Equivalent Blows Approach to the Calibration of a Minicompactor for Laboratory Use

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Abstract

Researchers and laboratory personnel often encounter some difficulties when using standard compaction methods to compact a soil sample before they are tested with the triaxial machine. The difficulties include; difficulties in extrusion, bulkiness of rammers, and non-uniformity in the distribution of blows, and associated sample disturbance when preparing specimens for triaxial testing. These problems have been curbed by the use of minicompactors which are newer technologies. A minicompactor (Nanjing Soil Minicompactor) manufactured to enable production of 39.1mm diameter that can fit into triaxial machine (Model TS2-1) was used for the compaction studies. The minicompactor is made of a split mold of 96.06cm^3 by volume. The rammer weight 600g fits well to the internal circumference of the mould. The drop height is 30cm, which is relatively short. These features are very desirable to contemporary researchers, but it will be very important to ensure uniformity with the standard compactors on which the experimental methodologies were originally based. Ignoring this will lead to an erroneous assumption that the minicompactors would achieve the same compaction as the standard ones using the same specifications, but this would result a level of inconsistency that would affect the results of the experiments. To bridge this gap, this study, attempts to determine the number of blows with the Nanjing minicompactor that will achieve the same MDD and OMC with those conventional standards: - British Standard Light (BSL), Reduced British Standard Light (RBSL), West African Standard (WAS), and British Standard Heavy (BSH), using the same lateritic soil material and same number of layers. The research shows that there is a consistent increase in Maximum Dry Density and decrease in Optimum Moisture Content as compactive efforts increased. A total of 11 compactions were made using the minicompactor; seven were made at 3 layers using 4,8,12,16,20,24, and 28 blows while four were made at 5 layers using 34, 38, 42, and 46 blows. Plots of the Maximum Dry Densities against Number of Blows were made for the 3 layers as well as the 5 layers. Using statistical models, the number of blows that are equivalent to the known standards were established. It was recommended that for the Reduced British Standard (Light), 22 blows at 3 layers; for the British Standard (Light), 27 blows at 3 layers; for the West African Standard, 42 blows at 5 layers; and for the British Standard (Heavy), 46 blows at 5 layers would be used to achieve a corresponding MDD and OMC.

Keywords; compactors, calibration, lateritic, blows, dry density, moisture content.

1.0: INTRODUCTION

1.1; Compaction

Compaction is one of the most essential ways of improving soil conditions (Dass, 2007; Parvizi, 2006; Bell, 1993; Hausman, 1990). It is the most obvious and simple way of increasing the stability and supporting the capacity of soil. Dunn *etal* (1980) defined compaction as the process of increasing the unit weight of soil by forcing soil solids into tighter state and reducing the air voids. In other words, it is the artificial rearrangement and packing together of soil particles into a state of closer contact by mechanical, electrical or any other means in order to decrease its porosity and increase dry density (Bell, 1993). Reynolds (2012) rightly gave a simple definition of compaction as the densification of soil materials by the use of mechanical energy. Compaction, therefore, affects soil structure, permeability, compressibility characteristics, strength of the soil and stress-strain characteristics in such a way that the engineering properties of the resulting soil is significantly improved. It is a method of soil stabilization without additives. According to Ingles and Metcalf (1973), compaction has been one of the most important methods of ground modification. The compaction process is achieved through many methods such as shallow compaction, dynamic deep compaction, blasting, water jetting, etc. Actually, the understanding of compaction traced back to the work of Proctor (1933). Proctor's hypothesis sees water as a lubricant that reduces capillarity forces and friction and brings about rearrangement of the particles of soils until the moisture becomes just sufficient to fill almost all the voids whilst the soil has the greatest density and lowest void ratio. Beyond this particular water content, the soil softens and the dry density reduces. This process of compaction brings about changes in the microstructure of soil samples which was revealed by the x-ray computed tomography test conducted by Al-Hattamleh *etal* (2008) which also agreed with the findings of Tollner (1994). The result of compaction, therefore, will be the increase of the soil dry density regardless of the object used. This might result in the increase of the soil shear strength and bearing capacity or the reduction of compressibility, permeability, and liquefaction potential which controls swelling and shrinkage as well as prolongs durability of the engineered soil (Rowe, 2000; Hansman,1990). Corollary to this, Lambe and Whitman (1979) summarized the objectives of compaction as; decrease in future settlement, increase in shear strength, and decrease in permeability.

