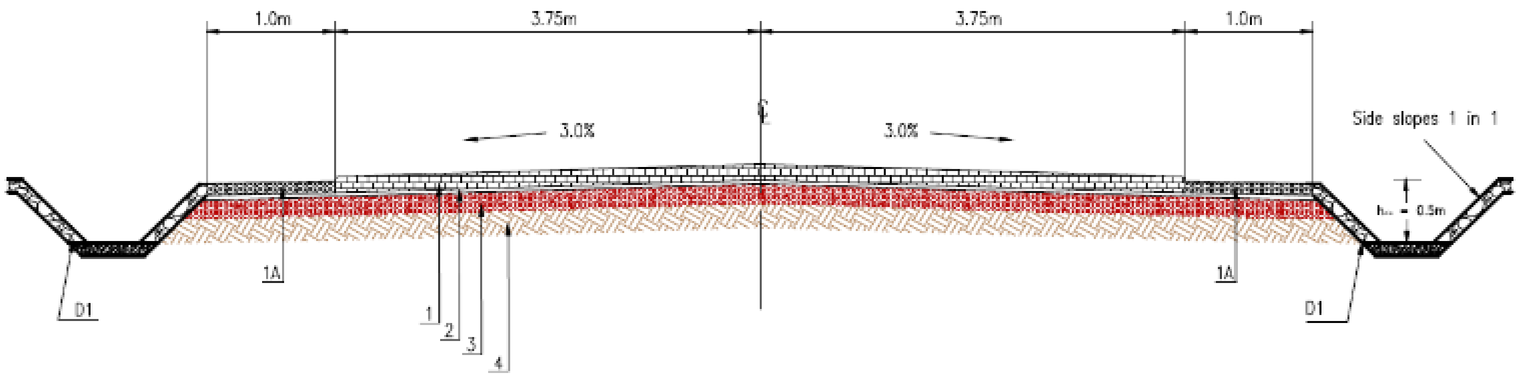
DESIGNED BY: Project Team
DRAWN BY: Project Team
CHECKED BY: Project Team
APPROVED BY: MRH/DFR

DRAWING DESCRIPTION: Typical Cross Sections

DESCRIPTION OF PROJECT: AfCAP Project GHA2065B – Alternative Surfacing for Steep Slopes [Akwesiho – Twenedurase Road]

PROJECT STATUS: Inception Drawing / Draft Design Drawing / Final Design Drawing / As Built Drawing

Figure 30 Typical cross section for HPS @ Chainage 2 + 235



MATERIAL SCHEDULE

LAYER NO.	DESCRIPTION	MATERIAL TYPE	SPECIFICATION	RELATIVE COMPACTION (% OF MOD. AASHTO)
1	150mm Wearing Course	Hand Packed Stones	Approx. 100mmx100mmx150mm shaped stones	
2	30mm Sand Bed Layer	Sand		
3	150mm Stabilized Base	Cement Stabilized Base	UCS = 1.5 – 3.0 MPa where UCS is stated at 14 days	
4	150mm Subbase	Granular Subbase course of natural material (G30)	Min CBR = 30%	95%
1A	Road Shoulder Surface Material	14mm Single Chip Seal		
D1	Trapezoidal lined drain	100mm thick concrete base with stone pitched walls	Min. Concrete Strength = C20; 100–150mm shaped stones	

AMENDMENTS

NR	DATE	APPROVED	DESCRIPTION	PAR

DESIGNED BY: Project Team
DRAWN BY: Project Team
CHECKED BY: Project Team
APPROVED BY: MRH/DFR

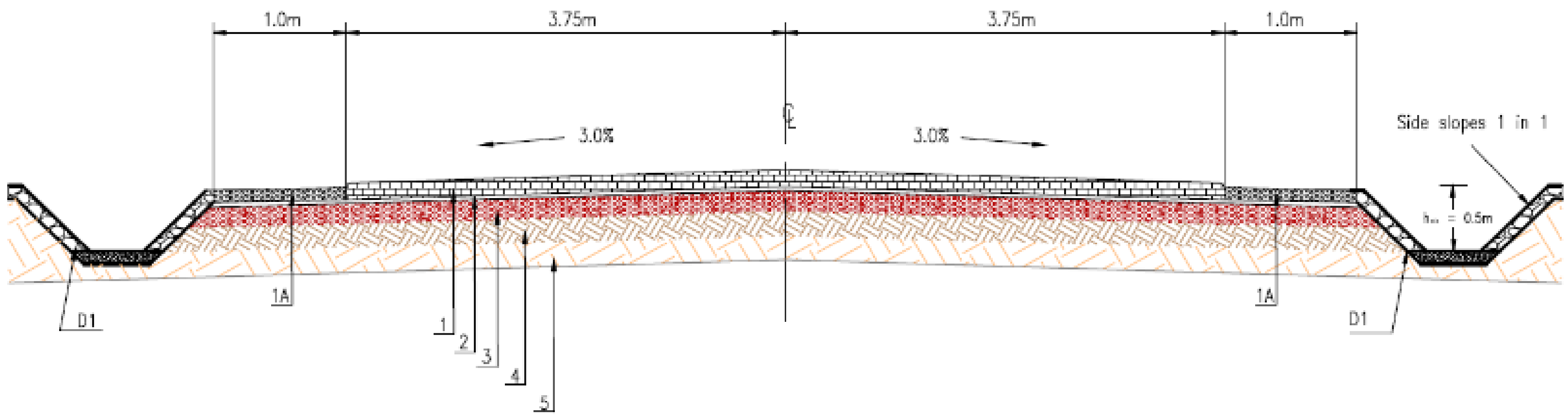
DRAWING DESCRIPTION: Typical Cross Sections

DESCRIPTION OF PROJECT: AfCAP Project GHA2065B – Alternative Surfacing for Steep Slopes [Akwesiho – Twenedurase Road]

PROJECT STATUS: Inception Drawing / Draft Design Drawing / Final Design Drawing / As Built Drawing

DATE : 13 / 01 /2018

Figure 31 **Typical cross section for ICBP @ Chainage 2 + 320**



MATERIAL SCHEDULE				
LAYER NO.	DESCRIPTION	MATERIAL TYPE	SPECIFICATION	RELATIVE COMPACTION (% OF MOD. AASHTO)
1	80mm Wearing Course	Interlocking Concrete block paving	Approx. 200mm X 100mm X 80mm; Min. Concrete Strength = C35;	
2	30mm Sand Bed Layer	Sand		
3	150mm Stabilized Base	Cement Stabilized Base	UCS = 1.5 – 3.0 MPa where UCS is stated at 14 days	
4	150mm Subbase	Granular Subbase course of natural material (G30)	Min CBR = 30%	95%
5	150mm Subgrade 1	Unbound Granular Material	Min CBR = 25% @ 95/97 BS heavy compaction ; Max Swell 1.0%–1.5% @ 100% BS heavy compaction ; Max grain size = 2/3 layer thickness	95%
1A	Road Shoulder Surface Material	14mm Single Chip Seal		
D1	Trapezoidal Lined drain	100mm thick concrete base with stone pitched walls	Min. Concrete Strength = C20; 100–150mm shaped stones	

AMENDMENTS				
NR	DATE	APPROVED	DESCRIPTION	PAR

DESIGNED BY: Project Team
DRAWN BY: Project Team
CHECKED BY: Project Team
APPROVED BY: MRH/DFR

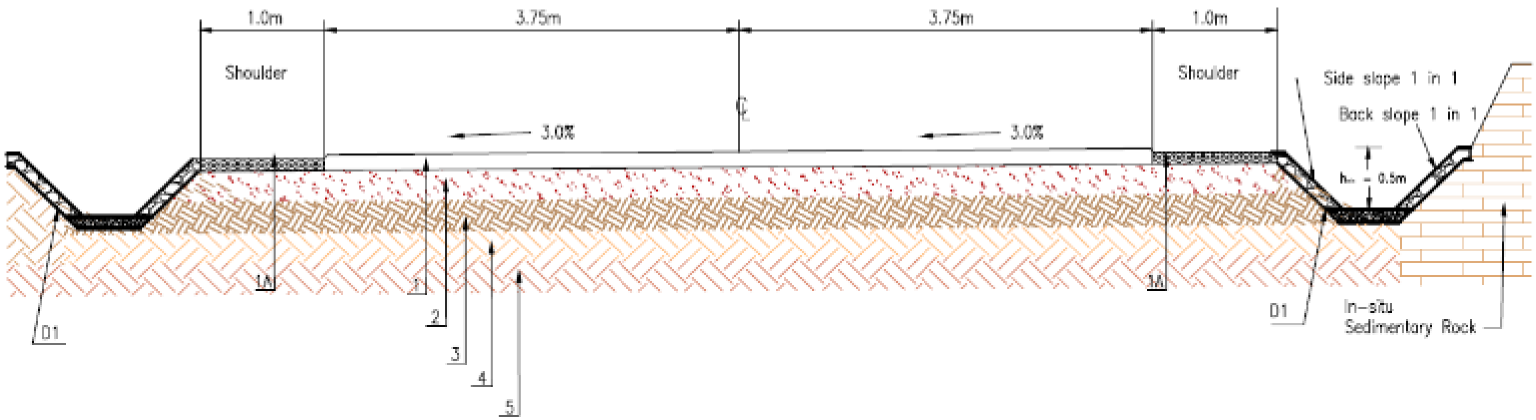
DRAWING DESCRIPTION: Typical Cross Sections

DESCRIPTION OF PROJECT: AfCAP Project GHA2065B – Alternative Surfacing for Steep Slopes [Akwesiho – Twenedurase Road]

PROJECT STATUS: Inception Drawing / Draft Design Drawing / Final Design Drawing (selected) / As Built Drawing

DATE : 13 / 01 /2018

Figure 32 Typical cross section for CMA mix 1-A @ Chainage 2 + 400



MATERIAL SCHEDULE

LAYER NO.	DESCRIPTION	MATERIAL TYPE	SPECIFICATION	RELATIVE COMPACTION (% OF MOD. AASHTO)
1	50mm Wearing Course	Cold Mix Asphalt with base emulsion (K1-70 cationic type) with all quarry stones		
2	150mm Stabilized Base	Cement Stabilized base	UCS = 1.5 – 3.0 MPa where UCS is stated at 14 days	
3	150mm Base	Granular Base course of crushed or natural material	G40 : CBR = 40%	
4	150mm Subgrade 1	Unbound granular material	Min CBR = 25% @ 95/97 BS heavy compaction ; Max Swell 1.0%-1.5% @ 100% BS heavy compaction ; Max grain size = 2/3 layer thickness	97%
5	150mm Subgrade 2	Unbound granular material	Min CBR = 15% @ 93/95 BS heavy compaction ; Max Swell 1.5% @ 100% BS heavy compaction ; Max grain size = 2/3 layer thickness	95%
1A	Road Shoulder Surface Material	14mm Single Chip Seal		
D1	Trapezoidal lined drain	100mm thick concrete base with stone pitched walls	Min. Concrete Strength = C20; 100-150mm shaped stones	

AMENDMENTS

NR	DATE	APPROVED	DESCRIPTION	PAR

DESIGNED BY: Project Team
DRAWN BY: Project Team
CHECKED BY: Project Team
APPROVED BY: MRH/DFR

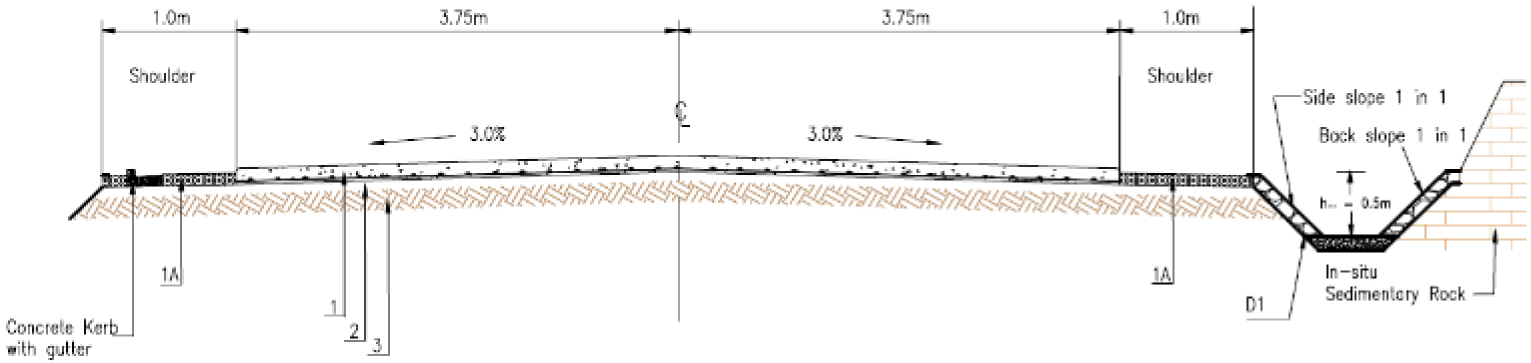
DRAWING DESCRIPTION: Typical Cross Sections

DESCRIPTION OF PROJECT: AfCAP Project GHA2065B – Alternative Surfacing for Steep Slopes [Akwesiho – Twenedurase Road]

