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Evaluation of the Effect of Moisture, Fines Content and Plasticity in the Fill Materials (G3) used for Roadwork in Tanzania Study Area Pwani Region

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Review Article

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ABSTRACT

Tanzania roadwork construction activities must adhere established guidelines of standard specification and pavement and materials design manual established by the ministry of work. The construction of fill layer requires the materials which constitute CBR equal or more than 3%, having minimum compaction of 90% and with maximum Swelling Index of 2%. Tests of gradations and plasticity properties are disregarded during the classification. This situation has resulted into the use of soil with high water susceptibility during the construction due to lack of control on the plasticity and the percentage of fines content. Tanzania comprises three climatic zones of dry, moderate and wet; the established guidelines had omitted the division of climatic zone during classification the fill material requirement. The study to evaluate the effect of fines content, plasticity and moisture change in the fill materials has been undertaken. The investigation test conducted comprised soil specimen having fines content to the proportional of 5%, 10%, 45%, 60% and 80% sampled from Pwani region. Each sample were investigated at three climatic zones whereas dry, moderate and wet with 75% of OMC, 100% of OMC and 125% of OMC respectively. The effects were investigated through resilient modulus (Mr) and strength (CBR) parameters. The laboratory results and analysis revealed that fines content and plasticity are detrimental to the performance of fill layer. CBR is inversely proportional to the fines content and PI. The Mr values are increased when the fines content increases up to optimal content of fines, and the soil structure with most fined grains has poor performance when exposed to the wet condition. The findings might have a great implication in the roadwork construction industry in Tanzania and other countries with similar characteristics. For instance, the ministry of work might utilize the findings by adding the fine content and plasticity limit. Roadwork construction specification urged to include the limit of fines content and plasticity. Also, the classification must be separated based on climatic zone. The minimum compaction effort must be improved from 90% to 93% together with CBR value from 3% to 5%.

Keywords: California Bearing Ratio (CBR); Resilient modulus; Fines content; Fill material; Moisture content; Plasticity index; Compaction

INTRODUCTION

The pavement structure is composed of subgrade, pavement layers and surfacing. The subgrade layer plays as the foundation of the pavement structure on which all other layers are built on. It must be properly designed and protected to ensure the long life of the pavement. The subgrade layer is usually consists of the *in situ*, fill, lower improved subgrade, and upper improved subgrade. Researchers have categories fill material in groups and minimum specifications requirements such as the California Bearing Ratio (CBR), Liquid Limit (LL), Plasticity Index (PI), Swelling Index (SI) and Grading Limits his study focused on the evaluation of the performance to the established requirement of fill material (G3) used for roadwork in Tanzania [1].

The main objective of the study is to evaluate the effect of moisture content, PI, and fines content in the fill material used for roadwork practice. The study has been undertaken to review the causes of premature deformation caused by the fill layer. Uneven settlement, permanent deformation and other distress have been experienced in Tanzania, whereby the contributed factors are associated with the subgrade deformation. Lack of an adequate engineering solution, difficulties in specifying, testing, and interpreting laboratory and field tests, geological set up, and stratification have accelerated the structural failure of the pavement roadbed, fill layer and improved subgrade [2-5].