Properly placed and compacted soil materials have better strength than natural soil deposits and formations. Such compacted soils are referred to as structural earth fill or compacted earth fill (Bell, 1993). This shows that compaction actually improves the structural qualities of soils. Such structural earth fills are extensively used in the construction of dams, embankments for highways, airfields among others. In the laboratory, the maximum dry density and the optimum moisture content are the two determined parameters. The optimum moisture content gives an indication of the amount of mixing water to use in the field (Altun *etal*, 2008). The degree of compaction depends upon the moisture content, the amount of compactive effort and the nature of the soil. For the quality control of highway construction, the unit weight achieved through compaction in the field should be a certain high percentage of the laboratory value. Reynolds (2012) explained that the percentage of the optimum compaction attained in the field should be as high as 90% for the modified proctor test and 95% for the standard proctor test. The procedures used in laboratory compaction involves the application of impact loads with the aim of arriving at the standard which may serve as a guide and a basis for comparison with what is achieved in the field. A good number of standard laboratory compaction tests exist. Four of such methods, namely; British Standard Light compaction, Modified British Standard Light compaction, West African Standard compaction, and British Standard Heavy compaction, have been covered in this research work. These standards vary by the fact that they lead to the exertion of different compactive efforts on the test soil.

1.2; Properties of Lateritic Soils

According to Eze-Uzoamaka and Agbo (2010), laterites are redish residual soils from rock. They have high iron oxide and aluminium hydroxide content but low silica content. Gidigasu (1976) also defined it as a vesicular rock composed essentially of mixture of hydrated oxides of aluminum and iron with small percentage of other oxides, such as manganese or titanium. Lateritic soils have good shear strength in dry condition but negligible shear strength in saturated condition (Narayanan,2006; Morin and Todor, 1975). As expected, there is an improvement of mechanical qualities of lateritic soils by compaction (Omotosho *etal*, 1992). In a research conducted by Fall *etal* (2003) it was concluded that the undrained behaviour of lateritic soils depends on the initial dry density and the pre-shear consolidation pressure. Lateritic soil was chosen for the purpose of this calibration exercise for two main reasons. First, they have relatively stable geotechnical properties and secondly they are extensively used in construction within South East Nigeria (Aginam etal, 2014).

1.3; The Advantages of Minicompactors

Minicompactors are newer technologies than the standard compactors. They are easier to handle due to many unique qualities which they possess. It will be important to note that before the Unconsolidated-Undrained (UU), Consolidated Undrained (CU), and Consolidated-drained (CD) tests, among other tests, should be carried out with the triaxial machine, the soil sample must first be compacted with a known standard compaction method under the optimum moisture content (OMC). There have been a lot of difficulties in trying to extrude the compacted soils from standard moulds and also the stress of trimming them to the testable size for the triaxial machine. These processes, as a matter of fact introduce some errors to the final test results. These problems have been curbed by the minicompactors with dimensions equivalent to the required size of the test specimens. The Nanjing Soil Instrument Factory based in China has fabricated a minicompactor to accompany the triaxial machine (Model TS2-1) produced by the company. This is just one of such minicompactors available in different Civil Engineering laboratories at present. This instrument was supplied to the Department of Civil Engineering, Nnamdi Azikiwe University, Awka for use in the Geotechnical laboratory. The minicompactor is made of a split mold of 96.06cm^3 by volume. The rammer of light weight 600g, and fits fairly to the internal circumference of the mould. The drop height is 30cm, which is relatively short. These features are very desirable to contemporary researchers and laboratory technicians. The problem of extrusion has been conquered by the split nature of the mould, the encumbrance of the heavy rammers was as well eliminated by the light weight rammer, and the uniformity in the distribution of blows ameliorated by the external circumference of the rammer fitting to the internal circumference of the split mould. This method of compaction that fits the rammer to the circumference of the mould, requiring no trimming afterwards, is refered to as static compaction, and have been viewed to be more effective than the impactful compaction (Milberger and Dunlap, 1966). Observing how small and light the mould and rammer of the Nanjing minicompactor were, it was suspected that it will not achieve the same maximum dry density (MDD) and OMC as any of the other established laboratory standards, if the same number of blows were used. This fact made it expedient to calibrate the minicompactor before it is put into use in the laboratory.