SHEET NUMBER: S-10
SCALE: Not Drawn to Scale

PROJECT STATUS: Inception Drawing / Draft Design Drawing / Final Design Drawing / As Built Drawing

Figure 33 Typical cross section for TMRC mix 3 @ Chainage 2 + 820



MATERIAL SCHEDULE

LAYER NO.	DESCRIPTION	MATERIAL TYPE	SPECIFICATION	RELATIVE COMPACTION (% OF MOD. AASHTO)
1	75mm Wearing Course	Thin Meshed Reinforced Concrete made from OPC, sand, quarry stones (70%), In-situ aggregates (30%)	Min. Concrete Strength = C35; Reinforcement = 6mm ø rods @ 200mm c/c in both direction	
2	50mm Bedding	Lean Concrete	C15 concrete compacted within 2 hours of mixture to 96% of target dry density	
3	150mm Base	Granular Base course of crushed or natural material	G40 : CBR = 40%	98%
1A	Road Shoulder Surface Material	14mm Single Chip Seal		
D1	Trapezoidal lined drain	100mm thick concrete base with stone pitched walls	Min. Concrete Strength = C20; 100–150mm shaped stones	

AMENDMENTS				
NR	DATE	APPROVED	DESCRIPTION	PAR

DESIGNED BY: Project Team
DRAWN BY: Project Team
CHECKED BY: Project Team
APPROVED BY: MRH/DFR

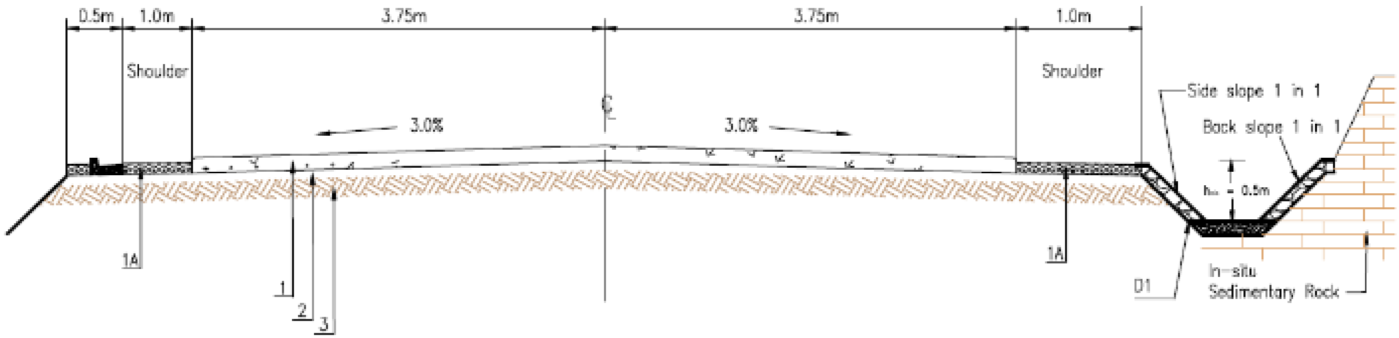
DRAWING DESCRIPTION: Typical Cross Sections

DESCRIPTION OF PROJECT: AfCAP Project GHA2065B – Alternative Surfacing for Steep Slopes [Akwesiho – Twenedurase Road]

PROJECT STATUS: Inception Drawing / Draft Design Drawing / Final Design Drawing (marked) / As Built Drawing

DATE : 13 / 01 /2018

Figure 34 Typical cross section for RCC mix 1-A @ Chainage 2 + 915



MATERIAL SCHEDULE

LAYER NO.	DESCRIPTION	MATERIAL TYPE	SPECIFICATION	RELATIVE COMPACTION (% OF MOD. AASHTO)
1	100mm Wearing Course	Roller Compacted Concrete made from OPC, sand, quarry stones	Min. Concrete Strength = C35;	
2	50mm Bedding	Lean Concrete	Min. C15 concrete compacted within 2 hours of mixture	98%
3	150mm Base	Granular Base course of crushed or natural material	G40 : CBR = 40%	98%
1A	Road Shoulder Surface Material	14mm Single Chip Seal		
D1	Trapezoidal lined drain	100mm thick concrete base with stone pitched walls	Min. Concrete Strength = C20; 100–150mm shaped stones	

AMENDMENTS

NR	DATE	APPROVED	DESCRIPTION	PAR

DESIGNED BY: Project Team
DRAWN BY: Project Team
CHECKED BY: Project Team
APPROVED BY: MRH/DFR

DRAWING DESCRIPTION: Typical Cross Sections

DESCRIPTION OF PROJECT: AfCAP Project GHA2065B – Alternative Surfacing for Steep Slopes [Akwesiho – Twenedurase Road]

SHEET NUMBER: 9-17
SCALE: Not Drawn to Scale

PROJECT STATUS: Inception Drawing / Draft Design Drawing / Final Design Drawing (selected) / As Built Drawing

DATE: 13 / 01 /2018

5.11 Geometric design

As per the design standards of the DFR (2009), the project road is classified as a connector feeder road with generated traffic of over 200vpd(i.e. 433 vpd) and economically viable to upgrade to a bituminous surface.

The following considerations were made during the geometric design:

- Vehicle characteristics adhere to GHA road design standards
- Effective drainage system is in place
- Need for adequate road safety signs and markings for hilly sections
- Provision of relatively flat gradients interspersed between high gradients sections as safety measures for heavy and truck vehicles.

5.11.1 Assessment of proposed road alignments

The geometric design covers vertical and horizontal alignments, cross-sections and drainage. Prior to the selection of the project road, the DFR had appointed a contractor, hence the draft geometric design had been completed. Therefore, the geometric design drawings presented in this final report were provided to the project team by the DFR.

A soft copy of the project road geometric design drawings is available upon request from the DFR. The designs were critically assessed and reviewed by the project team as against the actual site investigations conducted. The purpose was to assess the viability of dovetailing the proposed designs with the research goals of the project. Both the horizontal and vertical alignments were subjected to critical scrutiny and the attributes of the proposed alternative surfacings were incorporated thereafter, with agreement between the project team and the DFR, Horizontal alignment review

The horizontal alignment was checked using the Ghana Road Design Guide and AfCAP LVRs design Manuals. Generally, the parameters establishing the horizontal elements were found to conform satisfactorily to the standards. However, based on the site investigations, it was realised that the two critical curves were too acute to facilitate adequate turning of long vehicles without much difficulty and posing safety issues. The necessary recommendations were presented for consideration, and agreed upon by the project team and DFR. . At these critical turning sections, road widening is imperative, as well as super-elevation, rather than following normal cross-camber of the road in other sections.

5.11.2 Vertical alignment review

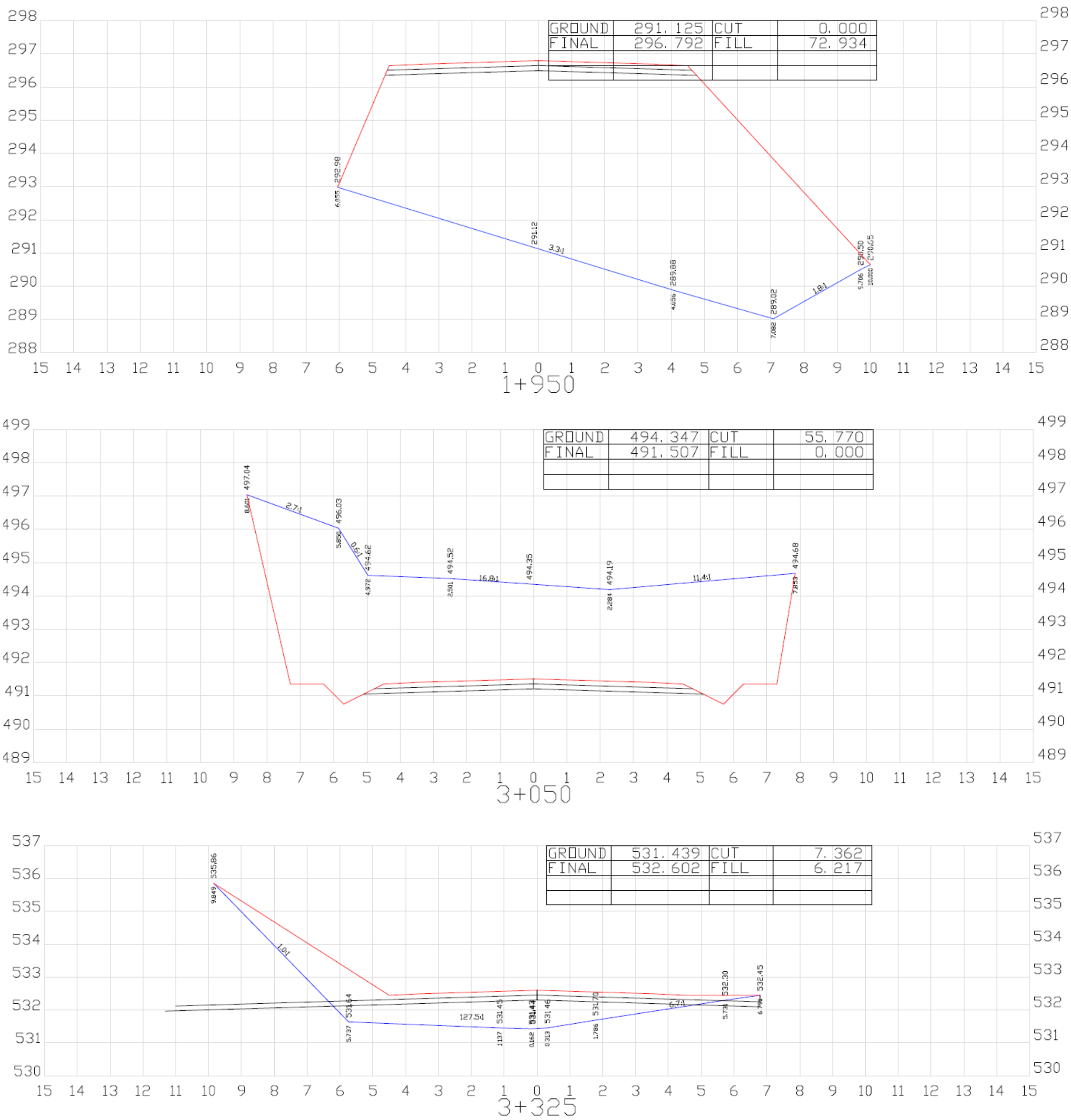
The vertical alignment, when checked against the Ghana Road Design Guide and AfCAP LVRs design manuals-(Ethiopia, Tanzania, Malawi), did not require any significant reviews. This is due to the nature of the terrain and topography of the project road corridor. The vertical alignment parameters were selected to meet both safety and the research requirements (i.e. minimum gradient of 12% was required for this research), and also minimise earthworks, especially cuts, and hence cost of construction.

5.11.3 Cross-sections

The project site is characterised by significant cuts and fills as depicted in the typical cross-sections presented in Figure 35. Based on the terrain, a carriageway width of 7.5 m and a paved shoulder width of 1 m (i.e. roadway with of 9.5 m) were accepted for the project road. These parameters were discussed and finalised at the first stakeholder workshop (24 October 2017) at the DFR offices in Accra. For paved low-volume roads on steep hills, a cross-fall of 3% is recommended by the AfCAP LVR design manuals (e.g. ERA LVR Manual, 2016).

Usually, 4 to 5% cross-fall would be required for the shoulders as the project carriageway has a 3% cross-fall. However, concerns over the contractor's ability to divide the cross falls into two (carriageway and shoulders) could be complicated; hence a common cross-fall of 3% will be used for both the carriageway and shoulders of the demonstration sections.

Figure 35 Geometric cross-sections



5.11.4 Design speed

The project road is classified as hilly. Based on practical observations during the project reconnaissance and site visits, a design speed of 30km/h can be adopted for this project in accordance with the specifications of the Ghana Road Design Guide (1991).

Table 79 Ghana Road Design Guide 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

Summary of geometric design elements

Parameter	Value
Width of lanes	3.75 m
Width of shoulder	1 m
Comber of carriageway	3%
Camber of shoulder	3%
Maximum super elevation	4%
Minimum vertical gradient	12%
Minimum curve radius	50 m

5.12 Drainage structures

The project area is characterised by steep hills, high rainfall and high temperature differential conditions under which the project road will function, and the underlying subgrade conditions.

Because of anticipated moisture from high levels of precipitation, a drainage system will be constructed with the assumption that it is capable of removing excess moisture in less than one week. Samples from existing borrow pits of the road alignment were found to be predominantly sand with varying proportions of clay, silt and gravel; and PI values ranged between 8% and 24%. Roadbed swell was thus not anticipated.

The drainage design for the demonstration sections was mainly based on the GHA Road Design Guide (RDG) (1991). References were however obtained from low-volume road design manuals of Ethiopia and Tanzania. Other policy documents such as A Policy on Geometric Design of Highways and Streets (AASHTO, 2001) were also consulted when necessary.

