Research for Community Access Partnership

UKaid from the British people

Investigation into the suitability of roller compacted concrete as pavement material in Ghana

Interim Laboratory Report

Aurecon

GHA2081A

December 2016

Cover Photo: RCC trial pavement constructed at the CSIR (South Africa) courtesy of the CSIR

Quality assurance and review table			
Version	Author(s)	Reviewer(s)	Date
0	Hartman, Mentz	Blaeser, Du Plessis	21 November 2016
		L Sampson, P Agyekum	23 November 2016
1			

ReCAP Project Management Unit
Cardno Emerging Market (UK) Ltd
Oxford House, Oxford Road
Thame
OX9 2AH
United Kingdom

Abstract

This project will investigate the suitability of Roller Compacted Concrete (RCC) for low volume road construction in Ghana and especially for the construction of pavements on rugged sections and steep slopes. The assignment will be carried out over a period of 48 weeks and include a literature review, selection of materials, testing and finalization of concrete mix proportions. A RCC demonstration road section will then be designed and a nominated contractor will construct the pavement using machine and labour based methods. The construction process will be monitored to allow for the development of construction specifications and a guideline document. The research will be disseminated through a workshop that will take place during the construction of the demonstration section.

Key words

Roller compacted concrete, low volume roads, labour intensive construction, concrete mixture design, construction specification

RESEACH 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.

See www.research4cap.org

Acronyms, Units and Currencies

%	Percentage
ºC	Degrees Celcius
ACV	Aggregate Crushing Value
AFCAP	Africa Community Access Partnership
AIC	Aggregate Impact Value
ASCAP	Asia Community Access Partnership
ASTM	American Society for Testing and Materials
BS	British Standard
CBR	California Bearing Ratio
CESA	Cumulative Equivalent Standard Axle
cm	Centimetre
DCP	Dynamic Cone Penetrometer
DFR	Department of Feeder Roads
E	Modulus of Elasticity/Resilient Modulus (when discussing concrete properties)
E	East (when discussing coordinates)
EN	English
FM	Fineness Modulus
ft^3	Cubic feet
g	grams
GHA	Ghana Highway Authority
GPa	Giga Pascal
GPS	Global positioning system
K	Potassium
km	Kilometre
kN	Kilo Newton
kg	Kilogram
lb	Pounds
LHS	Left Hand Side
LL	Liquid Limit
LVR	Low volume roads
mm	Millimetre
m	Metre
m^3	Cubic metre
Max	Maximum
MB	Methylene Blue
Min	Minimum
ml	Millilitre
MPa	Mega Pascal
MR	Flexural strength
N	Newton (when discussing forces)
N	North (when discussing coordinates)
Na	Sodium
O	Oxygen
PI	Plasticity Index
PL	Plasticity Limit
RCC	Roller Compacted Concrete
RECAP	Research for Community Access Partnership
RHS	Right Hand Side

TP	Test Pit
TFV	Ten Percent Fines
UK	United Kingdom (of Great Britain and Northern Ireland)
UKAid	United Kingdom Aid (Department for International Development, UK)

Contents

Figures

Tables

Photographs

1 Executive Summary

An interim laboratory report has been drawn up to highlight how materials for Roller Compacted Concrete (RCC) will be sampled, tested and ultimately used to yield an RCC mix design for Ghana. The report also provides details on the approach used to select an appropriate location for the construction of the RCC experimental section.

The location of the planned RCC experimental sections was selected on the existing Akosombo to Gyakiti road. The section has a relatively uniform subgrade, requires minimal pavement structure preparation, has existing drainage available along both sides of the road, has a relatively steep slope section and will provide good comparison with other pavement structures (gravel and bitumen seals).

A field investigation was completed and samples from the existing pavement extracted for laboratory testing. DCP tests were also conducted to confirm in-situ bearing capacity. The data will be used to evaluate the appropriate RCC thickness requirement using the Spanish Institute for Cement Design Method.

Four sources of coarse aggregate were located and sampled. In addition, three different types of fine aggregates, in close proximity of the test site, were sampled. Three different cement types have also been sampled and submitted for testing. Laboratory testing of the collected samples is currently underway. Once the screening test results are available, two coarse and two fine aggregates will be selected and together with one cement type, a series of consistency and strength tests will be performed to evaluate the potential use of the different RCC mixtures.

The importation of a Vebe test frame is currently underway. The equipment is required to verify the consistency of the RCC mixtures during the laboratory mix design process and also to confirm quality during construction.

Due to delay in the selection of the experimental site and the possible hold-up in the importation of the test equipment, the finalisation of the Pavement and Mix Design Report will possibly only happen in the beginning of March 2017. This should not affect the anticipated construction of the RRC experimental section and the provision of the final project deliverables.

2 Background to Laboratory and Field Investigation

An interim laboratory report has been drawn up to highlight how materials for the construction of the Roller Compacted Concrete (RCC) experimental section will be sampled, tested and ultimately used to yield an RCC mix design. The aim of the field and laboratory investigations is to:

- Determine the most appropriate site taking reconnaissance of the terms of reference, the availability of material sources, ease of access and other operational factors (such as: conference facilities and accommodation in proximity of selected site, distance to international airports, availability of cement/ready-mix producers, and construction equipment).
- Determine the in situ bearing capacity by way of Dynamic Cone Penetrometer (DCP) testing.
- Determine the in situ soil profile by way of test pit profiling.
- Determine the in situ soil layerworks properties by sampling and laboratory testing.
- Sample coarse and fine aggregates to be laboratory tested to determine their suitability for the RCC mix design.
- Sample and test available cement in Ghana to find the most suitable cement for the RCC mix design.
- Determine the minimum required laboratory tests of various mix designs to find a suitable RCC composition.
- Describe the RCC mix design method adopted, taking reconnaissance of local conditions/availability of specialised agents/modifiers and laboratory equipment.

Upon completion of the laboratory and field investigation, a clear path of how to proceed with the mix design, pavement design and construction of the test section will be available.

3 Progress and Programme

An updated programme is provided in Appendix A. The Interim Laboratory Report is the second key deliverable for the implementation of the project. The next deliverable is the Mix Design and Pavement Design Report due 30th January 2017. There has been a delay in the selection of the location of the RCC experimental section. It was anticipated that the possible locations would have been known earlier, but this information only became available in late September. Final approval of the selected test site was received on the 25th October 2016

Also, some laboratory equipment, specifically a Vebe test frame, is not available in Ghana and is in the process of being imported into the country. Due to the late sampling and possible delay in mix design testing, it is estimated that the Mix Design and Pavement Design Report will only be available at the beginning of March. It is proposed that a progress report be submitted early February 2017 when some of the mix design test results become available. The overall project should still be completed within the allocated 48 weeks ending in May 2017.

4 Test Site Identification

4.1 Introduction

A site visit to potential locations for the construction of the Roller Compacted Concrete (RCC) trials in Ghana was undertaken on 26th of September 2016. The visit included:

- A meeting with the Department of Feeder Roads (DFR) to discuss the identified sites.
- A visit to the identified sites with DFR representatives.

The site visit provided an opportunity to analyse and select a suitable site for the test section. Each site was analysed according to slope, length, provision of drainage structures, location relative to construction supply locations and ease of construction.

4.2 Investigated Site Locations

Figure 1 shows the possible test site locations, marked with red stars with respect to the capital, Accra. The Akosombo to Gyakiti site is the red star to the east, while the red star to the west indicates the relative position of the Opesika to Samlesi route as well as the Bosotwi to Boti sites.

Figure 1: Site locations

4.3 Bosotwo to Boti potential sites

Two routes were identified while travelling this region. The first route, Bosotwi to Nsuta, was situated between two existing concrete sections with drainage along both sides of the road in the form of concrete u-drains. The section had a moderate slope and an existing gravel (red laterite) wearing course with a few isolated erosion damaged areas. The geometric details of the section is summarised in Table 1 and Figure 2.

Table 1: Bosotwi to Nsuta route information summary

Elevation Information		
Min	235	m
Average	269	m
Max	302	m
Gain	66.8	m
Loss	0	m

Elevation Information		
Max Slope	12%	%
Min Slope	2.2%	%
Average Slope Max	9%	%
Length	741	m

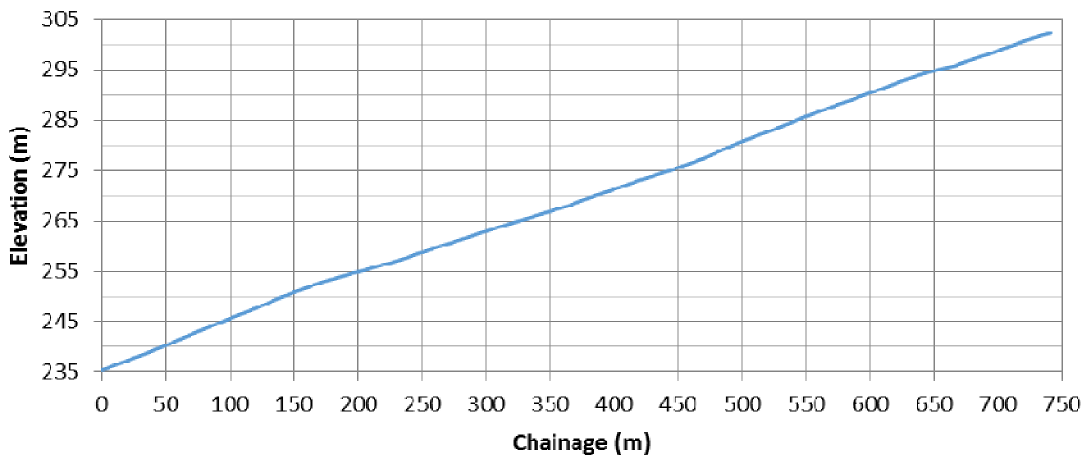


Figure 2: Bosotwi to Nsuta – Ascending longitudinal profile

A typical image displaying the route as it was driven along, is shown in Photograph 1.