1.4; The Essence of Calibration

Calibration is in essence a comparison between measurements. A measurement with known magnitude or correctness is made with one device and another measurement is made in a similar way with a second device. The device with a known or assigned correctness is called the standard while the second is the unit under test or test instrument (Moris, 1997). Instruments are calibrated in different ways for different purposes. To calibrate any given instrument, some operations will be undertaken to establish the relationship between the values indicated by a measuring instrument or measuring system and the corresponding known values of the parameter being measured which is referred to as a measurand (UNIDO, 2006; IOS, 1993). It is therefore a demonstration that a particular instrument or device produces results within specified limits by comparison with those produced a reference standard over a substantial range of measurements (Growrisankar *etal*, 2010). This captures the very basics of this study. Reasons for the calibration of instruments can include; new instrument, after repairs of instruments, after shock or vibration, after serious weather changes, as specified by the manufacturer, among others. The most important of all is when new equipment is fabricated; it must be calibrated before use. This is much more quintessential in civil Engineering works involving the strength of materials for use in construction works. Such materials are expected to be durable enough to carry the expected imposed load through the service life of the structure. Calibration will no doubt ensure uniformity and conformity to standard design codes. Milberger and Dunlap (1966) presented the calibration of an electrical split mould gyratory compactor by varying the number of revolutions, the vertical loads, speed of gyration, and gyratory angle. In the calibration of a mechanical rammer by the American Standard Testing Laboratory (ASTM D 2168, 2010), the weight of the mechanical rammer was adjusted in order to provide for the mechanical compactor to produce the same result as the manual compactors. It was also pointed out that the quality of result produced by this standard would be dependent on the competence of the personnel performing the experiment, and also on the equipment and facilities used. ASTM D 2166(1998) recommended 25 blows per layer for five layers using the Harvard miniature mould for preparing the samples for Unconfined Compression Test in order to determine the unconfined compression strength and the undrained shear strength. To improve the quality of calibration and have the results accepted by outside organisations, it is desirable for the calibration and subsequent measurements to be traceable to the internationally defined measurement units. This research work adopted the equivalent number of blows approach to the calibration of the minicompactor. The number of blows with the Nanjing minicompactor that will achieve the same MDD and OMC with these known standards- BSL, RBSL, WAS, and BSH, using the same lateritic material and same number of layers were established.

2.0: MATERIALS AND METHODS

The lateritic soil used for the purpose of this experiment was obtained from a borrow pit at Obinagu-Awka in Awka South Local Government, Anambra State, Nigeria. The sample was collected at a depth of 1.5m. Portable Sachet water supplied at vendors close to the Engineering Cad laboratory was used for the purpose of this experiment. The specimen was air dried in the laboratory before the tests were run. The Following tests were conducted on the material; natural moisture content, specific gravity, Consistency limits, particle size distribution, and compaction tests. The test procedures described by Dass (2007) and Venkatramaiah (2006) were followed.

The compaction was carried out using the standard testing methods of MBSL, BSL, WAS, and BSH. The same laterite was also compacted using the minicompactor at three layers using 4, 8, 12, 16, 20, 24, and 28 blows. It was also compacted at five layers using 34, 38, 42, and 46 blows. The three layer compactions were used to pro rata the MBSL and BSL that has lesser compactive efforts (2.5kg rammer at three layers) while the five layer compactions were used to pro rata the WAS and BSH with higher compactive efforts (4.5kg rammer at five layers).

The particle size distribution curve and compaction curves were ploted. The maximum dry density (MDD) and optimum moisture content (OMC) were determined and plots of MDD against number of blows were made for the five layer as well as the three layer compaction. Using the Microsoft excel, statistical models were fitted from the curves. With the aid of these models, the most equivalent number of blows for each of the four standards considered were established.

3.0: RESULTS AND DISCUSSION

3.1; Properties of the Soil

Table 1; Index Properties of the Lateritic Soil

Property	Value
Natural Moisture Content	6.59%
Specific Gravity	2.56
Colour	Red
Liquid Limit	24.80%
Plastic Limit	17.70%
Plasticity Index	7.10%
Mean Size D_{50}	0.4mm
Weight of fines(silt and clay) - < 0.075mm	25.68%
Weight of Sand – 0.075mm to 2mm	74.32

Table 1 is the result of the index properties of the lateritic soil used in the study. The tests to determine the specific gravity, particle size distribution, and Atterberg's limits of the lateritic soil was carried out in accordance with BS1377(Part2;1990). As can be seen from the table and also from figure 1, the sizes of the lateritic sand particles ranges from 0.075mm to 2mm, which forms up to 74.32% of the weight of the soil sample. The fines contributed 26.68% of the soil. The value of D_{50} is the mean size of the particles which was observed to be 0.4mm. The reddish colour of the soil is characteristic of lateritic soils. The specific gravity of 2.56 is also normal for most laterites.

