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Determination of Dynamic Cone Penetration Index (DCPI) of Borrow Pit Materials for Construction of Low Volume Roads in Dodoma Tanzania

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ABSTRACT

The study for determination of dynamic cone penetration index (DCPI) of borrow pit materials for construction of low-volume roads was conducted in the Dodoma region in Tanzania. Samples for tests were collected from five borrow pits, which are Nkulabi, Zuzu, Mahomanyika, Dinda, and Ntyuka. Results of plasticity indices were 14%, 11%, 10%, 16%, and 13% for Nkulabi, Zuzu, Mahomanyika, Dinda, and Ntyuka borrow pits, respectively. Results of grading coefficients and shrinkage products were 33.7 and 148.1 units for Nkulabi, 19.9 and 295.9 units for Zuzu, 32.3 and 56.0 units for Mahomanyika, 25.4 and 391.3 units for Dinda, and 32.8 and 111.2 units for Zuzu borrow pits, respectively. Results of dynamic cone penetration indices were 5.8 mm/blow, 5.2 mm/blow, 4.7 mm/blow, 6.0 mm/blow, and 4.5 mm/blow for Nkulabi, Zuzu, Mahomanyika, Dinda, and Ntyuka borrow pits, respectively. Specifications require DCPI values for the tested material not to exceed 5.69 mm/blow in order to be suitable for use as gravel-wearing course material. Therefore, these results indicate that materials from Zuzu, Mahomanyika, and Ntyuka borrow pits have satisfied the requirement and hence qualify to be used as gravel-wearing course material. However, materials from Dinda and Nkulabi borrow pits have DCPI values above the limiting value of 5.69 mm/blow, and therefore they did not meet strength requirements as gravel-wearing course material. Based on grading coefficient, shrinkage product, and strength parameters, which are used for the selection of suitable materials, only Zuzu borrow pit materials qualified for the construction of the gravel wearing course. Therefore, engineering properties of materials from Dinda, Mahomanyika, Nkulabi, and Ntyuka need to be improved through the blending process.

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1.0 Introduction

The Dynamic Cone Penetrometer (DCP) is a soil-penetrating device that was initially intended to be used for assessment of the bearing capacity of in situ materials during upgrading or design of new roads (Paige-Green, 2021). Records of its development go back to 1956 when Scala developed the original DCP device in Australia (Paige-Green & Van Zyl, 2019). The DCP comprises three essential features, which are weight (hammer), a drop height, and a cone tip. The original Scala DCP device had a 9 kg weight hammer, a 508 mm drop height, and a 30° cone tip angle. This DCP was mainly used for evaluation of the strength of in-situ pavement materials (Paige-Green P. & Du Plessis, L. 2009). The DCP was improved to the current standard in the 1970s in South Africa, and since then, its use was advocated, and it was later accepted worldwide. Before improvements were done, various researchers designed the three features of DCP, which are hammer weight, drop height, and cone tip angle, based on individual requirements of the test outputs. The approved standard DCP device in use today has a hammer weighing 8 kg, dropping through a height of 575 mm and a cone tip angle of 60° (MnDOT, 1993).

The assembly of DCP apparatus involves the upper rod, which connects the handle and anvil, and the lower rod, which connects the anvil and the cone. Both the upper and lower rods are made of 16 mm steel. The upper rod is used to guide plumbness and also limits the drop height of the hammer. The lower rod, which is standardised to 1000 mm penetration length, is used for the transmission of impact energy caused by the free-dropping hammer from the anvil fixed at its upper end to the cone, which is fixed to its lower end. The lower rod can always be extended by an extension rod to a length beyond 1000 mm to suit the investigation depth. The DCP with these features is currently an approved testing method that is used to determine the strength of shallow pavement materials worldwide (ASTM, 2015).

The strength of pavement materials tested by using the DCP device is measured in terms of DCP index (DCPI), and the unit of measurement is mm/blow (Paige-Green & Van Zyl, 2019). Characteristically, the DCPI is inversely proportional to strength, in which the higher the strength of pavement materials, the lower the DCPI (Hagström, 2017). Currently, DCP devices are mostly used for measuring the strength of pavement layers such as subgrade, subbase, and base course layers (Siekmeirer et al., 2009; Wu & Sargand, 2007). Moreover, results of material strength obtained from DCP tests are also acceptable to be used for the design of new pavements and rehabilitation works (SANRA, 2014). To validate DCP test results, various studies have successfully been conducted to correlate DCPI with other strength parameters such as California bearing ratios (CBR), unconfined compressive strengths (UCS), and resilience modulus (MR) (Wu & Sargand, 2007). Equations 1, 2, and 3 present relationships between DCPI and CBR, UCS, and MR, respectively (Paige-Green & Du Plessis, 2009; Mohammad, 2006).

$$\mathrm{CBR} = 410\mathrm{DN}^{-1.27} \tag{1}$$

$$\mathrm{UCS} = 2900 \text{ x } \mathrm{DN}^{-1.09} \tag{2}$$

$$\mathrm{M_R} = 122.4\left(\frac{1}{\mathrm{DCPI}}\right) \tag{3}$$

In Tanzania, roads are the most used mode of transport, carrying more than 90% of passengers and 75% of cargo traffic (McGuinness et al., 2023). Out of all classified road networks in Tanzania, about 75% of road networks are low-volume roads (LVRs) that serve more than 80% of the Tanzanian population (Chengula & Mnkeni, 2021). Putting roads into their high- and low-volume categories is normally decided according to requirements set out by responsible authorities such as the Ministry of Works and Transportation (Rolt & Pinard, 2016). The LVRs category in Tanzania is defined as roads carrying less than 1 million equivalent standard axles (MESA) and less than about 300 vehicles per day over their design life (Lingwanda, 2023).

