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Geotechnical Investigation of Borrow-Pit Material Quality for Construction of Sustainable Gravel Roads in Palapye- Botswana

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Abstract—The Geotechnical investigation of the gravel material used in the construction of gravel roads in Palapye is important as it ensures that the quality of the gravel material used complies with the Botswana Bureau of Standards (BOBS), Road Department standard and the Client standard Botswana International University of Science and Technology (BIUST). The geotechnical investigation also helps the contractors to construct gravel roads of high quality that can last longer without developing gravel road defects such as potholes, dust, stoniness and corrugation. It helps reduce the cost incurred to maintain the gravel roads. This study investigates the quality of the gravel material used to construct gravel roads in Palapye. The Atterberg limit tests (shrinkage limit, Plastic limit and liquid limit tests) and the moisture and dry density tests are being carried out at Rockefeller Laboratories to test the quality of the gravel material. Rockefeller is the company currently constructing the BIUST access road and they want to ensure that the quality of the gravel material they are using complies with the BOBS.

Keywords: Geotechnical Investigation, quality, gravel material.

INTRODUCTION

Gravel material refers to the unconsolidated material composed of particles of different range sizes. Gravel is a mixture of three sizes or types of material: stone, sand and fines (12). Gravel is composed of soil material between 2mm and 6mm. Gravel roads are the unpaved or untarred roads made of the gravel material.

Gravel material is largely composed of the pebbles of 4 to 63, sand of 0.063 to 2mm and the finer particles (8). A good gravel material should be well graded from the coarse particles to the finer particles. The mineralogical composition of the gravel material depends on the mineralogical composition of the parent rock. Most of the gravel material in Botswana is formed through weathering of granite rocks. Granite is mostly composed of quarts and feldspar with minor mica, amphiboles and other minerals (9)

Gravel is formed due to the process of weathering and deposition of rock particles containing pebbles, sand and finer particles. Gravel is either a natural gravel or crushed stone to form gravel (4). Natural gravel is formed from materials of a weathered rock and crushed stone is when the rock is artificially broken down into pieces and graded to certain sizes to produce an aggregate in a quarry (8). Crushed stone is mostly used when the natural gravels are not available.

Gravel material is used in construction of roads (both tarred and untarred roads), construction of foundations and as a subbase for pavements. Gravel material forms the bases of every construction project. The performance of the gravel road depends on the; Quality of the gravel, the load of the vehicles using the gravel, the design of the gravel.

LITERATURE REVIEW

Classification of gravel material

(1), highlighted that gravel material is classified using the soil classification systems. Soil classification system is simply categorising of soil in groups based on the properties of the soil. Soil classification systems rely on physical and the engineering properties of the soil. Different classification systems classify the soil into many different groups. The two mostly used systems are the Unified Soil Classification System (USCS) and the American Association of State Highway and Transportation Officials (AASHTO)

The Unified Soil Classification System (USCS) uses the grain size analysis and the atterberg limit tests to group the soils into two major groups (2). The system groups the soil into 6 groups and each group is denoted with a letter or symbol. According to (1), a soil is classified as a gravel or sandy soil if more than 50% is retained on a No.200 sieve and as a fine grained soil if 50% or more passing through a No.200 sieve. Below is the table that shows how the soils are grouped and

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the symbols used when using the Unified Soil Classification System (USCS).

According to (2), the Association of State Highway and Transportation Officials (AASHTO) is used to classify soils used in the construction of highways and it uses the grain size analysis, liquid limit and plasticity index and the soil type and group name are determined from the AASHTO table. Also according to (1) The AASHTO classifies the soils into seven major groups A-1 to A-7. A-1 to A3 are coarse grained soils (gravels and sands) whereas A-4 and A-7 are mostly finer materials(silt and clays).

Gravel Roads

Gravel road refers to a road made of gravel material (material containing the coarse, medium and small amount of fine particles) that are not paved or sealed with any material. Similarly, (13), defines unsealed roads as a road that has no permanent surface proofing of water in contrast of sealed roads. Meanwhile some Authors define a gravel road as any unpaved road.

A gravel road is composed of three layers which are the roadbed, the subgrade, and the surface layer (7). The road bed is indigenous soil evenly graded to make it uniform. The subgrade is the gravel material with bigger particles to improve drainage and to make a more stable base. The top layer is the surface layer made of mostly medium grained gravel of uniform size.