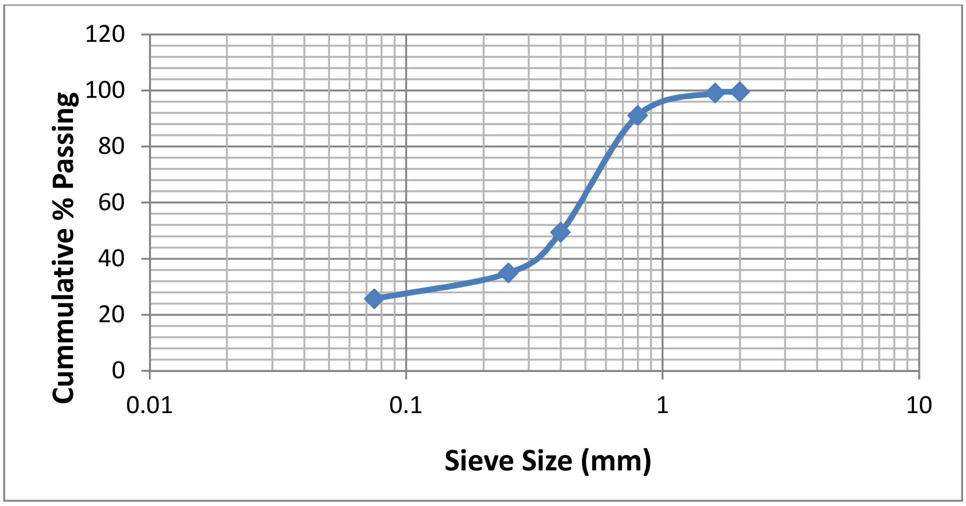

Figure 1, Particle Size Distribution of the soil.

3.2; Compaction with Standard Compaction Procedures

Figure 2 shows the results of the compaction of the soil with standard compactors. The moisture content varied from 5.47% to 20.15%, 4.27% to 18.18%, 4.84% to 15.26%, and from 4.31% to 14.01% for the Reduced British Standard Light, British Standard Light, British Standard Heavy, and West African Standard compaction methods respectively. The dry densities computed from each of the standards at any given moisture content were also displayed. From the compaction curves as shown in figure 2, the Maximum Dry Densities and the Optimum Moisture Contents were read for the four methods. The MDDs were 1850Kg/m^3, 1890 Kg/m^3, 1940 Kg/m^3, and 1990Kg/m^3 respectively while the OMCs were 12.5%, 12.2%, 11.0%, and 9.5% in that order. This result shows that as the compactive efforts increases, there is an increase in the MDD and a decrease in the OMC. This is in agreement with most previous works done in this subject of compaction (Muazu, 2007; Kumar & Sharma, 2004; Graig *etal*, 1999).

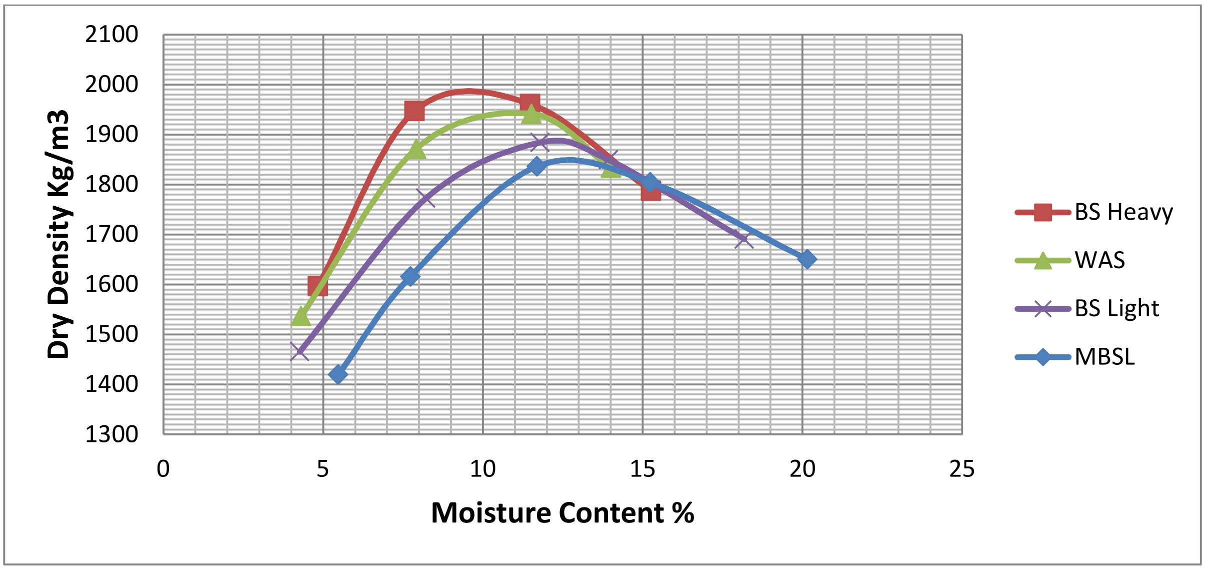

Figure 2; Compaction Curves for the RBSL, BSL, BSH, and WAS.

