Prediction of Compaction Density of Lateritic Soil Base Pavement Layers from Dynamic Cone Penetration Values in Uganda

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Prediction of Compaction Density of Lateritic Soil Base Pavement Layers from Dynamic Cone Penetration Values in Uganda

Prédiction de la densité de compactage des couches d'assise de la chaussée à partir des résultats d'essais de pénétration dynamique au cône

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ABSTRACT – The study focused on obtaining a correlation between sand replacement method density values and dynamic cone penetration (DCP) rate values (mm/blow) for base pavement layers of lateritic soils in Uganda. A maximum depth of 500 mm of gravel of lateritic soil on existing roads, in Rubaga division in Kampala (Uganda), was penetrated using the DCP to obtain the rate of penetration (mm/blow). They were also investigated for their index properties and field density values using sieve analysis, Atterberg limits and sand cone replacement methods. The gravel was generally classified as reddish-brown clayey sand with an AASHTO class of A-2-6. The correlation obtained between dry density values from the sand-cone replacement method and DCP rates showed an inverse relationship with R2 coefficient of 0.5999 indicating a moderate correlation between the two variables. The correlation was validated with data from other lateritic base layers of roads in Wakiso district, Uganda.

RÉSUMÉ – Cette étude a porté sur l'obtention d'une corrélation entre les valeurs de la densité de sol déterminées avec le densitomètre à membrane et celles du taux d'enfoncement dans le sol du pénétromètre dynamique à cône (PDC) (mm/coup). Une profondeur maximale de 500 mm de sols graveleux sur les routes existantes, dans la division de Rubaga du district de Kampala en Ouganda (route de Mutesa 1, de Sentema et des environs de l'hôpital Mengo), a été pénétrée à l'aide du PDC pour obtenir le taux d'enfoncement (mm/coup). Ils ont été également étudiés pour leurs indices et valeurs de la densité de sol sur le terrain à travers les essais d'analyse granulométrique, de limites d'Atterberg et de densitomètre à membrane. Le sol graveleux était généralement classé comme sable argileux brun-rougeâtre avec une classe de l'AASHTO de A-2-6. La corrélation obtenue par une simple analyse de régression linéaire, entre les valeurs de la densité sèche du densitomètre à membrane et celles du taux d'enfoncement du PDC a montré une relation inverse avec un coefficient, R2, de 0,5999 indiquant une forte corrélation entre les deux variables. La corrélation était validée avec les données de la route de Matugga dans le district de Wakiso. La corrélation peut être utilisée pour prédire des valeurs de la densité sèche à partir du taux d'enfoncement du PDC avec une précision de plus de 90%, supérieure à 50%, donc valide et fiable.

1 INTRODUCTION

All civil engineering construction works including construction of dams, buildings, highways and other structures are founded on or in soil. As such the stability and hence performance of such construction works are dependent on the suitability of the foundation and quality of soils (Rahaman, 2010). However, uncertainties are abundant in geotechnical engineering and possible sources include inherent variabilities, measurement errors and modeling uncertainties. In recent years, the probabilistic framework has been adopted to rigorously quantify such uncertainties. The standard way of achieving so is to transform the information of the field or laboratory test data, denoted by "test indices" later, into the probability density functions (PDF) of the quantities of interest. Quite frequent, transformation equations between soil parameters are very useful in converting test index information into field density information through parametric correlation (Kulhawy and Mayne, 1990). Though very much needed in the determination of parameters for pavement design and monitoring in Uganda, their application is still very limited.

Pavement structure design in Uganda is based on three factors; loading (projected traffic), paving material properties (strength, aging, environmental effects, etc.), and subgrade support. But many uncertainties exist in pavement design; even when a road is opened to traffic, the engineer cannot verify the accuracy of the traffic projection until the project has been through its design life. During the design stage the engineer selects a subgrade support value based on a few samples taken from the project site, some engineering assumptions and evaluation of indices. The engineer controls paving material properties through quality assurance/ control (QA/QC) programs during construction. Most countries use density of the in- place subgrade and unbound base for construction quality control, (Kulhawy and Mayne, 1995).

