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Characterization of gravel borrow pits materials for construction of low volume roads in Dodoma Tanzania

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ABSTRACT

The study was conducted to investigate suitability of gravel materials from borrow pits which are used for low volume roads construction in Dodoma region Tanzania. Characterization of four borrow pits gravel materials from Dinda, Mahomanyika, Nkulabi and Ntyuka were conducted. Blending process of the borrow pits materials with sand from Ihumwa and clay from Michese in order to improve missed engineering properties were conducted. The GC, SP and PI were 25.4 units, 391.3 units and 16% for Dinda, 32.3 units, 56.0 units and 10% for Mahomanyika, 33.7 units, 148.1 units and 14% for Nkulabi and 32.8 units, 111.2 units and 13% for Ntyuka borrow pit materials respectively. Results of CBR for source materials were 14%, 16%, 29%, and 30% for Dinda, Nkulabi, Mahomanyika, Ntyuka borrow pits materials respectively. The results indicated that all source gravel materials did not comply with requirements as gravel materials for low volume roads. This is because Mahomanyika borrow pit materials has low SP values which required blending with clay materials and Dinda, Nkulabi and Ntyuka have high PI values which required blending with sand. Results of GC, SP and PI for the blended materials were 20.1 units, 259.9 units and 12% for 75Dind25San, 31.3 units, 126.7 units and 11.9% for 85Mah15Cla, 31.0 units, 120.0 units and 11.2% for 80Nku20San and 30.3 units, 104.2 units and 10.4% for 80Nty20San respectively. CBR values of blended materials were 19%, 32%, 16% and 26%, for 75Din25San, 85Mah15Cla, 80Nku20San and 80Nty20San respectively. It has been investigated that all blended materials are suitable for construction of low volume roads in Dodoma region since they have satisfied GC, SP, PI and CBR requirements as surfacing materials for construction of low volume roads. It is important to characterized source materials before use in order to investigate engineering properties. In case source materials lack some engineering properties it is necessary to blend with other materials in order to improve missing engineering properties before use.

Keywords: Gravel Materials, Low Volume Roads, Characterization, CBR, Blending

INTRODUCTION

Roads, especially low volume roads (LVRs) are the most feasible door-to-door means of service delivery used for transportation of goods and passengers worldwide (Berg, Deichmann, & Selod, 2015). In Tanzania, LVRs are those which carry a load not exceeding 1 million cumulative equivalent standard axles (CESA) throughout their service life and a volume of about 300 vehicles per day (MTPW, 2020). They catalyse socio-economic growth of a country through education, health services, agriculture, business and many other (SATCC, 2003). Low volume roads constitute up to about 90% of the road networks in the least developed countries (Sampson, Rust & Smit, 2022). In Tanzania, they account for 75% of the classified roads network serving a population of about 80% of Tanzanians (Chengula & Mnkeni, 2021). Most LVRs in Tanzania are unpaved having natural earth or gravel surfaces. These roads are therefore naturally susceptible to conditions which cause rapid deterioration especially during rainfall (Kuleno & Lera, 2020). To ensure they persistently provide uninterrupted service, timely construction and maintenance involving the use of good materials which meet specifications is inevitable (MTPW, 2020).

In most cases, construction and maintenance of LVRs rely on the use of naturally occurring materials which are often marginal or non-standard (Austroads, 2018). In order to make optimum use of such materials, it is important to device means of improving them so that they can meet the specified standards (Mwita, Chengula & Msambichaka, 2024). Blending is one of such possible ways of treating the materials in order to achieve the goal (MRH, 2019). Suitable materials for construction of unpaved LVRs gravel wearing courses are mainly dependent on binding, packing, interlocking and strength properties of the materials. These engineering properties are determined through laboratory testing methods which are Atterberg limits, sieve analysis, compaction and California bearing ratio (CBR) tests (MOW, 2000).

Scarcity of suitable materials which meet all requirements for construction of gravel wearing courses for LVRs is a prevailing challenge throughout the world (Rahaman & Mostafa, 2020). With such shortage, the locally available materials need to be improved so that they can successfully be utilized for road works. Four parameters which are plasticity index (PI), grading coefficient (GC), shrinkage product (SP) and CBR are the governing factors for selection of suitable materials for construction of LVRs. Specifications for suitable gravel materials for construction of LVRs are 6% - 12%, 16 - 34 units, 100 – 365 units and a minimum value of 15% soaked CBR at 95% maximum dry density (MDD) for PI, GC, SP and CBR respectively (ERA, 2011). When one or more values of the four parameters does not comply with the specifications, the constructed roads are deemed to provide poor service and will deteriorate rapidly. When PI is below 6% the materials will not bind together and when it is above 12% the road materials will be slippery during rain fall. When GC is below the specified range, the road erodes and when it is above the range, the road ravels. For SP, when the value is below the range, the road ravels and forms corrugations whereas higher values make the road slippery. Likewise, when the CBR value is below the specified requirement, the road cannot withstand traffic loading imposed on it (RDA, 2014).

Most existing borrow pit materials in Dodoma lack one or more of the requirements stipulated in the manuals, making them unsuitable for construction of gravel wearing course for LVRs. This study investigated engineering properties of four borrow pits materials which are used for construction of LVRs in Dodoma region. The aim was to examine engineering properties of existing materials and propose methods to improve non-compliant materials based on results of the tests.

MATERIALS AND METHODS

Materials

Materials used in this study are gravel soils collected from Dinda, Mahomanyika, Nkulabi and Ntyuka borrow pits, sand from Ihumwa and clay from Michese in Dodoma region. Collection of samples for the study handling and transporting material for laboratory testing were done according to procedure stipulated in MOW, 203. Collected samples were then characterized in order to determine values of parameters which are used to select suitable materials for construction of gravel wearing course of LVRs.