3.3; Compaction with the Mini Compactor

The compaction which was done with the mini compactor was to determine the number of blows that would give the same MDD and OMC as the standard compaction methods, adopting the same number of layers as the standard procedures. The same lateritic soil was used under the same laboratory condition. It was done in two phases; in the first phase, the soil was compacted in three layers to prorate the RBSL and BSL that are also done in three layers, while in the second phase, the compaction was done in five layers to prorate BSH and WAS. The results are as shown in figures 3, 4, and 5 with the number of blows ranging from 4 to 28 at three layers and 34 to 46 at five layers. The MDDs achieved with blows less than 16 were actually found to be far less than the 1850Kg/m^3 which is the least MDD achieved using the standard compactors.

Figures 3, 4, and 5 are, therefore, the compaction curves for the higher number of blows for three layers and five layers as shown. The MDD increased from 1750Kg/m^3 at 16 blows to 1900Kg/m^3 at 28 blows and also from 1880Kg/m^3 at 38 blows to 2010 Kg/m^3 at 46 blows. This further shows that the compactive effort is directly proportional to the MDD and inversely proportional to the OMC.

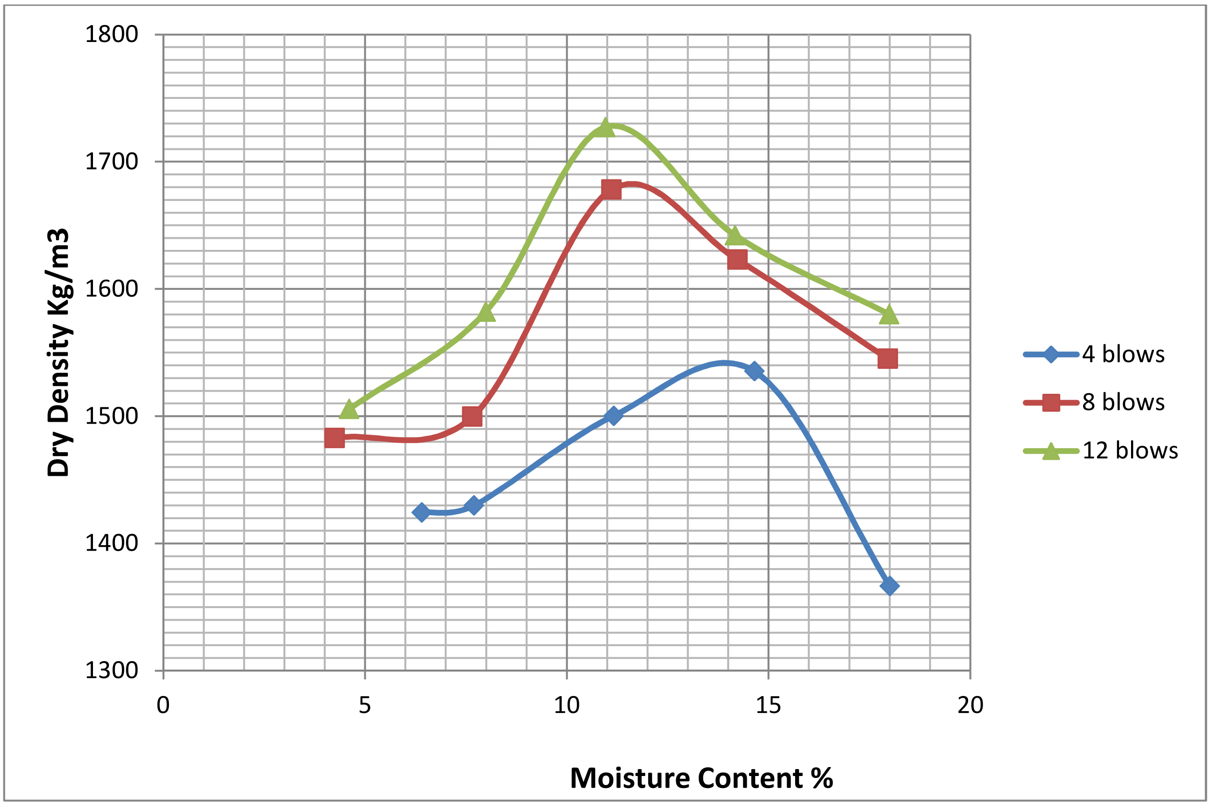

Figure 3; Compaction Curves for 4 to 12 blows made at three layers.