In Uganda, the dry density of the compacted soil or pavement material, calculated from field density, is a common measure of the amount of the compaction achieved during construction. There are several methods for the determination of field density of soils such as core cutter method, sand replacement method, rubber balloon method and heavy oil method. Present practice mainly involves the use of the sand-cone method and a nuclear gauge. Though the nuclear gauge is quick and very convenient to obtain the in-situ soil density and water content, it is very expensive and radioactive. It also requires a special operator with a registered operating license. The sand replacement method (SRM) is time consuming and demand significant effort, (Peck et al., 1974). Therefore a study into a correlation between the values obtained from these methods and other frequently utilized non-destructive insitu methods used in the determination of the strength of base layers is necessary.

In-situ penetration tests like DCP, SPT and CPT have been widely used in geotechnical and foundation engineering for site investigation in support of analysis and design. The DCP is the most widely used, non-destructive insitu, test in determining the strength of compacted base pavement layers in Uganda. In this study, the correlation between sand replacement method density values and dynamic cone penetration (DCP) rate values (mm/blow) in lateritic base pavement layers in Uganda was obtained. Laterite soils, otherwise called red tropical soils, are extensively used in the tropics, specifically in Uganda, for road construction (Arulanandan and Turnbridge, 1969), since they are readily available and relatively cheap where haulage distances are short.

2 MATERIALS AND METHODS

2.1 Sampling and sample preparation

Lateritic soil samples were collected randomly from different sections of the proposed roads around Ndejje University, Kampala campus, located in Rubaga division Kampala district, Uganda. It involved digging shallow trial pits and carefully taking disturbed bulk samples from depths between 0.1 and 0.3 m by means of pick-axe and shovel. Depths between 0.1 and 0.3 m were chosen to limit the sampling within the base layer of each road. The samples were then carefully put in black and airtight polythene bags to limit moisture loss and labelled according to sampling location. 5 – 10 kgs of sample material were obtained at each location, deemed enough to carry out all the required tests. Table 1 shows details in terms of sampling locations and depth, field soil description and moisture content.

The bulk samples were brought to the laboratory and air-dried for two to three (2-3) days depending on the initial moisture content. They were then riffled to obtain representative samples of the subsequent laboratory tests. This initial preparation was done following the procedures described in BS 1377: part 1:1990.

Table 1. Sampling location and depth and description of sampled material

Sampling location	Sampling depth (m)	Sample description	Moisture content (%)
Sentema Rd, CH 0+400 CL 32.525258E, 0.332647N	0.1 – 0.30	Reddish brown clayey sandy gravel	6.4
Sentema Rd, CH 0+800 LHS 32.524082E, 0.333384N	0.1 – 0.30	Reddish brown very dense sandy clayey gravel	8.6
Sentema Rd, CH 1+200 RHS 32.5021727E, 0.334408N	0.1 – 0.30	Reddish brown light clayey gravel	6.6
Mengo Rd, CH 0+050 CL 32.558293E, 0.311203N	0.1 – 0.30	Reddish brown very dense sandy gravel	8.6
Mengo Rd, CH 0+250 LHS 32.557669E, 0.311709N	0.1 – 0.30	Reddish brown very dense sandy gravel	8.6
Mutesa 1 Rd, CH 0+300 CL 32.558585E, 0.323248N	0.1 – 0.30	Reddish brown clayey sandy gravel	6.3
Mutesa 1 Rd, CH 0+800 LHS 32.555872E, 0.326440N	0.1 – 0.30	Light reddish brown, very dense sandy clayey gravel.	8.7
Mutesa 1 Rd, CH 1+300 RHS 32.554825E, 0.316205N	0.1 – 0.30	Reddish brown clayey sandy gravel	6.4

2.2 Laboratory tests

2.2.1 Moisture Content test

The objective of the moisture content test was to determine the amount of water in the soil expressed as a percentage of the dry mass of the soil sample based on BS 1377: Part 2:1990. Containers were cleaned and weighed (M_1), crumbled sample placed in the containers and weighed again (M_3), and the weights recorded. They were then placed in the oven for 24 hours at temperature of 110^0C. After 24 hours, the containers with the dried soil were removed from the oven, cooled to room temperature and weighed (M_2).

Moisture content of the sample = $\dfrac{M_2 - M_3}{M_3 - M_1} \times 100$

2.2.2 Atterberg Limits test

These were done to determine the plasticity characteristics of the soil samples. The parameters that were determined under the test included liquid limit, plastic limit and plasticity index. The test sample was obtained by sieving the air- dried specimen through 0.425mm sieve. The sieved material was prepared and tested for liquid limit in accordance with BS 1377: part 2:1990 clause 4.3 using the cone penetrometer method. On the same sample, plastic limit according to BS 1377: part 2:1990 clause 5.3 was determined and finally plasticity index (PI) was calculated as PI (%) = LL- PL.