Methods

Samples of materials collected from borrow pits were tested in the laboratory to determine their engineering properties. Suitable materials for construction and maintenance of gravel wearing course of LVRs are selected using specified engineering properties (Pinard & Hongve, 2020). Laboratory tests conducted for each borrow pit material were particle size distribution (sieve analysis), Atterberg limits (liquid limit, plastic limit and shrinkage limit), compaction test and California bearing ratio (CBR) test. Testing for strength parameters of gravel materials was conducted by using CBR test method.

The particle size distribution tests were carried out to determine gradation of particle size and percentage passing for four designated sieves used to compute GC and SP. Percentage of material passing sieve sizes of 26.5 mm, 4.75 mm, 2 mm, and 0.425 mm were used to compute grading coefficient (GC) and shrinkage product (SP) while percentage of material passing through sieve sizes of 2 mm, 0.425 mm and 0.075 mm were used together with Atterberg limits to classify the materials based on AASHTO soil classification system (MOW, 2000). Figure 1 shows gradation curves of the borrow pit materials.

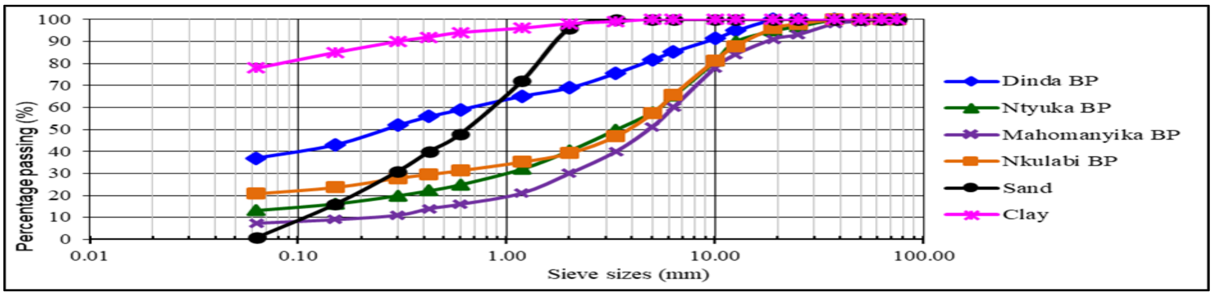

Figure 1: Gradation Curves of Source Materials

The Atterberg limits tests for determination of liquid limit and plastic limit were carried out so as to compute plasticity indices (PI) and determine linear shrinkage limit (MOW, 2000). The

PI provides indication of binding properties of materials and recommended range for construction of LVRs is 6% – 12% (MOWTC, 2016). PI is also a deterioration parameter for estimation of gravel loss (Henning, Giummarra & Roux, 2008). Likewise, linear shrinkage limit provides indication of shrinkage and swelling potential of the material when subjected to changing weather condition and also is used for computation of shrinkage product (Rolt, Otto, Mukura, Reeves, Hine & Musenero, 2020).

Compaction tests were also conducted in order to determine optimum moisture contents (OMC) and maximum dry densities (MDD) using modifies BS heavy proctor test. OMC and MDD are useful parameters during CBR testing. For this study, the value of CBR at 95% MDD was considered as strength of the material (MRH, 2019).

RESULTS AND DISCUSSION

Source Materials

The particle size gradation test was conducted in order to examine physical characteristics, type and classes of the material. The test is also used to establish values for computation of GC and SP parameters (ERA, 2011). Table 1 shows physical characteristic, type of materials and their classes according to AASHTO soil classification system (Chengula & Mnkeni, 2021).

Table 1

Classification of Source Materials

Description	Name of borrow pit materials					
	Dinda	**Mahomanyika**	**Nkulabi**	**Ntyuka**	**Sand**	**Clay**
Sample Abbreviation	Din	Mah	Nku	Nty	San	Cla
Physical properties	Reddish brown	Reddish brown	Reddish brown	Reddish brown	Pale brown	Redish brown
AASHTO Classification	A-6 Clayey soil	A-2-4 Silty or clayey gravel and sand	A-2-6 Silty or clayey gravel and sand	A-2-4 Silty or clayey gravel and sand	A-3 Fine sand	A-7-6 Clayey soil
% Fines	37	7	21	13	1	78
% Sand	32	23	18	27	97	20
% Gravel	31	70	61	60	2	2

The Atterberg limits tests include liquid limit (LL), plastic limit (PL) and linear shrinkage limit (LS) tests. Plasticity Index (PI) which is an indicator for binding property of the soil is also computed from the LL and PL. Table 2 summarizes results obtained from Atterberg limits tests of source materials.

From the results, plasticity indices (PI) for Dinda, Mahomanyika, Nkulabi, Ntyuka, sand from Ihumwa and clay from Michese source materials are 16%, 10%, 14% 13.0%, 0 and 23% respectively (refer Table 2). PI values for Dinda, Nkulabi and Ntyuka borrow pit materials are higher that the specified range of 6% to 12% which makes them unsuitable for construction of gravel wearing course of LVRs (MOWTC, 2016). Therefore, materials from Dinda, Nkulabi and Ntyuka need to be blended with non-plastic materials to reduce the PI in order to meet requirement.

Table 2

Atterberg Limits Data of Source Materials

Parameter	**Name of Sampled Borrow Pit**					
	Dinda	**Mahomanyika**	**Nkulabi**	**Ntyuka**	**Sand**	**Clay**
Abreviation	**Din**	**Mah**	**Nku**	**Nty**	**San**	**Cla**
Liquid limit (LL) (%)	35	26	32	30	NP	56
Plastic limit (PL) (%)	19	16	18	17	NP	30
Plasticity index (PI) (%)	16	10	14	13	NP	26
Linear shrinkage limit (SL) %	7	4	5	5	0	13

