

Investigation of Geotechnical Properties of Gravel Materials for Improved Quality of Unpaved Roads

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ABSTRACT

Addressing issues of quality in gravel material by introducing proper testing of material will greatly reduce poor gravel road performance and the costs of maintenance. Locally, shortage of land and settlement in rural areas increases considerably every year and gravel roads are increasingly becoming important and useful. Nevertheless, gravel roads are faced by deterioration by different factors, and because of these factors, corrugation, potholes, ruts, dust (loose gravel), and loss of gravel, stoniness and cracking will be the final output on gravel roads. Researchers have focused on improving performance through monitoring and improving maintenance procedures in order to increase the life of unsealed roads worldwide. This study investigates the geological properties of gravel materials from borrow pits that are currently being used within Palapye for improved quality of unpaved roads. This study involves carrying out full tests on samples collected from borrow pits including the Lecheng borrow pit and comparing the results with the set quality standards for gravel material from Botswana Bureau of Standards which positively contributes to the economy of Botswana and to the development goal of achieving good quality gravel roads.

Keywords: Quality; Gravel material; unpaved roads performance

I. INTRODUCTION

Gravel is very useful as a road construction material for both sealed and unsealed roads. In unsealed roads, gravel usually gets lost during the life of the road because no surface mix has been used or applied to hold it in place. Therefore the required characteristics of gravel for sealed roads will always be different from those of unsealed roads. There are many factors that affect the performance of a gravel road, and these include those related to shape and

those related to the properties of the gravel material being used. On the basis of shape, the main idea is for drainage, to keep water away from the surface of the road.



Figure 1: Shows how water contributes to gravel road deterioration [1].

The suitability of a gravel material differs according to how it is going to be used. Base course gravel requires large amounts of coarse particles and less amount of fine particles, whereas for surface gravel enough amounts of fines are necessary for providing the binding characteristics. One biggest problem in gravel roads is wash boarding, whose primary cause is poor gradation. Gradation is the most important element of gravel that needs to be considered carefully, a blend of coarse particles has to form a tight surface, and fine particles will act as a binder to fill the spaces between the coarse particles. Good surface gravel should have top-sized stone no larger than $\frac{3}{4}$ inches or certainly no larger than 1 inch. It should have a good percentage of true fines (material that passes a number 200 sieve). The ideal percentage of fines should run somewhere between 7 and 12% of the total sample passing the number 200 sieve [2]. Surface gravel roads are faced by a lot of problems including corrugation, gravel loss and bearing capacity failures. Therefore a proper selection of gravel

material is essential for excellent performance and life of a gravel road.



Figure 2: Example of a very good gravel road [1].

Gravel roads are increasingly becoming important and useful in developing countries such as Botswana. As the population continues to increase there comes a need for any state to offer land to its citizens for settlement, with limited availability of land, settlement in rural areas increases considerably. This can be challenging in developing countries such as Botswana in terms of transportation network. Proper attention has to be given to improving the transportation network in order for people in rural areas to be connected to the social and economic development of the state. However construction and maintenance of sealed or paved roads can be highly costly so attention should be given to other cheaper alternatives. Gravel or unpaved roads are very cheap to construct as compared to sealed or paved roads, which is why they are normally adopted for rural areas. This calls for attention to be given to the quality and performance of gravel roads and the material that is being used for construction. Nevertheless gravel roads can be very costly to maintain, especially when the material that is used is not of the required quality. Problems with wash boarding, rutting in wet weather or loosening (floating) in dry weather are greatly reduced when some money is spent on testing the material for quality, and maintenance costs are greatly reduced, as sourced out from the Federal Highway Administration (FHWA) [1]. There is not “one size fits all” gravel, different uses require different types of material and only by testing can you really determine if it is suitable for a specific purpose [2]. All managers and decision makers in local government need a good understanding of the benefit of testing the material in order to work towards better quality in road. Knowing about the importance of quality gives power to decision makers to specify good materials, to know when to accept or reject materials, and to communicate better with crushing contractors, consultants, commercial suppliers and others involved in the business of constructing and maintaining roads [1]. Pits and quarries can change as material is removed over the years, so testing prior to use can also solve many problems that can show up later.

Material quality is of utmost importance, if money is spent on testing and analysis of the material to check the

geological and geotechnical properties to ensure quality, the costs of maintenance are greatly reduced [1].