Photograph 1: Section of the Bosotwi to Nsuta route

The second section, near Boti, was an existing dirt track to be upgraded to a full road section. No drainage structures were observed along this section, while the slope seemed excessively steep. The geometric details of the section are summarised in Table 2 and Figure 3. The image displayed in Photograph 2 shows the start of the route on the hilltop. The route further extends down around the hill and could not be travelled on during the site visit due to a heavy down pour at the time.

Table 2: Dirt track near Boti route information summary

Elevation Information		
Min	421	m

Elevation Information		
Average	481	m
Max	535	m
Gain	114	m
Loss	0	m
Max Slope	31.6%	%
Min Slope	2%	%
Average Slope Max	12.6%	%
Length	902	m

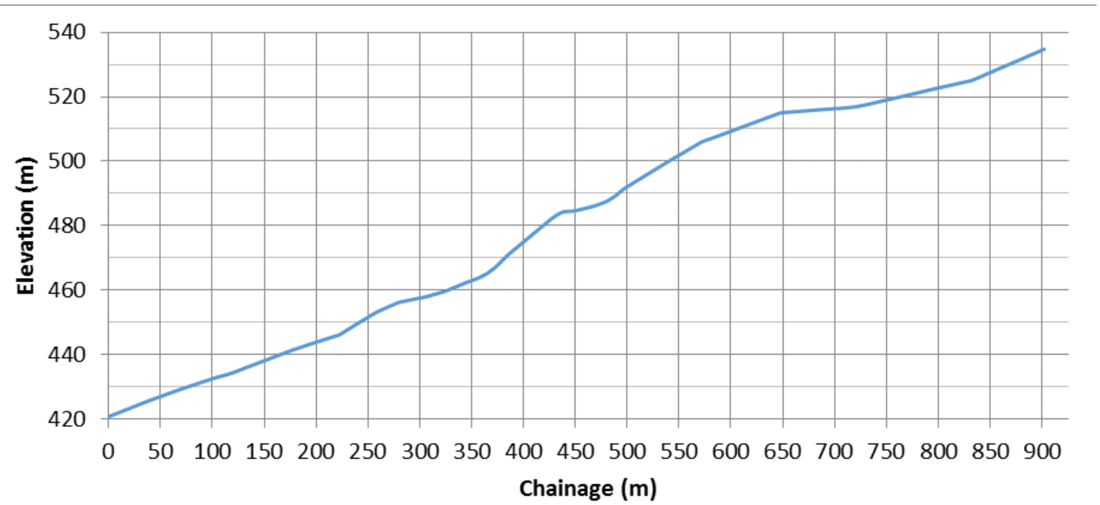


Figure 3 Dirt track near Boti – Ascending longitudinal profile

Photograph 2: Top section from the dirt track near Boti

4.4 Opesika to Samlesi potential site

One route was identified while travelling this region. The route had drainage on the northern side with a retaining wall on the southern side. The section had a red lateritic wearing course and is on a rolling landscape with a moderate slope. The section runs through a built-up area and accommodation of traffic during the construction of the experimental section will be problematic. The geometric details of the section is summarised in Table 3 and Figure 4. Photograph 3 shows a section of the route, with the retaining wall on the northern side (RHS) of the route and the drainage channel on the southern side (LHS).

Table 3: Opesika to Samlesi route information summary

Elevation Information		
Min	382	m
Average	389	m
Max	396	m
Gain	15.8	m
Loss	-16.1	m
Max Slope	7.2%	%
Min Slope	-5.5%	%
Average Slope Max	5.8%	%
Average Slope Min	-2.4%	%
Length	1456	m

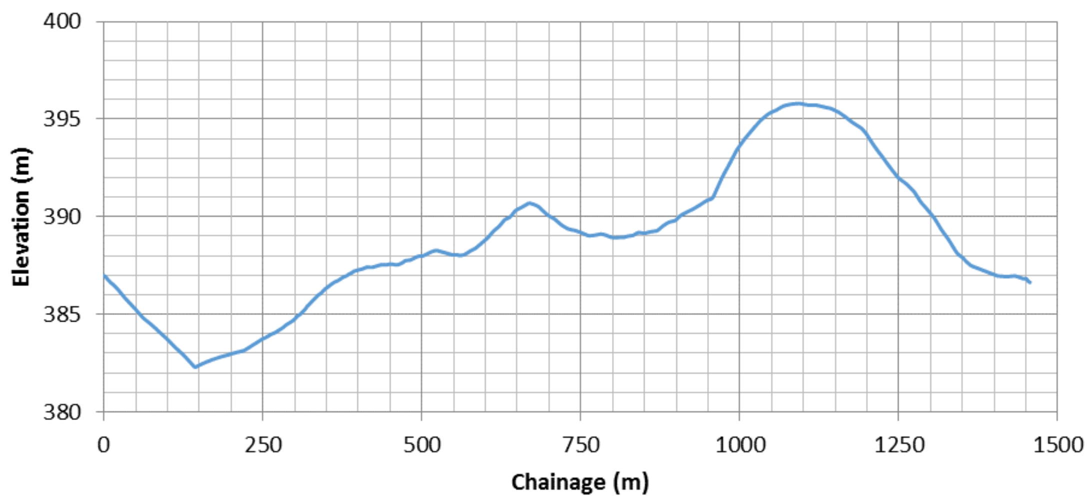


Figure 4: Opesika to Samlesi – rolling longitudinal profile

Photograph 3: Section of the Opesika to Samlesi route

4.5 Akosombo to Gyakiti potential site

One route was identified while travelling this region. The route had drainage in the form of concrete u-drains on both sides while the road had a bitumen seal as a surfacing layer. The road showed extensive damage and some sections of the road had been degraded to a gravel surface. The road is currently up for rehabilitation. The selected section is on a continuous, moderate slope. The geometric details of the section is summarised in Table 4 and Figure 5. Photograph 4 shows a general view with the existing bitumen seal and drainage structures visible on both sides of the road.

Table 4: Akosombo to Gyakiti route information summary

Elevation Information		
Min	157	m
Average	174	m
Max	189	m
Gain	32.4	m
Loss	-0.1	m
Max Slope	6.7	%
Min Slope	-1.7	%
Average Slope Max	6.5	%
Average Slope Min	-0.5	%
Length	732	m

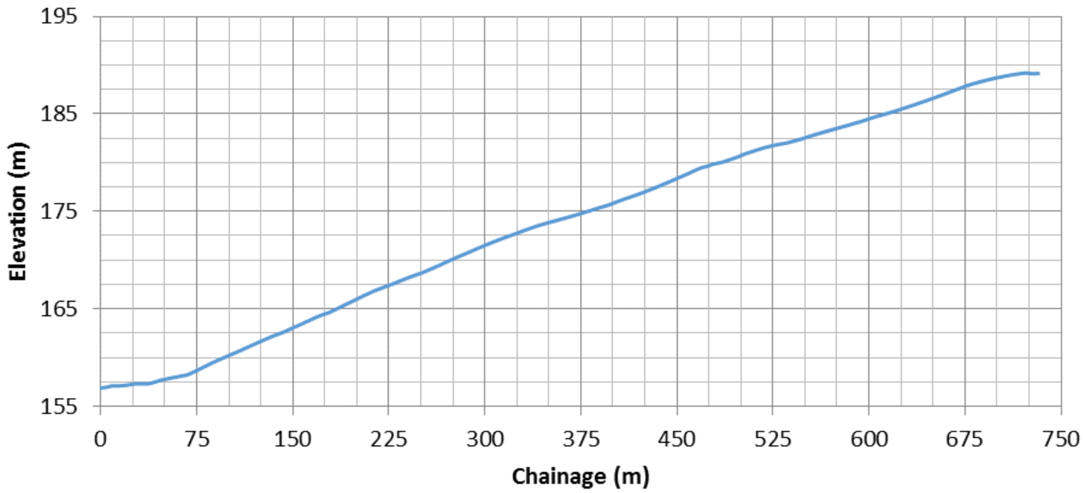


Figure 5: Akosombo to Gyakiti – Ascending longitudinal profile

Photograph 4: Section of the Akosombo to Gyakiti route

4.6 Preferred route selection

A matrix was drawn up to assist with the identification of the best site for the RCC experimental section. The matrix incorporated design aspects such as drainage, subgrade condition, pavement structures in place and the slope suitability. Other aspects were also considered such as traffic accommodation, ease of access and availability of materials. Traffic along the routes are limited, but the roads cannot be closed completely since there are limited access roads to some of the villages on these routes. The proximity of the route relative to a regional town was considered as important due to the materials that will need to be transported to site. The results are show in Table 5.