Results of grading coefficient (GC) and shrinkage product (SP) which were basically computed from the particle size gradation test were 25.4, 391.3 units for Dinda, 32.3, 56.0 units for Mahomanyika, 33.7, 148.1 units for Nkulabi, 32.8, 111.2 units for Ntyuka 4.0 and 0 units for sand and 2.0 and 1196 units for clay materials respectively. Through these results, materials from Nkulabi and Ntyuka complied with the specifications of 16 – 34 units for GC and 100 – 365 units for SP respectively (MWT, 2018). Materials from Dinda borrow pit has high SP values which indicate that they are slippery during rainy season and dusty during dry season. However, materials from Mahomanyika borrow pit has low SP value which indicates that they ravel and corrugate when used for construction of gravel wearing course of LVRs (MHID, 2019). The GC and SP are computed from equations 1 and 2 respectively (MPW, 2019). Table 3 shows particle size data, grading coefficient and shrinkage product results of source materials.

$$\mathrm{GC} = \frac{\mathrm{P4.75(P26.50-2.00)}}{100} \qquad (1)$$

Where: Letter "P" denotes percentage passing and number in front of letter "P" denotes sieve size in mm.

$$\mathrm{SP} = \mathrm{P0.425SL} \qquad (2)$$

Where: Letter "P" denotes percentage passing, number in front of letter "P" denotes sieve size in mm and "SL" denotes shrinkage limit.

Table 3

Particle Sizes, Grading Coefficients and Shrinkage Products of Source Materials

Description	**Sieve Sizes**	**Name of borrow pits**					
		Dinda	**Mahomanyika**	**Nkulabi**	**Ntyuka**	**Ihumwa sand**	**Michese clay**
Percentage of materials Passing	26.50 mm	100	93	98	97	100	100
	4.75 mm	82	51	57	58	100	100
	2.00 mm	69	30	39	40	96	98
	0.425 mm	56	14	30	22	40	92
Grading coefficient (GC)		25.4	32.3	33.7	32.8	4.0	2.0
Shrinkage product (SP)		391.3	56	148.1	111.2	0.0	1196.0

The four borrow pit gravel materials were blended with sand and clay materials at different proportions. Equation 3 was used to estimate proportions of materials to be blended (Chengula & Mnkeni 2021).

$$PA = \frac{260-(GC_B+SP_B)}{(GC_A+\mathrm{SP}_A)-(GC_B+SP_B)} \text{ and } P_B = 1 - P_A \qquad (3)$$

Where: P_A and P_B are proportions of material A and B respectively in decimal, GC_A and GC_B are grading coefficients of material A and B respectively, SP_A and SP_B are the shrinkage products of materials A and B respectively.

Results of OMC and MDD determined from compaction test were 9.5% and 2032 kg/m^3 for Dinda, 8.4% and 2109 kg/m^3 for Mahomanyika, 8.8% and 2054 kg/m^3 for Nkulabi and 9.3% and 2007 kg/m^3 for Ntyuka, 1620 kg/m^3 and 9.2% for sand from Ihumwa and 1620 kg/m^3 and 25% for clay material from Michese respectively. The OMC and MDD were useful parameters during materials preparation and determination of CBR tests. Figure 2 shows compaction curves for the source materials.

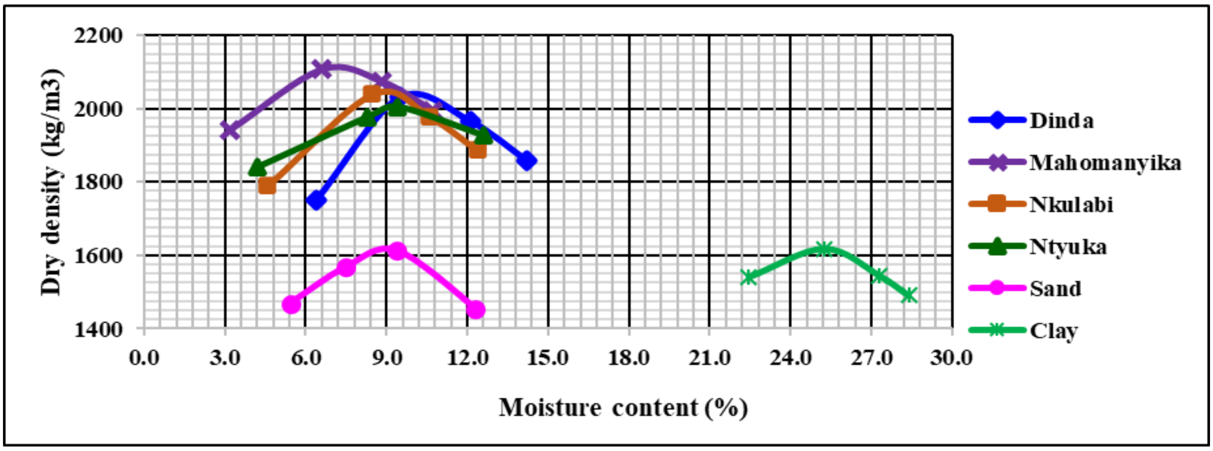

Figure 2: Compaction Curves for Source Materials

Results of CBR tests for source materials were 14.0%, 16.3%, 29.4%, 29.6%, 11.2% and 4.5% for Dinda, Nkulabi, Mahomanyika, Ntyuka, sand from Ihumwa and clay from Michese respectively. CBR value for suitable gravel materials to be used for construction of wearing course of LVRs stipulated in most of the low volume roads manuals is a minimum of 15% at 95% MDD soaked condition (ERA 2011, MOWTC 2016, MHID 2019). Materials from Nkulabi, Mahomanyika and Ntyuka complied whereas materials from Dinda, sand from Ihumwa and clay from Michese did not comply with CBR requirement. Figure 3 shows CBR graphs of source materials.