2.2.3 Particle size analysis

The sieve analysis test was carried out to determine the particle size distribution and gradation properties of the obtained soil samples. Wet sieving of the samples was done following procedures based on BS 1377:part2:1990 clauses 7.3 and 7.4.5.

2.3 Field Tests

2.3.1 Determination of in- situ Density Test

The sand replacement method was utilized carried out according to BS 1377: part 9:1990 (Test 15). The surface of the testing point was cleaned and leveled. A metal tray with a central hole of 100 mm was placed on the prepared surface. A 150 mm deep hole was excavated, as material was collected in an airtight polythene bag. Weights of excavated material were recorded and their moisture contents determined. A known weight of sand was poured into the calibrating cylinder up to the top and placed centrally over the excavated hole. The shutter was opened till the sand filled the excavated hole and the cone completely. The shutter was closed and the weight of the remaining sand in the cylinder measured. The volume, bulk and dry densities of excavated soil were determined.

2.3.2 Dynamic Cone Penetrometer(DCP) test

The DCP test was carried out in accordance with BS 1377: part 4:1990. The steel rule attached to the guide foot was placed through the slot in the hand guard. The foot was then placed on the surface to be tested and cone tip passed though the guide hole. The entire apparatus was held by the handle perpendicular to the surface as the technician observed the readings on the rule at the top of the hand guard and recorded as zero reading. The drop weight of 8 kg was then raised to its maximum height and released through a falling height of 575 mm. Extreme care was taken to gain maximum height for each drop but not to strike the handle base as this would cause the instrument to withdraw and results affected. The number of blows and depth reading were recorded on the DCP test forms. For this study, DCP testing reading required were up to a depth of 150mm corresponding to the depth at which the sand replacement test was conducted. The field data was condensed in terms of penetration versus corresponding number of blows, plotted vertically along the y- axis and horizontally along the x- axis respectively. The slope values were then computed as the change in penetration versus the change in the number of blows observed over the range – expressed as mm/blow.

3 RESULTS AND DISCUSSION

3.1 Index tests

The percentages of the lateritic soil samples passing BS Sieves 2.36 mm, 425 µm and 75 µm are shown in Table 2. The percentages passing through No. 200 (75 µm) BS sieve ranged between 0.3% and 38.1%. Samples from, Mutesa 1 road CH 0+800 LHS and CH 1+300 RHS whose percentage finer than 75µm was greater than 35% indicated fine grained soils while the rest were coarse grained soils. The soil samples were suitable for subgrade construction since their percentages by weight finer than No. 200 BS sieve was less than 35%, according to the Uganda Ministry of Works, Housing and Communication (MWH&C) general specifications for national roads of 2004. Soil samples from Sentema road CH 0+400 CL and CH 1+200 LHS belonged to A-7-6 class while the other samples were classified as A-2-6 according to AASHTO method of classification.

Table 2. Index Test Results

Location		Grading (% passing BS sieve)			Atterberg Limits			Grading Modulus	AASHTO Classification
		2.36mm	425µm	75µm	LL (%)	PL (%)	PI (%)		
Sentema Road	CH 0+400 CL 32.525748E, 0.332647N	27.7	13.3	0.6	43.7	37.3	16.4	2.58	A-7-6
	CH 0+800 RHS 32.524082E, 0.333384N	32.7	18.3	0.3	35.5	18.1	17.4	2.49	A-2-6
	CH 1+200 LHS 32.521727E, 0.334408N	51.0	33.1	22.1	40.9	20.2	20.7	1.94	A-7-6
Mengo Road	CH 0+400 Cl 32.558293E, 0.311203N	77.1	55.8	13.3	31.0	18.8	12.2	1.54	A-2-6
	CH 0+250 LHS 32.557669E, 0.311709N	63.2	40.7	12.2	28.8	17.6	11.2	1.84	A-2-6
Mutesa 1 Road	CH 0+300 Cl 32.558585E, 0.323248N	52.1	42.5	33.9	33.7	19.6	14.1	1.72	A-2-6
	CH 0+800 LHS 32.555872E, 0.326440N	36.2	22.5	35.9	35.9	21.4	14.5	2.36	A-2-6
	CH 1+300 RHS 32.554825E, 0.316205N	53.5	36.6	38.1	38.1	22.4	15.7	1.84	A-2-6