Table 5: Route selection matrix

Parameter	Bosotwi to Nsuta	Dirt track near Boti	Opesika to Samlesi	Akosombo to Gyakiti
Subgrade uniformity	Yes	No	Yes	Yes
Slope suitability	Yes	No	No	Yes
Existing pavement structure	Yes	No	Yes	Yes
Drainage structures	Yes	No	Yes	Yes
Easy traffic accommodation	No	Yes	No	Yes
Close to regional town	Yes	No	No	Yes

The capability of the contractor will be important to evaluate the ease of construction on site as well as the possible equipment hire that may be required to bridge any shortcomings in his plant.
For construction the contractor will require at least:

- Grader for levelling of road surface where required and possible spreading of the concrete;
- Smooth wheel roller compactor (10 ton) with vibratory capability;
- Asphalt paver for placing the mix should a machined based construction approach be considered;
- Basic equipment to ensure that correct layer thicknesses, level and cross-fall requirements are met;
- Small, manual operated vibratory roller compactor for edge preparation;
- Formwork for construction joints;
- Concrete cutter for controlling shrinkage crack spacings, and to finish longitudinal edges if no formwork is used;
- A mobile concrete batch plant (preferable capacity > $10m^3$ per hour) will be required for producing the RCC on site;

The route from Akosombo to Gyakiti was identified as the best candidate for the RCC experimental section. This was mainly due to:

- Expected uniform subgrade conditions;
- Minimal pavement structure preparation requirements;
- Existing drainage available along the road section;
- Location relative to a regional town (Akosombo < 20 km away);
- Relatively flat and acceptable steep grade sections are available;
- Good comparison with other pavement structures, gravel and bitumen seals, will be possible.

An additional short steep slope section (> 9%) on the Akosombo to Gyakiti route was identified and analysed. The information of the steep section is described in full detail in sections 5.1 and 5.2.

5 Field Investigations – Akosombo to Gyakiti

The centreline investigation was performed during the second week of November and involved the following:

Main section:

- 12 DCP's (Dynamic Cone Penetrometer) at 50m intervals (staggered left, centre, right, centre, left, etc.)
- 2 Test pits excavated, profiled, sampled and reinstated

Steep section:

- 5 DCP's positioned as above
- 1 Test pit excavated, profiled, sampled and reinstated

The DCP test results are provided in Appendix C. For each test pit, each horizon was sampled for laboratory analysis (75kg). The laboratory testing to be carried out is listed in Table 6. DCP analyses will be performed with the AfCAP LVR-DCP software version 1.03. The results will be presented in a final RCC mixture and pavement design report.

Table 6: Test list

Number	Test to be carried out	Number of tests
1	Grading Test (Sieve Analysis)	8
2	Atterberg's Limits	8
3	CBR test	8

5.1 Main Section

The positions of the various tests are available in Table 7.

Table 7: Main section test positions

<table>
<tr><th rowspan="2">DCP Number</th><th colspan="2">Coordinates</th><th rowspan="2">TP Number</th><th colspan="2">Coordinates</th></tr>
<tr><th>Northing</th><th>Easting</th><th>Northing</th><th>Easting</th></tr>
<tr><td>1</td><td>06° 19' 40.83" N</td><td>00° 02' 53.30" E</td><td rowspan="6">1</td><td rowspan="6">06° 19' 36.91" N</td><td rowspan="6">00° 02' 49.48" E</td></tr>
<tr><td>2</td><td>06° 19' 39.52" N</td><td>00° 02' 52.03" E</td></tr>
<tr><td>3</td><td>06° 19' 38.22" N</td><td>00° 02' 50.75" E</td></tr>
<tr><td>4</td><td>06° 19' 36.91" N</td><td>00° 02' 49.48" E</td></tr>
<tr><td>5</td><td>06° 19' 35.61" N</td><td>00° 02' 48.21" E</td></tr>
<tr><td>6</td><td>06° 19' 34.31" N</td><td>00° 02' 46.93" E</td></tr>
<tr><td>7</td><td>06° 19' 33.00" N</td><td>00° 02' 45.66" E</td><td rowspan="3">2</td><td rowspan="3">06° 19' 30.39" N</td><td rowspan="3">00° 02' 43.11" E</td></tr>
<tr><td>8</td><td>06° 19' 31.70" N</td><td>00° 02' 44.38" E</td></tr>
<tr><td>9</td><td>06° 19' 30.39" N</td><td>00° 02' 43.11" E</td></tr>
</table>

DCP Number	Coordinates		TP Number	Coordinates	
	Northing	***Easting***		***Northing***	***Easting***
10	06° 19' 29.09" N	00° 02' 41.83" E			
11	06° 19' 27.78" N	00° 02' 40.56" E			
12	06° 19' 26.48" N	00° 02' 39.28" E			

5.2 Steep Section

The information for the section is shown in Table 8 while the section profile is as shown in Figure 6.

Table 8: Steep section - Akosombo to Gyakiti

Elevation Information		
Min	129	m
Average	135	m
Max	141	m
Gain	11.6	m
Loss	0.00	m
Max Slope	10.7%	%
Min Slope	6.4%	%
Average Slope Max	9.5%	%
Average Slope Min	-	%
Length	122.5	m
Coordinates		
Start position	Northing	06° 18' 30.57" N
	Easting	00° 01' 38.92" E
End position	Northing	06° 18' 26.95" N
	Easting	00° 01' 37.27" E

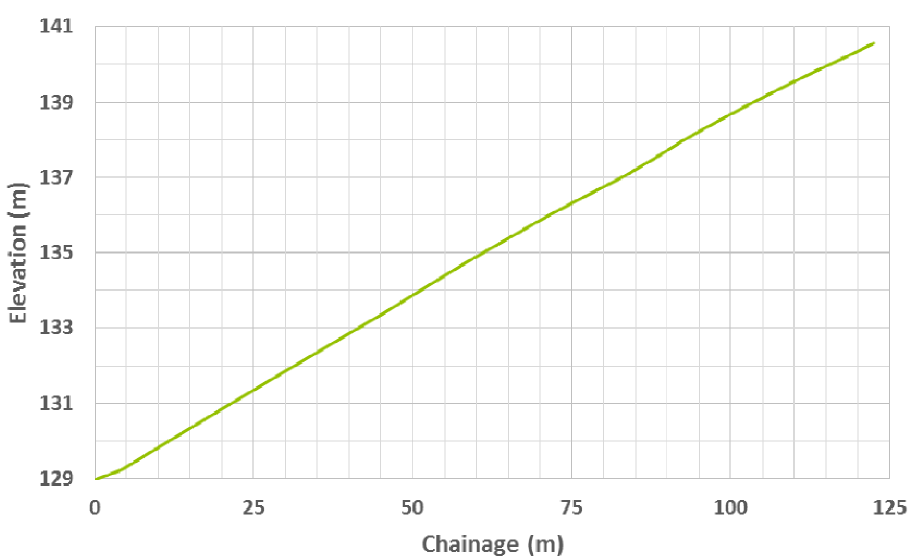


Figure 6: Steep section - Ascending longitudinal profile

The positions of the tests are available in Table 9.

Table 9: Steep section test positions

<table>
<tr><th rowspan="2">DCP Number</th><th colspan="2">Coordinates</th><th rowspan="2">TP Number</th><th colspan="2">Coordinates</th></tr>
<tr><th>Northing</th><th>Easting</th><th>Northing</th><th>Easting</th></tr>
<tr><td>1</td><td>06° 18' 29.96" N</td><td>00° 01' 38.65" E</td><td rowspan="5">1</td><td rowspan="5">06° 18' 28.76" N</td><td rowspan="5">00° 01' 38.10" E</td></tr>
<tr><td>2</td><td>06° 18' 29.36" N</td><td>00° 01' 38.37" E</td></tr>
<tr><td>3</td><td>06° 18' 28.76" N</td><td>00° 01' 38.10" E</td></tr>
<tr><td>4</td><td>06° 18' 28.16" N</td><td>00° 01' 37.82" E</td></tr>
<tr><td>5</td><td>06° 18' 27.55" N</td><td>00° 01' 37.55" E</td></tr>
</table>

6 Concrete Material Sampling and Screening

Aggregates were sampled from commercial sources in the surrounding area of Akosombo. Fine and coarse aggregates were sampled and will be screened in the laboratory to verify their suitability for use in RCC mix designs. The coarse and fine aggregates were sampled during the week of the 7th to the 11th of November.