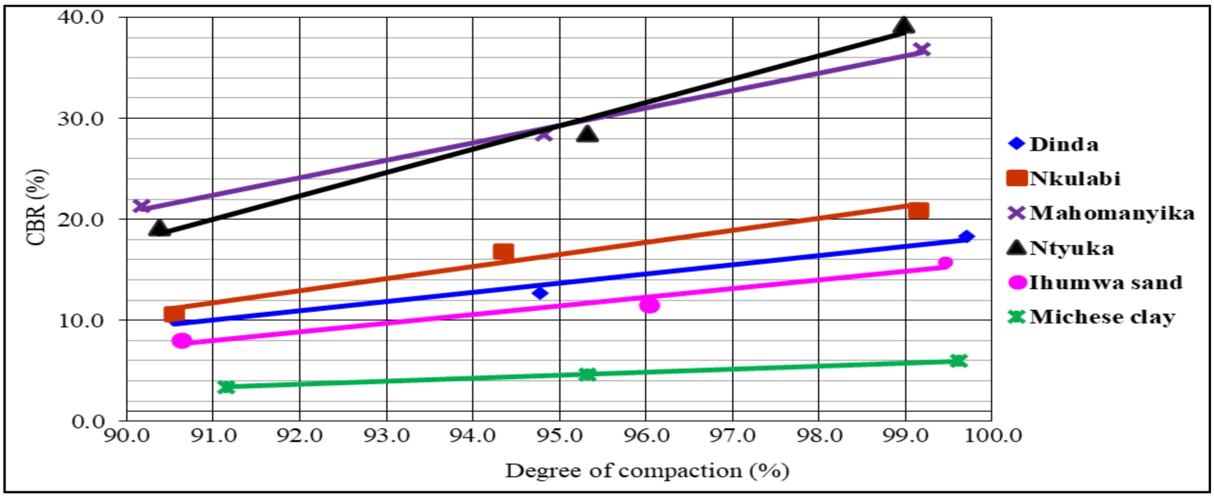

Figure 3: Three Points CBR Graphs for Source Materials

Results from the characterization process indicated that none of the borrow pit materials complied with all requirement for use as LVRs gravel wearing coarse materials. Materials from Dinda borrow pit complied with grading coefficient (GC) requirement but not with plasticity index (PI), shrinkage product (SP) and strength requirement (CBR). In order to improve its properties, materials from Dinda borrow pit required to be blended with non-plastic materials such as sand.

Materials from Mahomanyika borrow pit complied with PI, GC and strength properties but they did not comply with SP requirements because the value is below the range which imply that it has low binding ability. These materials required to be blended with plastic materials such as clay to improve their binding properties.

Materials from both Nkulabi and Ntyuka borrow pits complied with GC, SP and CBR properties but not with PI. The source materials required to be blended with non- plastic materials in order to improve their PI properties in order to be used for construction of LVRs gravel wearing course (MRRD, 2020).

Blended Materials

Construction of roads need the use of materials which comply with specified requirements. However, borrow pits with suitable materials are being depleted especially in most developing countries (Rahaman & Mostafa 2020). Materials found in most existing borrow pits no longer meet all specifications for packing, interlocking, binding and strength properties to suit the use as gravel wearing course for low volume roads. Due to fast growth of Dodoma region and high demand of road construction, natural gravel resources are scarce and little available gravel materials are being depleted having limited requirements suitable for construction of LVRs. Therefore, it is necessary to ensure that little available natural gravel materials are blended with other marginal locally available materials in order to obtain suitable materials for construction of LVRs wearing courses. This study therefore focused on blending available borrow pit materials with sand and clay to improve engineering properties in order to be use as gravel wearing course materials for LVRs in Dodoma (MTIHUD, 2017).

The proportions obtained for borrow pit gravel materials with sand and clay materials are 75% for Dinda gravel materials by 25% for Ihumwa sand (75Din25San), 80% for Nkulabi gravel materials by 20% for Ihumwa sand (80Nku20San), 80% for Ntyuka gravel materials by 20% for Ihumwa sand (80Nty20San) and 85% for Mahomanyika gravele materials by 15% for Michese clay (85mah15Cla). After blending, the particle size gradation was conducted on the blended samples to determine gradation and percentage passing for four designated sieve sizes (MOW, 2000). Figure 4 shows gradation curves for blended materials.

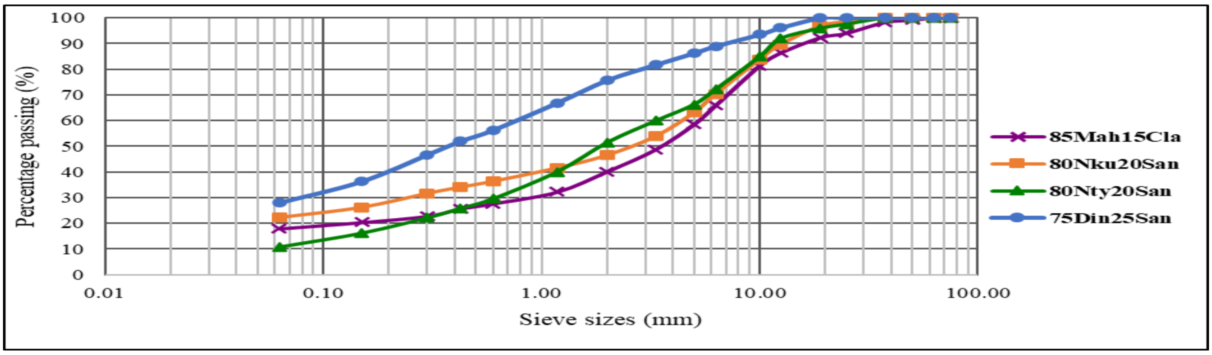

Figure 4: Gradation Curves for Blended Material

Results of GC and SP for blended materials were 20.1 and 259.9 units for 75Din25San, 31.3 and 126.7 units for 85Mah15Cla, 31 and 120 units for 80Nku20San and 30.3 and 104.2 units for 80Nty20San respectively. All blended materials complied with the requirements of 16 to 34 units for GC and 100 to 365 units for SP (Chengula and Mnkeni, 2021; MTPW, 2020). Table 4 shows particle sizes, grading coefficient (GC) and shrinkage products (SP) of the blended material.