Gravel Road Defects

The rate at which the gravel material is deteriorated is mainly affected by the quality of the gravel material, the design of the gravel road, number and the gross weight of the vehicles using the gravel road, the environmental effects such as floods or rainfall amount (13). Poor quality gravel and a large number of vehicles can cause further weathering of gravel material into smaller pieces that will be easily eroded. Poor design of the gravel also worsens the impacts of environmental issues such as floods. The gravel road defects are:

Potholes

Potholes are bowl-shaped, round and elongated depression in gravel road surface (7). Similarly according to (10) potholes are depressions or holes in the road surface. The pot holes may differ in sizes and the intensity along the whole road. The major contributing factors to potholes are: poor road design, poor and unevenly compaction, low quality gravel material, cracked road (7).

The potholes may be joined together or evenly spaced. Potholes are controlled by reshape or regrade to cut out the potholes (10).

Road Design

Road design influences the performance of the road. Poor road design will speed up the deterioration of the gravel road. The road should be designed such that more water will flow through the culverts not at the top of the road and it is easily drained from the road. If water is stagnant on the flat gravel it will soften the gravel leading to potholes and rutting. According to (6) Where the profile is flat, water tends to pond in localised depressions resulting in softening of the wearing course and the development of potholes and other deterioration. A proper gravel road design should be bulged at the centre so that water can easily flow from the road. According to (6) the road profile is rated on a five-point scale where one is very good Surface and will shed water easily, and five is very uneven road that result in accumulation of water that may cause potholes.

Road dust

Road dust is the dry solid matter consisting of clay and silt-sized particles that is entrained by wind, the wind shear forces created by vehicles and the interaction of vehicle tyres with the road and which disperses and remains in suspension for a period before eventually falling back to the earth's surface (5). Dust is a result of moving vehicles on a road with less moisture content and too much finer materials. The quality of the aggregate and the amount of vehicles using the road affect the amount of dust. Dust reduces the visibility on the road, increases gravel loss due to loss of fine material, poses health threads and also affect the surrounding vegetation (5) . Dust from the road can be controlled by watering of the gravel during dry periods which will increase the expenses on the maintenance of gravel.

Stoniness of the Road

Stoniness is the relative percentage of material embedded in the road that is larger than a recommended maximum size (usually 37.5 mm) (7). Stoniness occurs when most of the material used contains the materials that are larger (the cobbles and pebbles). The finer particles will be carried away leaving behind the rocky, bumpy or uneven surface. As such it is important to use the recommended gravel material for gravel roads. According to (6) .Stoniness leads to rough roads, poor compaction in areas with large rocks, difficulties during maintenance, development of corrugations.

Corrugation/washboard

According to (10) Corrugation or washboard refers to the series of evenly spaced bumps that make a vehicle chatter rather than bounce around like potholes. Corrugation/ washboard of gravel is when the gravel material is carried and deposited on certain intervals creating crest and troughs in the gravel road creating a bumpy rough road. corrugation is caused by the action of passing vehicles. According to (11)There are four primary causes of corrugation/ washboarding which are the driving habits of people, lack of moisture, poor quality of gravel, lack of crown on the surface

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METHODOLOGY

The samples that were tested was collected from Maope Quarry (Stockpile 1) in Palapye. The sample were tested check if it complies with the Bobs standard for G6 material. The tests carried out were the Sieve analysis, Atterberg limits, and the maximum dry density and optimum moisture content were also determined from a graph.

Sieve Analysis

The sample was passed through the stack of sieves of aperture indicated in the table below and the percentage retained, mass retained and percentage passing were calculated. The details are as follows:

Sieve Analysis of Aggregate

Date: 19/05/2017

Project: BIUST Access Roads

Client: BIUST

Source: Maope Quarry

Location: Maope Sample No: 2

Mass After Washing: 2240

Mass Before Washing: 2529

Grading Modules: 2.23

Dust Content:289

Table 1: Sieve Analysis of Aggregate

SIEVE APERTURE	MASS RETAINED	% RETAINED	% PASSING
75			
53			
37.5			100.1
25.5	47	1.9	98.2
19	149	5.9	92.3
13.2	123	4.9	87.4
9.5	145	5.7	81.7
6.7	184	7.3	74.4
4.75	208	8.2	66.2
2.36	527	20.8	45.4
1.18	278	11	34.4
0.6	257	10.2	24.2
0.425	93	3.7	20.5
0.3	75	3	17.5
0.15	114	4.5	13
0.075	38	1.5	11.5
<0.075	2+289	11.5	
	2529	100.1	

Atterberg limit tests

The plastic limit, liquid limit and plastic index of the sample were tested using the soil sample that passes through sieve no 425. The results were as follows.