6.1 Location of Quarries Sampled

Coarse aggregates were sampled from the following locations for screening tests:

- PW stone Quarry off Tema-Akosombo road,
- Gokay Quarry off Tema - Akosombo road,
- Zina Quarry at Afienya off Accra-Akosombo Road,
- Twin Rock Quarry at Afienya off Accra-Akosombo Road.

Fine aggregates were sampled from the following locations for screening tests:

- Kudi-Kope Sand Pit - 11km north of Gyakiti (the fine aggregate was deemed not suitable and was not sampled),
- Tsepue sand pit (near Juapong) - 16 km south west of Akosombo, near Asutuare,
- Regional Building and Contracting Company Limited sand factory on the shores of River Volta at Asutuare (2 types were sampled here).

The quarries are generally located in the Greater Accra region, roughly 54 km from Aksombo on the Tema Aksombo Road. The relative location of all four coarse aggregate quarries is indicated with the blue star in Figure 7, the fine aggregates sampled at Asutuare is indidcated in blue while the research section location is indicated as a green star. It is expected that all the aggregates that were sampled should present with relatively similar properties due to the proximity of the sources to each other.

Figure 7: Relative location of the quarries

6.2 Coarse Aggregates

Twelve (12) types of tests for the coarse aggregate are suggested for the screening tests of the commercial sources near the site location. The list of tests is available in Table 10.

Table 10: Test list for coarse aggregates samples

Number	Test to be carried out	Method
1	Aggregate Soundness Test (Na_2SO_4)	BS 812-121:1989 – Testing aggregates – Part 121: Method for determination of soundness
2	Grading Test (Sieve Analysis)	BS EN 933-1:2012 – Tests for geometrical properties of aggregates – Part 1: Determination of particle size distribution – Sieving method
3	Determination of Flakiness Index	BS EN 933-3:2012 – Tests for geometrical properties of aggregates – Part 3: Determination of particle shape – Flakiness Index
4	Determination of Impact Value	BS 812-112:1990 – Testing aggregates – Part 112: Methods for determination of aggregate impact value (AIV)
5	Determination of Crushing Value	BS 812-110:1990 – Testing aggregates – Part 110: Method for determination of aggregate crushing value (ACV)

Number	Test to be carried out	Method
6	Determination of Ten Percent Fine Value (dry and soaked)	BS 812-111:1990 – Testing aggregates – Part 111: Methods for determination of ten per cent fines value (TFV)
7	Water Absorption	BS 812: Part 2:1995 – Testing aggregates – Part 2. Methods of determination of density / ASTM C127C - Standard test method for relative density and absorption of coarse aggregate
8	Determination of Specific Gravity	BS 812: Part 2:1995 – Testing aggregates – Part 2. Methods of determination of density
9	Determination of Elongation Index	BS 812-105.2:1990 – Testing aggregates – Part 105: Method for determination of particle shape – Section 105.2 Elongation index of coarse aggregate
10	Los Angeles Abrasion Test	ASTM C131/C131M – Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
11	Bulk density (loose and compacted)	BS 812: Part 2:1995 – Testing aggregates – Part 2. Methods of determination of density
12	Petrographic examination	BS 812-104:1994 – Testing aggregates – Part104: Method for qualitative and quantitative petrographic examination of aggregates

6.3 Fine Aggregates

Nine (9) types of testing for the fine aggregate are suggested for the screening tests of the commercial sources near the site location. The list of tests is available in Table 11.

Table 11: Test list for fine aggregates samples

Number	Test to be carried out	Method
1	Grading Test (Sieve Analysis)	BS 1377-2:1990 – Methods of test for Soils for civil engineering purposes – Part2: Classification tests
2	Water Absorption	BS EN 12620:2002+A1:2008 – Aggregates for Concrete
3	Determination of Specific Gravity	BS 1377-2:1990 – Methods of test for Soils for civil engineering purposes – Part2: Classification tests
4	Determination of Silt Content	BS 1377-2:1990 – Methods of test for Soils for civil engineering purposes – Part2: Classification tests
5	Atterberg Limits (< 0.425 mm)	BS 1377-2:1990 – Methods of test for Soils for civil engineering purposes – Part2: Classification tests
6	Determination of Organic Content	BS 1377-3:1990 – Methods of test for Soils for civil engineering purposes – Part 3: Chemical and electro-chemical tests
7	Bulk density (loose and compacted)	BS 1377-2:1990 – Methods of test for Soils for civil engineering purposes – Part2: Classification tests
8	Fineness Modulus	BS EN 12620:2002+A1:2008 – Aggregates for Concrete

Number	Test to be carried out	Method
9	Sand equivalent	BS EN 933-8:2012+A1:2015 – Tests for geometrical properties of aggregates – Part 8: Assessment of fines – Sand equivalent test

6.4 Cement Sampling and Testing

Sampling of the three main cements available in Ghana was performed. Cement bags from the three suppliers, Ghacem, Diamond and Dangote were purchased and sent to the Ghana Standards Authority for analysis. Both chemical and physical properties are being tested as indicated in Table 12.

Table 12: Test list for cement samples

Number	Test to be carried out	Method
1	Initial setting time	BS EN 196-3:2005+A1:2008 – Method of testing Cement – Part 3: Determination of setting times and soundness
2	Compressive strength	BS EN 196-1:2016 – Methods of testing cement – Part 1: Determination of strength
3	Chemical composition	BS EN 196-2:2013 – Method of testing cement – Part 2: Chemical analysis of cement

Cement chemical and physical compositions may differ significantly depending on supplier, region and batch. Concrete strength is also greatly dependant on the type of cement used. Pozzolanic reactions can be affected by the alkalinity of the cement. Various other factors can also be affected by the alkalinity and a limitation is usually in place with regards to alkali content (Na_2O + 0.658 K_2O).

6.5 Fly Ash/Calcined Clay Sampling

Although fly ash is not readily available in Ghana, the extensive use of the pozzolanic material in RCC technology requires that the admixture be evaluated during the mix design process. Fly ash was sampled in South Africa and being exported to Ghana.

Calcined clay is a recognised pozzolan and naturally available in Ghana. Its use in RCC will further be explored during the mix design process.

7 Concrete mixture design testing

Upon completion of the field investigation and associated testing, along with the screening tests on both coarse and fine aggregates, mix design testing will commence. The mix design will be provided to the laboratory where after a certain amount of testing is required on each mix design and its associated samples. The associated mix design tests are listed in Table 13.

Table 13: Test list for concrete mixture design

Number	Test to be carried out	Method
1	Vebe consistency	BS EN 12350-3:2009 – Testing fresh concrete – Part 3: Vebe test
2	Compressive strength (cubes)	BS EN 12390-3:2009 – Testing hardened concrete – Part 3: Compressive strength of test specimens
3	Flexural strength (beams)	BS EN 12390-5:2009 – Testing hardened concrete – Part 5: Flexural strength of test specimens
4	Density of fresh concrete	BS EN 12350-6:2009 – Testing fresh concrete – Part 6: Density

7.1 Mix Design Matrix

By incorporating the parameters set out in Table 14, the following amount of beams and cubes are required at to complete the laboratory mixture design investigation:

- Beams = 48
- Cubes at 7 day compressive strength = 144
- Cubes at 28 day compressive strength = 144

The amount of testing may be reduced as some of the parameters may be excluded upon completion of the screening tests of the coarse and fine aggregates and the screening of the cement available in Ghana.

Table 14: Parameters for test matrix

Parameter	Count
Coarse aggregate types	2
Fine aggregate types	2
Grading	2
Admixtures	2
Pozzolan	3
Cement type	1
Beams per mix	1
7 day Cubes per mix	3
28 day cubes per mix	3

7.2 Vebe Testing Apparatus

The Vebe testing apparatus complies with the specifications set out in the BS EN 12350-3 (2009) test code. The equipment consists of:

- A vibrating table with a steel deck;
- A cylindrical mould;
- A swivel arm and guide sleeve;
- A surcharge with a plastic base plate attached to the bottom

Due to the equipment not being available in Ghana, the apparatus was ordered from Matest, a material testing equipment supplier in Treviolo, Italy. At the time of the report the equipment was on route to Accra, Ghana.

7.3 Selection of Appropriate Mix Design

The pavement design method requires a minimum concrete flexural strength of 3.5 MPa, as described in section **Error! Reference source not found.**. Mix designs with flexural strengths below this might not be considered for construction. If multiple RCC mix designs meet the minimum strength requirements, the cost associated with the mix composition, early age strength comparisons, setting time, consistency of the mix and constructability will be considered to determine the most appropriate mix for use on the test section in Ghana.

It is anticipated that two mix designs will be selected for construction of the test section. The selection will depend on the results of the comparisons mentioned in section **Error! Reference source not found.**.

8 Pavement Design

RCC pavement design has many different approaches. For local use in Ghana, a simple, repeatable pavement design method is be preferred. One such method was identified as the Spanish Institute for Cement and its Applications Design Method (Jofré & Zabala, 1998). The method requires minimal inputs and it is believed that it could easily be replicated in Ghana.