Table 4

Particle Sizes, GC and SP of Blended Material

Description	Sieve Sizes	Abbreviations of blended materials			
		75Din25San	**85Mah15Cla**	**80Nku20San**	**80Nty20San**
Percentage of materials Passing	26.50 mm	100	94.1	98.4	97.6
	4.75 mm	86.5	58.4	65.6	66.4
	2.00 mm	76.8	40.4	51.2	52.0
	0.425 mm	49.5	25.9	30.0	40.0
Grading coefficient (GC)		20.1	31.3	31.0	30.3
Shrinkage product (SP)		259.9	126.7	120.0	104.2

Results of Atterberg limits test show that plasticity indices (PI) for 75Din25San, 85Mah15Cla, 80Nku20San and 80Nty20San were 12%, 11.9%, 11.2% and 10.4% respectively. Plasticity indices (PI) for all blended materials are within the specified range of 6% to 12% which make them suitable for construction of LVRs gravel wearing course. Table 5 shows Atterberg limits data for blended materials.

Table 5

Atterberg Limits Data for Blended material

Parameter	Abbreviations of blended materials			
	75Din25San	**85Mah15Cla**	**80Nku20San**	**80Nty20San**
Liquid limit (LL) (%)	32.8	30.8	30.8	29.2
Plastic limit (PL) (%)	20.8	18.9	19.6	18.8
Plasticity index (PI) (%)	12.0	11.9	11.2	10.4
Linear shrinkage limit (SL) %	5.3	4.9	4.0	4.0

Results of OMC and MDD from compaction tests were 14.2% and 1860 kg/m^3 for 75Din25San, 7.0% and 1890 kg/m^3 for 85Mah15Cla, 14.1% and 1905 kg/m^3 for 80Nku20San and 8.0% and 2110 kg/m^3 for 80Nty20San respectively. Figures 5 shows compaction curves of blended materials.

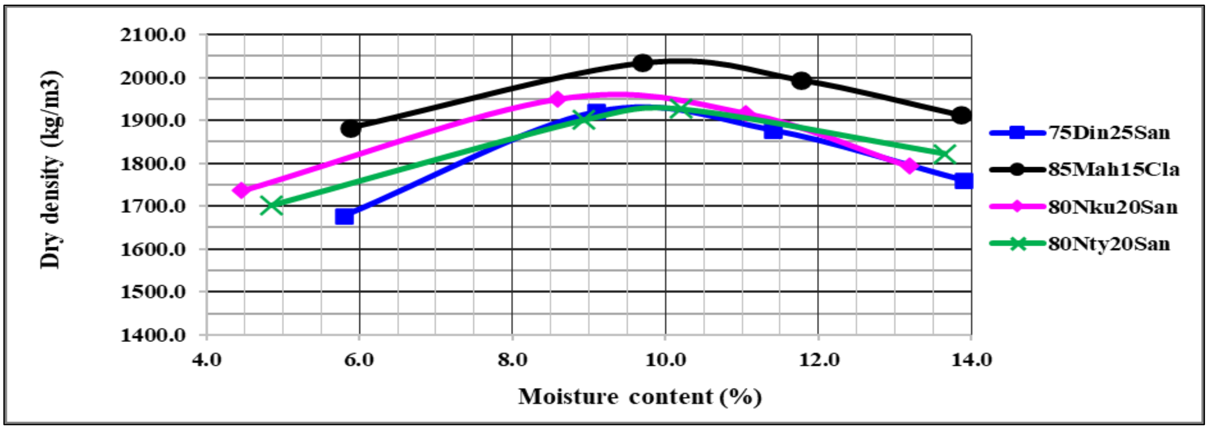

Figure 5: Compaction Curve for Blended Materials

Results of CBR tests at 95% MDD soaked samples for blended materials were 19%, 32%, 16% and 26%, for 75Din25San, 85Mah15Cla, 80Nku20San and 80Nty20San respectively.

Requirement of suitable materials for construction of LVRs gravel wearing course is a minimum of 15% CBR at 95% MDD. All blended materials complied with the requirement. Figure 6 shows CBR test graphs for blended materials.