LITERATURE REVIEW

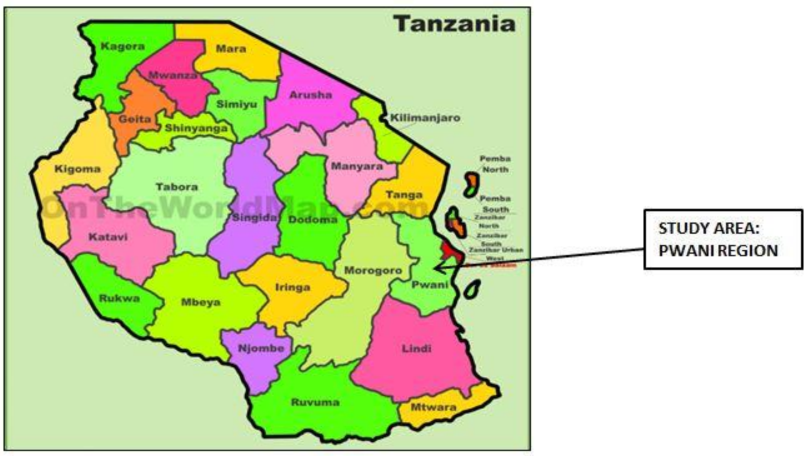
The studies by Elliott, Dennis, Qiu nd, Gao, et al. have stated that fill layer contribute the occurrence of uneven settlement and rutting to the pavement in great extent compared with others factors. The permanent deformation associated with fill layer is a difficult point to ascertain in the field of highway engineering but has affected the road performance by deteriorating the stiffened of other pavement structures to withstand the vertical strain of other layers. Gao et al. found that through the construction of micro piles between subgrade and pavement layer, the deformation at the toe of the slope, the shoulder, and the center of the roadbed was reduced by more than 96%.

METHODOLOGY

The soil test samples were collected from the borrow pit used for fill layer. The preference for selection was based on soil with CBR values ranging between 3 to 7 (G3). The experiments exercise undertaken was based on empirical and mechanistic empirical method which examines the performance CBR and Mr values. The Mr value was opted to characterize the effect of moisture under variation of fine content [6].

The borrow pit sampling exercise was conducted according to the standard procedures stated in the field testing manual established by ministry of Work. The fill material representative were collected from four (4) borrow pits, namely Lulanzi, Pangani, Viziwaziwa and Miwaleni located in Pwani region. Pwani region is located along the coast zone of Indian Ocean in Tanzania. It possesses moderate climatic condition. The Figure 1 below indicates the geographic location of Pwani region attempted for soil sampling used for investigation [7].

Figure 1. The Map of Tanzania indicating the study area.



The soil properties tests founded meet the standard specification for roadworks. The sample identification was classified based on the amount of fines in the soil specimen [8]. The sample identifications used are shown to the Table 1 below.

Table 1. Illustrate the sample identification number.

S/N	Sample label	Explanation
1	LUL/80/FLM	Fill material sampled from the Lulanzi borrow pit constitute 80% of fine content (original sample)
2	PAN/21/FLM	Fill material sampled from Pangani borrow pit constitute 21% of fine content (original sample)
3	LULPAN/45/FLM	Fill material sample obtained by blending Lulanzi and Pangani borrowed sample by 50/50 proportional. The material constitutes 45% of fine content.
4	LUL/60/FLM (a)	Fill material obtained by reducing the weight of fine content through sieve analysis test. (a), (b) and (c) constitute 60%, 10% and 5% of fine content respectively.
5	PAN/10/FLM (b)	
6	PAN/05/FLM (c)	
7	MIW/21/FLM	Fill material sampled from miwaleni borrow pit constitute 21% of fine content (original sample)
8	VIZ/42/FLM	Fill material sampled from viziwaziwa borrow pit constitute 42% of fine content(original sample)

Method for investigation the effect of moisture variation to the fill material

Evaluation of effect of moisture variability in the fill layers has been investigated. The corresponding test used for investigation is resilient modulus. The fabricated samples were prepared at three moisture conditions in the base from optimum moisture content. Since the standard specifications specify that, the lowest moisture content required for earthwork activities is 75% of the optimum moisture content. The amount deviation of ± 25% from Optimum Moisture Content (OMC) and 100% at OMC have been used as a representative to investigate the effect of moisture variability to each sample [9].

Systematic steps used to undertake the investigation fill material

Step I: Determination of the soil characteristics: The soil properties test undertaken by using empirical method. The tests conducted comprise of sieve analysis, compaction, CBR and waterberg limit. Table 2 indicates type of test undertaken.