Regardless of their importance in serving rural populations, LVRs are usually vulnerable to rapid deterioration, making them difficult to use, especially during rainy seasons (ERA, 2011). To cope with such deterioration speed and restore their functions, quick methods of evaluating the strength of pavement materials are of paramount importance (AltafHossain & Palit, 2017). In such a case, the DCP testing method is deemed to be quick and effective for maintenance, rehabilitation, and reconstruction of LVRs (Gill et al., 2010). The Roughton International, in collaboration with the University of Birmingham and the University of Nottingham, conducted a study in 2000 to assess the viability of different field testing methods for LVRs. The study selected the DCP test as the most suitable method of assessing the strengths of low-cost road pavements since it was found to be a robust and low-cost device that is quick and simple to use (Roughton et al., 2000). With regard to the huge LVRs network in Tanzania, the use of the DCP testing method for determination of pavement material strength needs more emphasis to ensure maintenance or rehabilitation is done in a timely manner.

Although there are additional benefits that are attributed to the use of the DCP testing method in evaluating the strengths of in-situ pavement materials, the use of laboratory DCP for determination of material strength as a selection criterion for construction of LVRs is minimal in Tanzania. Most practicing engineers are conversant with and prefer to use conventional methods due to the popularity caused by the emphasis these methods get from the learning institutions and the workplaces. Conventional methods such as CBR and UCS are still the most taught methods in academic institutions, and therefore they are widely relied on to determine the strength parameters of soil materials even under emergency works. The confidence of most pavement-designing engineers in Tanzania about material strengths rests on the interpretation of CBR test results, which causes few engineers who opt to use DCP to still convert DCPI into CBR values to understand what they portray in the pavement performance. There are many benefits that are associated with the use of the DCP testing method, which include time saving, quick application of the test, simplicity of use, portability, and non-requirement of electric power for its operations, and the apparatus is cheap (Paige-Green & Du Plessis).

This study has therefore focused on the laboratory unsoaked DCP test method to determine DCPI as a strength parameter of borrow pit materials used for the construction of the gravel wearing course of LVRs in Dodoma. The unsoaked DCP test is a laboratory DCP test in which the four-day soaking period of the moulded sample exercised in the CBR and normal DCP tests is excluded. The procedures followed in the laboratory unsoaked DCP test are similar to those used for the CBR test, except that in the laboratory unsoaked DCP test, samples are compacted at OMC and tested immediately without soaking as done in the CBR test. Also, it is penetrated by using a DCP cone instead of a CBR plunger. The method saves more time as it excludes the soaking time (MOWTC, 2016).

The Dodoma region is a semi-arid area located in a low rainfall zone. The region is currently growing rapidly in terms of business, road infrastructures, and buildings. Due to the fast growth of road infrastructures in the region, there is an obvious demand for the use of quick, simple, and cost-effective material testing methods, such as laboratory unsoaked DCP, to evaluate the strength of soil materials for the construction of road pavements. If an unsoaked laboratory DCP test is used for the determination of LVRs material strength in Dodoma, stakeholders will realise quick execution of projects to the required standard, hence saving time and money.

2.0 Materials and Methods

2.1 Materials

Materials used in the study were gravel soils collected from five different borrow pits within the Dodoma region. The sources of material were the Dinda borrow pit in Chemba district, Mahomanyika, Ntyuka, and Zuzu borrow pits in Dodoma district, and the Nkulabi borrow pit in Chamwino district.

The procedure used for investigation in the study involved the identification of borrow pits, the collection of materials, the classification of materials based on the AASHTO classification system, and the determination of strength by using the laboratory unsoaked DCP test.

The selection of material sources commenced with a preliminary investigation, which encompassed nine potential sources where materials were being collected for various construction works during the data collection period. These areas were Buigiri and Nkulabi in the Chamwino district, Kigwe in the Bahi district, Njedengwa, Mahomanyika, Ntyuka, Michese, and Zuzu in the Dodoma district, and Dinda in the Chemba district. Material samples were collected from these areas, and indicator tests, which involved particle size gradation and Atterberg limits, were performed. Results of the tests indicated that materials from Kigwe, Buigiri, and Michese were clay soils, whereas materials from Njedengwa contained a large proportion of coarse materials retaining on sieve size 37.5 mm. On this account, the remaining five borrow pit materials that contained acceptable proportions of particle grains were selected for the study. The borrow pits selected for the study were Dinda, Mahomanyika, Nkulabi, Ntyuka, and Zuzu.

The procedure used for investigation involved the identification of borrow pits, the collection of materials, the classification of materials based on the AASHTO classification system, and the determination of strength by using the laboratory unsoaked DCP test. Table 1 shows borrow pit materials, physical characteristics, and types of materials for road construction according to the AASHTO soil classification system.

Tab 1

Classification of Borrow Pits Materials According to AASHTO Classification System

Borrow pits name	Physical properties	AASHTO Classification	% Fines particles	% Medium particles (Sand)	% Course particles (Gravel)
Nkulabi	Reddish brown	A-2-6 Silty or clayey gravel sand	21	18	61
Zuzu	Reddish Brown	A-2-6 Silty or clayey gravel sand	30	49	21
Mahomanyika	Reddish brown	A-2-4 Silty or clayey gravel sand	7	23	70
Dinda	Reddish brown	A-6 Clayey soils	37	32	31
Ntyuka	Reddish brown	A-2-6 Silty or clayey gravel sand	13	27	60

2.2 Methods

The collected source materials were characterized in order to determine their engineering properties under laboratory conditions. The tests that were carried out included particle size distribution (sieve analysis), Atterberg limits (liquid limit, plastic limit, and linear shrinkage limit), compaction, and laboratory unsoaked DCP tests. Most available LVRs manuals specify requirements for the gravel wearing course, the subject of this study, based on their compliance to grading coefficient (GC), shrinkage product (SP), and strength in terms of dynamic cone penetration index (DCPI) or number (DN) (MRB, 2013; MOWTC, 2016; MHID, 2019; MPW, 2019; MTPW, 2020; MRRD, 2020). The listed testing methods were therefore conducted for the purpose of obtaining values of GC, SP, PI, and DCPI, or DN.