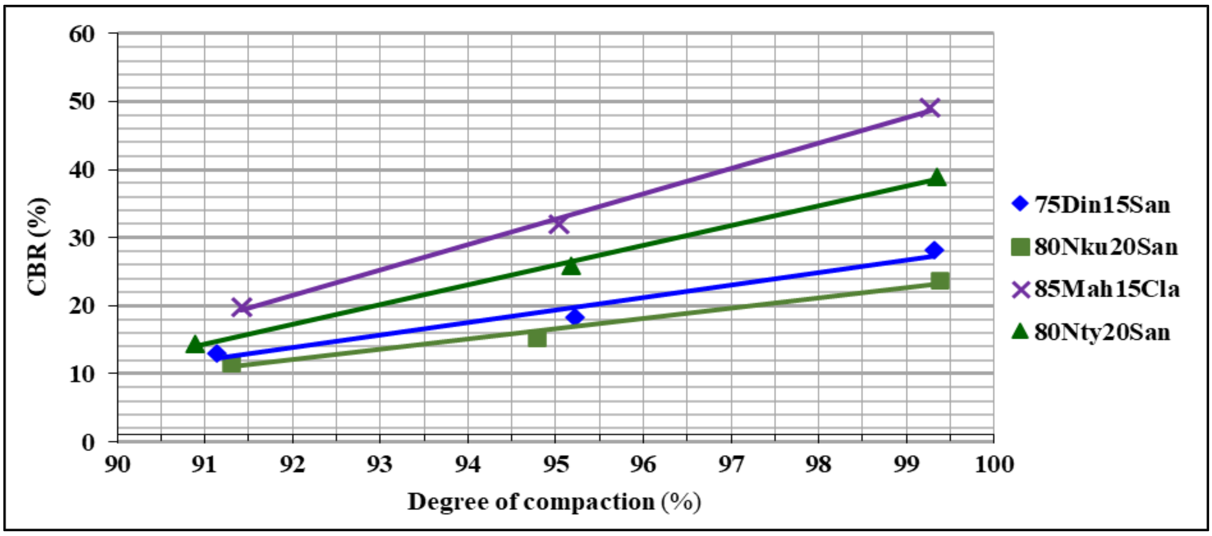

Figure 6: Three Points CBR Test Graph for Blended Materials

CONCLUSION AND RECOMMENDATIONS

This study characterized both source and blended materials to determine their engineering properties. The California bearing ratio (CBR) test was used to evaluate strength of materials currently used for various construction activities in Dodoma. Results of plasticity index (PI), grading coefficient (GC) and shrinkage product (SP) of the source materials were 16%, 25.4, 391.3 units for Dinda, 10%, 32.3, 56.0 units for Mahomanyika, 14%, 33.7, 148.1 units for Nkulabi, 13%, 32.8, 111.2 units for Ntyuka NP, 4.0 and 0 units for sand from Ihumwa and 26%, 2.0 and 1288 units for clay materials from Michese respectively. None of the materials complied with requirements of grading and binding properties for construction of LVRs gravel wearing course.

The strength values of source materials in-terms of CBR at 95% MDD were 14%, 15%, 29%, 30%, 11% and 4.5% for Dinda, Nkulabi, Mahomanyika, Ntyuka, sand from Ihumwa and clay from Michese respectively.

This study found that after blending of gravel borrow pits materials with sand and clay, all borrow pit materials improved their engineering properties and complied with requirements for construction of LVRs gravel wearing course. It is recommended that, materials with PI values higher than 12 should be blended with non-plastic materials such as sand to lower the PI to acceptable range and materials with low SP values should be blended with plastic materials such as clay to improve binding properties.

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Appendices

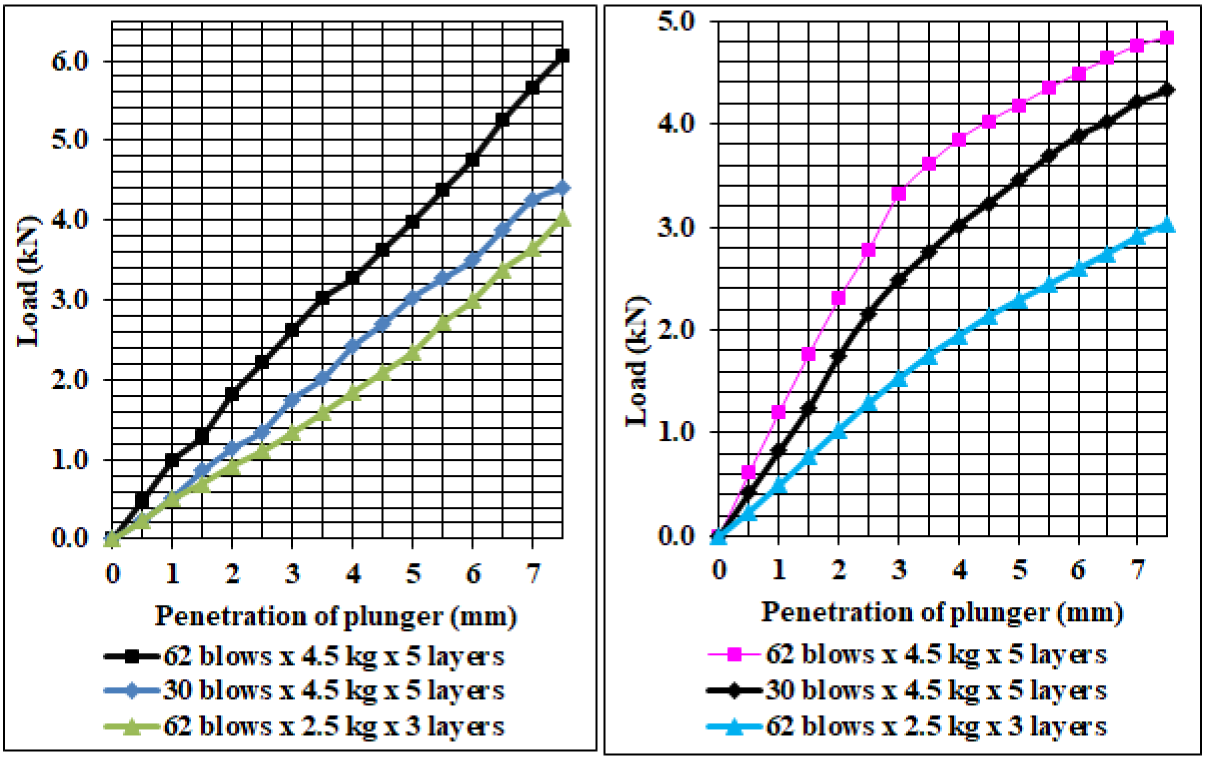

Figure 1A: CBR penetration resistance of source materials for Dinda (left) and Nkulabi (right) borrow pits