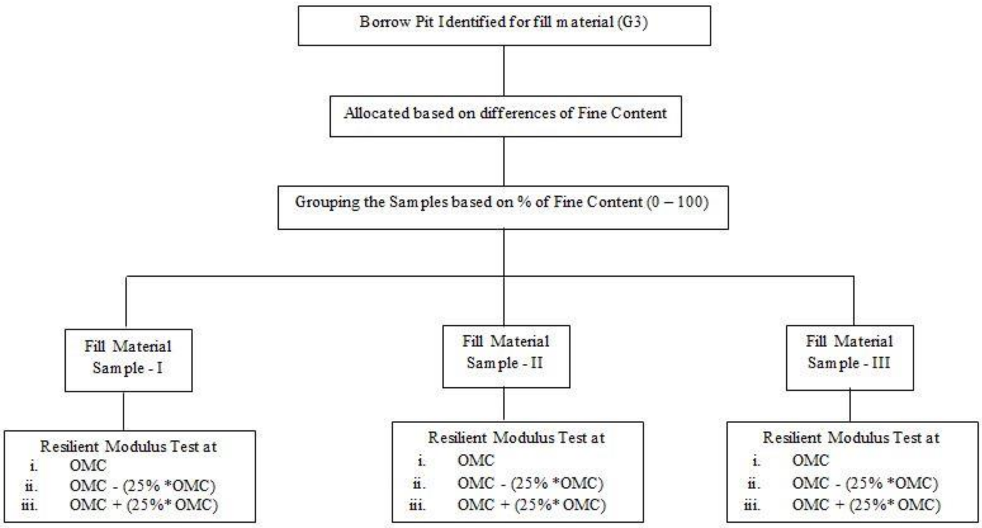
Table 2. Indicate type of soil properties tests conducted.

SN	Soil characteristics	
1	Moisture content	Natural moisture content
2	Waterberg limit test	Liquid limit (%) Plastic limit (%) Plasticity index (%) Linear shrinkage
3	Sieve analysis test	Gravel fraction, percent retained above sieve 4.75 mm (%) Coarse fraction, percent retained above sieve 0.075 mm (%) Fine fraction, percent passing sieve 0.075 mm (%) Evaluate GM and GC
4	Soil classification	USCS classification

5	Compaction Test	Optimum Water Content (OMC) (%) Maximum Dry Density (MDD) gr/cm^3
6	CBR Test	Soaked CBR testing at 93% of MDD Swell index (%)

Step II: Identified soil matrix for undertaking the resilient modulus for fill material: The soil matrix used to undertake the resilient modulus tests indicated in Figure 2 herein below.

Figure 2. Represent the soil index.



Step III: Determination the effects due to variation of moisture content: The assessment regarding the effect of moisture has been opted to the range of +25% and -25% from OMC. This has been adopted to fit the range of ± 25% as indicated in the standard specification. The tests of resilient modulus (Mr) were conducted according to AASHTO T307-99, 2017, and were undertaken at Tan roads central materials laboratory through the use of the UTM -130 installed equipment. Table 3 illustrates the procedure attempted to investigate the effect of moisture and fines content to the fill material specimen [10].

Table 3. Illustrate the procedure used to investigate the effect of moisture and fines content.

Sn	Testing	Sample group	Moisture condition	Moisture state	Test no.
1	Resilient modulus for subgrade (Fill material)	A	OMC	Moderate	1
			(OMC+25% × OMC)	Wet	2
			(OMC−25% × OMC)	Dry	3
2	Resilient modulus for subgrade (Fill material)	B	OMC	Moderate	4
			(OMC+25% × OMC)	Wet	5
			(OMC−25% × OMC)	Dry	6
3	Resilient modulus for subgrade (Fill material)	C	OMC	Moderate	7
			(OMC+25% × OMC)	Wet	8
			(OMC−25% × OMC)	Dry	9
4	Resilient modulus for subgrade (Fill material)	D	OMC	Moderate	10
			(OMC+25% × OMC)	Wet	11
			(OMC−25% × OMC)	Dry	12
5	Resilient modulus for subgrade (Fill material)	E	OMC	Moderate	13
			(OMC+25% × OMC)	Wet	14
			(OMC−25% × OMC)	Dry	15

6	Resilient modulus for subgrade (Fill material)	F	OMC	Moderate	16
			(OMC + 25% × OMC)	Wet	17
			(OMC – 25% × OMC)	Dry	18

RESULTS AND DISCUSSION

The soil engineering properties were conducted based on laboratory tests procedure of Central Materials Laboratory (CML) 1.2 – 14, 1.7, 1.9 and 1.1, of 2000 affiliated from BS 1377, 1990. The summary of soil index has been submitted in the Table 4 below.

