The performance of shale as fill and embankment material for a trunk road in Ghana

La performance du schiste comme matériau de remblai pour une route destinée au trafic de camions au Ghana

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ABSTRACT: As part of the Millennium Challenge Account (MCA) Compact, some roads in the Afram plains, including Agogo – Dome trunk road of Ghana was constructed. Since it was uneconomical to haul suitable material over longer distance for the project, shale which abounds in the area was evaluated during construction for use as embankment and fill material. Representative samples were subjected to index property test, compaction, California Bearing Ratio (CBR) and triaxial protocols at six different laboratories. The results, especially CBR values indicated variations between 8% and 12%, which are below the contract special specification minimum value of 15%. This was therefore considered as having marginal quality for its intended purposes. However a 100 meter, 1.00m thick, field trial road section was constructed using the shale as fill under normal environmental conditions for traffic flow and monitored for a period of two months. The monitoring evaluation comprises conducting in situ CBR test, using the dynamic cone penetrometer and plate load bearing test including petrographic laboratory studies. Results obtained from the field evaluation indicated high CBR and bearing resistance values including insignificant settlement. Pavement performance indicators such as rutting and potholing were not evident. These performance based characteristic of the shale merited its selection for use in the project. This paper also presents the results of laboratory tests as well as field studies.

RÉSUMÉ : Dans le cadre du Millénium Challenge Account (MCA) Compact, un certain nombre de routes ont été construites dans les plaines d'Afram, dont celle d’Agogo – Dome. Puisque pour ce projet, il était trop coûteux d’approvisionner des matériaux de remblai adéquat sur de longues distances, l’utilisation du schiste qui abonde dans cette région a été évaluée en tant que matériau de remblai. Des échantillons représentatifs ont été soumis à différents tests, indice de propriété, compactage, essai CBR et essais triaxiaux, essais effectués par six laboratoires différents. Les résultats, en particulier les valeurs CBR ont montré des valeurs variables comprises entre 8 % et 12 %, inférieures à la spécification minimale de ce contrat qui était de 15 %. Ce matériau a donc été considéré comme ayant des propriétés trop faibles pour son utilisation envisagée. Cependant un tronçon d’essai de 100 mètres de longueur et 1 mètre d’épaisseur a été réalisé en utilisant le schiste comme matériau de remblai dans un environnement normal de conditions de trafic, et suivi pendant une période de deux mois. Ce suivi a comporté des essais CBR en place, en utilisant le pénétromètre dynamique, et des essais de chargement à la plaque, avec des études pétrographiques en laboratoire. Les résultats obtenus lors de l'évaluation sur le terrain ont indiqué de hautes valeurs CBR et de portance, ainsi que des tassements insignifiants. Les indicateurs de performance du revêtement tels que l’orniérage et la cavitation n'étaient pas apparents. Ces caractéristiques du schiste, tirées de l’expérimentation sur site, ont donc permis son utilisation pour ce projet. Cet article présente les résultats des tests de laboratoire aussi bien que les études de terrain.

KEYWORD: MCA, Shale, embankment, fill, CBR, plate loading

1 INTRODUCTION

The Millennium Challenge Account (MCA) Compact is an intervention muted by the United States of America to support the alleviation of poverty stricken areas in the Ghanaian economy. The intervention focused mainly on agriculture infrastructure, which included some road construction. The Agogo – Dome trunk road, 75.21km, was one of such that received attention to the Afram Plains, a major agriculture area. The project spanned between October 2009 and October 2011.

The geology of the area is a well-defined regional sedimentary terrain of the Voltaian System of Ghana, which abounds in consolidated and unconsolidated sediments or materials with other low degree metamorphism associations [Ghana Geological Survey Department]. Locally the main lithological units underlying the area are the Upper to Lower Paleozoic Voltaian Afram shale and sandstone. Lateritic depositions (residual in nature) that are commonly used for road fill, sub-base and base layers including embankment for this project were scarce within the geological environment during the feasibility studies. Also earlier geotechnical appraisal of materials within the project area was silent about the shale.

The project special specification requested the use of geogrid membrane to provide reinforcement for soft and weak in situ materials, and lateritic materials of class G30 for fill and embankment, G40 for sub-base and G80 for base courses. During the construction stages shale, which abounds in the area was also evaluated in the laboratory with conventional test protocols such grading, Atterberg's limits and soak California Bearing Ratio (96hr-CBR). However laboratory test results classified the shale as marginal material to be utilized as a fill for road and embankment structures. Due to this marginal condition, there was the need to evaluate its performance from a trial section. A 100m length, 1.0m thick, trial section was constructed as part of the length of the road under normal environmental and traffic conditions for two months. The field evaluation processes included dynamic cone penetrometer (DCP) test for CBR determination and plate loading for settlement and shear strength coupled with petrographic and X-ray fluorescence laboratory studies. Field test results were convincing enough for the shale to be used as intended.