The hydrological data from the project catchment area was used to finalise the design of drainage structures. Based on the project site investigation results presented in the Draft Design Report, the expected major challenges with drainage would be the following:

- The safe discharging of road surface run-off in the side drains without scouring
- The effects of sub-surface water action, especially around Chainage km 2+850.
- Containment of the ground water that was seen draining from the cut rock surfaces

To keep the drainage system working efficiently, a lined trapezoidal drain was the preferred choice for the project road. Since the project location is in mountainous terrain, with gradients between 8 and 12%, and prolonged high annual rainfall, it was necessary to consider lining the side drains in the steep sections to avoid severe erosion. The most cost-effective drain lining is made from mass concrete at the base, and mortared stones at the sides.

5.12.1 Surface drainage input parameters and factors

The recommended survey by GHA Road Design Guide (focusing on rainfall intensity of catchment area; nature of topography; the type of earth surface; geology; and ground water condition) for drainage design was done and the results were presented in the Draft Design Report of the project.

The following steps were followed for the drainage design (adapted from GHA Road Design Guide, 1991):

Step 1: Determine catchment area and run-off coefficients

The nature of the project site terrain shows that, generally, the total catchment area (A) for a given drainage section should comprise the following:

- Demonstration paved road surface area of one carriage lane of width 3.75 m, designated (a1)

- Bituminous paved shoulders of 1.0 m (on each side where there are no space and terrain constraints) designated (a2)
- Contiguous catchment area along the proposed roadway which encompasses the cut exposed rock surfaces and vegetated area on the hills, designated (a3)

Based on the vertical profile of the project road and the results of site investigations, three distinct drainage sections were identified for the demonstration sections. Table 80 summarises the three drainage sections with the corresponding catchment area and run-off coefficients.

Table 80 Drainage sections with estimated catchment area and runoff coefficients

Drainage Section	Section Chainage	Proposed surfacing type	Catchment area, A (m^2)		Composite runoff coefficient, C	
1	3+500 to 2+700 (800m)	Concrete (RCC and TMRC)	$a_1 = 3200$	54000	$c_1 = 0.95$	CA =0.346
			$a_2 = 800$		$c_2 = 0.80$	
			$a_3 = 50000$		$c_3 = 0.30$	
2	2+700 to 2+300 (400m)	Bituminous (CMA)	$a_1 = 1500$	21900	$c_1 = 0.85$	CA =0.347
			$a_2 = 400$		$c_2 = 0.80$	
			$a_3 = 20000$		$c_3 = 0.30$	
3	2+300 to 2+000 (300m)	Modular paving (HPS, CSP, ICBP); Control (Double chip seal)	$a_1 = 1125$	7425	$c_1 = 0.80$	CA= 0.396
			$a_2 = 300$		$c_2 = 0.80$	
			$a_3 = 6000$		$c_3 = 0.30$	

Notes:

- *The individual run-off coefficient depends on the nature of material, for instance in Section 1, c1 was taken as 0.95 because of the concrete surfaces in Drainage Section 1, while c3 was 0.30 for the vegetation catchment areas.*
- *In determining the individual run-off coefficient (c1) of the paved carriage lane section for a particular drainage section, the predominant demonstration surfacing types were taken into account. For instance, in Drainage Section 1, we have the variables of the Thin Mesh-Reinforced Concrete and the Roller-Compacted Concrete. These are concrete-based and thus, the recommended run-off coefficient (c1) for Drainage Section 1 is 0.95, while c1 for Drainage Section 2 is assumed as 0.85 because this surface is predominantly bituminous. The modular paving demonstration sections for Drainage Section 3 were taken as 0.80 because of its relatively poor surface drainage abilities.*
- *The composite run-off coefficient (C) for a given drainage section is the weighted factor due to the individual catchment components calculated from Equation 14.*

$$C = \frac{\sum a_i C_i}{\sum a_i} \qquad \text{(Eq. 14)}$$

For Section A, for example, C_A is calculated as:

$C_A = [(a_1)\,(c_1) + (a_2)\,(c_2) + [(a_3)\,(c_3)]/(\,a_1 + a_2 + a_3)$ *Eq.?*

$C_A = 0.346$

- *The total catchment area (A) is the sum of the individual catchment components (a_1, a_2, and a_3).*
- *For Drainage Section 1,*
  - *200 m^2 additional space is added to the paved road surface area (a_1) [3.75 m x 800 m + 200 m^2] for the widening at the horizontal curved sections around ch 3+000 and ch 2+850; and*
  - *the contiguous vegetated catchment area (a_3) extends beyond the end of the demonstration section around ch 3+130, to the crest (summit of the hilly section which is the end of the project*

ch 3+500). Run-off from all this area must be channelled through the proposed trapezoidal drains.

- *For Drainage Section 2, the contiguous vegetated catchment (a_3) is captured as 50 m offset from the outer side of the proposed trapezoidal drain. It has to contain the maximum area to generate the run-off, including water that would be intercepted from the rock cut surface noted in this section, i.e. a_3 = 400 m x 50 m.*

- *For Drainage Section 3, the contiguous vegetated catchment (a_3) is taken as 20 m offset from the outer side of the proposed trapezoidal drain, which is due to the small area that generates the expected run-off from the natural catchment area, i.e. a_3 = 300 m x 20 m.*

Step 2: Determine rainfall intensity

The design rainfall intensity takes into account the rainfall history of the area (2006 to 2016 rainfall data) and the frequency of occurrence in years. Based on the charts in Appendix C of the RDG and data from the GMet, a rainfall intensity (I) of 125 mm/hr with frequency of occurrence of a 10-year return period (i.e. the number of years before the rainfall intensity is likely to recur) was used for the design and assessment for the proposed drainage structures.

Step 3: Determine inlet time

Inlet time, also called the time of concentration, is the time taken for a particle of water to travel from the remotest part of the catchment area to the inlet of the drainage structure. Generally, for road drainage structures such as side drains, the inlet time is very short because water is assumed to have travelled from the centre line of the road. Therefore, in such a design, 0.2 hours of rainfall intensity is recommended by the RDG.

Step 4: Determine maximum run-off

The maximum run-off for each drainage section was obtained based on the following Equation 15

$$Q = 0.278 \times 10^{-6} \times C \times I \times A \quad (\text{m}^3/\text{s}) \qquad \text{(Eq.15)}$$

where

Q: *Maximum run-off from the catchment area (m^3/sec)*

C: *Run-off coefficient (a coefficient which represents ratio of run-off to rainfall)*

I: *Average rainfall intensity (mm/h)*

A: *Total Catchment area (m^2)*

Thus, from Equation 15, the estimated total maximum run-off for the three drainage sections 1, 2 and 3 is calculated as follows:

$$Q_1 = 0.278 \times 10^{-6} \times 0.346 \times 125 \times 54{,}000 = 0.649 \text{ m}^3\text{/sec}$$

$$Q_2 = 0.278 \times 10^{-6} \times 0.347 \times 125 \times 21{,}900 = 0.264 \text{ m}^3\text{/sec}$$

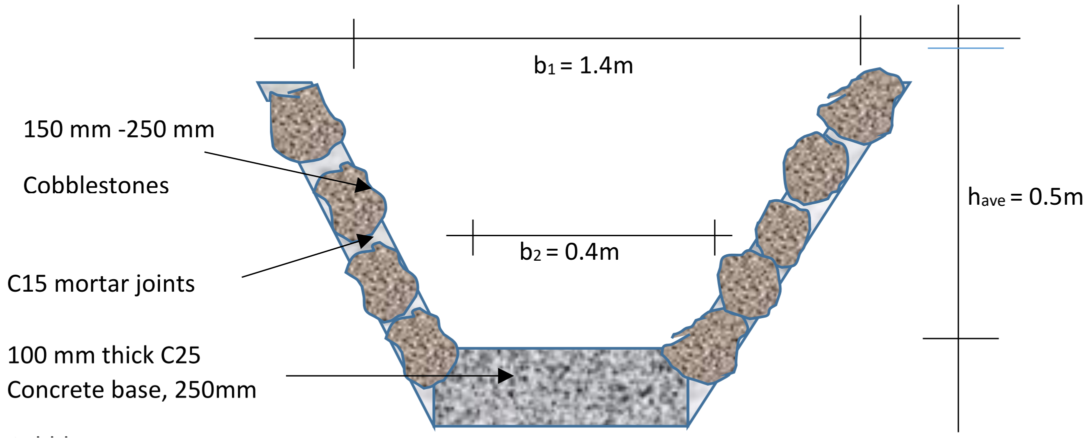
$$Q_3 = 0.278 \times 10^{-6} \times 0.396 \times 125 \times 7{,}425 = 0.102 \text{ m}^3\text{/sec}$$

Step 5: Capacity assessment of side drainage structure

Assessment of the capacity of the selected trapezoidal channel with concrete base and mortared stone-lined slanted side walls (width average typical dimensions) is shown schematically in

Figure 36. The size of the stone should be a minimum of 200 mm to avoid the rock being washed away by water.

Figure 36 **Cross-section of the trapezoidal drain**



The flowing water section area (A) is given by:

$$A = \frac{1}{2} h \,(b_1 + b_2)$$

(Eq.16)

The hydraulic mean depth (R) is defined as the area of the flow section (A) divided by the wetted perimeter. The Road Design Guide (1999) requires that the hydraulic mean for trapezoidal shaped drains be calculated as follows:

$$R = \frac{A}{b_2 + \sqrt{4h^2 + (b_1 - b_2)^2}}$$

(Eq.17)

The average velocity (V) of flow (m/sec) in the drains is dependent on the following:

- The hydraulic radius (R)
- The average slope (i) of the drain base (which is usually dictated by the natural topology/terrain)
- Coefficient of roughness (n) of the drain line (the mortared stone in this case)

$$V = \frac{1}{n} R^{2/3} . i^{1/2}$$

(Eq.18)

It is worthy to note that due to the nature of the terrain of the project road (steep slopes), the average slope (i) is taken as 0.12 (the limiting 12%). Therefore, very high velocities of flows are expected in the discharge of run-offs in the trapezoidal side drains. Though the drains are lined, these high velocities have to be checked to avoid erosion of the lining of the drains.

Scour checks are recommended to break the expected high flowing discharges in the drains.

For the proposed trapezoidal drain (Figure 36), the area of the flow section A is calculated as 0.36 m2. Based on the dimensions of the drain (i.e. b1; b2; h) and using Equation 4, the hydraulic mean depth, R, is computed as 0.198 m.

The RDG (1991) recommends an average value of 0.025 (within a range of 0.017 to 0.030) as coefficient of roughness (n) for a mortared stone-lined drain. Thus, the average velocity of flow in the trapezoidal side drains is calculated as 4.71 m/sec (using Equation 18), and substituting for n, R, and i values.

As expected, the 3.39 m/sec is more than twice the typical average velocity of flow for a stone/block pitched drain of 1.8 m/sec (Road Design Guide, 1991) due to the relatively high drainage slope value of 0.12.

The flow capacity of the proposed drain is calculated as 1.697 m3/sec, which is in excess of the expected discharges for all three drainage sections of the project road (QA = 0.649 m3/sec; QB = 0.264 m3/sec and QC = 0.102 m3/sec, respectively).

However, the proposed drain size is maintained in view of the following:

- Construction according to standards as specified in the design
- Good construction and maintenance practices
- Accommodation of future additional run-off flows (potential increase in economic activities and development in terms of social infrastructure in the project catchment area)

5.12.2 Additional drainage structures

Where the available capacity would be smaller than the runoff, mitre drains, kerbs with gutter would replace trapezoidal drains.

The following drainage systems are considered for the project road:

- The trapezoidal drains have to be shaped along the road reserve to ensure effective drainage. Where necessary, the edge drains or storm water pipes will be constructed to divert water from the fill slopes.
- It is expected that construction of the pavement layers will adhere to the proposed cross fall of 3% to allow for effective surface runoff water drained off the road way and discharge to the side drains.
- From chainage 1+825 to 2+075, there is a constructed embankment of about 100 m long with an approximate height of between 20 m and 25 m. The side slopes were estimated to be above 45 degrees. This section will be used for construction trails of the five surfacing types. Based on the terrain, both sides of the section require concrete kerbs with gutter.
- At chainage 2+000 km, there is an access at the left side leading to a settlement. This access also served as a turnout or mitre drains for surface runoff from the road and the left side drain.
- At chainage 2+360 km, where there is an outer circle of the sharp cure, turnout drains are introduced.
- From chainage 2+700 to 2+975: A gully erosion of about 1.0 to 1.5 m deep and about 100 m long was noted on the left side. The width of the gully varied between 0.5 m and 2.5 m. It was believed that the erosion was occurring as a result of surface runoff that washed almost all placed material and exposed the underlying rock formation.
- Between chainages 2+450 and 2+960, from Akwesiho to Twenedurase- Due to the terrain of this section, the drainage structure proposed for left hand side is concrete kerb withconcrete line channels (gutters).
- Section 6 [from 2.975 km to 3.250 km]: There is evidence of siltation at the inlets which means runoff is ponding at the inlets. Water dripping from the rock face is more intense here, with some water flowing on the road surface. It is recommended that the smallest pipe culvert to be used for drainage purposes be 600mm in diameter and that the box culvert be 450 mm x 600 mm. These are easier and cheaper to maintain. A small culvert (skewed, due to the nature and direction of flow) should be provided.
- Turnouts or mitre drains are also needed along some portions of the project site

6 Construction

6.1 Construction approaches

The impact of employment generation, based on the choice of construction technique, was emphasised at the inception of this project. Since the DFR intends to use an already existing contractor for the construction of the demonstration sections, the capability of the contractor to execute labour-based contracts was assessed (e.g. equipment, personnel, background in terms of experience in similar jobs). The method of construction that is to be used may have an impact on the selection of materials and the structural design. The construction method should be clearly understood before the design proceeds, as a design suitable for plant-intensive construction may be unsuitable for labour-based construction (and vice versa). Stabilisation techniques would be employed as a way to strengthen the in-situ materials for subgrade, subbase and base layers of the pavement options.