Table 4. Show the summary of soil properties.

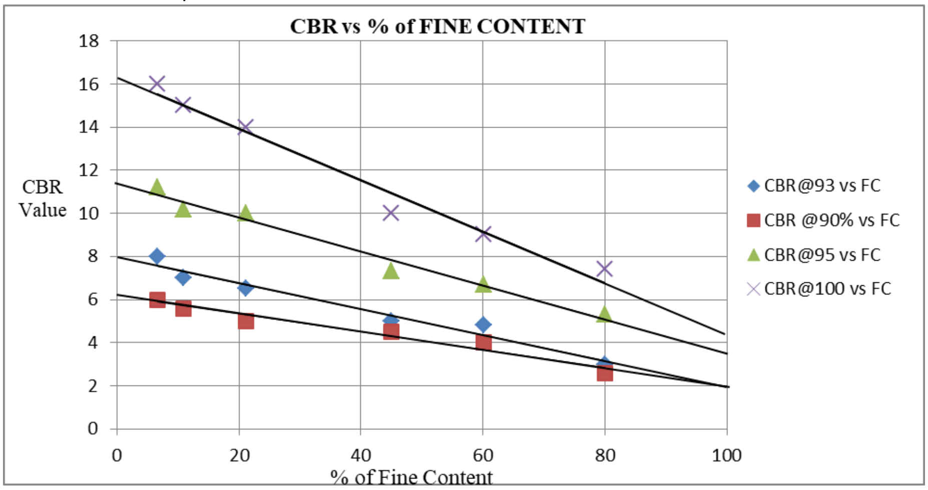
SUMMARY OF SOIL INDEX AND STRENGTH PARAMETERS																								
Borrow pit name	Sample No.	Atterberg Limits				Grading Modulus	Grading % passing												BS Compaction heavy		4 days Soaked CBR Value (%)			
							Sieve size (mm)												MDD	OMC	90%	95%	100%	Swell
		LL(%)	PL(%)	PI(%)	LS(%)		20	14	10	6.3	5	2	1.18	0.6	0.43	0.212	0.15	0.075	(kg/m³)	(%)	A	B	C	(%)
Lulanzi	LUL/80/FLM	51	21	30	13	0.3	100	100	100	100	100	100	97	94	90	86	82	80	1752	14	3	6	7.4	1.52
	*LUL/60/FLM	46	17.4	28.6	11	0.6	100	100	100	100	100	100	94	89	80	71	63	60	1817	11.2	4	7	9	1.24
Lulpan	*LUP/45/FLM	43	16	27	12	0.78	100	100	100	100	99	97	92	83	80	64	55	45	1874	9.6	5	7	10	2.91
Pangani	PAN/21/FLM	36.4	13.2	23.2	10	1.45	100	100	99	97	96	86	70	57	49	42	32	21	1888	7.8	5	10	14	1.441
	*PAN/10/FLM	30.3	10.1	20.2	8	1.6	100	100	99	97	96	84	67	51	42	34	23	11	1920	6.2	6	10	15	0.91
	*PAN/05/FLM	22.3	9.7	12.6	6	1.7	100	99	99	96	95	83	65	49	40	31	19	7	1966	5.5	6	12	16	0.6
Miwaleni	×MIW/21/FLM	21.1	12	9.08	7	1.4	100	98	97	95	94	86	79	64	50	39	26	21	1895	11.1	6	9	16	0.79
Viziwa ziwa	×VIZ/42/FLM	31.3	15.2	16.15	9	0.9	100	100	100	100	100	100	98	83	72	61	46	32	1880	9.2	9	13	23	1.58
CBR type A=62 blows 3 layers of BS light; CBR type B=30 blows 5 layers of BS heavy; CBR type C=62 blows 5 layers of BS heavy.																								
Note: *represent samples obtained from laboratory; × indicate untested samples for M_r																								

Evaluation of the relationship of CBR versus fines content

The study revealed that any increase of fine content in the soil structure affect the CBR value in the linear trend line. Increase of the fine content decreases the CBR value and decrease the fine content the CBR value is upgraded. Figure 3 represents the relationships of CBR at 90%, 93%, 95% and 100% of MDD versus the percentage of fines content [11-

15].