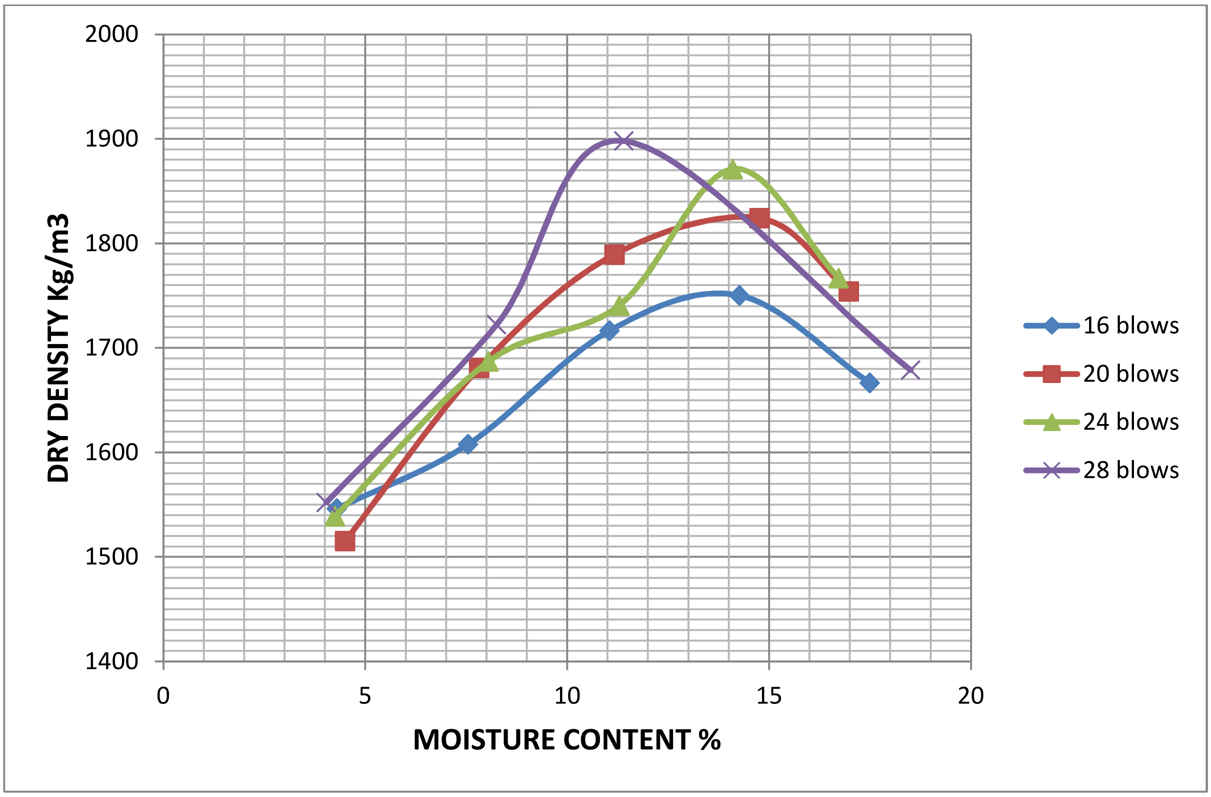

Figure 4; Compaction Curves for 16 to 28 blows made at three layers.