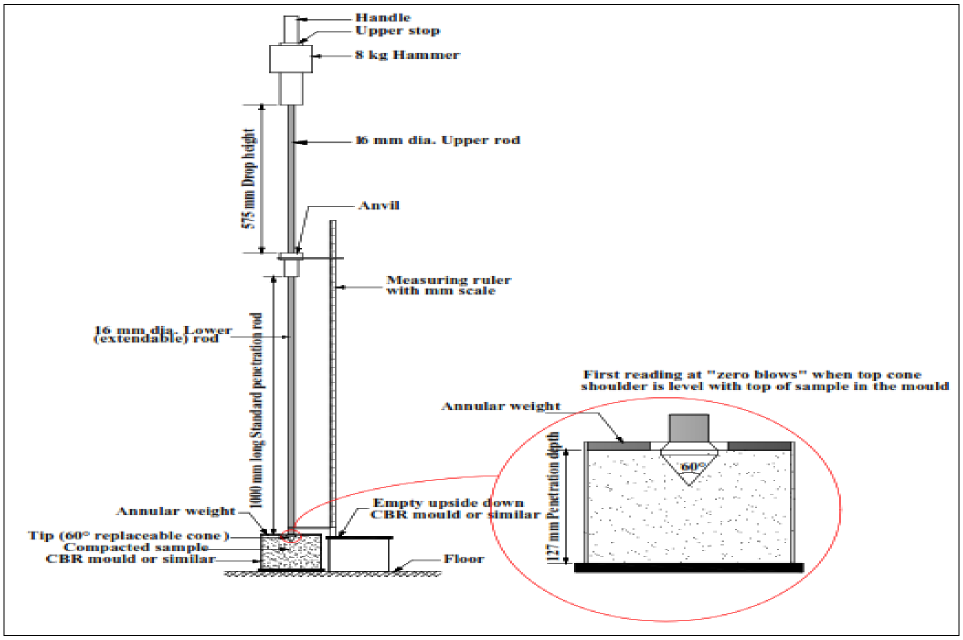
Particle size distribution analysis was conducted to determine particle size grades and percentages passing each sieve size in order to classify the soil for engineering purposes. Percentage passing for some individual sieve sizes was also used to compute shrinkage products (SP) and grading coefficients (GC) (ERA, 2011). To compute the SP value of a material, only the shrinkage limit value and percentage of materials passing the 0.425 mm sieve are required. For computation of GC, only percentages of materials passing sieve size 26 mm, 4.75 mm, and 2 mm are required. This is why not all sieves used for classification are also used for the computation of SP and GC.

To find the plasticity index and the linear shrinkage limit, the Atterberg limits tests were also done according to the steps spelled out in BS 1377: Part 2: 1990 and the CML Laboratory Testing Manual

(MOW, 2000). These tests find the liquid and plastic limits. The plasticity index and linear shrinkage of soil materials provide an indication of their binding properties and swelling potential when subjected to changing weather conditions. Moreover, linear shrinkage limits are used for the computation of shrinkage products (MOWTC, 2016). The shrinkage product is related to the binding property of soil materials. Most LVRs manuals have specified values of SP to range between 100 and 365 units for suitable gravel-wearing course material. When values are below this range, the material will corrugate and ravel, and when the values are above the range, the materials will be slippery when wet and produce dust when dry.

Compaction tests were also performed according to procedures stipulated in BS 1377: Part 4: 1990 and CML Laboratory Testing Manual (MOW, 2000) in order to determine maximum dry densities (MDD) and optimum moisture contents (OMC) of soil materials, which are useful parameters when conducting laboratory strength determination tests. For this study, a three-point, laboratory-unsoaked DCP test approach was adopted. The primary benefit of the unsoaked laboratory DCP test is its ability to yield DCPI results in just a few hours per day, unlike the soaked DCP or CBR tests that necessitate soaking the sample in water for four days. The DCPI results from unsoaked DCP tests are preferably used in semi-arid areas like Dodoma, where rainfall is of little intensity and where road drainage systems are ensured (Paige-Green & Van Zyl, 2019). The test followed a procedure similar to the three-point CBR test stipulated in BS 1377: Part 4:1990, TMH1: method A8:1986, and the Laboratory Testing Manual (MOW, 2000). The main difference between the CBR and DCP methods is that the CBR test uses a plunger to penetrate the sample, and average CBR values are found by averaging the forces at 2.5 mm and 5.0 mm plunger penetration depths. The DCP test, on the other hand, uses a DCP cone to penetrate the sample, and DCPI values are found by averaging the penetration depth and number of blows (Pinard & Hongve, 2020). Fig. 1 shows the laboratory DCP test setup for testing the strength of soil materials. The strengths of borrow pit materials for this study were determined as DCPI values at 95% MDD. The DCPI values at 95% MDD of unsoaked samples were considered as the strength of the materials (MRRD, 2020; ERA, 2011).

Fig. 1
Laboratory DCP Test Setup for Determination of DCPI of Soil Material



The three points DCP tests for five borrow pit soil samples were conducted using modified BS heavy density to determine DCPI values at 95% MDD (MOWTC, 2016). The materials were mixed and compacted at optimum moisture contents and penetrated to determine number of blows for each sample penetration depth.

The three point DCP tests adopted the use of three different configurations for material compaction. The materials in the first mould were compacted using 4.5 kg pistol weight, 62 blows for 5 layers, the materials in the second mould were compacted using 4.5 kg pistol weight, 30 blows for 5 layers and the materials in the third mould were compacted using 2.5 kg pistol weight, 62 blows for 3 layers. This test was conducted in order to determine variation of material strength with degree of compaction.