Figure 3. Relationship between CBR with fluctuation of fines content in the soil structure.

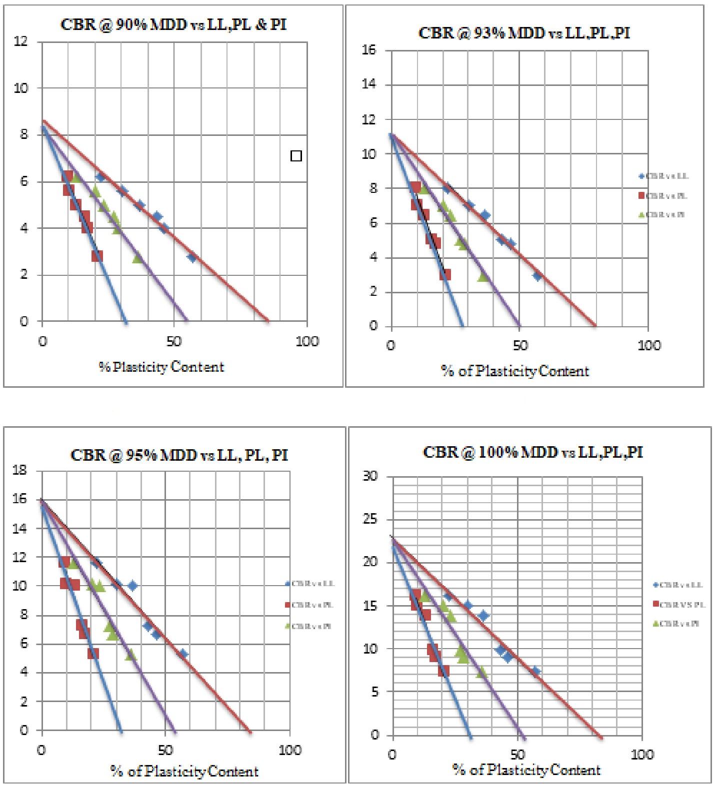


The CBR values founded to change according to the compaction energy employed. At 0% of fines content (0% passing sieve size 0.075 mm) and 100% of compaction has resulted the maximum CBR value compared with 90% of compaction. This implies that the highest CBR is achieved at highest degree of compaction [16-19]. Thus, the CBR value to the compaction of 95%>compaction of 93%>compaction of 90%. This observation is founded the same with the study undertaken by Inan, et al. that with an increase in fines the CBR value tends to decrease and vice versa.

Relationship between CBR versus liquid limit, plastic limit, and plasticity index

Any increment of LL, PL and PI decreases the CBR value and vice versa. Figure 4 represent the simple linear relationship between CBR as dependent variable at (90%, 93%, 95% and 100%) of MDD against plasticity parameters as independent variable.

Figure 4. (a). CBR @ 90% MDD *vs.* LL, PL and PI; (b). CBR @ 93% MDD *vs.* LL, PL, PI; (c). CBR @ 95% MDD *vs.* LL, PL, PI; (d). CBR @ 100% MDD *vs.* LL, PL, PI.