Training and capacity building in construction of all alternative surfacings is an integral part of this project.

6.1.1 Labour-intensive techniques

Table 81 highlights different labour-intensive tasks and methods for the construction of low-volume sealed roads. The table demonstrates that high-quality low-volume sealed roads can be successfully constructed by adopting employment-intensive approaches. It also indicates that more appropriate design specifications and locally derived techniques for using locally available resources can make the construction of low-volume sealed roads far more cost-effective. The techniques included in the table will be evaluated during actual construction of the demonstration sections, and refined for the construction report of the project.

Table 81 LIC techniques for the project

Section	Description	Activities
Earthworks	Earthworks	Labour based method – by transverse balancing
	Hauling by labour	Use of wheel barrow for haulage
	Ditching and sloping	Construction of open drains by labour based methods
	Excavation requirements	Excavating trenches, measuring quantities,
	Quarry operations	Borrow pit identification and layout
Pavement layers	Centre line survey	DCP testing
	Construction of base layer using in-situ materials, stabilised or un-stabilised gravel	Excavate, place shutters, pegs and material. Spread and compact base layer, Screening of stockpiles,Haulage of materials, Removal of oversize materials
	Compaction of layers	Understanding of moisture content and dry density curves
	Improving in-situ materials for base courses	Understanding of stabilisation
Drainage	Side drains, mitre drains, etc.	Setting out, excavation and construction
	Catch water drains,	Construction process
	Scour checks	Scour spacing to be checked
	Culverts	Setting out of culverts
	Drifts	Construction process
	Stone pitching	
	Side drainage	Lined (concrete) open drains, construction

	Subsurface drainage	Stone collection, loading, hand placing, construction.
Concrete works	Hand mixing	Use of shovels, spades and water.
	Machine mixing	Transporting material, follow procedures
	Placing and compacting	Set formwork and shuttering, hand or vibrator compacting
	Reinforcement	Placement (manual)
	Kerbing and edging	Laying of kerbing and edging units
Sealing options using labour based methods	Prime and seal work	Hand spraying of prime, manufacture and laying of slurry, Construction procedure (labour based)
	Binder application	Procedure (labour based)
	Modular paving	Construction procedure (labour based)
	Construction of cold-mix asphalt	Construction procedure (Labour and light equipment)
	Construction of thin-mesh reinforced concrete	Construction procedure (Labour and light equipment)
	Construction of roller-compacted concrete	Construction procedure (Labour and light equipment)

6.1.2 Light machinery

The use of light equipment essentially allows for labour-intensive construction techniques. Table 82 highlights some of the construction equipment identified for the project.

Table 82 Light machinery for road construction

Parameter/Construction	Equipment
Crushing and screening	Jaw, impact, cone crushers, screening
Asphalt production	Drum mixer
Concrete plant	Tilting drum mixers
Milling machines	Small machines: maximum cut width of 1,000 mm
Concrete paving	Vibrating beams, bowel bar inserters, Burlap drag, spreader, finishers
Compaction	Small steel-wheel rollers, vibratory plate compactors, and rammers
Earthworks	Light earthmoving equipment (compact track loaders, mini excavators, skid steers)

6.2 Construction materials

Details of construction materials properties and designs for the demonstration sections were evaluated, and their properties were presented in Section 3 and Section 4 of this report. Materials properties and the relevant test methods of natural gravels, crushed stones, bituminous materials, cement, and concrete are presented in Section 3 of this report. The BS, AASHTO, and modified GHA standards were followed to establish the physical and engineering properties of the construction materials in Ghana.

The material for surfacing, drainage, stabilisation and concrete works will be obtained from commercial sources in Nkawkaw (district capital, Eastern Region) and surrounding areas, including Kumasi (regional capital, Ashanti Region). This will not only support entrepreneurs through the labour-intensive construction philosophy, but also reduce transportation costs.

The modified material shall be the stabilised pavement layers. It is envisaged that Ghacem 32.5R cement will be utilised as the stabilising agent. Prior to construction, trial stabilisation tests will be conducted in the laboratory to determine the cement content required for stabilisation. It should be noted that the cement content is dependent on the maximum dry density of the particular neat sample. Thus, determining the cement content that is required will be an on-going procedure on site during implementation.

Currently, anecdotal evidence shows that mechanical production of cobblestones and stone setts is virtually absent, hence no data is available for their properties. It is yet to be established whether, existing and operational quarries close to the project road can be the main source of supply for these stones.

6.3 Tender

Standard tender documents for civil engineering works in Ghana are available at the Ghana Public Procurement Authority website (www.ppaghana.org)

Preliminary preparations should be made to establish a bill of quantities (BoQs) for all pavement options. Since the contractor for the project was selected by the DFR, the BoQs will only serve as a guideline to monitor the contractor's activities and expenses during construction.

Construction of the experimental demonstration sections did not go through a tender process.

6.4 Contractor selection

Prior to this research project, the DFR had awarded the project road on contract. Hence, contractor selection was done solely by the DFR through the Ghana Procurement Act. As the current project involves new pavement types and related construction techniques, the project team will provide technical guidance to the contractor's team during construction and implementation of the research.

6.5 Construction guidelines

The procedures to be used for interlocking block paving, cold mix asphalt, thin mesh-reinforced concrete and roller-compacted concrete construction require control over quantities, proportions (i.e. aggregate, emulsion, additives) and construction tolerances to achieve a mix with good performance.

6.5.1 Guidelines for the cold mix asphalt pavements

Three different cold mix asphalt mixes will be demonstrated in this project:

1. Base emulsion (K1-70 cationic type) – with all quarry stones
2. Base emulsion K1-70 cationic type (with optimum cement/lime additives) – with quarry stones
3. Base emulsion (with optimum lime/cement additives) – with blended stones (70%) and screened laterite (30%)

The following aspects require special attention during the construction phase:

Site and base/subbase preparation

The base layer on which the cold mix asphalt will be laid must conform to the following requirements:

- The base must be swept clean of all dust, debris and foreign matter before the cold mix asphalt is placed. Any defects in the prime must be repaired by reapplying prime and letting it cure.
- The width of road to be surfaced must be staked out by marking the edge of the road with a 6 mm rope.
- The cold mix asphalt should be laid in strips usually not wider than 1.2 m at a time. The strips should be marked out such that the joints do not come in the wheel paths. The number and width of the strips depend on the width of the lane. The strips should also not be too narrow as

this will increase the number of longitudinal joints. A 3.0 m wide lane is then constructed in three strips of 1 m width each.

- The base must have a perfect camber to attain close to even thickness across the pavement width. This should be checked using a straight edge before the cold mix asphalt is laid.
- The surface must be firm and well compacted. In the current project, the G40 base should be compacted to a minimum of 98% of modified AASHTO density and measurements to this effect by using a nuclear density gauge or performing the sand replacement test as per GSSRB (2007) method.
- Both prime coat and tack coat must be applied to the G40 base layer prior to the application of the cold mix asphalt.
    - For prime coat, the binder shall be specified in the Special Specification and will generally be a medium-curing cutback AMC0 (MC30), AMC1 (MC70) or a slow-setting cationic emulsion (CSS-1). Priming should be done at a minimum application rate of ± 1.0 l/m2 about a week before the surfacing construction starts.
    - Before the application of the tack coat, excess dust should be swept away with a broom. The guide rails must be fixed in lanes as required. Diluted bitumen emulsion (30% of bitumen and 70% of water) is then applied on the primed surface at a spray rate of 0.4 l/m2. The tack coat shall be spread to a very light application using brooms and it should be allowed to set and dry before the sealing operations commence.
    - The tack coat should be dry before the cold mix asphalt is laid, to avoid pick-up of bitumen during the laying.
    - The area to be sprayed from a given quantity of binder should firstly be established and marked out to assist in achieving the correct application rate.
    - Spraying should be carried out in wide sweeping movements of the hand with 1/3 overlaps between successive applications. The actual spray rate should be continuously checked by comparison of the area covered and the area marked.
    - The spray operation should not advance too far ahead of the chipping operation.

The cold mix asphalt pavements will be constructed on a sharper curve, hence super-elevation should be applied to fall fully across the carriageway towards the inside of the curve.

Material quality

- The material components – i.e. aggregates, bitumen emulsion, and additives/filler – required for the production of the cold mix must comply with the materials requirements as discussed in Section 4.1 of this report.
- It is important to make provision for adequate testing of materials during the construction phase of any potential labour-intensive road works project.

Control of mix proportions

- The nominal mix proportions, as indicated in Section 4.1 of this report and confirmed during the pavement design stage, must be implemented. Mixing should be done in a concrete mixer by pouring chippings and quarry dust and mixing for at least 30 seconds. Water is then added and mixed for an additional 30 seconds. Following this, the emulsion should be added at the right proportion/quantity and mixed for another 60 seconds.
- Containers used for proportioning of the mix components will have to be cut and/or marked to hold the correct volumes, thus eliminating incorrect measurements and ensuring that the correct proportions are consistently mixed.
- The mix volume should be limited to 40 litres of aggregates, possibly with the addition of some sand if needed to improve the grading. If the mix volume gets bigger, it becomes much harder for the labourers to mix and the mix may not be done properly.
- An on-site trial should be used to validate the mix proportions and bitumen emulsion content determined from the laboratory mix designs.

Construction tolerances and finish requirements

- The cold mix asphalt should be laid in accordance with tolerances and finish requirements of the GSSRB (2007). It should be mentioned that the specified construction tolerances and finish requirements apply more to machinery-/plant-laid cold mix asphalt and may be not be easy to achieve in the case of labour-intensive construction.
- Level and thickness control can be achieved by placing thickness guides at pre-determined intervals along the road to be surfaced, thus ensuring that the required minimum asphalt thickness is placed. Post-construction coring of the finished surfacing layer will determine whether the layer complies with the specified thickness requirements. Three cores should be taken per lot for thickness measurements and quality control tests in the laboratory (grading, emulsion/bitumen content, etc.).
- Ideally, the cold mix asphalt should only be mixed and placed during the day and only in good weather conditions when rain is not imminent. The road surface temperature should be above10°C.
- Construction joints, both transverse and longitudinal, are potential weak spots. The joints therefore require special attention as shown in the following:
    - The joint face should be squared up and trimmed neatly. All loose material should be removed.
    - The emulsion should be applied to all joint faces by means of a watering can or a soft brush by dipping the brush and squirting emulsion on the joint face. This will ensure good bonding with the fresh material applied against the joint face.
    - For longitudinal joints, placing the 6 mm flat bar about 10 to 15 mm from the edge of the compacted asphalt will ensure a tight joint with no gaps after compaction. After the first pass, the material lying on top of the compacted asphalt must be carefully removed with a spade.
    - If the joint is open after compaction, a small amount of emulsion should be poured carefully into the gaps and crusher dust applied on top.

Compaction

- The first pass with the pedestrian roller is done in static mode. With careful manoeuvring, the guide rails may be left in place for the first pass of the roller. This will ensure a neat edge of the strip when the guide rails are removed for the subsequent passes.
- Compaction should be done from the shoulder/edge towards the centre and always in the longitudinal direction of the road.
- Wherever possible, at least half the roller drum should be supported on compacted asphalt. Wrong rolling can result in undulations in the surface of the asphalt.
- Once rolling has been completed and before proceeding with the construction of the adjacent asphalt strip, the edges of the compacted asphalt against which the new strip will be laid must be neatly trimmed and squared, and any loose material should be removed.
- For construction of the adjacent strip, 70 mm guide rails must be placed and secured on the base as for the first strip.

Once the cold mix asphalt has been placed to line and level, the surface must be compacted as follows:

- Two lifts (layers) of 25 mm thickness each (tack coat should be applied after the first lift has been properly compacted). Wheel barrows and hand tools should be used to place about 35 to 40 mm loose thickness of the cold mix asphalt between the guide rails. The placed asphalt is then compacted to a 25 mm thickness. For each lift, apply the following:
    - Two to 4 passes with a pedestrian steel roller, with vibration, immediately after application of the surfacing

- An additional 2 to 3 passes with a pedestrian steel roller, without vibration, after initial compaction
- An additional 2 to 3 passes with a pedestrian steel roller, without vibration, 24 hours after initial compaction (i.e. the following day)

The compacted cold mix asphalt layer must achieve one of the following density requirements:

- Density as measured on recovered core equal to or greater than 97%, minus the percentage air voids in the production mix.
- Density as measured on recovered core equal to or greater than 95% of the 75 blow Marshall Density.