3.0 Results and Discussion

3.1 Results of Borrow Pit Material Tests

In this study, the selection of suitable soil materials for the construction of the LVRs gravel wearing course was primarily guided by three parameters, among others, that guide the performance of the wearing course. These parameters are grading coefficient (GC), shrinkage products (SP), and strength in terms of dynamic cone penetration index (DCPI) (MWT, 2018; MRH, 2019). The acceptable ranges for shrinkage products and grading coefficients for the gravel wearing course of unpaved roads are 16 to 34 units and 100 to 365 units, respectively. Meanwhile, DCPI values at 95% of maximum dry density (MDD) for unsoaked samples should be less than 5.69 mm/blow (Pinard & Hongve, 2020; ERA, 2011). In order to obtain these specified engineering properties of materials for the construction of gravel wearing courses of LVRs, characterisation of material and analysis of test results were performed.

3.1.1 Atterberg Limits Tests

Atterberg limits tests were conducted for the five borrow pit materials to determine plasticity indices (PI) and linear shrinkage limits (SL). Results indicate that plasticity indices for Nkulabi, Dinda, and Ntyuka borrow pits were 14%, 16%, and 13%, respectively. These values are above the range of 6% to 12%, which is suitable for the construction of gravel wearing courses of LVRs (MOW, 1999). Materials with PI values higher than 12% cause roads to be slippery during the rainy season and dusty during the dry season, and they are associated with rapid loss of wearing course material. On the other hand, materials with PI values lower than 6% cause corrugation and ravelling during the service period of the roads (ERA, 2011; MOWTC, 2016). The three borrow pit materials having high PI above 12% need to be blended with non-plastic materials such as sand and pozzolanic soils to meet requirements for unpaved LVRs gravel wearing course (MOW, 1999). In this study, two gravel materials from Zuzu and Mahomanyika borrow pits with PI values of 11% and 10%, respectively, met the requirement.

The linear shrinkage testing, abbreviated as “SL, is a method of quantifying how soil material experiences shrinking when wetted, which is also applicable to the contrary condition of expansion. (MOW, 2000). It is a reduction of one dimension when moisture is decreased from the liquid limit to the oven-dried condition, and it is expressed as a percentage of the weight of the original soil material sample (MPW, 2019). The range of suitable linear shrinkage values for gravel wearing course material is 0 to 16% (Paige-Green & Netterberg, 1987). Values of linear shrinkage for all borrow pit materials used in this study are within the acceptable range; therefore, they were suitable for use as LVRs gravel-wearing course material. Table 2 shows the results of the Atterberg limits test for the five borrowed pit materials.

Table 2

Atterberg Limits Data of Borrow Pit Materials

Borrow pit name	Liquid limit (LL) (%)	Plastic limit (PL) (%)	Plasticity index (PI) (%)	Linear shrinkage limit (SL) %
Nkulabi	32	18	14	5
Zuzu	33	22	11	6

Mahomanyika	26	16	10	4
Dinda	35	19	16	7
Ntyuka	30	17	13	5

3.1.2 Particle Size Distribution Test

The particle size distribution (sieve analysis) tests The particle size distribution (sieve analysis) tests were performed to determine particle size gradation and percentage passing for sieve sizes 26 mm, 4.75 mm, 2 mm, and 0.425 mm, which are used to compute GC and SP. The GC and SP are calculated from equations 4 and 5, respectively (MOW, 1999; MOW, 2000). Through these curves, all materials indicate that they have exhibited a well-graded behaviour in which a certain percentage of materials is retained in every sieve that was used for gradation. Table 3 presents the percentage passing sieve sizes of 26.0 mm, 4.75 mm, 2.0 mm, and 0.425 mm, as well as the computed GC and SP for each borrow pit material (Pinard & Hongve 2020). Fig. 2 shows the particle size distribution curves for the five borrowed pit materials.

$$GC = \frac{P4.75(P26.00-2.00)}{100} \tag{4}$$

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

$$\mathrm{SP} = \mathrm{P0.425SL} \tag{5}$$

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

Tab 3

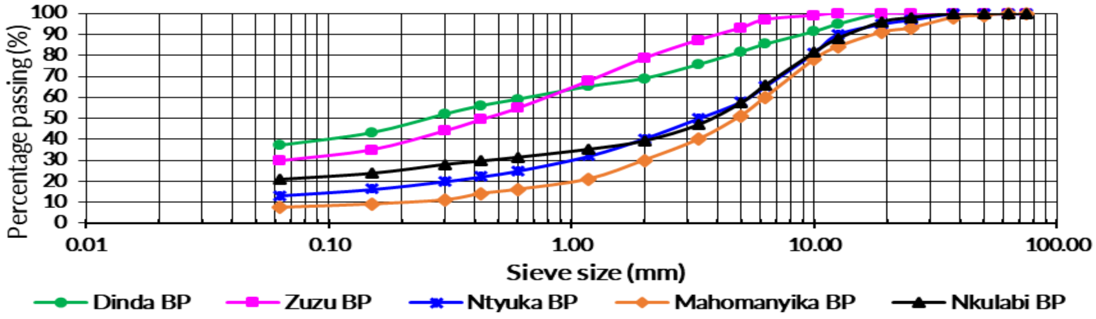
Particle Size Data, Grading Coefficient and Shrinkage Product Results of Borrow Pits Materials

Borrow pit materials	**Percentage Passing on Sieve Sizes**				**Grading coefficient (GC)**	**Shrinkage product (SP)**
	26.0 mm	**4.75 mm**	**2.0 mm**	**0.425 mm**		
Nkulabi	98	57	39	30	33.7	148.1
Zuzu	100	93	79	49	19.9	295.9
Mahomanyika	93	51	30	14	32.3	56.0
Dinda	100	82	69	56	25.4	391.3
Ntyuka	97	58	40	22	32.8	111.2

The GC and SP for Nkulabi, Zuzu, and Ntyuka borrow pits are within the range of 16 to 34 units and 100 to 365 units (refer to table 3); therefore, materials from these sources can be used for the construction of the gravel wearing course of LVRs. Generally, the GC of all borrow pit materials is within the specified range. However, the SP for the borrow pit materials from Mahomanyika and Dinda falls outside the specified range. The binding properties of the two borrowed pit materials need to be improved in order to be suitable for the construction of the gravel-wearing course of LVRs (MTPW, 2020).