The method requires four parameters for RCC pavement design:

- the subgrade bearing capacity. Typically the California Bearing Ration (CBR) or resilient modulus is used, but in the low volume road (LVR) environment an equivalent DCP penetration rate can also be used;
- the traffic category, based on daily heavy vehicle passes;
- the design life of the pavement, either 20 or 30 years; and
- the concrete strength to be used for the pavement.

The concrete strength of the pavement is defined by the flexural strength of the concrete. The two concrete strengths used in the design methodology is either 3.5 MPa or 4.0 MPa flexural strength concrete. The proposed subgrade categories are available in Table 15, traffic categories in Table 16 and the pavement design catalogue in Table 17. The design catalogue is for 4.0 MPa flexural strength concrete. If 3.5 MPa flexural strength concrete is to be used, the thickness of the pavement needs to be increased by 20 mm.

The CBR index in the design method has been correlated with the DCP penetration rate according to the formula published by AfCAP (Ministry of Transport and Public Works, 2013). The traffic design classes has also been adapted according to the same document.

Table 15: Subgrade types

Subgrade Type	CBR Index	Resilient Modulus (MPa)	DCP penetration rate (mm/blow)
S0	3 - 5	15 - 25	32 - 48
S1	5 - 10	25 - 50	19 - 32
S2 (*)	> 10	> 50	< 19

(*) assumed in all overlay works

Table 16: Traffic Categories

Traffic Category	Design Traffic (Average Daily Truck Traffic during the opening year)	DCP design method equivalent traffic class
C1	25 - 50	LE 0.10 (0.03-0.10 CESA)
C2	15 - 24	LE 0.03 (0.01-0.03 CESA)
C3	5 - 14	LE 0.01 (0.003-0.01 CESA)
C4	0 - 4	LE 0.01 (<0.003 CESA)

(CESA – Cumulative Equivalent Standard Axles)

Table 17: Catalogue of pavement sections

<table>
<tr><th rowspan="3">Subgrade Type</th><th colspan="8">Thickness of Concrete Pavement (mm)</th><th></th></tr>
<tr><th colspan="2">C4</th><th colspan="2">C3</th><th colspan="2">C2</th><th colspan="2">C1</th><th>Traffic Category</th></tr>
<tr><th>20</th><th>30</th><th>20</th><th>30</th><th>20</th><th>30</th><th>20</th><th>30</th><th>Design Period (Years)</th></tr>
<tr><td>S0</td><td rowspan="3">140</td><td rowspan="2">160</td><td rowspan="2">160</td><td>180 $^{(*)}$</td><td>180 $^{(*)}$</td><td>200 $^{(*)}$</td><td>200 $^{(*)}$</td><td>220 $^{(*)}$</td><td></td></tr>
<tr><td>S1</td><td>180</td><td>180</td><td>180 $^{(*)}$</td><td>180 $^{(*)}$</td><td>200 $^{(*)}$</td><td></td></tr>
<tr><td>S2</td><td>140</td><td>140</td><td>160</td><td>160</td><td>180</td><td>180</td><td>200</td><td></td></tr>
</table>

$^{(*)}$ plus granular untreated subbase, 150 mm thick

This design method has been used throughout the Basque province in Spain with great success. The method is easy to understand and can easily be repeated if the four input parameters are known and well defined for the section of pavement to be constructed.

For the main section and the additional steep section, DCP analysis was carried out. Two test pits on the main section and one test pit on the steep section were excavated and samples were taken for the different pavement layers. Upon completion of the laboratory testing of the samples taken, the subgrade CBR and DCP average penetration rates will be available.

Traffic data can be made available upon request from the Department of Feeder Roads (DFR) site representative at Akosombo, Mr Alex Nuamah. A 20 year design life will be considered.

The concrete flexural strength will be available once the mix design laboratory testing has been completed, in particular the flexural beam strength tests. Documented strength relations between concrete compressive cube strength tests exists and these relationships can be used to verify the flexural beam strength test results.

9 Conclusion

The location of the planned RCC experimental sections was selected on the existing Akosombo to Gyakiti road. The section has a relatively uniform subgrade, requires minimal pavement structure preparation, has existing drainage available along both sides of the road, has a relatively steep slope section and will provide good comparison with other pavement structures (gravel and bitumen seals).

A field investigation was completed and samples from the existing pavement extracted for laboratory testing. DCP tests were also conducted to confirm in-situ bearing capacity. The data will be used to evaluate the appropriate RCC thickness requirement using the Spanish Institute for Cement Design Method.

Four sources of coarse aggregate were located and sampled. In addition, three different types of fine aggregates, in close proximity of the test site, were sampled. Three different cement types have been sampled and also submitted for testing. Laboratory testing of the collected samples is currently underway. Once the screening test results are available two coarse and two fine aggregates will be selected and together with one cement type, a series of consistency and strength tests will be performed to evaluate the potential use of the different RCC mixtures.

Annex A: Updated Work Plan

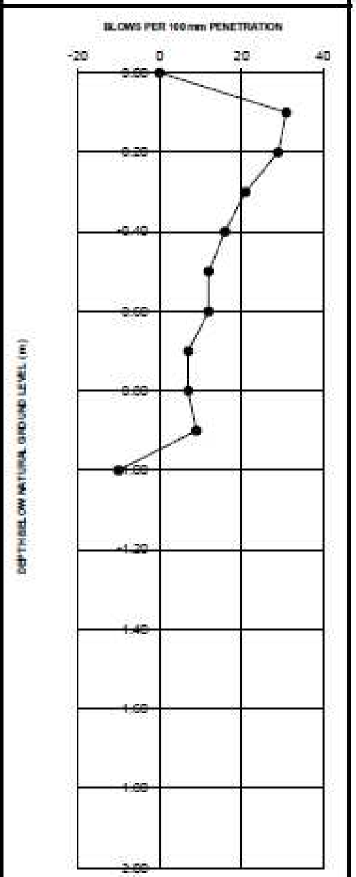
ACTIVITY	Start in week	Duration - weeks
Desktop study of RCC	1	2
Methodology outline	2	1
Client engagement - Accra, Ghana	3	1
Inception report	4	1
Sample collection - Ghana	17	3
Sample testing - Ghana	20	4
Mix design - method statement	20	4
Mix design	23	10
Pavement design and analyses	30	5
Interim laboratory testing report	21	1
Mix design and pavement design report	35	1
Demonstration section - final design	37	1
Demonstration section - maintenance planning	37	1
Demonstration section - maintenance scheduling	37	1
Demonstration section - construction	38	4
Demonstration section - monitoring and evaluation	41	4
Stakeholder site visit	42	1
Stakeholder workshop and report	42	1
Construction report	44	1
Life cycle cost analysis	42	6
LCC comparison - RCC to other methods	44	3
Guideline document for future use	41	8
Final report	45	4

Weeks: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48

Annex B: DCP test results

PROJECT	ReCAP RCC Project Ghana
PROJECT NUMBER	112877
TEST LOCATION	RCCDCP1
STARTING DEPTH FROM N.G.L. (m)	0
DATE	16-Nov-16
UTM N	173375
UTM E	700392
ELE (m)	160

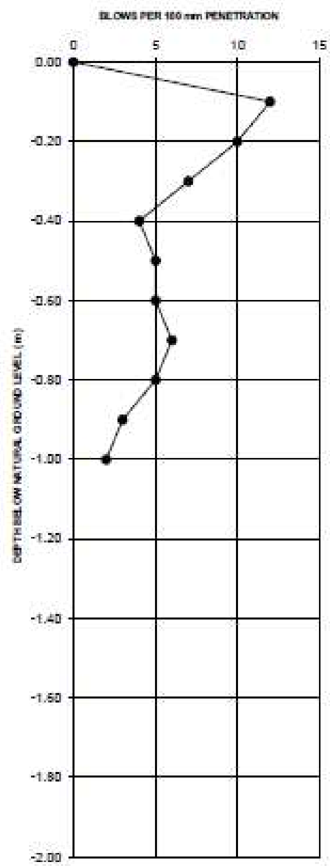
NUMBER OF BLOWS	PENETRATION DEPTH [mm]	DEPTH FROM N.G.L. [m]	PENETRATION RATE [mm / blow]	BLOWS/ 100 mm PENETRATION	GRAPH
0	0	0.000	0	0	
31	100	-0.100	3	31	
60	200	-0.200	3	29	
81	300	-0.300	5	21	
97	400	-0.400	6	16	
109	500	-0.500	8	12	
121	600	-0.600	8	12	
128	700	-0.700	14	7	
135	800	-0.800	14	7	
144	900	-0.900	11	9	
134	1000	-1.000	-10	-10	



PROJECT	ReCAP RCC Project Ghana
PROJECT NUMBER	112877
TEST LOCATION	RCCDCP2
STARTING DEPTH FROM N.G.L. (m)	0
DATE	16-Nov-16
UTM N	173547
UTM E	700351
ELE (m)	162

NUMBER OF BLOWS	PENETRATION DEPTH [mm]	DEPTH FROM N.G.L. [m]	PENETRATION RATE [mm / blow]	BLOWS/ 100 mm PENETRATION
0	0	0.000	0	0
12	100	-0.100	8	12
22	200	-0.200	10	10
29	300	-0.300	14	7
33	400	-0.400	25	4
38	500	-0.500	20	5
43	600	-0.600	20	5
49	700	-0.700	17	6
54	800	-0.800	20	5
57	900	-0.900	33	3
59	1000	-1.000	50	2