Curing and traffic accommodation

The cold mix asphalt should be left to cure for a minimum of 24 hours to give the bitumen emulsion sufficient time to 'break' and for the asphalt to gain strength. This will require the road to be closed to traffic during this time and traffic accommodation measure will have to be put in place, e.g. sufficient signage, delineators, barriers, flagmen, etc.

Construction equipment and tools

The following equipment and tools are required:

- Bitumen sprayer
- Concrete mixer
- Plate compactor
- Pedestrian vibratory roller (750 kg – 1.5 tonnes)
- Guide rail /thickness guide (70 x 70 mm steel box section)
- Mixing pan(s) constructed of 3mm steel
- 75mm nails for holding down guide rails
- Steel tapes (two; 5 m and 50 m)
- 70 mm steel box sections as guide rails for placing asphalt (four lengths each of 2m and 3m long) with three 4mm diameter nail holes per section; 6mm x 50mm steel flat bar to accommodate wet to dry asphalt (four lengths each of 2m and 3m long)
- Chalk line equipment
- 2m straight edge (Screed)
- Wheelbarrows
- Steel framed stand and 50 mm diameter ball valve for decanting emulsion drums
- Steel squeegees (a steel plate with a handle)
- Watering can
- Spray screens
- 6 No. 20 litre measuring containers; 5 No. 10 litre measuring containers; 1 No. 5 litre measuring jug
- Others (Hammer, flat square nosed spades, hard brooms, 6mm rope, 2 x 50m rolls, etc.

6.5.2 Guidelines for the thin mesh-reinforced concrete pavements

General description of the pavement

The thin mesh-reinforced concrete pavement conforms to the designs presented in Section 4.2 (mix design) and Section 6.8 (structural design).

- Thickness: 75 mm (Tolerance, 5mm)
- Minimum strength: specified 30 MPa after 28 days

- Aggregate: 12.5 mm nominal stone and sand from the identified material sources.

Requirements of support layer

The support layer should be constructed to levels to accommodate the concrete within 5mm of designed level. In order to facilitate this, levels are established at every 10 meters.

The surface of the base layer must be firm and well compacted. In this project, the G40 base should be compacted to a minimum of 98% of modified AASHTO density and measurements to this effect - using a Nuclear Density Gauge if available or performing the sand replacement test as per ASTM D 4914M (2016).

Erection of shutters

- The side shutters should be of 75 x 75 mm steel box sections with a minimum of three lugs per section.
- In placing and fixing the side shutters care must be taken to ensure that no bumps are built into the surface
- Once the side forms have been placed, the levels must again be checked by placing the straight edge across the tops of the side forms and taking dip readings to ensure that the thickness of the concrete will be within tolerance.
- The formwork must be cleaned and oiled before use to ensure that it is easily removed.
- Side forms should not be removed before the concrete has hardened sufficiently to prevent damage being done to the sides and not earlier than 6 hours after completion of the slab.

Placing of the wire mesh

- Before placement of the wire mesh, all loose material must be removed from the surface and a diluted stable grade anionic emulsion (diluted 1 part emulsion: 8 parts water). A course broom can be used to evenly distribute the emulsion. The broom must be dipped in water at frequent intervals to prevent the build-up of bitumen
- The mesh must be Reference 200x200x 6 mm (high yield steel with characteristic strength of about 450 MPa; nominal mass per metre = 0.22 kg/m; Area = 28.3 mm^2; 0.24% steel imbedded in the concrete). In this project 6 mm wires are to be bound on site to form the required mesh.
- The cover to the mesh should be 37.5 mm and the mesh shall be laid bound in both the longitudinal and transverse direction and the overlap achieved by splicing the individual bars of the mesh with a splice bar 400mm long of the same diameter as the mesh.
- The mesh of the thin concrete is to be placed on the neutral axis (in the middle of the slab thickness) to reduce the risk of corrosion.
- The mesh must continue through any construction joints.
- Walking on the mesh reinforcing or newly placed concrete is not acceptable.

Mixing of concrete and materials requirements

Except for possible minor variations in moisture content, the mix proportions determined from the mix design (Section 4.2) shall be used for the entire project.

- Both coarse aggregate (stone) and fine aggregate (sand) must be clean, hard and durable and shall be natural sand, crushed gravel sand or crushed rock sand complying with GSSRB (2007).
- Cement and pozzolana additives shall comply with the requirements of GSSRB (2007). Cement shall be classified according to strength class and constituents and the cement classification should be clearly indicated when delivered to site.
- Mixing water shall be clean and free from harmful matter such as detrimental concentrations of acids, alkalis, salts, sugar and other organic or chemical substances that could impair the durability and strength of the concrete or the imbedded steel. Water shall conform to GSSRB (2007).
- Concrete should be mixed on site, using a suitably sized concrete mixer.

Placing of concrete

- The concrete shall be uniformly placed by wheelbarrow, with care being taken not to walk on or disturb the mesh reinforcing
- Where a section of concrete is to be cast against a section of previously cast concrete a 2 to 3 mm thick galvanized sheet approximately 300 mm wide should be placed on the top
- In this project the layer below the concrete pavement is a lean concrete, hence the timing of placing the concrete pavement will depend on the time required for the concrete to cure.
- In order to prevent "drying out," the concrete shall at all times be covered with a suitable canopy.
- "Starter" and "end" beams, must be provided for the thin concrete pavement at the commencement and end of the paving. The mesh must be folded down into the beams.
- End anchorage for the slabs should be between 30 m intervals
- Compaction shall be carried out by mechanical poker vibrator
- The finishing of the concrete pavement layer should be done by a bull float
- Broom the surface with a bristle broom at right angles to the edge of the pavement. The broom must be dipped in water at frequent intervals to prevent the build-up.

Construction joints

- Construction joints should only be provided to provide a clear, neat joint at the end of a day's work. As the mesh reinforcing is to be laid continuously, special attention must be given to the construction joints
- It is recommended that the formwork be removed as soon as the concrete has set sufficiently so as not to cause spalling of the concrete +/- 1 hour after casting the concrete.
- Before proceeding with casting the concrete for the next shift, the surface (face) of the joint must be cleaned of any laitance, lightly roughened and treated with cement slurry.

Longitudinal joints

- A longitudinal joint shall be formed along the centreline of the road by casting the second member against the first, sawing and sealing with appropriate sealant. Before proceeding with the concrete for the second member the road, the surface (face) of the joint must be cleaned of any laitance and lightly roughened.

Curing of concrete

- The exposed surfaces, including the sides of the pavement slab, must be protected, with plastic sheeting, as soon as possible after the required texturing of the surface has been effected
- Care must be taken to ensure that the bags holding down the plastic sheeting are not placed on the "wet" concrete. This plastic sheeting must be kept in place for as long as is feasible but for a minimum of seven days
- The mesh-reinforced concrete should be left to cure for 14 days before it is opened to traffic.
- Curing agents shall be tested in accordance with ASTM C 156 and shall comply with the requirements of ASTM C 309 except that the loss of water within 72 hours shall not exceed 0.40 kg/m^2

Sealing of concrete joints

- The construction joints and longitudinal joint shall be sawn 10 mm wide to a depth of 13 mm and sealed with appropriate sealant.

Equipment

The following equipment and tools are required:

- Concrete mixer, preferably a reverse drum mixer or small batch plant
- 75x75 mm steel box sections (2m and 1m lengths) for side shutters of the concrete pavement

- 38x25 and 38x19x2mm rectangular tube for shuttering for end of day construction joints
- Wheel barrows, shovels, steel squeegees, etc. to suit size of job.
- Transport for moving concrete from mixer to placing area. Wheelbarrows will be used in this project.
- Equipment for compaction of the concrete (a poker vibrator for the edge beams and a roller screed beam will be used in this project)
- Mechanical concrete screeding equipment. The Roller screed comprising 100mm diameter steel pipe of sufficient length to span shutters, driven by an external power source such that it spins at approximately 300 rpm in the opposite direction to which it is being moved similar to “Spin Screed“ has proven a successful piece of equipment to achieve the required spreading of the concrete
- Movable bridge to prevent walking on mesh when placing and screeding concrete.
- Bass broom to provide macrotexture.
- Equipment for spraying the curing compound where used.
- Concrete saw fitted with a 10 or 8mm wide blade for cutting of joints (preferably self-propelled)
- Gun for injecting sealant into joint
- Suitably sized containers for measuring ingredients at mixer
- Steel pegs (size Y10) with sharpened point for securing shutters
- Steel squeegees for spreading the concrete
- Straight edge of sufficient length to span between shutters
- Wooden/plastic trowels
- Bull float
- Suitably sized containers for measuring ingredients at mixer
- 25 litre containers with clip-on lid for storing cement
- 210 litre drums for storing water
- Suitable canopy for covering concrete after casting prior to brooming and after brooming, prior to covering with plastic sheeting (length equal to one hour’s production)
- Bass broom with extended handle for texturing of concrete

6.5.3 Guidelines for the roller-compacted concrete (RCC) pavements

General description of the pavement

The roller-compacted concrete pavement conforms to the designs presented in Section 4.2 (mix design) and Section 6.8 (structural design).

- Thickness: 100 mm (Tolerance, max 10 mm)
- Minimum strength: specified 30 MPa after 28 days
- Aggregate: 12.5 mm nominal stone and sand from the identified material sources.

Construction of RCC at ambient temperatures is suitable for labour-based construction – only simple, inexpensive construction equipment is required. In this project, RCC shall be constructed without formwork of shuttering and will be hand-placed.

Requirements of support layer

Same as that for the thin mesh-reinforced concrete pavement (Section 7.5.2).

Mixing of concrete and materials requirements

Same as that for the thin mesh-reinforced concrete pavement (Section 7.5.2).

Placing/compaction of concrete

- Smooth-wheel vibrating rollers are used to achieve compaction, with some contractors preferring to use pneumatic-tire rollers for finish rolling.

- If adjacent material is placed after one hour, then a cold joint should be constructed. The face of the cold joint should be trimmed so that a vertical face exists and any slumped material is removed.
- Compaction of the lift is achieved by using a vibrating steel-wheel roller. Compaction of the lift should be performed as soon as possible, typically within 10 minutes after spreading and no more than 40 minutes after mixing.
- All side forms shall be mild steel channel sections of depth equal to the thickness the pavement. The forms should be held firmly in place by stakes driven into the ground, and they should be cleaned and oiled each time they are used.
- The dry consistency of RCC causes difficulty in bonding fresh concrete to hardened concrete. This bond can be improved between the lifts by reducing the time of casting the lifts or by increasing the paste content in the mixture.

Curing of concrete

- The finished surface should be kept in a moistened condition until the next lift is placed (use a water sprinkler system for 7 days). Conventional concrete curing compounds can be used. However, because of the more open texture of RCC, application rates of 1.5 to 2.0 times that used with conventional concrete may be required.
- Curing starts within one hour to two hours after laying by covering the RCC pavement with wet hessian in two or three layers for the first 24 hours.
- Curing agents must be tested in accordance with ASTM C 156 and shall comply with the requirements of ASTM C 309, except that the loss of water within 72 hours shall not exceed 0.40 kg/m^2.

Joints

- To improve the appearance of the final RCC product, control joints can be sawn every 8 to 12 metres to eliminate most of the random shrinkage cracking. Saw cutting can be performed on RCC usually within a few hours of compaction.
- No longitudinal joint is provided.
- Transverse contraction joints at 5 m centre-to-centre should be provided after 18-24 hours of laying.

Equipment for RCC

Equipment and tools for the roller-compacted concrete are covered under the thin mesh-reinforced concrete section.

6.5.4 Construction of the modular pavements

The modular pavements considered in this project are hand-packed stones, concrete stone pitching and interlocking paving block.

Requirements of support layer

Same as that for the thin mesh-reinforced concrete pavement (Section 7.5.2).

Materials requirements

Shall comply with requirements of Ghana Standard Specifications for Roads and Bridges (2007):

Construction

- All modular paving materials will be bedded on a 30 mm thin layer of sand/gravel.
- An edge restraint or kerb constructed of large or mortared stones, or concrete is required.
- The bedding sand for concrete block paving shall comply with the grading requirements stipulated in the GSSRB (2007).100% of the sand used to fill the joints between the concrete

blocks shall pass through a 1.18 mm sieve and between 10% and 15% of it shall pass through a 0.075 mm sieve.
- The bedding sand shall be placed immediately before the concrete paving blocks are laid and shall not be compacted before the blocks have been laid.
- In current practice, a small plate vibrator is used to bed the blocks into a sand bedding of approximately 20 mm in depth and to compact jointing sand between individual blocks. The selection of the right type of sand for these purposes is important, since a non-plastic material serves best as bedding, while some plastic content is required to fill the joints.
- Experience has shown that joints of interlocking block paving should be 2 to 5 mm wide.
- Special attention will paid to joints/ transition from one surfacing type to another.

Equipment

Simple tools (mason's hammer, tape, straight edge, brush), and vibrating/non-vibrating roller, light plate compactor, string lines, etc. are required for the construction of the modular paving demonstration sections.