Fig 2

Particle Size Distribution Curves of Borrow Pits Materials

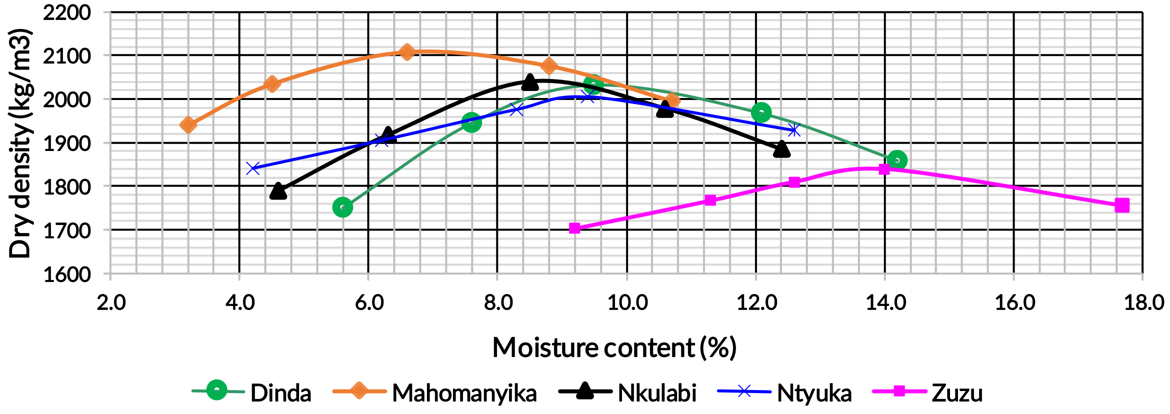


3.1.3 Compaction Tests

Compaction tests for the five borrowed pit materials were carried out to obtain optimum moisture contents (OMC) and maximum dry densities (MDD), which are useful parameters when determining the strength of soil material. Provided GC and SP requirements are met, materials for construction of the wearing course of LVRs also require a minimum DCPI value of 13.5 mm/blow, which is equivalent to a 15% CBR value for soaked samples, or 5.69 mm/blow, which is equivalent to a 45% CBR value for unsoaked samples at 95% MDD. These strength values are sufficient to resist traffic loading and rainfall conditions (Pinard & Hongve, 2020; ERA, 2011).

The compaction tests were carried out using the modified BS heavy Proctor test as stipulated in BS 1377: Part 4: 1990 and the CML Laboratory Testing Manual (MOW, 2000). Results of MDD and OMC were 2032 kg/m^3 and 9.5% for Dinda, 2109 kg/m^3 and 8.4% for Mahomanyika, 2054 kg/m^3 and 8.8% for Nkulabi, 2007 kg/m^3 and 9.3% for Ntyuka, and 1838 kg/m^3 and 13.8% for Zuzu borrow pits, respectively. The standard maximum dry density (MDD) for gravel wearing course material ranges from 1913 kg/m^3 to 2209 kg/m^3, and optimum moisture content (OMC) ranges from 7.0% to 24.0% (Paige-Green & Netterberg, 1987). Results of MDD and OMC for all borrow pit materials complied with the requirement of MDD and OMC for LVRs gravel wearing course material. The study shows that the highest MDD was for Mahomanyika materials, followed by Nkulabi, Dinda, and Ntyuka, while the highest OMC was for the Zuzu borrow pit, followed by Dinda, Ntyuka, and Nkulabi. The lowest determined MDD was for Zuzu borrow pit materials, while the lowest OMC was for Mahomanyika. Fig. 3 shows compaction curves of borrow pit materials.

Fig 3
Compaction Curves for Borrow Pits Materials



3.1.4 Laboratory DCP Tests

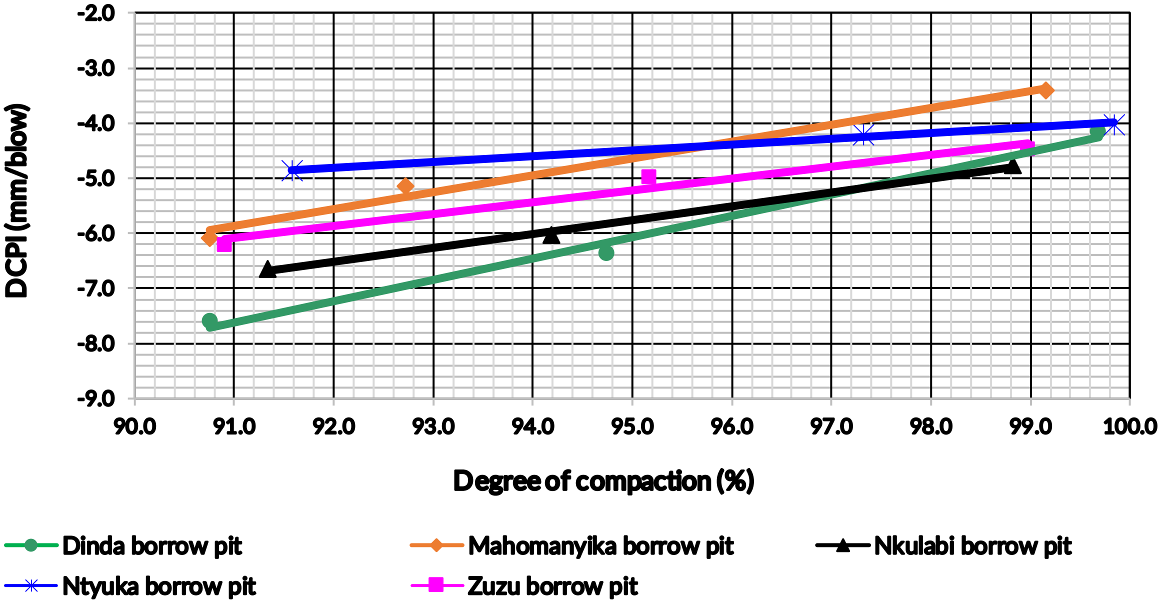
Three-point unsoaked laboratory DCP tests were conducted in order to determine the variation in material strength with the degree of compaction. The DCPI values of the sample materials were determined at 95% MDD. The weighted average DCPI values of the soil materials for each compaction effort were computed by using equation 6. Fig. 4 shows the three-point DCPI graph for all borrow pit materials. Appendices A to E are graphs of percentage cumulative penetration depths versus number of blows for five borrow pit materials used for computation of DCPI.