Table 2: Atterberg Limits

Description of material	MOISTURE CONTENT		PLASTIC LIMIT	LL, PL & PI
Tin no	A1	E2	68	LL =23.7
Mass Tin & Wet Material	18.15	18.05	18	PL = 17.0
Mass Tin & Dry Material	16.2	16.05	16.5	
Mass Tin	7.7	7.7	7.7	PI=6.7
Mass Moisture	2	2	1.5	
Mass Dry Material	8.5	8.4	8.8	
% Moisture	23.5	23.8	17	
Number of Taps	23	23		
SHRINKAGE				
LINEAR SHRINKAGE = 3.3%				

Maximum dry density and optimum moisture

The maximum dry density and optimum moisture were determined using the graph of dry density and moisture content. They were determined to be 2146kg/m and 7.3%. The table for the maximum dry density and optimum moisture content and the graph of dry density versus moisture content are shown below.

Table 3: Determination of maximum dry density and optimum moisture content

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MAXIMUM DRY DENSITY AND OPTIMUM MOISTURE CONTENT								
PROJECT: BIUST ACCESS ROAD								
SAMPLE NO:2						DATE: 24/05/2014		
LOCATION: MAOPE QUARRY STOCK PILE 1						TECHNICIAN: PATRICK		
SAMPLE DISCRIPTION						CLIENT: BIUST		
Hygroscopic				0.6	0.8	0.7	Ave=0.7	
% Added				4%	6%	8%	10%	
ml				280	420	560	700	
Mould no				B22	B22	B22	B22	
Mould factor				4456	4456	4456	4456	
Wt.Mould + Wet Soil				9564	9836	9856	9790	
Wt.Mould				4701	4701	4701	4701	
Wt. Wet Soil				4863	5135	5155	5089	
Wet Density (kg/m)				2176	2288	2297	2268	
Container no:				A1	A9	A4	A7	
Wt. Con + Wet Soil				500	500	500	500	
Wt. Con + Dry Soil				478	468	460	452	
Wt. Water				22	32	40	48	
Wt.Dry Soil								
Moisture Content (%)				4.6	6.8	8.7	10.6	
Dry Density (kg/m)				2050	2142	2113	2051	
			M.D.D: 2146		O.M.C: 7.3			

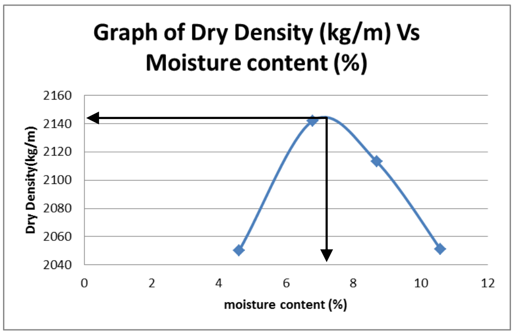

Figure 1: Graph of dry density (kg/m) Vs Moisture Content

Results Analysis

According to the Botswana Bureau of Standards (BOBS) Civil engineering Part 32 Roads specification the G6 material shall have a Plastic Index of less than 12, Linear Shrinkage of less than 5% and the product of the percentage passing the 0.425mm sieve does not exceed 320. In comparison with our results the plastic is 6.7, the linear shrinkage is 3.3% hence the gravel material at Maope Quarry is correctly classified as G6.

CONCLUSION

The results of the tests carried out so far confirmed that the quality of the borrow pits material around Palapye are in the range of gravel G5 and G6 materials used for road construction which complied with the BOBS standards. The Maope Quarry is G6 material hence it can be used as a fill or subbase material according to the BOBS standards.

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