II. LITERATURE REVIEW

Botswana and many other African countries are landlocked, and roads are the main modes of transport that are being used more than other modes of transport. In 1993 the roads department in Botswana sourced out some important figures through the Botswana Road Maintenance Study Report. These figures are shown in a table below as obtained from the Rural Road Management in Botswana article by Khan. There are about 18 327 km of roads in Botswana, which are divided into four categories based on importance. The Roads Department and Local Councils own about 48% and 52% of roads respectively [5].

Table 1: The road network in Botswana [5].

Type of roads	Description of roads	Responsibility	Total: km (%)
Primary roads	Major national highways	Roads Department	3,789 (21%)
Secondary roads	Secondary national highways that connect at least two district headquarters	Roads Department	4,882 (27%)
Tertiary roads (rural roads)	Rural roads that connect at least two villages	Local Councils	2,644 (14%)
Access roads (rural roads)	Village internal roads	Local Councils	6,922 (38%)
Total			18,237 (100%)

However, in 2011 Ministry of Transport and Communications (MOTC) noted in the Botswana Roads-Basic Facts report that the public highway network consists of 6116 km of paved and 2 800 km of unpaved road. This is complemented by a further 9000 km of District roads which fall under the responsibility of the District [6].

However, when we look closely at the figures, a major share of responsibilities is on the local council's side, and as shown on the table above, the councils are mostly responsible for rural roads which connect villages both internally and externally. This means that the rural roads dominate in the roads network of Botswana, and the numbers continue to increase as years pass.

Nevertheless, gravel roads are faced by deterioration by different factors, and because of these factors, corrugation, potholes, ruts, dust (loose gravel), loss of gravel, stoniness and cracking will be the final output on gravel roads [4]. Khan further noted that road performance assessment and maintenance is considerably being neglected, and more emphasis is on road construction. Using the council maintenance-budget data for the current and previous years, it appears that maintenance funding has been reduced, whereas the road network has increased by almost 50% in the last two years. This indicates that maintenance is not getting proper attention [5]. Gravel roads are adopted in almost all cases because of low costs of construction, but maintenance costs for gravel roads (or just rural roads) can be very high especially if material used does not meet the proper quality standards. When combinations of factors that cause deterioration meet a poor gravel road material, the rate of deterioration increases highly, performance is lowered, and the frequency of need for maintenance continues to increase considerably.

Therefore material quality is highly important to the performance and life span of a gravel road. Emphasis on the gravel material quality and characteristics can limit deterioration factors and improve performance. However a lot of attention is on the construction stage, the performance stage, and the maintenance procedures, and the analysis and rating of material is not getting proper attention. Engineers frequently write ideal specifications for gravel that is not obtainable, and contracts are let to use practical grades, on a price or availability basis [3]. This being the case, the government ends up dealing with the consequences of poor gravel material, because a lot of compromises were made on quality, on a price or availability basis.

Although this study is based on gravel material quality, it is only limited to that and does not get much into how gravel deteriorates, it focuses on what good gravel is made of and how to obtain it, and this is only limited to the Palapye region.

III. METHODOLOGY

Data Collection. Data was collected in the form of tests on the samples collected from Lecheng Borrow Pit. Four laboratory tests were carried out on each sample, and these are; Sieve Analysis, Atterberg Constants Determination, California Bearing Ratio (CBR), Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) Determination.

IV. DATA ANALYSIS AND DISCUSSION OF RESULTS

Since the investigation process is still ongoing, only sample 1 of stockpile B from Lecheng Borrow Pit was used for this paper to present the geotechnical properties the stockpile.

To analyze the results, they were capture in an excel sheet and were presented in tables and graphs for easy reading and interpretation. They were used again for comparison with the Botswana Bureau of Standards specifications with the aim of determining whether they fall within the boundaries of quality or not.

Table 2 shows results from sieve analysis process giving a grading modulus of 2.47, a percentage (by mass) of 31.2% passing the 2.00 mm sieve, and a percentage of 19.8% passing the 0.425 mm sieve.

Table 2: Sieve Analysis results.