$$\mathrm{DCPI}_w = 0.0001\, D_T \sum \left(\frac{(\%\Delta_{Pen})^2}{\Delta_{blow}} \right) \qquad (6)$$

Where: DCPI$_w$ – is weighted average dynamic cone penetration index (mm/blow), D_T – is Total penetration depth (mm), Δ_{pen} – is change of penetration depth (mm), Δ_{blow} – is change of blows for each change of penetration.

Fig 4

Three Points DCPI Graph for All Borrow Pit Materials



The laboratory DCPI values at 95% MDD of the unsoaked samples for the five borrow pit materials were found to be 6.0 mm/blow, 4.7 mm/blow, 5.8 mm/blow, 4.5 mm/blow, and 5.2 mm/blow for Dinda, Mahomanyika, Nkulabi, Ntyuka, and Zuzu borrow pits, respectively. These results show that the soil materials from Dinda, Mahomanyika, Ntyuka, and Zuzu borrow pits meet the required DCPI values of 5.69 mm/blow, which is the maximum value. According to the strength requirement of LVRs in terms of DCPI values of soil materials, the four borrow pit materials can be used for the construction of the wearing course of LVRs. However, when considering all the requirements of SP, GC, and DCPI, only the materials from Zuzu borrow pits qualify for the construction of the gravel wearing course of LVRs. The other four borrow pits—Nkulabi, Mahomanyika, Dinda, and Ntyuka—may have better binding, gradation, and strength properties that could be made better by blending them so that they can be used as gravel for building low-volume roads.

Despite being located within Dodoma city, the Zuzu borrow pit, the only suitable source identified by the study, is situated to the southwest of the city and fails to meet the material demand for numerous scattered ongoing and anticipated projects. The borrow pit is also not an economically viable source for projects that are implemented in other locations of the city, as in most cases it will attract extra costs due to overhaul distance.

4.0 Conclusion

The Dynamic Cone Penetration (DCP) test is one of the fast methods of determining the strength of soil materials, especially for the construction of LVRs worldwide. This study used three points of laboratory unsoaked DCP to evaluate the strength of borrow pit materials currently used for the construction of LVRs in Dodoma. Characterisation was conducted on samples of gravel materials for each of the five selected borrow pits, namely, Nkulabi, Zuzu, Mahomanyika, Dinda, and Ntyuka. The results of the grading coefficient (GC) and shrinkage product (SP) of the five borrow pits are 33.7 and 148.1 units for Nkulabi, 19.9 and 295.9 units for Zuzu, 32.3 and 56.0 units for Mahomanyika, 25.4 and 391.3 units for Dinda, and 32.8 and 111.2 units for Ntyuka, respectively. Three borrowed pit materials from Nkulabi, Zuzu, and Ntyuka satisfied both the requirements of gradation and binding properties for the construction of LVR's gravel-wearing course.

The DCPI results obtained from the three-point laboratory DCP test at 95% MDD for unsoaked samples from five borrow pit materials showed that materials from Dinda and Nkulabi borrow pits did not meet specifications; therefore, they do not qualify to be used as the gravel wearing course of LVRs.

However, by considering PI values and all criteria for the selection of gravel materials, which are gradation, binding, and strength properties, only Zuzu borrow pit materials are suitable for the construction of the gravel wearing course of LVRs among the other investigated borrow pits in Dodoma.

5.0 Recommendations

After investigating materials from the five borrow pits, this study recommends the following:

Materials from Nkulabi, Dinda, and Ntyuka borrow pits that have plasticity indices (PI) values higher than the specified range need to be treated so as to lower their PI values into an acceptable range. Improving properties of materials from these borrow pits to meet specified requirements for use as LVR gravel roads wearing coarse needs blends them with non-plastic materials such as sand or pozzolanic soil. For the Dodoma region, an economically feasible option is to blend them with sand due to the local availability of sand.

Materials from the Mahomanyika borrow pit, which have low shrinkage product (SP) value, have low binding strength due to low contents of plastic fines. Improving properties of materials from this borrow pit needs increasing content of plastic fine particles, particularly clayey soil.

Further study is required to determine appropriate proportions to be used for blending of the borrow pit materials with sand and clay accordingly.

6.0 Funding Statement

The study was self-supported by the authors.

7.0 Conflict of Interest

The authors declare no conflict of interest.