This paper presents the laboratory and field results obtained. The observed field test results merited the use of the shale as fill and embankment structures for about 30.0km stretch of the road.

1.1 *Shale*

Shale is generally a clastic water depositional material composed chiefly of silt and clay. There are varying classification of shale depending on the mineral content, fossil content and depositional history.

The use of shale as road construction material is not very common. Sethi and Schieber (1998) have commented on the use of the Ordovician Martinsburg Shale and Devonian Brailler Shale, in West Virginia, as lightweight (expanded) aggregate for concrete, brick, asphalt, railroad, ballast, road base and fill. Okogbue and Aghamelu (2010) also compared the geotechnical properties of three shale Formations from southeastern Nigeria. In summary they concluded that they are likely to be satisfactory as fill and embankment materials.

Afram Shale in the Eastern part of Ghana has not been utilized as construction material probably due to perceived geotechnical challenges associated with Shale in general. The Shale within the project corridor is mostly moderately weathered and deep seated; physically observed to be friable when expose to the atmosphere.

1.1.1 *Design Method for test section*

The 100m long test section spans between, chainage, ch29+675 and ch29+775. The intended pavement design for soft and weak zones of the road was to place a biaxial geogrid reinforcement followed by a 200mm thick layer of selected granular material complying with the requirements for material class G30 of the standard specification. However the geogrid was eliminated at the test section and instead substituted with the 1.00m thick moderately weathered shale. Conventional procedure included clearing the vegetative cover and topsoil followed by 200mm thick lifts of the shale. Each lifts was compacted using the vibratory roller for twenty (20) passes and, visual indication that, close contact was being obtained between aggregates. In order to check on adequate compaction proof-rolling was implemented. A twenty ton fully loaded truck was engaged to move slowly on the compacted surface and concurrently observing any movements made by wheels (tyres) for the proof-rolling. Any observed movement was corrected by further compaction. This test section provided the platform as formation level for sub-base, base and bituminous layers at the reference chainage. The compacted section is presented at Figure 2.

1.1.2 *Laboratory test results*

Tests were carried out in five laboratories in Ghana and one laboratory in Nairobi, Kenya while the construction was in progress. The soil and aggregate results obtained from the laboratories is shown in Table 1. Table 2 shows the petrography of the Afram Shale and their major oxides composition obtained from X-ray fluorescence analysis is shown in Table 3.

Table 1. Summary of soil and aggregate laboratory results on Afram Shale.

Lab	Test						
	MDD g/cm^3	LL %	PL %	PI %	CBR %	<425µm %	PM
1	1.88	30.9	19.9	11.0	11	16	176
	2.11	27.7	11.0	16.7	12	21	350.7
2	1.77	45.0	20.7	24.3	10	19	461.7
	1.79	44.2	19.6	24.6	10	1.2	24.0
3	1.78	33.8	20.1	13.7		1	13.7
	1.85	40.5	19.4	21.1		1	21.1
4	1.73	45.0	21.0	24.0	8	10	240.0
5	1.93	38.8	21.4	17.4		1	17.4
6	1.90	36.0	19.0	17.0	10	1	17.0

Reference laboratories: 1 – Ghana Highway Authority (GHA) Kumasi Lab, Ghana; 2 – Building and Road Research Institute, Kumasi, Ghana; 3 – Nairobi Lab, Kenya; 4 – GHA, Accra Lab, Ghana; 5 – China WE Suhum Lab, Ghana; 6 – China Jiansu Jianda Corporation Lab, Agogo, Ghana.

Table 2. Summary of Petrographic thin section result on Afram Shale (Source: Department of Geology, Univ. of Ghana).

	Sample (%)	
Mineralogy	1	2
Quartz	60 - 70	55 - 65
Feldspar	5 - 15	10 - 20
Clay	10 - 20	15 - 20
Organic	Nil	Nil

Table 3. Summary of X-ray fluorescence results based on major oxides. Source: Ghana Geological Survey Department

Element	Percentages
Na_2O	1.39
MgO	1.52
Al_2O_3	8.57
SiO_2	74.96
Fe_2O_3	2.63
CaO	0.26
others	2.57
L.O.I	8.10

1.1.3 *Field test*

The field test carried out on the 100m stretch were the dynamic cone penetrometer (DCP) based TRRL specification and plate load bearing based on BS 1377:part9 1990

A total of eight (8) test points were carried out for the DCP between chainage 29+662 and 29+712. Summary of results is presented in Table 4.