SIEVE APERTURE (MM)	MASS RETAINED (g)	PERCENTAGE RETAINED (g)	PERCENTAGE PASSING (%)
75.000			
53.000			99.9
37.500	476	23.0	76.9
25.500	163	7.9	69.0
19.000	125	6.0	63.0
13.200	92	4.4	58.6
9.500	142	6.9	51.7
6.700	139	6.7	45.0
4.750	110	5.3	39.7
2.360	176	8.5	31.2
1.180	38	1.8	29.4
0.600	73	3.5	25.9
0.425	126	6.1	19.8
0.300	86	4.2	15.6
0.150	132	6.4	9.2
0.075	150	7.2	2.0
<0.075	20 + 22	2.0	DUST CONTENT (g) : 20
TOTAL	2070	99.9	GRADING MODULUS:2.47

Table 3 summarizes the atterberg constants, giving a Liquid Limit of 21.9, a Plastic Limit of 18.3, a Plasticity Index of 3.6 and a Linear Shrinkage of 2.0%.

Table 3: Atterberg Constants

	MOISTURE CONTENT		PLASTIC LIMIT	
TIN NUMBER	A33	C6	42.00	LL = 21.9
MASS TIN & WET MATERIAL (g)	20.30	20.05	20.05	PL = 18.3
MASS TIN & DRY MATERIAL (g)	18.35	18.15	18.35	
MASS TIN (g)	9.40	9.40	9.10	PI = 3.6
MASS MOISTURE (g)	2.00	1.90	1.70	
MASS DRY MATERIAL (g)	9.00	8.80	9.30	
% MOISTURE	22.20	21.60	18.30	
NUMBER OF TAPS	18.00	26.00	LINEAR SHRINKAGE= 2.0 %	
SHRINKAGE (mm)	3.00			

The graph in figure 3 plots the Dry Density values at varying amounts of water as shown in table 4, in order to determine the Optimum Moisture Content (OMC) and the Maximum Dry Density (MDD). The graph gives an MDD of 2073 kg/m and an OMC of 8.3%.

Table 4: Maximum Dry Density and Optimum Moisture Content.

HYDROSCOPIC	0.6	0.8	0.7	Ave = 0.7
% ADDED	4%	6%	8%	10%
ML	280	420	560	700
MOULD NUMBER	B22	B22	B22	B22
MOULD FACTOR	4456	4456	4456	4456
WT. MOULD + WET SOIL	9356	9590	9753	9701
WT. MOULD	4701	4701	4701	4701
WT. WET SOIL	4655	4889	5052	5000
WET DENSITY (kg/m)	2074	2179	2251	2228
CONTAINER NUMBER	A1	A2	A8	A5
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)	1983	2040	2071	2014
	M.D.D: 2073		O.M.C: 8.3	

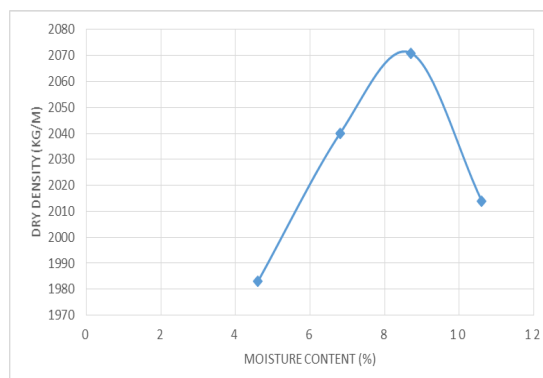


Figure 3: Dry Density against Moisture Content for determination of OMC and MDD.

Below is a table that summarizes all the tests that were carried out on the sample, by outlining the important parameters that are being used for classification.

Table 5: A summary of the important parameters of the sample.

LECHENG BORROW PIT	
STOCKPILE B; SAMPLE 1	
GRADING MODULUS	2.47
% PASSING 2.00 mm SIEVE	31.20
% PASSING 0.425 mm SIEVE	19.8
LIQUID LIMIT	21.90
PLASTIC LIMIT	18.30
PLASTICITY INDEX	3.60
LINEAR SHRINKAGE	2.00

Discussion of results and findings: To analyze the results, the BOBS specifications for roads which are outlined in Part 32, were used for classification, and determination of suitable use of the material. Table 3B of the BOBS Part 32 and the table showing a summary of the important parameters of the material, show that the gravel material under investigation, complies with the requirements of Grade 5. This implies that this material qualifies to be used as a compacted pavement layer.

Conclusion: The findings of this research reveal the importance for testing of gravel material before actually being used for construction. It shows that there is no “one size fits all” type of gravel, different uses require different types of material and only by testing can you really determine if it is suitable for a specific purpose.

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