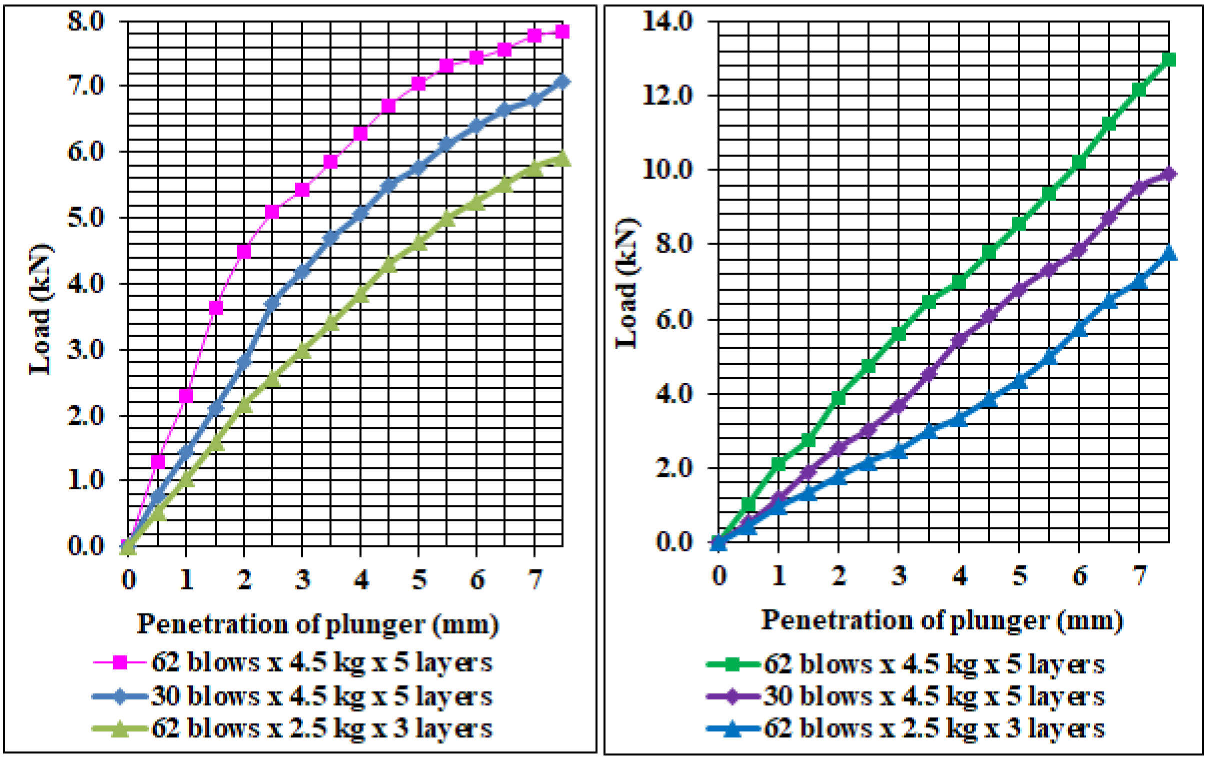

Figure 2A: CBR penetration resistance of source materials for Mahomanyika (left) and Ntyuka (right) borrow pits

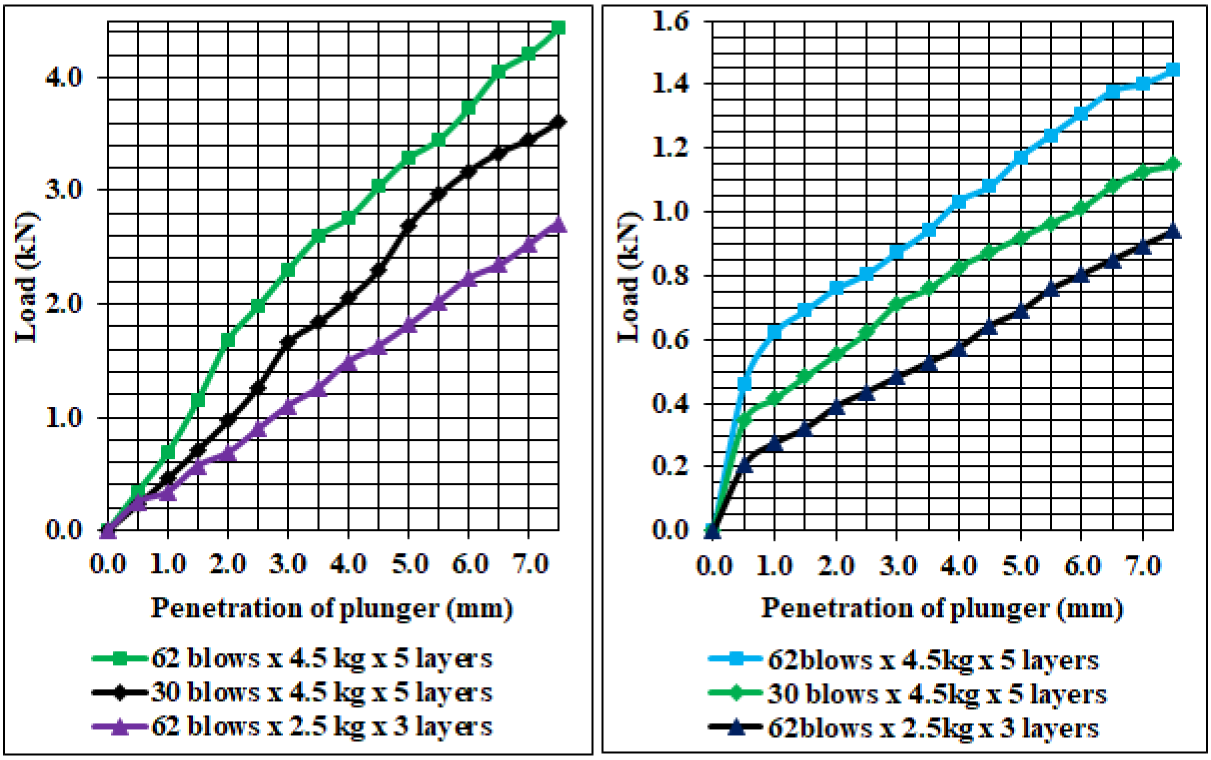

Figure 3A: CBR penetration resistance of source materials for Ihumwa sand (left) and Michese clay (right) borrow pits