Table 4. Summary of DCP test results

Chainage	Thickness, mm	Ave CBR, %
29+625	131	150
29+637	43	150
29+650	103.5	140.42
29+662	35	150
29+675	221	130.33
29+687	154	150.14
29+700	69.8	150
29+712	73.5	145.07

Graphical presentation of plate load bearing test and typical field test performance are shown in Figure 1 and Figure 3 respectively.

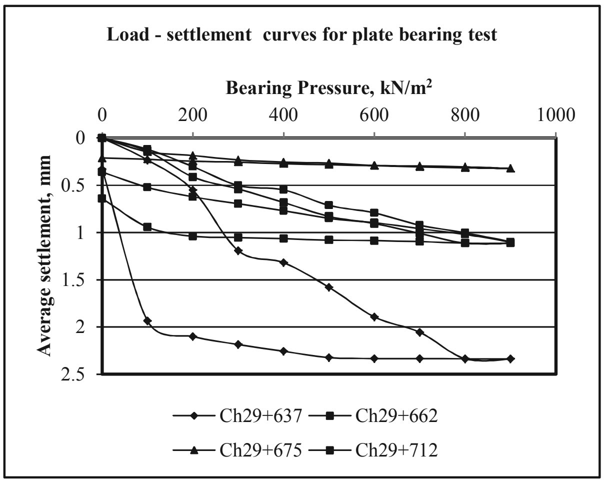

Figure 1. Plate load bearing graphs

1.1.4 *Discussion*

For quality assurance and statistical representation purposes, the shale was tested in six different laboratories to evaluate its geotechnical properties in order to understand its intended utilization. The conventional laboratory tests that are normally used for classifying materials in pavement works are gradation, Atterberg's limits, plasticity modulus and CBR.

Atterberg's limits results, in Table 1, indicate that fine content is mostly clay and inorganic of low to medium plasticity. The plasticity modulus (PM) as per the contract specification stated that values of, at most, 200 are assigned as base course; those between 200 and 250 are assigned sub-base course. The PM values obtained from the laboratories varied between 13.7 and 461.7. These observed values indicate that the shale could be used as base, sub-base and fill materials. The CBR, four day soaking, values obtained range between 8% and 12%, which falls below the expected 15% contract specification for fill.

During the construction stages an exposed section of the shale material on the road corridor, under traffic and environmental conditions, gave an interesting outlook. This prompted the implementation and evaluation of the trial section using conventional road construction methods.

From Table 2, the petrographic analyses revealed that the subject material is mostly siliceous. The study revealed that the quartz had been re-worked, an indication of a transported clastic sediment or an occurrence of a low grade metamorphism of the material. The high SiO_2 content of about 75% shown in Table 3 and the low clay content indicate the siliceous nature of the shale material.

The eight DCP test points were selected randomly within the 100m stretch. CBR values were obtained using the Kleyn and Van Harden equation below.

$$\text{Log (Cbr)} = 2.628 - 1.273\log(\text{DCP})$$

Table 4 presents the DCP test results varying thicknesses for CBR evaluation. The thickness column, in the Table 4, represents total thicknesses run-by each DCP test at the various chainage. CBR values represent average values within the total thicknesses. Table 4 also shows that within the chainage explored CBR values estimated were very high and these were confined between the upper 35mm and 221mm of the 1.0m thick layer. This is an indication of high blow counts as well as refusal to penetration.

Four plate loading tests were carried out within the 100m stretch. Results are presented in Figure 1. Generally, the modulus of subgrade reaction (k – kN/m^3) is the ratio of loading stress (p) at 1.25mm average settlement to 1.25mm. The loading stress is determined from the load – settlement graph at average settlement of 1.25mm. It is observed from Figure 1 that 3 out of 4 (75%) of the test did not attain the 1.25mm settlement criteria at the ultimate stress of $900kN/m^2$. However at chainage 29+637, k value is estimated as $272MN/m^3$.This value may be considered as lower bound value for the test section and gives an indication of very low or negligible settlement of a compacted layer. The graphs also indicate that no distinct shear failure occurred and so the final load could be considered as the ultimate load. The finished road of the trial section is presented in Figure 4.

Figure 2. Compacted shale at trial section

Figure 3. Plate load bearing test at trial section

Figure 4. Finished road at trial section

2 CONCLUSIONS

The four day soaking CBR values from the laboratories were below required specification. However field implementation indicated a very good geotechnical strength measure for the shale as fill and embankment material within the 100m test section for the two months observations. The performance characteristics of the shale encouraged its utilization as fill for 30km stretch of the road including a 2.0km length, 5m high, of embankment. For nearly two and half years, including the defect liability period, that the road has been in service there has been continuous monitoring and observations. Pavement failure indicators such as rutting and potholing have not been observed as well as significant shear failures in embankments.

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