8.0 Acknowledgement

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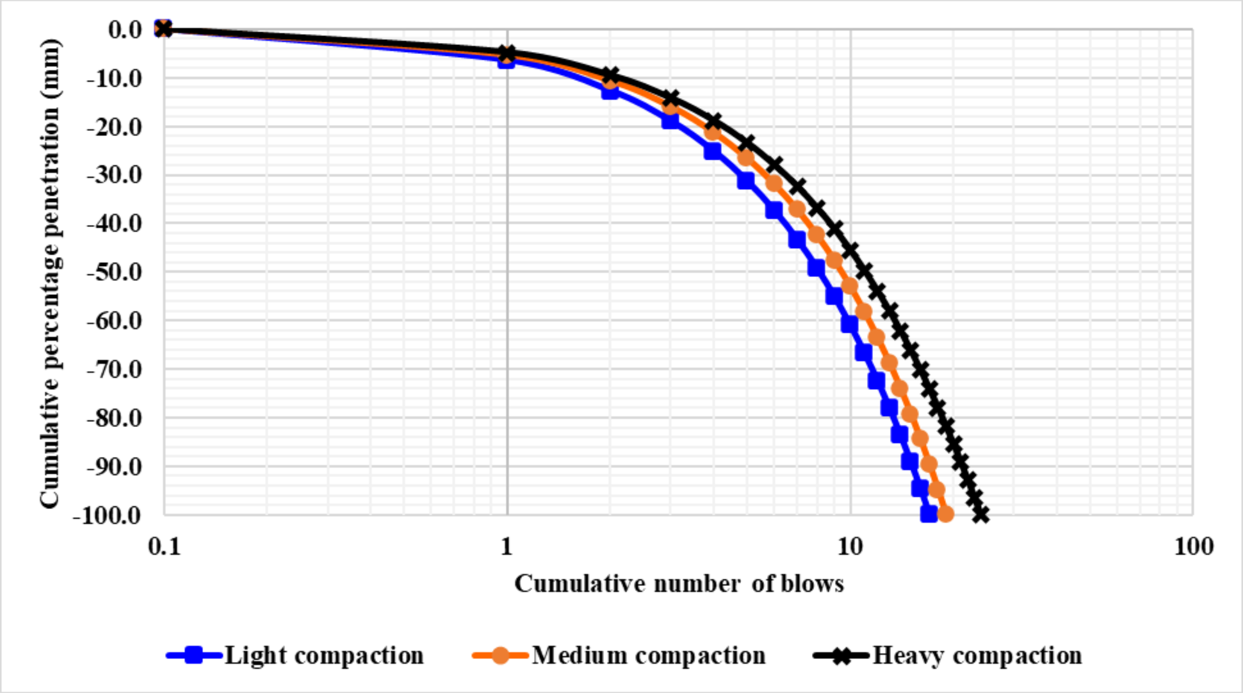
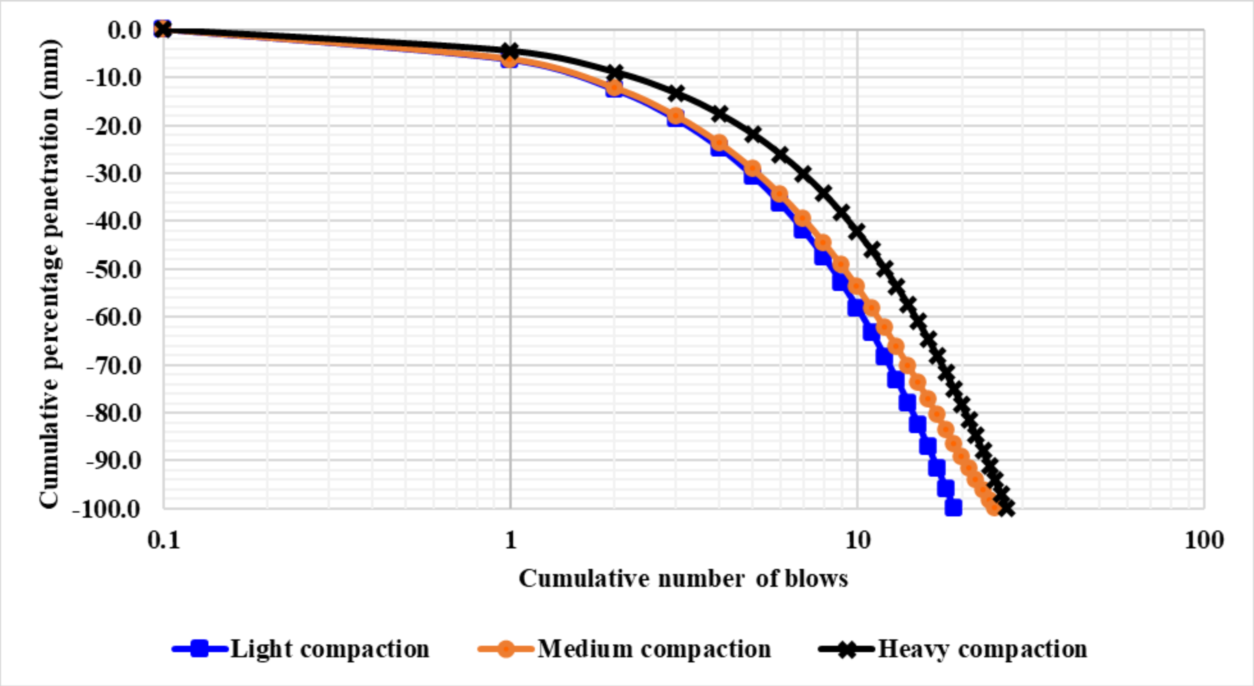
10.0 Appendices