6.5.5 Compaction of underlying soils and gravels

The design procedures assume that the specified material properties are satisfied in the field. To achieve sufficient compaction and field density, the following should be noted:

- Compaction problems may result from material grading deficiencies or poor construction practices.
- Blending of material from different sources to improve the grading and compaction potential of the material may be better than trying to achieve density with excessive rolling.
- When compacting a layer, the support layer needs sufficient support to act as an anvil, otherwise the compaction energy is transmitted and lost through the pavement structure.
- The use of impact rollers can improve the strength and support from the subgrade substantially.
- Hand-held rollers may be inadequate to achieve the required density.

Table 83 gives the minimum compaction criteria required for various layers (natural gravels) of the pavement structure. These values meet the compaction specifications stipulated in GSSRB (2017).

Table 83 Compaction requirements for pavement layers of natural gravel

Pavement layer	Material class	Compacted density
Base course	G80, G60, or G40	98% Mod AASHTO density
Subbase	G30 or G40	95% Mod AASHTO density
Subgrade	G15	93% to 95% Mod AASHTO density
	G7	
Proof rolled roadbed	Sand	100% Mod AASHTO density
	Gravel	93% to 95% Mod AASHTO density

6.6 Erosion control measures

6.6.1 Climate adaptation measures

The prevailing climate of the project catchment area (especially high annual rainfall) will influence the supply and movement of water and the impact on the project road in terms of erosion through run-off. The general adaptation measures identified to benefit the current project site (steep gradients) include the following:

- Provision of sufficient drainage structures such as, culverts, lined side drains in potential venerable areas (at chainage 2+000 where water is dripping from cut surfaces).

- Good quality control for the construction of cross-sections and shoulders.
- Raise road where necessary to allow adequate and effective side-and mitre-drains to be installed.
- Construct demonstration sections to the highest quality, particularly the compaction.
- Ensure that the wearing course complies with both materials and pavement designs presented in Section3 and Section 4 of this report.

6.6.2 Drainage structures

- Adequate trapezoidal side drains (Section 5.6) and turnout drains are provided to manage the discharge of water collected from the road surface.
- Kerbs and gutters are provided (see project drawings) to prevent edge erosion and to confine storm water to the road surface. The following were considered in terms of the type and method of construction of kerbs:
  - It is common practice to construct kerbs upon the (upper) subbase layer to provide edge restraint for the base course.
  - At changes 1+825 to 2+000 (both sides), and 2+425 to 2+915 (one side), the kerb size should conform with the base thickness (e.g. the cold mix asphalt with a wearing course of 50 mm and a base course of 150 mm G40 should have a gutter face of 200 mm).

6.6.3 Specific erosion measures

Single chip seal shoulders (1m in width) are provided along the entire demonstration sections. In addition to providing support, sealed shoulders would provide moisture protection for the pavement layers and also reduce erosion of the shoulders (especially on steep gradients).

For the concrete pavement sections (i.e. the roller-compacted and thin-mesh reinforced concrete) the following erosion measures are considered:

- The two concrete surfacing swill be placed directly on a lean concrete base to increase the resistance to erosion as well as strength and bearing capacity.
  - Lean concrete with approximately 8% cement or with 28-day compressive strength > 13.8 MPa is appropriate for erosion control.
- The width of the base course for all pavements should be extended beyond the carriageway to provide increased edge support and reduce erosion potential.
- It is possible for erosion to take place beneath the lean concrete layer. Providing a granular base/subbase (as is the case in this project) is important to minimise the potential for erosion and loss of support beneath the lean concrete.

At least one layer of all pavements to be demonstrated in this project will be stabilised with cement /lime stabilisation or mechanical modification.

6.7 Slope stability and protection

The project site has a lot of steep cut surfaces or fill embankments (average gradients > 45%).As both design and construction of slope stability of the project site is the responsibility of the DFR, the project team is only providing technical advice in this report (i.e. the suggested technique can be reviewed for adoption, or replace entirely by the DFR during implementation).

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

During the project site investigation, it was noted that a significant slope failure has occurred at sections along the project road, e.g.

- At chainage 2+900, the water table appears to be high (close to road surface). Towards the summit, at around 2.9 km, sub-surface water was seen to drain from the cut (exposed) surface of the side slopes of the rock.
- From chainage 2+425 to 2+700, for example, several landslides occurred on the cut slope surfaces due to heavy rains. The slides occurred in the conglomeration of silty sandstone rock fragments. Slopes cut in the granitic residual soils were seen to be stable.
- Visual examination of the cut slope surface at chainage 2+780 suggests an unstable slope with trees at the top of the slope
- From chainage 2+840 to 2+975, water was seen dripping from the cut slope surface of the moderately weathered sandstone formation.

Bio-engineering technique (e.g. the use of trees, shrubs and other grasses to stabilise slopes, protect embankments, and provide live check structures in drains) is identified as a more cost-effective technique to reduce erosion and slope instability. In bio-engineering techniques, there is an element of slope stabilisation as well as slope protection. The following are the main advantages of bio-engineering techniques:

- Surface run-off is slowed by stems and grass leaves.
- Vegetation increases the soil infiltration capacity, helping to reduce the volume of runoff.
- Vegetation cover protects the soil against rain splash and erosion, and prevents the movement of soil particles down slope under the action of gravity.
- Plant roots bind the soil and can increase resistance to failure, especially in the case of loose, disturbed soils and fills.
- Plants transpire considerable quantities of water, reducing soil moisture and increasing soil suction.
- The root cylinder of trees holds up the slope above through buttressing and arching.
- Tap roots or near vertical roots penetrate into the firmer stratum below and pin down the overlying materials.

Prior to bio-engineering treatments, the project site must be properly prepared.

- The surface should be clean and firm, with no loose debris. It must be trimmed in order to create a semi-stable slope with an even surface to form a suitable foundation for the bio-engineering intervention.
- The soil and debris slopes must be trimmed to the final desired profile, with a slope angle of between 30°and 45°.
- Excessively steep sections of slope must be trimmed off, whether at the top or bottom. In particular, slopes with an over-steep lower section should be avoided since a small failure at the toe can destabilise the whole slope above.

6.8 Initial Construction Costs

6.8.1 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 /stone pitching drain constitutes the main side drains of the demonstration sections

- Pavement layer materials and construction
- The work-method principle guided by Civil Engineering Standard Method of Measurement, 3rd edition (CESSM3, Ghana) 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 US Dollar 1 USD = 4.41 GHS, (www.xe.com; February, 2017).

6.8.2 Cost of preliminaries and initial preparation of road formation

Provisional sums were used for the cost components of the preliminary general items and earthworks leading to road formation at the demonstration sections. This provision is assumed to be the same for all pavement options. Detailed preliminary cost is available on a DVD (attached to this Report).

6.8.3 Cost estimation procedure

An initial cost assessment was made of the 12 pavement design options and associated drainage structures capable of providing the required performance over the design life. A demonstration road section matrix (one surfacing variable) is 85 m long and 7.5 m carriageway width. The initial construction costs were computed based on the current construction rates used in Ghana. 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, the initial cost of the pavement structure designed for the control section, i.e. "control pavement" (has the same dimensions as a demonstration road matrix) was determined to compare the construction cost with the pavement options.

Construction cost data for each of the different pavement types was computed based on the final designs. The quantity surveying division of the DFR prepared the actual cost for review by the project team. Costs were prepared for each demonstration section matrix (i.e., all three mix types of the cold mix asphalt, roller compacted and thin mesh-reinforced concrete mixes had separate bills of quantities). 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.

The demonstration sections have the same shoulder dimensions and construction materials, hence there would be no effect of the cost of shoulders on the initial construction costs. On the other hand, side drains and pavement foundation layers (subgrade) vary with the various pavement options, hence their costs were excluded from initial construction costs—for fair cost comparisons.

A detailed costing for the 12 pavement options is presented in the bill of quantities that is available on a DVD attached to this report.

6.8.4 Cost of pavement options

Figure 37 and Figure 38 show the initial construction cost per square metre of the 12 pavement options, respectively. Cost of the control pavement structure (double chip seal surfacing) is included as a reference to the demonstration sections. In comparison, the 50 mm cold-mix asphalt surfacing designed with emulsion and quarry stones have the highest cost, whereas the 100 mm roller-compacted concrete with processed lateritic gravel and quarry stones has the lowest cost. The costs of all three variables of the 75 mm thin mesh-reinforced concrete pavement (6 mm diameter high yield steel) are comparable to the three variables of the roller-compacted pavement.

Furthermore, the initial costs were normalised against the cost of the control pavement for ease of comparison (see Figure 39). It can be seen that the initial costs of the modular paving units (i.e. concrete stone pitching, hand-packed stones and interlocking concrete block paving) and cold-mix asphalt pavements far exceed the cost of the “control pavement”(more than 100% in all cases). On the other hand, the initial construction costs of the thin mesh-reinforced concrete and roller-compacted concrete pavements were comparable or lower than the “control pavement” structure.

The initial cost estimates presented are for analysis and reporting purposes. In particular, it is important for thorough review by the quantity surveying division of the DFR for the actual procurement of the works. The common practice is to use the whole life-cycle cost to determine the most cost-effective options for road construction projects. At this stage of the project, only the initial construction costs could be determined. However, whole life cycle cost evaluation of the demonstration sections will be done after performance monitoring is undertaken.