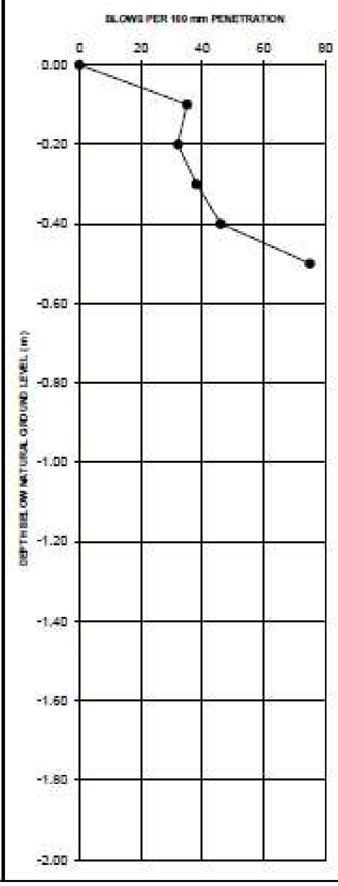
GRAPH



PROJECT	ReCAP RCC Project Ghana
PROJECT NUMBER	112877
TEST LOCATION	RCCDCP3
STARTING DEPTH FROM N.G.L. (m)	0
DATE	16-Nov-16
UTM N	173301
UTM E	700311
ELE (m)	168

NUMBER OF BLOWS	PENETRATION DEPTH [mm]	DEPTH FROM N.G.L. [m]	PENETRATION RATE [mm / blow]	BLOWS/ 100 mm PENETRATION
0	0	0.000	0	0
35	100	-0.100	3	35
67	200	-0.200	3	32
105	300	-0.300	3	38
151	400	-0.400	2	46
226	500	-0.500	1	75
	Center of road DCP landed on rock			

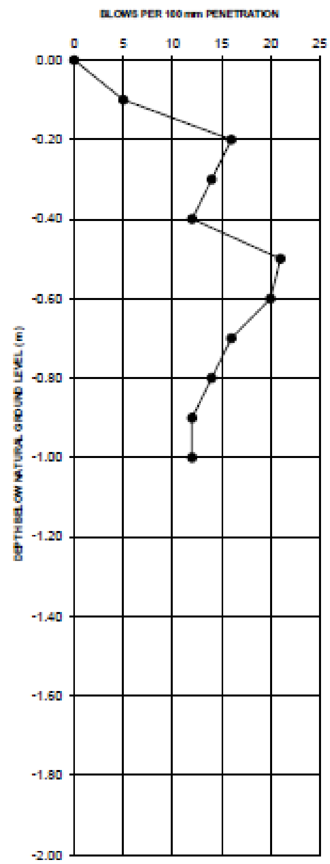
GRAPH



PROJECT	ReCAP RCC Project Ghana
PROJECT NUMBER	112877
TEST LOCATION	RCCDCP4
STARTING DEPTH FROM N.G.L. (m)	0
DATE	16-Nov-16
UTM N	173264
UTM E	700268
ELE (m)	171

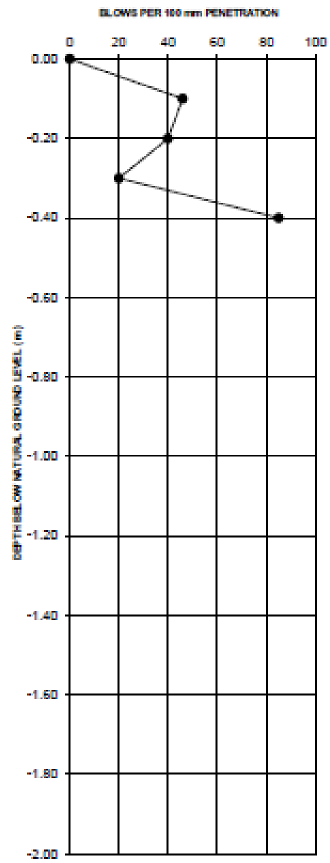
NUMBER OF BLOWS	PENETRATION DEPTH [mm]	DEPTH FROM N.G.L. [m]	PENETRATION RATE [mm / blow]	BLOWS/ 100 mm PENETRATION
0	0	0.000	0	0
5	100	-0.100	20	5
21	200	-0.200	6	16
35	300	-0.300	7	14
47	400	-0.400	8	12
68	500	-0.500	5	21
88	600	-0.600	5	20
104	700	-0.700	6	16
118	800	-0.800	7	14
130	900	-0.900	8	12
142	1000	-1.000	8	12

GRAPH



PROJECT	ReCAP RCC Project Ghana
PROJECT NUMBER	112877
TEST LOCATION	RCCDCP5
STARTING DEPTH FROM N.G.L. (m)	0
DATE	16-Nov-16
UTM N	173219
UTM E	700233
ELE (m)	173

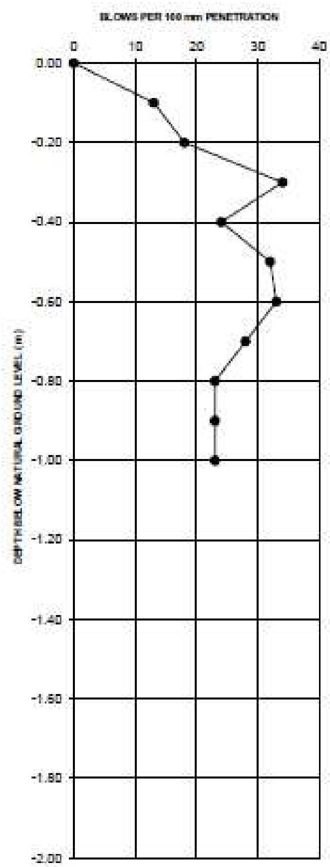
NUMBER OF BLOWS	PENETRATION DEPTH [mm]	DEPTH FROM N.G.L. [m]	PENETRATION RATE [mm / blow]	BLOWS/ 100 mm PENETRATION	GRAPH
0	0	0.000	0	0	
46	100	-0.100	2	46	
86	200	-0.200	3	40	
106	300	-0.300	5	20	
191	400	-0.400	1	85	
	Center of Road				
	DCP landed on rock				



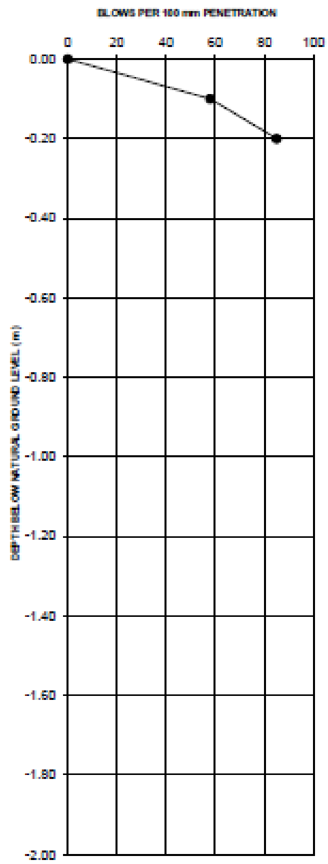
PROJECT	ReCAP RCC Project Ghana
PROJECT NUMBER	112877
TEST LOCATION	RCCDCP6
STARTING DEPTH FROM N.G.L. (m)	0
DATE	16-Nov-16
UTM N	173180
UTM E	700192
ELE (m)	175

NUMBER OF BLOWS	PENETRATION DEPTH [mm]	DEPTH FROM N.G.L. [m]	PENETRATION RATE [mm / blow]	BLOWS/ 100 mm PENETRATION
0	0	0.000	0	0
13	100	-0.100	8	13
31	200	-0.200	6	18
65	300	-0.300	3	34
89	400	-0.400	4	24
121	500	-0.500	3	32
154	600	-0.600	3	33
182	700	-0.700	4	28
205	800	-0.800	4	23
228	900	-0.900	4	23
251	1000	-1.000	4	23

GRAPH



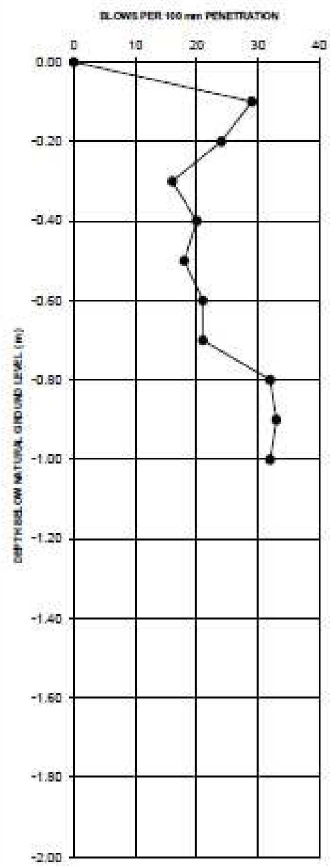
PROJECT	ReCAP RCC Project Ghana
PROJECT NUMBER	112877
TEST LOCATION	RCCDCP7
STARTING DEPTH FROM N.G.L. (m)	0
DATE	16-Nov-16
UTM N	173143
UTM E	700152
ELE (m)	178