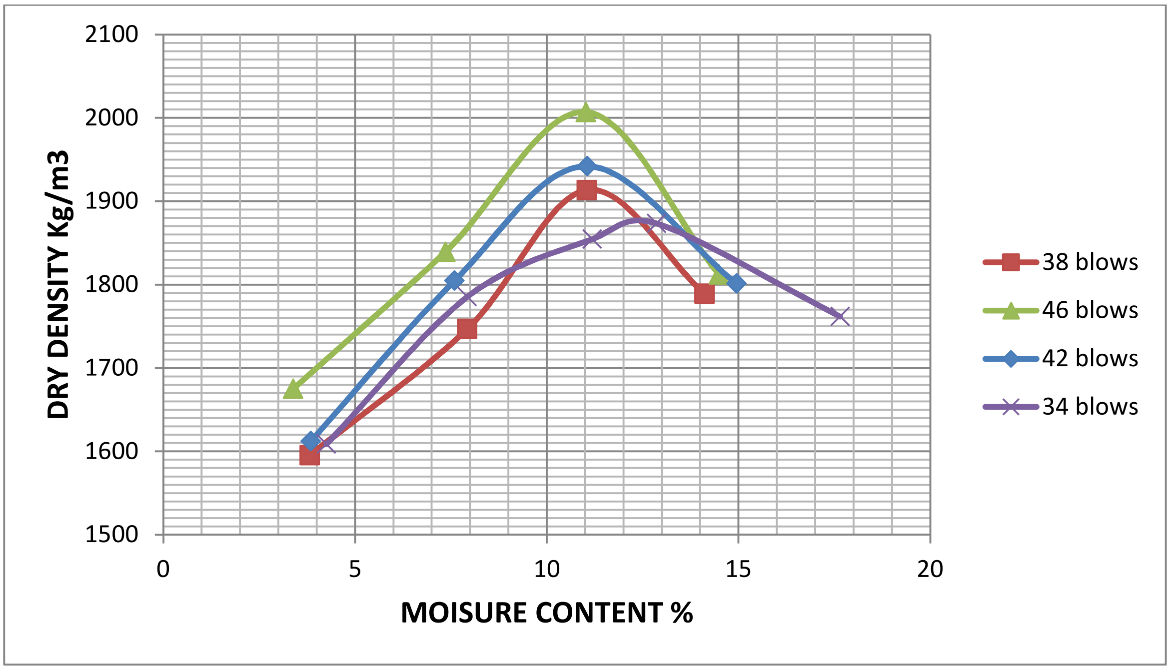

Figure 5; Compaction Curves for blows made at five layers.

3.4; The Calibration; Statistical Analysis and Estimations

Figures 6, 7 and 8 are plots of the MDD against the number of blows for the minicompactor. This plot was made using the MICROSOFT EXCEL software. The actual values of the MDD reported in the tables 2 and 3 are those derived from the equations (Exponential, Logarithmic, Power, Linear, Third-order polynomial, and Second-order polynomials) generated from the curves of figures 6, 7, and 8 using MICROSOFT EXCEL.

Figure 6; Number of blows verses Maximum Dry Density curve for 4 to 8 blows at three layers

Figure 7; Number of blows verses Maximum Dry Density curve for 16 to 28 blows at three layers