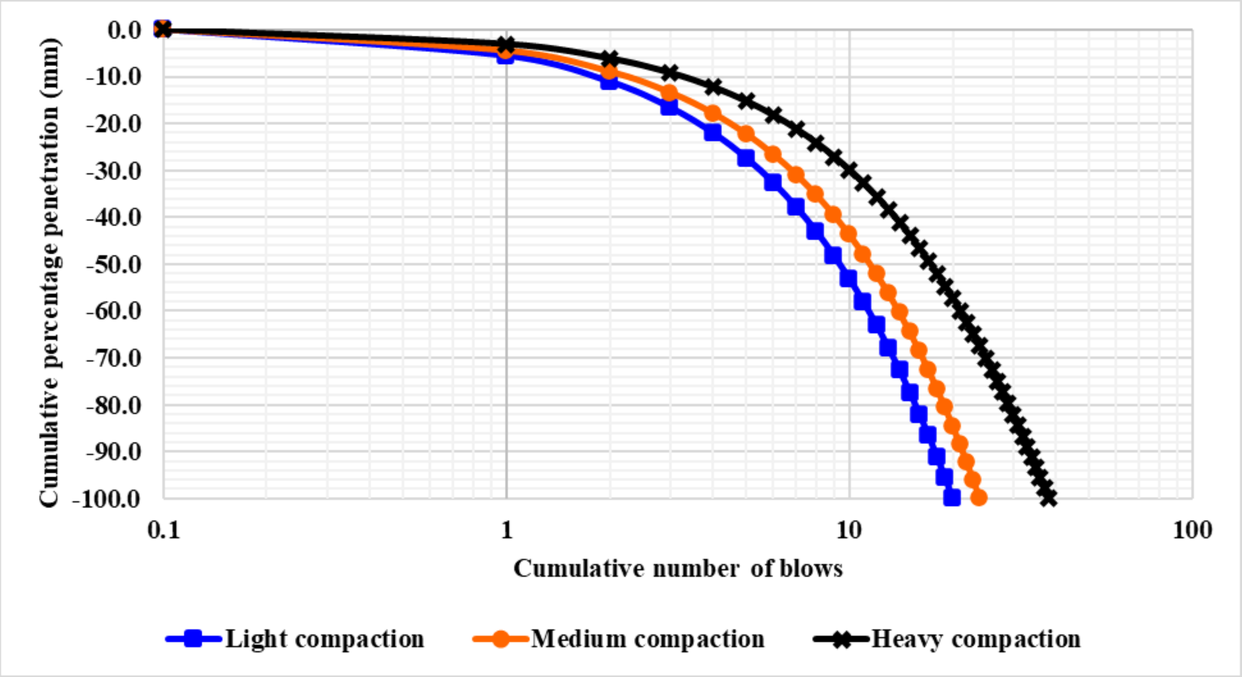
Appendix A: DCP penetration resistance graphs for Nkulabi borrow pit materials



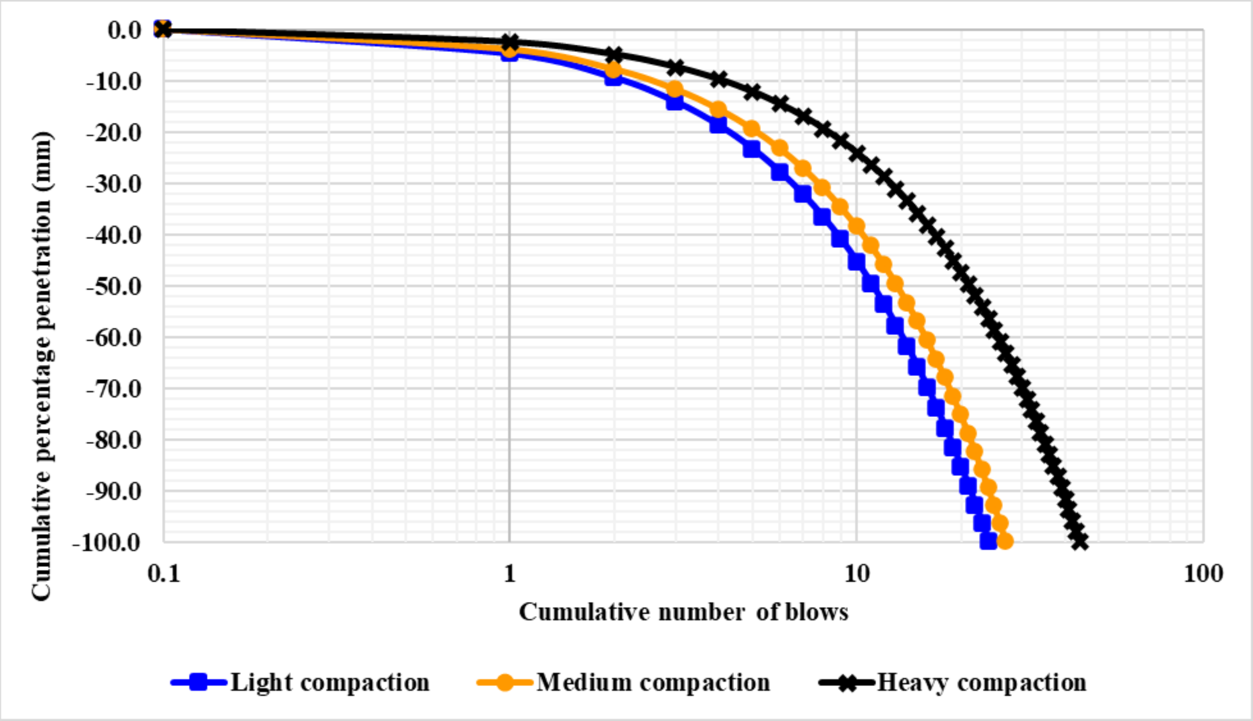
Appendix B: DCP penetration resistance graphs for Zuzu borrow pit materials



Appendix C: DCP penetration resistance graphs for Mahomanyika borrow pit materials



Appendix D: DCP penetration resistance graphs for Dinda borrow pit materials



Appendix E: DCP penetration resistance graphs for Ntyuka borrow pit materials