NUMBER OF BLOWS	PENETRATION DEPTH [mm]	DEPTH FROM N.G.L. [m]	PENETRATION RATE [mm / blow]	BLOWS/ 100 mm PENETRATION	GRAPH
0	0	0.000	0	0	
58	100	-0.100	2	58	
143	200	-0.200	1	85	
	Center of road				
	DCP Landed on rock				
	Shoulder of road				

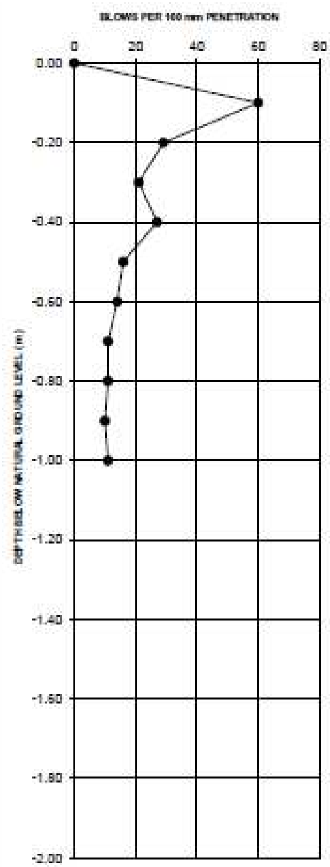
PROJECT	ReCAP RCC Project Ghana
PROJECT NUMBER	112877
TEST LOCATION	RCCDCP8
STARTING DEPTH FROM N.G.L. (m)	0
DATE	16-Nov-16
UTM N	173102
UTM E	700113
ELE (m)	181

NUMBER OF BLOWS	PENETRATION DEPTH [mm]	DEPTH FROM N.G.L. [m]	PENETRATION RATE [mm / blow]	BLOWS/ 100 mm PENETRATION
0	0	0.000	0	0
29	100	-0.100	3	29
53	200	-0.200	4	24
69	300	-0.300	6	16
89	400	-0.400	5	20
107	500	-0.500	6	18
128	600	-0.600	5	21
149	700	-0.700	5	21
181	800	-0.800	3	32
214	900	-0.900	3	33
246	1000	-1.000	3	32

GRAPH



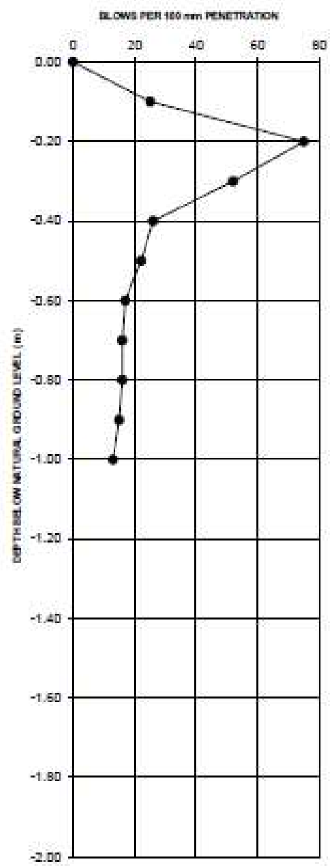
PROJECT	ReCAP RCC Project Ghana
PROJECT NUMBER	112877
TEST LOCATION	RCCDCP9
STARTING DEPTH FROM N.G.L. (m)	0
DATE	16-Nov-16
UTM N	173068
UTM E	700066
ELE (m)	186

NUMBER OF BLOWS	PENETRATION DEPTH [mm]	DEPTH FROM N.G.L. [m]	PENETRATION RATE [mm / blow]	BLOWS/ 100 mm PENETRATION	GRAPH
0	0	0.000	0	0	
60	100	-0.100	2	60	
89	200	-0.200	3	29	
110	300	-0.300	5	21	
137	400	-0.400	4	27	
153	500	-0.500	6	16	
167	600	-0.600	7	14	
178	700	-0.700	9	11	
189	800	-0.800	9	11	
199	900	-0.900	10	10	
210	1000	-1.000	9	11	

PROJECT	ReCAP RCC Project Ghana
PROJECT NUMBER	112877
TEST LOCATION	RCCDCP10
STARTING DEPTH FROM N.G.L. (m)	0
DATE	16-Nov-16
UTM N	173026
UTM E	700032
ELE (m)	193

NUMBER OF BLOWS	PENETRATION DEPTH [mm]	DEPTH FROM N.G.L. [m]	PENETRATION RATE [mm / blow]	BLOWS/ 100 mm PENETRATION
0	0	0.000	0	0
25	100	-0.100	4	25
100	200	-0.200	1	75
152	300	-0.300	2	52
178	400	-0.400	4	26
200	500	-0.500	5	22
217	600	-0.600	6	17
233	700	-0.700	6	16
249	800	-0.800	6	16
264	900	-0.900	7	15
277	1000	-1.000	8	13
	Shoulder of road			

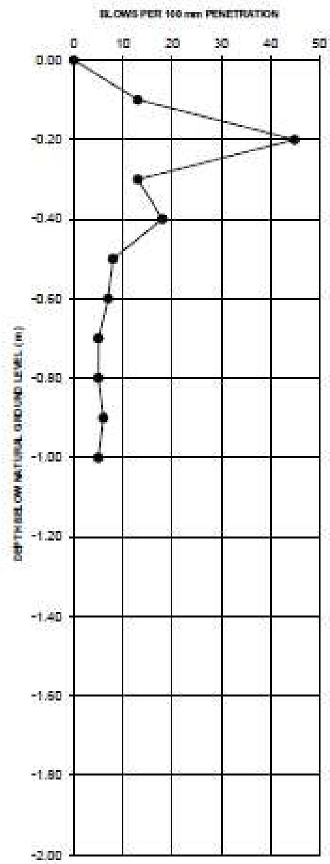
GRAPH



PROJECT	ReCAP RCC Project Ghana
PROJECT NUMBER	112877
TEST LOCATION	RCCDCP11
STARTING DEPTH FROM N.G.L. (m)	0
DATE	16-Nov-16
UTM N	172991
UTM E	699983
ELE (m)	199

NUMBER OF BLOWS	PENETRATION DEPTH [mm]	DEPTH FROM N.G.L. [m]	PENETRATION RATE [mm / blow]	BLOWS/ 100 mm PENETRATION
0	0	0.000	0	0
13	100	-0.100	8	13
58	200	-0.200	2	45
71	300	-0.300	8	13
89	400	-0.400	6	18
97	500	-0.500	13	8
104	600	-0.600	14	7
109	700	-0.700	20	5
114	800	-0.800	20	5
120	900	-0.900	17	6
125	1000	-1.000	20	5
	Centre of road			

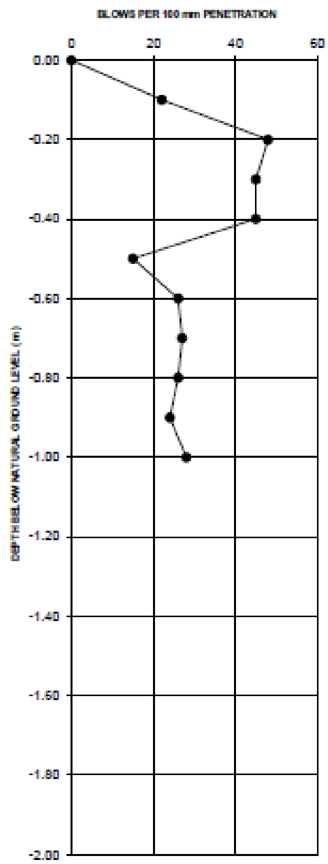
GRAPH



PROJECT	ReCAP RCC Project Ghana
PROJECT NUMBER	112877
TEST LOCATION	RCCDCP12
STARTING DEPTH FROM N.G.L. (m)	0
DATE	16-Nov-16
UTM N	172951
UTM E	699956
ELE (m)	201

NUMBER OF BLOWS	PENETRATION DEPTH [mm]	DEPTH FROM N.G.L. [m]	PENETRATION RATE [mm / blow]	BLOWS/ 100 mm PENETRATION
0	0	0.000	0	0
22	100	-0.100	5	22
70	200	-0.200	2	48
115	300	-0.300	2	45
160	400	-0.400	2	45
175	500	-0.500	7	15
201	600	-0.600	4	26
228	700	-0.700	4	27
254	800	-0.800	4	26
278	900	-0.900	4	24
306	1000	-1.000	4	28