Figure 37: Initial construction cost of pavement structure

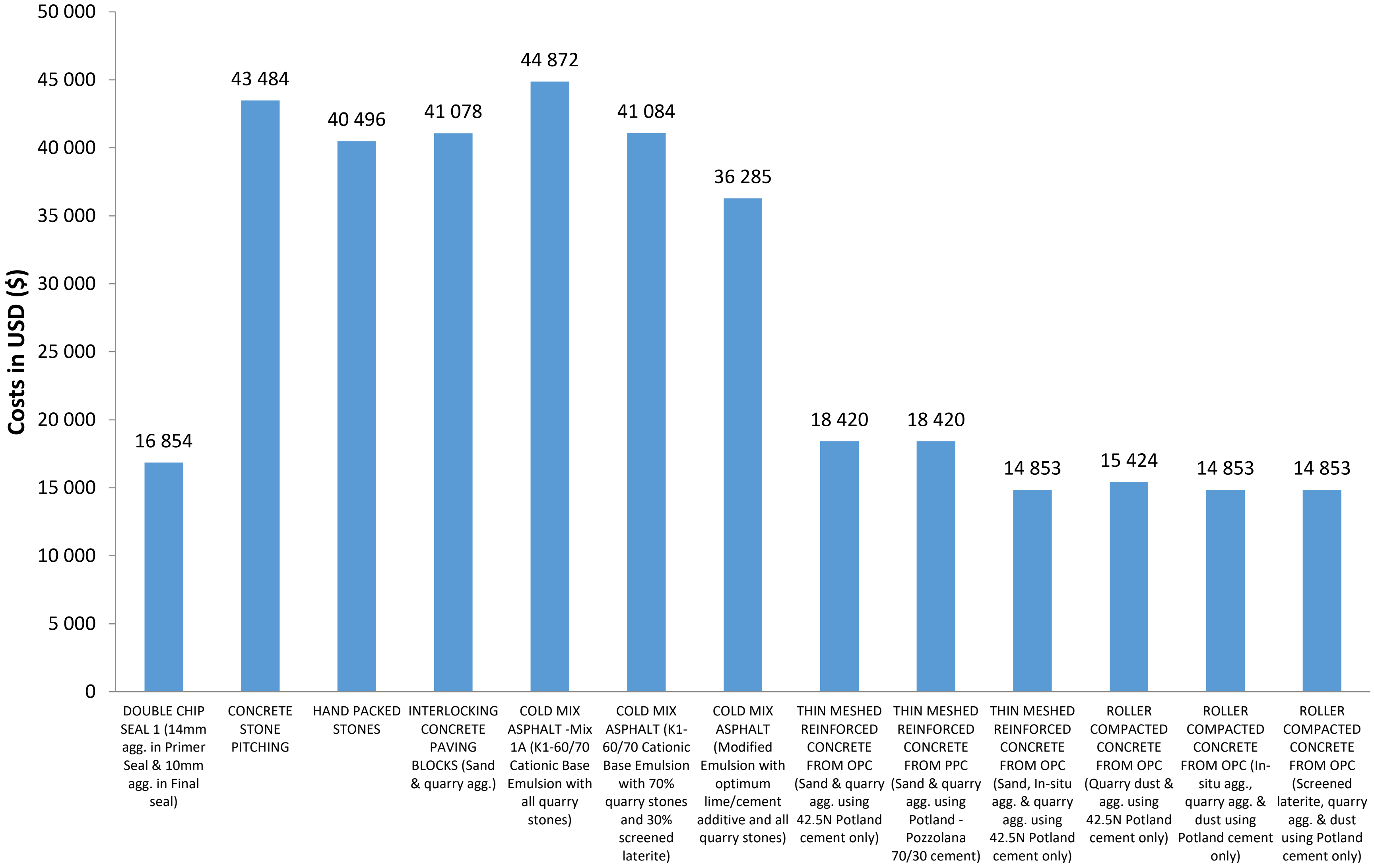


Figure 38: Initial construction cost per m² of pavement structure

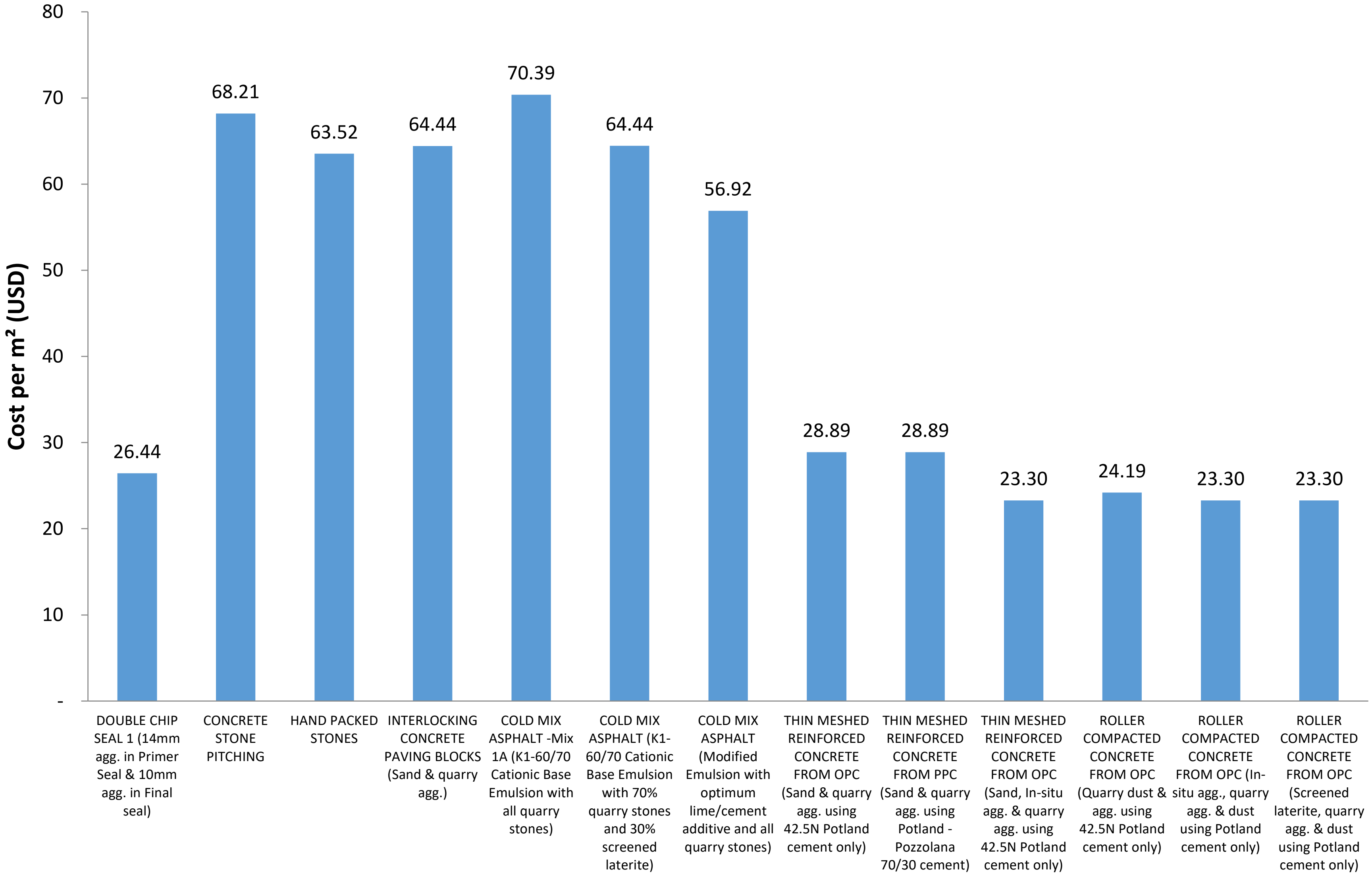
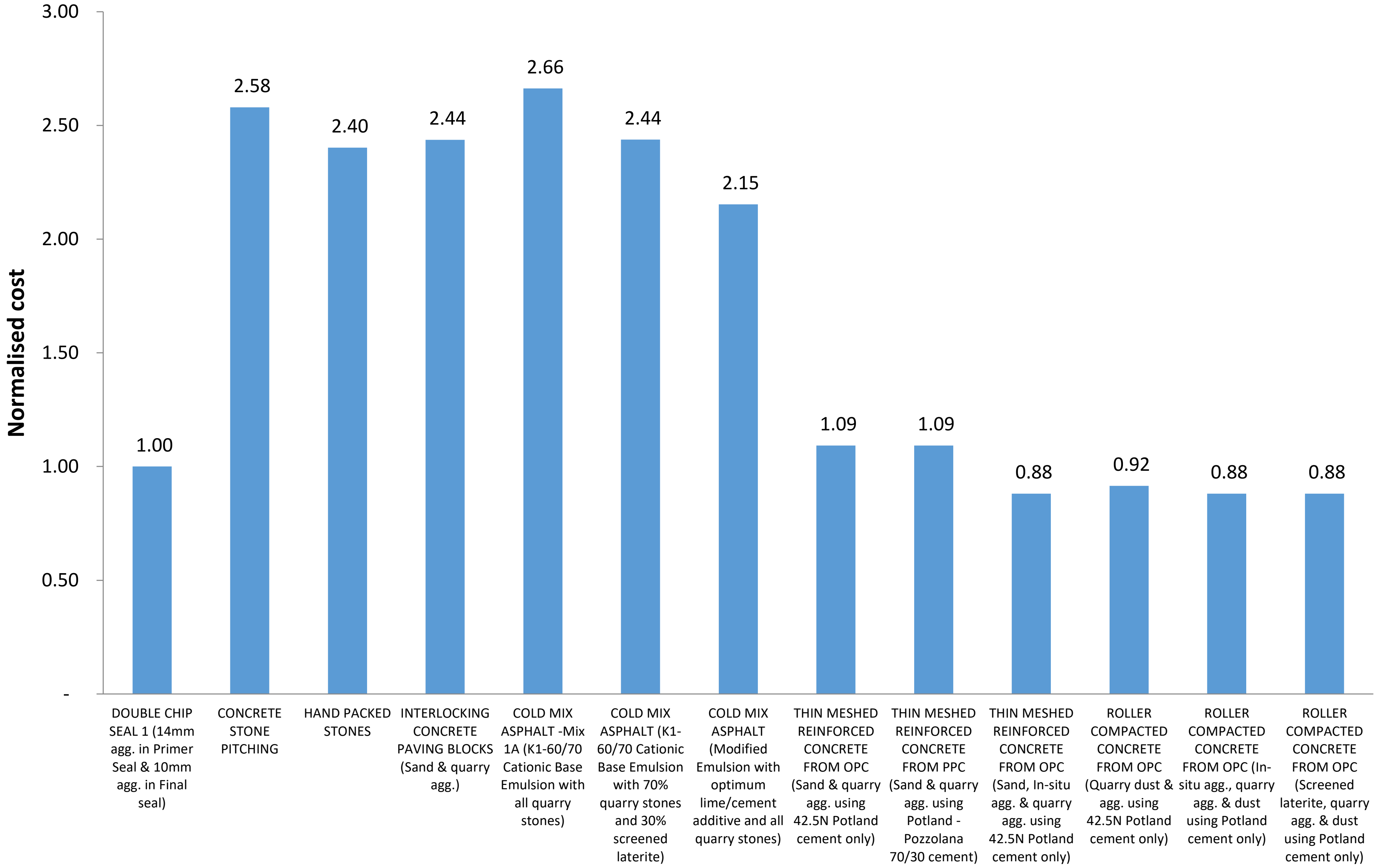


Figure 39: Normalised initial construction cost relative to double chip seal (control section)



7 Conclusions and Recommendations

7.1 Conclusions

The final design stage of the project was carried out successfully and some innovative materials and pavement design ideas and construction guidelines are currently being developed for the DFR and Ghana MRH. The implementation of the thin mesh-reinforced and roller-compacted concrete, cold mix asphalt and the modular paving technologies should have a positive impact on the socio-economic aspects of the communities within the project catchment area. These are technologies that can easily be implemented by small- and medium-scale contractors, and thus the sustainability and long-term involvement of the feeder roads contactor can be more certain. The successful implementation of the alternative surfacing technologies will also depend on training, supervision and good quality control during the construction phase. Furthermore, the long-term performance of the alternative surfacing materials is dependent on ensuring adequate drainage and timely removal of water from the pavement. This means that the installation of proposed drainage systems including kerbs and gutters, side drains, culverts, etc. will be required in many instances, and would add to the labour-intensive nature of the project.

Another important aspect to consider is the riding quality of the finished surfacing. The functional characteristics of these surfacings will be better understood during the monitoring stage of the project.

The conclusions made during the project final design phase are summarised as follows:

- Successful utilisation of naturally occurring and locally produced materials such as calcined clay pozzolana or screened lateritic gravels in cold-mix asphalt and concrete (both thin mesh-reinforced and roller-compacted) mix designs for the project will reduce construction costs for the DFR when these surfacing techniques are fully implemented on steep sections of feeder roads.
- All five surfacing options proposed for the project constitute new knowledge that will be transferred to the DFR and MRH engineers, consultants, and contractors who will take part in the training and capacity-building activities of the project. Specifically, the use of thin mesh-reinforced concrete, roller-compacted concrete and cold-mix asphalt on steep gradients is new to the DFR. The use of labour intensive-based construction is the primary and guiding philosophy of the selection and design of these alternative surfacing materials.
- Procedures/guidelines have been established for the design of materials and pavement purposes. A summary of material properties and the test methods used in their evaluation are to be documented and included in future specifications for the DFR and Ghana MRH. The designs and proposed guidelines need to be understood by the contractors and the DFR. The process includes visits and meetings with staff in the DFR, MRH, consultants and the contractors.
- The production of the asphalt and concrete mixes will require control over quantities, mix proportions and construction tolerances, as well as strict supervision to achieve a mix with good performance. Adequate on-site training of the contractor, supervisory staff and the labour force on the project is required. Specifically, the use of thin mesh-reinforced concrete, roller-compacted concrete and cold-mix asphalt will be new to the DFR.
- Mechanical stabilisation of the base/subbase materials is proposed, although a separate cost comparison is needed to compare it with a cement/lime-treated base before the final decision is made for construction.
- Relevant sections of the Ghana Standard Specifications for Road and Bridge Works (GSSRB) section on concrete works are inadequate to assist in mix designs; hence the procedures in the ACI manual were followed for the concrete mix designs. A mix concrete design workbook/spreadsheet has subsequently been established for this project
- The CSIR and ReCAP PMU have agreed to include non-reinforced concrete surfacing to compare performance with the roller-compacted and thin meshed-reinforced concrete surfacings. This surfacing was proposed during a meeting between the AfCAP PMU (represented by Deputy Team Leader – Infrastructure), and two AfCAP Consultants (Aurecon and the CSIR) on 6 March 2018 in South Africa

- The construction guidelines presented for the alternative surfacings are interim. These guidelines will be further developed into a separate Guideline document for construction of alternative surfacing for steep sections on low-volume roads. The Guideline will form part of the final project deliverable (i.e. Final Report).
- Similarly, the initial construction cost presented in this report is interim, and will be updated after construction of all five alternative surfacings is completed. It should be mentioned that the initial cost is based on the current USD exchange rate and may vary at the time of construction.

7.2 Recommendations

Based on the findings of the final design stage of the project, the following recommendations are made:

- The slope stability works for demonstration sections should be top priority, and preferably should be completed before construction of demonstration sections.
- The construction of demonstration sections must be of the highest quality, conforming fully to the standards prepared for the project. Conventional quality control measures based on the DFR requirements should be implemented during construction.
- DFR should clarify deviations from current norms and standard approach of feeder roads construction to the contractor, and highlight research as key component in this project.
- The project has already experienced a challenge of delays, and that has impacted some deliverables. The DFR in consultation with the project team should enforce all obligations of the contractor, such as
  - detailed construction works programme, and
  - making available the list of key project staff (Resident engineer, materials technician/ supervisor, foreman, and surveyor) and equipment holding for capability assessment. This would also guide the project team in the development of training materials for the project.
- As it is critical to establish base line data for monitoring, it is important that the contractor does not execute any activity without the consent of the project team.
- The contractor should strictly adhere to the drainage system and erosion control measures to minimise the life-cycle costs of the pavement options.
- The AfCAP project on RCC (previously not on steep slopes) will be demonstrated on the project road, although material sources and the design approach appear different from those in the steep gradient project. However, the compressive strength results do not significantly differ. The establishment of a demonstration section for the RCC project on the steep gradient project road will have the following benefits:
  - Performance monitoring will be done in a similar environment under the same supervision
  - Construction services will be provided by the same contractor
  - Opportunity to experiment different RCC mix designs and construction methods
    - The steep gradient project will demonstrate three RCC mixes with varying materials including naturally occurring gravels and quarry materials with water/cement ratio of 0.33 for all mixes.
    - The AfCAP RCC project recommended four mixes with water/cement ratios of 0.46 and 0.48 and all used stones from commercial quarries only.
  - On-site training opportunity – whereas training is a main component in the contract for the RCC project, the steep gradient project does not have such an activity in the contract. This is so because the demonstration of RCC was not part of the original contract on steep gradients. Thus, it is possible to have only one training programme organised for the two projects.
  - The pavement foundation of the steep gradient project road is already prepared, so there will be no need for further site investigations prior to the construction of the RCC sections. In addition, the steep gradient project team has already evaluated materials (gravels) for the construction of base and subbase layers for the demonstration sections. The RCC project can utilise these materials.
  - Crushed stones and quarry materials for surfacing, drainage, stabilisation and concrete works are available at commercial sources in Kumasi (100 km from project site) and the surrounding areas (Nkawkaw, 5 km from project site). Thus, the RCC project can source locally available materials from the same quarry that will supply materials to the steep gradient project.