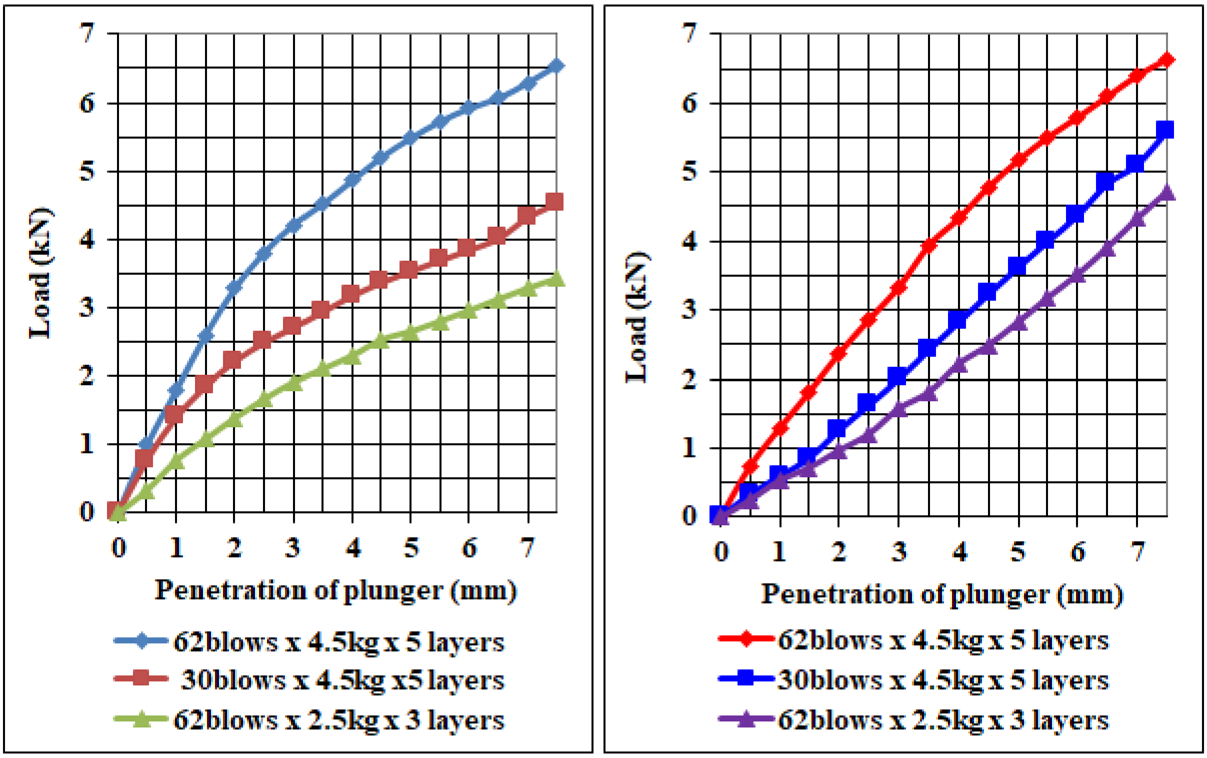

Figure 4A: CBR penetration resistance of blended materials for 75Din25San (left) and 80Nku20San (right)

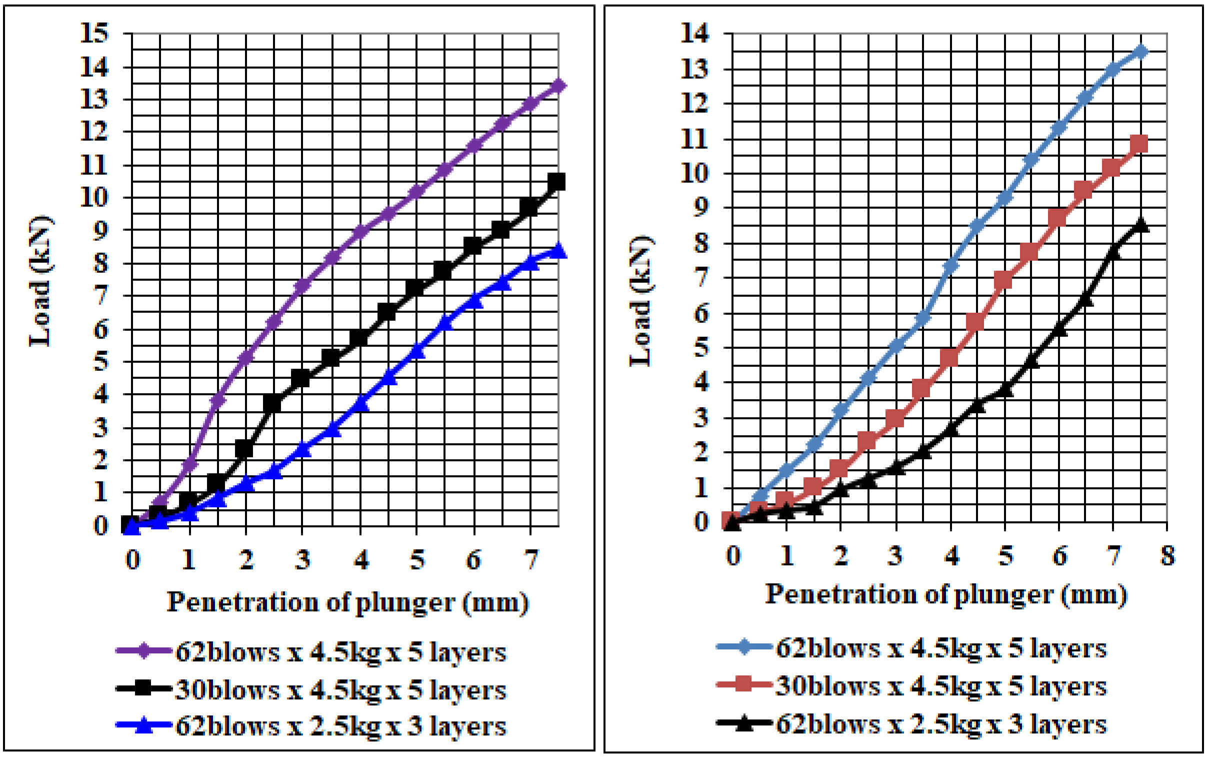

Figure 5A: CBR penetration resistance of blended materials for 55Mah15Cla (left) and 80Nty20San (right)