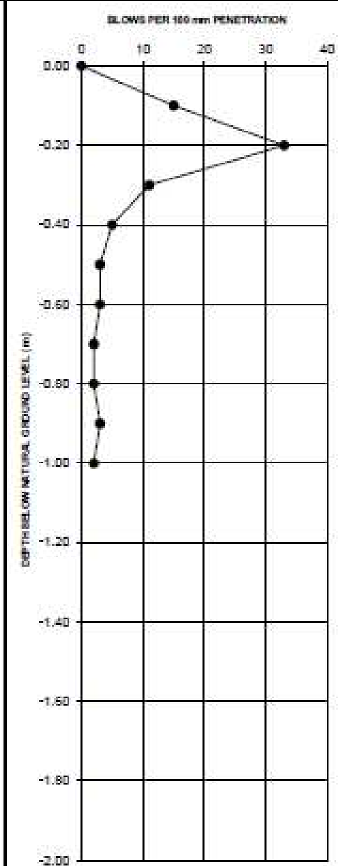
GRAPH



PROJECT	ReCAP RCC Project Ghana
PROJECT NUMBER	112877
TEST LOCATION	RCCDCPSS1
STARTING DEPTH FROM N.G.L. (m)	0
DATE	16-Nov-16
UTM N	171070
UTM E	698223
ELE (m)	148

NUMBER OF BLOWS	PENETRATION DEPTH [mm]	DEPTH FROM N.G.L. [m]	PENETRATION RATE [mm / blow]	BLOWS/ 100 mm PENETRATION
0	0	0.000	0	0
15	100	-0.100	7	15
48	200	-0.200	3	33
59	300	-0.300	9	11
64	400	-0.400	20	5
67	500	-0.500	33	3
70	600	-0.600	33	3
72	700	-0.700	50	2
74	800	-0.800	50	2
77	900	-0.900	33	3
79	1000	-1.000	50	2

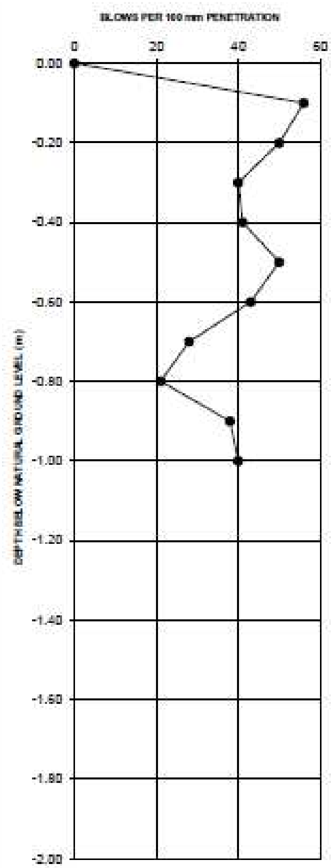
GRAPH



PROJECT	ReCAP RCC Project Ghana
PROJECT NUMBER	112877
TEST LOCATION	RCCDCPSS2
STARTING DEPTH FROM N.G.L. (m)	0
DATE	16-Nov-16
UTM N	171062
UTM E	698209
ELE (m)	146

NUMBER OF BLOWS	PENETRATION DEPTH [mm]	DEPTH FROM N.G.L. [m]	PENETRATION RATE [mm / blow]	BLOWS/ 100 mm PENETRATION
0	0	0.000	0	0
56	100	-0.100	2	56
106	200	-0.200	2	50
146	300	-0.300	3	40
187	400	-0.400	2	41
237	500	-0.500	2	50
280	600	-0.600	2	43
308	700	-0.700	4	28
329	800	-0.800	5	21
367	900	-0.900	3	38
407	1000	-1.000	3	40
	Centre of road			

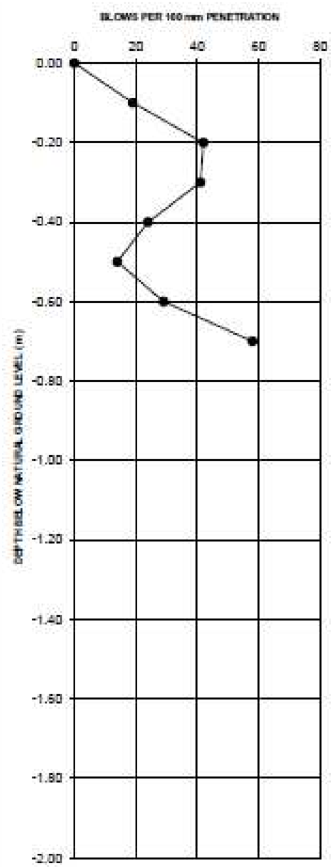
GRAPH



PROJECT	ReCAP RCC Project Ghana
PROJECT NUMBER	112877
TEST LOCATION	RCCDCPSS3
STARTING DEPTH FROM N.G.L. (m)	0
DATE	16-Nov-16
UTM N	171053
UTM E	698190
ELE (m)	141

NUMBER OF BLOWS	PENETRATION DEPTH [mm]	DEPTH FROM N.G.L. [m]	PENETRATION RATE [mm / blow]	BLOWS/ 100 mm PENETRATION
0	0	0.000	0	0
19	100	-0.100	5	19
61	200	-0.200	2	42
102	300	-0.300	2	41
126	400	-0.400	4	24
140	500	-0.500	7	14
169	600	-0.600	3	29
227	700	-0.700	2	58
	DCP Landed on rock			
	Shoulder of road			
	DCP stopped on rock			

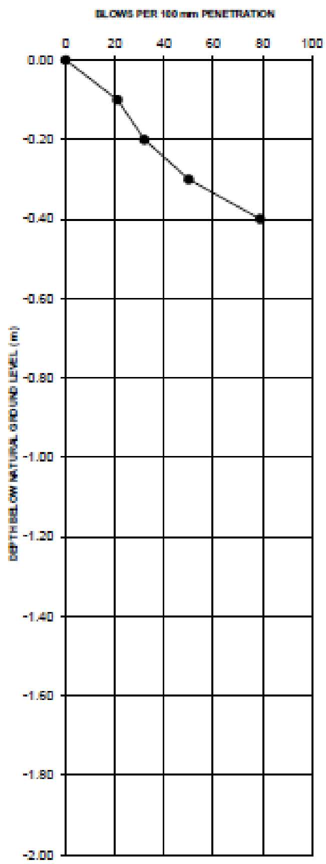
GRAPH



PROJECT	ReCAP RCC Project Ghana
PROJECT NUMBER	112877
TEST LOCATION	RCCDCPSS4
STARTING DEPTH FROM N.G.L. (m)	0
DATE	16-Nov-16
UTM N	171041
UTM E	698172
ELE (m)	138

NUMBER OF BLOWS	PENETRATION DEPTH [mm]	DEPTH FROM N.G.L. [m]	PENETRATION RATE [mm / blow]	BLOWS/ 100 mm PENETRATION
0	0	0.000	0	0
21	100	-0.100	5	21
53	200	-0.200	3	32
103	300	-0.300	2	50
182	400	-0.400	1	79
	DCP Landed on rock			
	Shoulder of road			
	DCP stopped on rock			

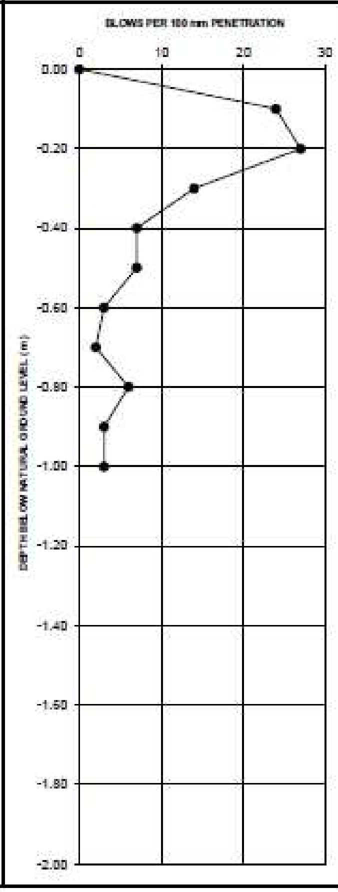
GRAPH



PROJECT	ReCAP RCC Project Ghana
PROJECT NUMBER	112877
TEST LOCATION	RCCDCPSS5
STARTING DEPTH FROM N.G.L. (m)	0
DATE	16-Nov-16
UTM N	171037
UTM E	698152
ELE (m)	134

NUMBER OF BLOWS	PENETRATION DEPTH [mm]	DEPTH FROM N.G.L. [m]	PENETRATION RATE [mm / blow]	BLOWS/ 100 mm PENETRATION
0	0	0.000	0	0
24	100	-0.100	4	24
51	200	-0.200	4	27
65	300	-0.300	7	14
72	400	-0.400	14	7
79	500	-0.500	14	7
82	600	-0.600	33	3
84	700	-0.700	50	2
90	800	-0.800	17	6
93	900	-0.900	33	3
96	1000	-1.000	33	3

GRAPH



Annex C: References

Jofré, C. & Zabala, I., 1998. Roller Compacted Concrete Pavements in the Basque Country. In 8th International Symposium on Concrete Roads. Lisbon, Portugal, pp. 159–164.

Ministry of Transport and Public Works 2013, 'Design Manual for Low Volume Sealed Roads Using the DCP Design Method', pp. 1–182.