- Pavement construction should not commence without at least two project team members present on site.
- The contractor should be well resourced to procure /source enough materials and equipment/tools before commencement of the works.
- The project team will establish a database of complete and accurate records of the construction process (including photographs and videos where appropriate), material sources and properties, construction procedures/guidelines, quality control procedures and results. This will form a baseline data for performance monitoring activities of the demonstration sections.

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Annex 1 First Stakeholder Workshop and Project Meetings

Workshop Venue: **DFR Conference Room, Head Office, Accra**

Date: **Tuesday, 24 October 2017**

Outcomes of workshop

A one-day workshop was held mainly to present preliminary designs that were incorporated in the Project Draft Design Report Draft to the DFR and ReCAP PMU and to other stakeholders for endorsement. The project stakeholders at the workshop provided their perspectives on the development and refinement of the research matrix and reviewed the designs of the selected demonstration sections and variables for the study. Suggestions provided by the stakeholders were considered and appropriate changes were incorporated into the final design report.

The key deliberations during the workshop are presented below:

Main objective

To discuss the research matrix and review the designs of the demonstration sections and variables. The outcomes of the first stakeholder workshop and subsequent meetings between the project team and the AfCAP PMU as well as the DFR were used to finalise the project designs. A summary of the meetings and the workshop outcomes is presented in Appendix A.

Research matrix

The proposed research matrix and associated variables for the five alternative surfacing options (i.e. stones, interlocking concrete, cold-mix asphalt, thin mesh-reinforced concrete and roller-compacted concrete) were all accepted by the DFR.

Issues related to gradients of demonstration sections

The discussion focused mainly on the changes made by the DFR to reduce gradients of the demonstration section of the road alignment. The main reason for these changes was attributed to operations and safety of users on the proposed steep gradients (alternative surfacing materials are to be demonstrated on varying gradients of 12% or more). It is noteworthy that the project road would serve as the third alternative route to the many communities (including towns) within the catchment area. However, it was emphasised that reducing the gradients would drastically defeat the purpose of the entire research in steep hill sections on low-volume roads in Ghana, and in other AfCAP regional countries. It was initially suggested that putting adequate safety measures in place while maintaining the proposed gradients (12 to 22%) could mitigate the safety concerns raised by the DFR. No firm agreement was reached on the issue of gradients during the workshop.

Follow-up discussions

- Following the workshop, further discussions were held between the project team and Dr KO Ampadu (Deputy Director of Planning, DFR) to agree on the final gradients for the experimental demonstration sections. He indicated that a variation order (VO) was already issued to the contractor to effect changes in the gradients between chainages 2+225 and 3+425 (i.e. 1.2 km). Accordingly, the project team was informed that the new gradients supersede the original gradients proposed at the project inception.
- Consequently, the team requested the final (revised) alignment designs for their internal deliberations. The new designs were provided by the DFR (Deputy Director, Dr Ampadu) on 24 October 2017 (same day as the workshop).
- Detailed revision/computations of the alignment designs were undertaken by the project team and reconciled with the DFR (Koforidua) to establish (a) gradients within shorter lengths (75 m), and (b) total length of road sections with gradients more than 12%. It was found that gradients (new) within the road length of approximately 1.15 km (chainage 2+025 to 3+175) range between 8 and 21%

(chainage 2+950 to 3+025, relatively flat – 4%). Thus, both the road length and gradients were deemed suitable for the demonstration sections. However, this finding is contingent on the following:

- Control sections of approximately 500 m will be eliminated from the study — a total length of about 1.0 km instead of 1.9 km should be available to fit in all five alternative surfacing materials options.
- Lengths of each demonstration section/ research variable (matrix) will be reduced by 10 to 20 m. An average length of 50 m instead of 70 m will be demonstrated for each variable within the alternative surfacing options.
- It is assumed that no further variation in gradients will be made in the new road section proposed for the demonstration surfacings. The DFR should make a commitment to maintain the new gradients, as further changes could jeopardise the entire study.
- There is a need to revise the BoQs to suit the new demonstration sections.

Meeting between project team and the DFR design team at Koforidua

Subsequent to the workshop, the project team met the DFR design team at Koforidua in the Eastern region. The meeting was held on 30 October 2017 at the design team's office. Present at the meeting were Dr J Anochie-Boateng, Project Team Leader; Ing Alfonso Quaye, DFR Eastern region Deputy Regional Manager; Ernest Gyimah, Materials engineer; Samuel Ofosu, Land surveyor; and Christopher Essel Ampah, Design engineer.

The main objective of the meeting was to further discuss and clarify pertinent technical issues related to the preliminary geometric designs of the road alignment. These issues were raised during the workshop, and it was agreed that further clarification was necessary to address the following:

- Geometric cross-sectional elements and drainage structures:
  - Carriageway width: the DFR proposed a width of 8 m (concerns were raised about the proposed road width of 6.5 m by the project team).
  - Shoulder width was agreed (1 m on each side, and paved with a single chip seal).
  - Camber slopes: the DFR design team agreed to 3% cross-fall proposed by the project team.
  - Drainage types: It was agreed that trapezoidal drainage structure be used for the project road. However, the project team proposed trapezoidal drains with stone pitching on the side slopes and concrete at the bottom width for the demonstration sections, whilst full concrete trapezoidal drains were recommended for the remaining road sections. At sections where the terrain would not allow a trapezoidal drain, it was emphasised that curbs with gutters should be used.
- Final geometric design drawings – It was agreed that the DFR design team should furnish the project team with all revisions (and related drawings) made after the project inception stage. The aim was to harmonise, and if necessary, revise all geometric design information on the project.
- DCP testing – Further tests are required since the existing natural road alignment has been modified because of the revised road geometric design elements (e.g. gradients) and alignment preparation (filling, blasting, etc.). The DCP tests will only be conducted at the new demonstration sections and the results will be used to revise the proposed pavement structural layers presented in the project's Draft Design Report.
- Slope stability and erosion control measures – The DFR would like to use its traditional treatments such as bio-engineering (grass and shrubs) and bench techniques (agreed by the project team). The project team was informed that a separate contract would be awarded for the slope stabilisation works. The DFR could not confirm how far this award process has proceeded.

Issues related to communication with the DFR

Communications between the project team and the DFR regional office in Koforidua on technical issues should be streamlined properly since the majority of the road alignment design team members reside there. The regional office is apparently not authorised to provide the project team with basic information on the project (e.g. cross-section drawings, drainage drawings, etc.) – they always place requests from the team on hold until they receive instructions from their Head Office. While the project team fully accepts this as the DFR's internal structured line of communication, some flexibility will be needed for the sake of progress with regard to critical decisions on pertinent design and construction issues.

Other issues

As far as the pavement structural design is concerned, it was suggested that the project team should consider a conventional pavement design approach instead of restricting all designs to the AfCAP procedures. This was a major talking point during the workshop. For instance, the expected traffic on the project road exceeds the AfCAP threshold traffic volume of 300 vpd and standard axles of 1 MESA for low-volume roads. The DCP-DN catalogue design for the pavement structure was therefore considered to be not appropriate for this project. The project team emphasised that other empirical and mechanistic design methods had to be considered for the final pavement structural designs.

Concluding remarks

- Consensus was reached on the research matrix and variables for demonstration sections.
- Gradients for the demonstration sections are assumed to be final, based on the revised road alignment designs. The DFR needs to confirm that no further changes will be made to the revised road alignment designs.
- The project team should be able to communicate directly with and obtain direct information from the DFR regional and district offices in the Eastern Region. Clarity is required on project information gathering from the DFR offices at Koforidua.
-

Workshop agenda

Item	Time	Topic	Responsibility
1	9:30 – 9:45	Opening and Introduction	Eric Duncan-William
2	9:45 – 10:00	General Remarks from AfCAP PMU	Dr. Paulina Agyekum
3	10:00 – 11:00	Technical Presentation: Research Matrix and Variables	Team Leader/Dr. Joseph Boateng
4	*11:00 – 11:30*	*Coffee/Tea Break & Group Photograph*	*ALL*
5	11:30 – 12:15	Technical Presentation: Site Investigation and Data Collection	Local Project Team/BRRI
6	12:15 – 13:00	Technical Presentation: Materials Testing and Design	Local Project Team/BRRI
7	*13:00 – 14:00*	*Lunch Break*	*ALL*
8	14:00 – 15:00	Technical Presentation: Road Design and Cost	Team Leader/Dr. Joseph Boateng
9	15:00 – 15:45	General Discussions and Conclusions	ALL
10	15:45 – 16:00	Closure - suggestions for further actions, recommendations	ALL

Attendance register

No.	Name	Institution
1	Dr. Paulina Agyekum	ReCAP
2	Dr. K.O. Ampadu	DFR
3	R.O. Otoo	DFR
4	K. N. Akosah-Koduah	DFR
5	Alphonso Quaye	DFR
6	Dr. Patrick A. Bekoe	DFR
7	Ben-Nelson K. Abledu	DFR
8	Gilbert Apau	DFR
9	SalifuHardi	DFR
10	Martin Kwasi Mensah	DFR
11	James Odonkor	DFR
12	Aboagye Emmanuel	DFR
13	Emmanuel Opon Tutu	DFR
14	Samuel N.Y. Buatsi	DFR
15	Ofosuhene Jonathan	DFR
16	MahamaShaibuSensau	GHA-CML
17	Mrs. Olivia Soli	GHA-CML
18	K. Omane-Brimpong	DFR
19	Lawrence Abbew	DFR
20	Anyidoho Eric	DFR
21	Mawusi Joseph	DFR
22	KiahAkalotse	DFR
23	Dan F. Kuubeterzie	DFR
24	Joseph A.M. Idun	DFR
25	E.A. Ghedago	MRH
26	Evans Tutu Akorsah	Ablin Consult
27	Stella Arthur	DFR
28	Frank AmofaAgyemang	DFR
29	L. Wellington	DFR
30	Juliet W. Amponsah	DFR
31	Essilfie Henry	DFR
32	Kingsley OseiOwusu	DFR
33	Dr. Joseph Anochie-Boateng	CSIR, South Africa
34	Edmund KwasiDebrah	BRRI
35	Bernice E. Adjorlolo	BRRI
36	Vincent Acquah-Bondzie	BRRI

Annex 2 Ad hoc Project Meeting

Subsequent to the first stakeholder meeting, there was a need to hold an ad hoc meeting to finalise all outstanding issues related to the research matrix and final designs.

Venue of Meeting: **Speke Resort, Munyonyo, Uganda**

Date: **21 November 2017**

Objective

To discuss and agree on outstanding issues related to research matrix and final project designs.

Attendees

1. Dr Paulina Agyekum — AfCAP PMU
2. Mr John Asiedu — MRH, Ghana
3. Dr KwasiOsafoAmpadu — DFR Ghana
4. Dr Patrick Bekoe — DFR Ghana
5. Dr Joseph Anochie-Boateng — CSIR, South Africa

Meeting action points

Item	Topic	Action /Responsibility
1	Demonstration sections research matrix	Include one control section in the research matrix /CSIR. Newly proposed research matrix / ALL
2	Use of conventional pavement design for demonstration sections	Use fundamental pavement design approach (e.g. AASHTO Structural Number) for structural designs (advanced design method preferred) / CSIR
3	Pavement design issues	
	• Traffic analysis to include heavy vehicles	• Revise sections of the project report on traffic analysis / CSIR
	• Use calculated ESA (>AfCAP max threshold) for design	• Take note during revision of pavement structural designs (item 2) / CSIR
	• Traffic growth 2% /4%?	• Use growth rate approach /CSIR
4	Geometric design (width of roadway 8 m; paved shoulder s – 1x chip seal on each side)	Agree on roadway width of 7.5 m, and 1 m shoulder width paved with single chip seal
5	Drainage structure (lined trapezoidal base lined with mass concrete, side slopes lined with mortared stone pitching)	Agreed
6	Slope stability works (construction /contract)	• Possible to award contract soon / DFR • Stability works for demonstration sections should be a top priority (preferably to be completed before construction of demo sections) / DFR
7	Construction of demonstration sections	Contingent on draft and final designs /
8	Others	Action points – should be addressed urgently/ ALL

Main outcome

Revised and final research matrix and demonstration section.