The liquid limits of the finer particles of soil samples ranged between 28.8% and 43.7% and plastic limits between 17.6% and 37.3% while plasticity indices were between 11.2% and 20.7% as shown in Table 2. Soils with liquid limit less than 30% are considered to be of low plasticity, those with liquid limit between 30% and 50% exhibit medium plasticity and those with liquid limit greater than 50% exhibit high plasticity. Other than the sample obtained at Mengo road CH 0+250 LHS which exhibited low plasticity, the rest of the samples exhibited medium plasticity primarily indicating that they were fair to good subgrade materials according AASHTO classification.

3.2 *Dry Density and DCP Test*

Sand replacement and DCP tests were carried out at thirty six (36) different chainages along Sentema, Mengo and Mutesa 1 roads (15 points, 6 points and 15 points for Sentema, Mengo and Mutesa 1 roads respectively). The field dry densities as obtained from the sand replacement test ranged between 1701 kg/m^3 and 2333 kg/m^3 representing a range of typical dry densities usually obtained for lateritic soils (Ministry of Works, Housing and Communications Specifications (Roads and Bridges), 2004) while the DCP values ranged between 0.45 mm/blow and 3.44 mm/blow as depicted in Figure 1. These values did not vary greatly on a given road tested.

3.3 *Correlation between Dry Density and DCP Values*

To obtain a good correlation, the dry density values of the lateritic soil base layers were divided with the corresponding DCP values to get the ratio $DD_{DCPRATE}$. The DCP rate values were then plotted against the corresponding $DD_{DCPRATE}$ values on a logarithmic scale as shown by the blue line in (Correlation) in Figure 1 with R^2 of 0.5999. Hence the correlation between dry density and DCP rate was written as;

$$DCPRate(mm/blow) = -0.949 ln\left(\frac{Drydensity(kg/m^3)}{DCPRate(mm/blow)}\right) + 8.7417 \quad (1)$$

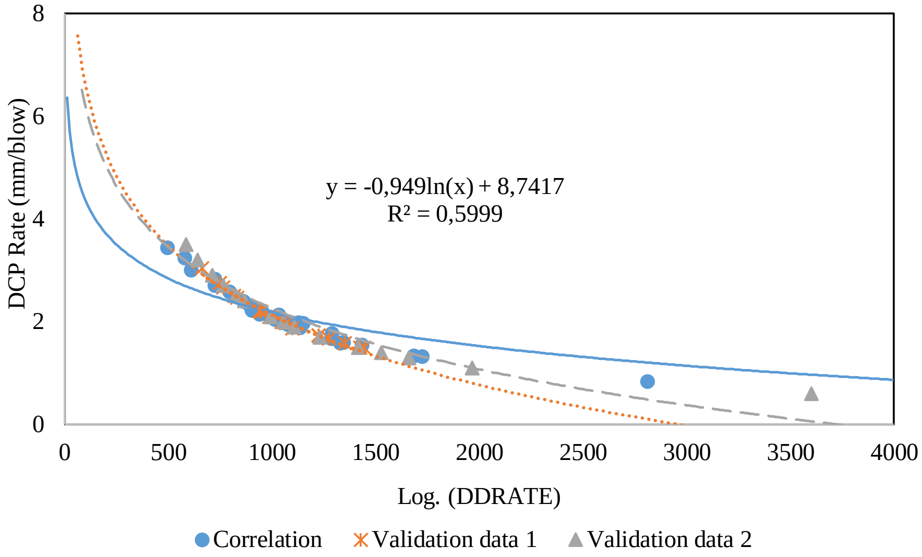

Figure 1. Plot of Dry density vs DCP rate

3.4 *Validation of the developed model*

The model that was developed for the lateritic soils was validated using data from two other independent roads (Matugga – Wakiso road and Lugoba road) with lateritic soil base layers in order to test its reliability and accuracy. The obtained (estimated from the equation 1) dry densities (DD) and DCP rate (mm/blow) were compared with the actual values obtained from these roads and the error calculated as a magnitude of the difference between the actual and estimated values as shown in Table 3 and 4. From statistical analysis carried out on the errors, it was determined that the model can be used to predict values of dry density with an accuracy of over 60%. This value is greater than 50%, therefore the model is valid and reliable.