It is noted that the rate of change of CBR against LL, PL and PI is not same. The rate of change of PL lead at the highest followed by LL and PI. The graphs showed that at maximum value of LL, PL and PI have resulted low CBR value and at minimum values of plasticity parameter the CBR value is improved. Thus, it can be concluded that all plasticity parameters influence the performance of CBR. Also, the graphs revealed that degrees of compaction affect CBR in great extent compared with plasticity parameters. By neglecting effect of LL, PL and PI (at 0% of plasticity content), the CBR value of 8.2%, 11%, 16% and 23% at compaction of 90%, 93%, 95% and 100% respectively were obtained (Table 5). This implies that, the maximum compaction result high CBR and minimum compaction result low CBR. Thus, plasticity parameters and compaction are vital factors to be considered to adhere good strength of the fill layer [20]. The observation was founded to be the same as the study undertaken by B Shirur, et al.

Determination of the relationship between M_r, fines content and moisture content

Table 5. Indicates the summary of the resilient modulus result of the fill material.

Borrow pit name	Sample no.	% of fine content	BS compaction heavy		Strength				% MDD			CBR at 93 %	M_r at OMC (Mpa)	M_r at dry (Mpa)	M_r at wet (Mpa)	Dust ratio
			MDD	OMC	CBR 4 days soak (%)			Swell								
		Passing 0.075	(kg/m³)	(%)	A	B	C	(%)	A	B	C		at 93%			
Lulanzi	LUL/80/FLM	80	1752	14	3	6	7.4	1.5	90	96	100	3.1	38.55	61.42	20.29	0.9
	LUL/60/FLM	60.1	1817	11.2	4	7	9	1.2	89	97	99	4.8	40.82	60.6	27.89	0.8
Lulpan	LUP/45/FLM	45	1874	9.6	3	5	8	2.9	89	93	99	5	42.86	60.23	39.95	0.6
Pangani	PAN/21/FLM	21.2	1888	7.8	4	6	13	1.4	90	93	96	6.8	46.63	47.55	43.35	0.4
	PAN/10/FLM	10.9	1920	6.2	5	7	14	0.9	89	92	99	7	38.55	40.35	36.44	0.3
	PAN/05/FLM	6.7	1966	5.5	6	8	16	0.6	89	93	99	8	34.25	36.66	32.14	0.2
CBR type A=62 blows 3 layers of BS light.																
CBR type B=30 blows 5 layers of BS heavy.																
CBR type C=62 blows 5 layers of BS heavy.																

It is observed that the highest M_r value achieved is 61 Mpa to the specimen with fine content of 60% and 80% at the moisture content of 75% of OMC. The lowest Mr value obtained is 20 Mpa achieved in the specimens with fine content 80% at the moisture content of 125% of OMC. The study by Albert, et al. has proposed that the effective Mr used for subgrade and fill layer through the method described in the AASHTO T294-92 shall be equal or greater than 30 Mpa. The stated Mr should be acted as lowest value for fill layer throughout the pavement life despite of seasonal variation of moisture content to the fill layer.

The M_r of 20 Mpa and 28 Mpa obtained at fine content of 80% and 60% at moisture content of 125% of OMC were founded unsatisfactory to withstand the stiffness of the fill layer. Although, these samples have resulted highest Mr in dry condition but have poor performance when exposed to the wet condition. Excessive of moisture content in the specimen result unsatisfactory resilient modulus. The rate of change of M_r is dependent with the amount of fines content in the soil specimen. For the specimen with fine content ranging between (45%-80%), the rate of decrease of M_r is higher compared with the specimen with fines content ranging between (6%-44%). From Figure 4, the analysis for the rate of change of M_r is presented below.

- For the specimen with fines content of 21%, the rate change of M_r is 2.1% and 9% with moisture change from (75%*OMC to OMC) and (OMC to 125%*OMC) respectively.
- For fine content for 45%, the rate change of M_r is 28% and 7% with moisture change from (75%*OMC to OMC) and (OMC to 125%*OMC) respectively.
- For fine content of 60% the rate change of M_r is 33% and 32% with moisture change from (75%*OMC to OMC) and (OMC to 125%*OMC) respectively and
- For fine content, 80% of the rate change of M_r is 39% and 49% with moisture change from (75%*OMC to OMC) and (OMC to 125%*OMC) respectively.

The changes of M_r depend on the climate condition, environment, and drainage factors. The amount of fines content in

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