Table 3. Matugga – Wakiso road validation

Actual Dry Density (kg/m^3)	Actual DCP rate (mm/blow)	Estimated Dry Density (kg/m^3)	Error Dry Density	(x-µ) Dry Density	$(x-\mu)^2$ Dry Density
2087	2.00	2111	24	-19.5	1914.06
2078	2.20	2076	2	-41.5	1072.56
2043	2.50	2022	21	-22.5	111723.06
2138	1.50	2201	63	19.5	588.06
2115	1.73	2160	45	1.5	12488.06
2060	2.09	2095	35	-8.5	13282.56

2012	3.04	1924	88	44.5	5513.06
2040	2.67	1991	49	5.5	564.06
2053	1.87	2135	82	38.5	8145.06
2050	1.87	2135	85	41.5	8055.06
2125	1.67	2171	46	2.5	14.06
2114	1.73	2160	46	2.5	4455.56
2135	1.58	2187	52	8.5	23485.56
2055	2.47	2027	28	-15.5	12825.56
2061	2.76	1975	86	42.5	8977.56
2100	1.97	2117	17	-26.5	10972.56
2078	2.20	2076	2	-41.5	6201.56
2075	2.21	2074	1	-42.5	8055.06
2150	1.49	2203	53	9.5	11395.56
2115	1.73	2160	45	1.5	3335.06
			μ = 43.5	0	sum = 14733

Standard deviation = $\left[\frac{\sum (x-\mu)^2}{n-1}\right]^{\frac{1}{2}} = \left[\frac{14733}{20-1}\right]^{\frac{1}{2}} = 27.8$

Coefficient of Variance = $\frac{27.8}{43.5} \times 100 = 64\%$

Table 4. Lugoba road validation

Actual Dry Density (kg/m^3)	Actual DCP rate (mm/blow)	Estimated Dry Density (kg/m^3)	Error Dry Density	(x-μ) Dry Density	(x-μ)^2 Dry Density
2080	2.10	2093	13	-83.15	6913.923
2090	1.70	2165	75	-21.15	447.3225
2155	1.30	2237	82	-14.15	200.2225
2078	2.40	2040	38	-58.15	3381.423
2160	1.10	2273	113	16.85	283.9225
2060	2.90	1950	110	13.85	191.8225
2060	2.50	2022	38	-58.15	3381.423
2135	1.40	2219	84	-12.15	147.6225
2053	3.20	1896	157	60.85	3702.723
2160	1.10	2273	113	16.85	283.9225
2160	1.10	2273	113	16.85	283.9225
2155	1.30	2237	82	-14.15	200.2225
2060	2.90	1950	110	13.85	191.8225
2045	3.50	1842	203	106.85	11416.92
2061	2.70	1986	75	-21.15	447.3225
2120	1.50	2201	81	-15.15	229.5225
2045	3.50	1842	203	106.85	11416.92
2100	1.90	2129	29	-67.15	4509.123
2110	2.00	2111	1	-95.15	9053.523
2160	0.60	2363	203	106.85	11416.92
			μ = 96.15	0	sum = 68100.55

Standard deviation = $\left[\frac{\sum(x-\mu)^2}{n-1}\right]^{\frac{1}{2}} = \left[\frac{68100.55}{20-1}\right]^{\frac{1}{2}} = 59.9$

Coefficient of Variance = $\frac{59.9}{96.15} \times 100 = 62\%$

4 CONCLUSION

The study was conducted to investigate the level of compaction (densities) of lateritic soil base pavement layers using a correlation approach of sand replacement method (dry density) and penetration rate (mm/blow) from DCP test. An inverse relationship existed between the dry density and DCP rate values (mm/blow). The statistical parameters indicated that the model developed for correlating dry density values with DCP rate fitted the data well with a coefficient of correlation of R2 of 0.5999 indicative of a moderate correlation between the two variables. From statistical analysis carried out on the errors, it was determined that the model can be used to predict values of dry density with an accuracy of over 60%. This value is greater than 50%, therefore the model is valid and reliable. With the additional economic benefits involved, this model is recommended for experienced engineers.

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