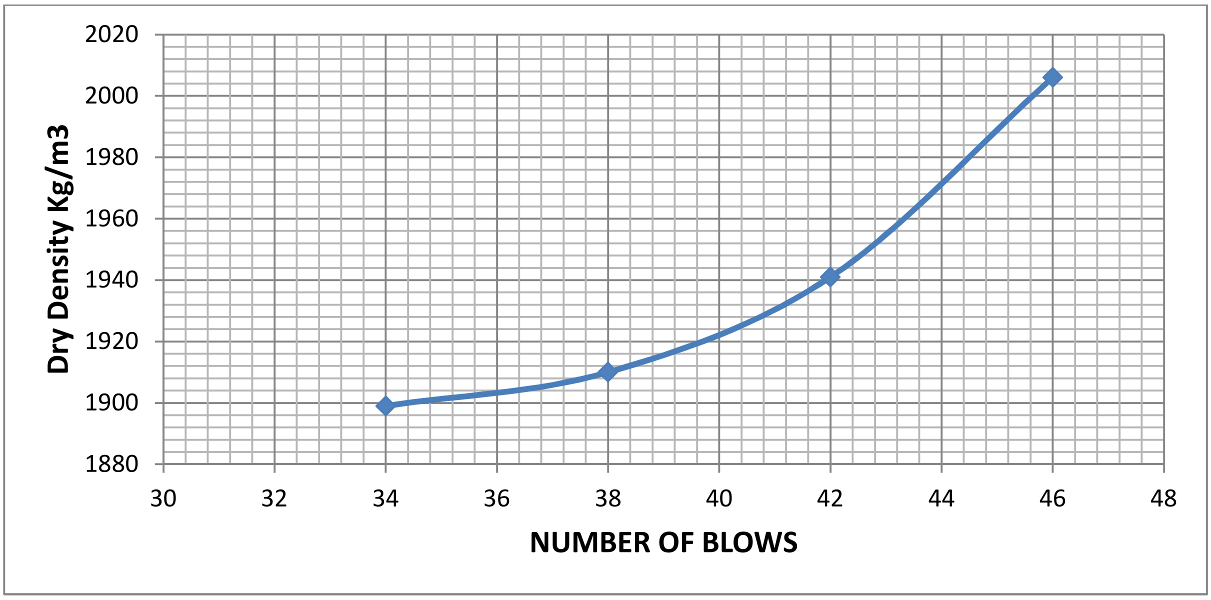

Figure 8; Number of blows verses Maximum Dry Density curve for five layers

Considering the R^2 values, which describes how much the variations in dry densities have been explained by the variations in the number of blows (Ledolter and Hogg, 2010; Keller,2001), both models (Linear, Power, Logarithmic, Exponential, the second order and the third order polynomial) performed quite well in describing the relationship between MDD and number of blows, based on this experiment. But considering the nature of the curve, the second order and the third order polynomial models would best represent this relationship and, as expected, they gave the highest R^2 values of 0.9987 and 1 respectively, for the three layers and 0.9986 and 1 respectively for the five layers, were adopted and used in the estimations. Equations 1 to 4 are the Mathematical expressions of the models. In the equations, N represents the number of blows while MDD is the corresponding maximum dry density. The curves for the lesser compactive effort models show an upward (crest) convexity while the curve from the higher compactive efforts displayed a downward (sag) convexity as shown the figures 7 and 8 above.

For the upward convex curve (three layers of compaction) the polynomial models are;
Second order, $MDD = -0.7812N^2 + 46.475N + 1209.3$ ……………….. (1)

Third order, $MDD = 0.0469N^3 - 3.875N^2 + 113N + 744$ ……………….(2)

For the downward convex curve (five layers of compaction) the polynomial models are;

Second order, $MDD = 0.8438N^2 - 58.7N + 2920.1$ ……………………. (3)
Third order, $MDD = 0.0365N^3 - 3.5313N^2 + 115N + 634.62$ …………. (4)

From the results, it was decided that 22 blows in three layers will be equivalent to the RBSL, 27 blows at three layers will be equivalent to the BSL, 42 blows at 5 layers will be equivalent to WAS, and 46 blows at 5 layers will be equivalent to BSH. This estimation also agrees with the number of blows corresponding to the MDD read directly from the figures 5 and 6.

3.5; Confirmation of the Estimates

An attempt to confirm the estimate was made by plotting the curve of Optimum Moisture Content against number of blows. This plots are shown in figures 9 and 10. The second order polynomial equation of the curve was used. With the number of blows as the independent variables, the corresponding OMC was read from the graph for the estimated 22, 27, 42, and 46 blows. These were compared with those from the standard procedures and were found to be comparable. Table 4 displays the comparison.

Table 2; R-squared values of the Statistical Models – three layers

Number of Blows		21 blows	22 blows	23 blows	24 blows	25 blows	26 blows	27 blows	28 blows
Type of Curve	R^2 Values	MDD (Kg/m^3)	MDD (Kg/m^3)	MDD (Kg/m^3)	MDD (Kg/m^3)	MDD (Kg/m^3)	MDD (Kg/m^3)	MDD (Kg/m^3)	MDD (Kg/m^3)
2nd order Polinomial	0.9986	1840.8	1853.6	1864.9	1874.7	1882.9	1889.6	1894.6	1898.1
3rd order Polinomial	1	1842.5	1853.9	1863.8	1872.3	1879.9	1886.8	1898.4	1899.5
Linear	0.9481	1825.9	1838.0	1850.1	1862.2	1874.3	1886.4	1898.5	1910.6
Power	0.9751	1830.8	1843.1	1855.0	1866.4	1877.4	1888.1	1898.4	1908.4
Logarithmic	0.9785	1831.4	1843.6	1855.3	1866.5	1877.3	1887.6	1897.5	1907.1
Exponential	0.9431	1824.1	1836.2	1848.3	1860.6	1872.9	1885.3	1897.8	1910.3

Table 3; R-squared values of the Statistical Models-five layers

Number of Blows		41 blows	42 blows	43 blows	44 blows	45 blows	46 blows
Type of Curve	R^2 Values	MDD (Kg/m^3)	MDD (Kg/m^3)	MDD (Kg/m^3)	MDD (Kg/m^3)	MDD (Kg/m^3)	MDD (Kg/m^3)
2nd order Polinomial	0.9986	1931.8	1943.1	1956.2	1970.9	1987.3	2005.4
3rd order Polinomial	1	1949.6	1943.8	1956.6	1971.6	1989.3	2009.8
Linear	0.8935	1947.8	1956.6	1965.4	1974.2	1983.0	1991.8
Power	0.8687	1948.9	1957.2	1965.3	1973.3	1981.1	1988.8
Logarithmic	0.8645	1949.7	1957.9	1966	1973.9	1981.6	1989.2
Exponential	0.8973	1946.2	1955.0	1963.8	1972.6	1981.5	1990.5

Table 4; Moisture content comparison.

Number of blows	**MC%**	**Standard Compaction Methods**	**MC%**
22	14.4	RBSL	14.5
27	12.2	BSL	12.3
42	11.1	WAS	12.4
46	11.0	BSH	12.8

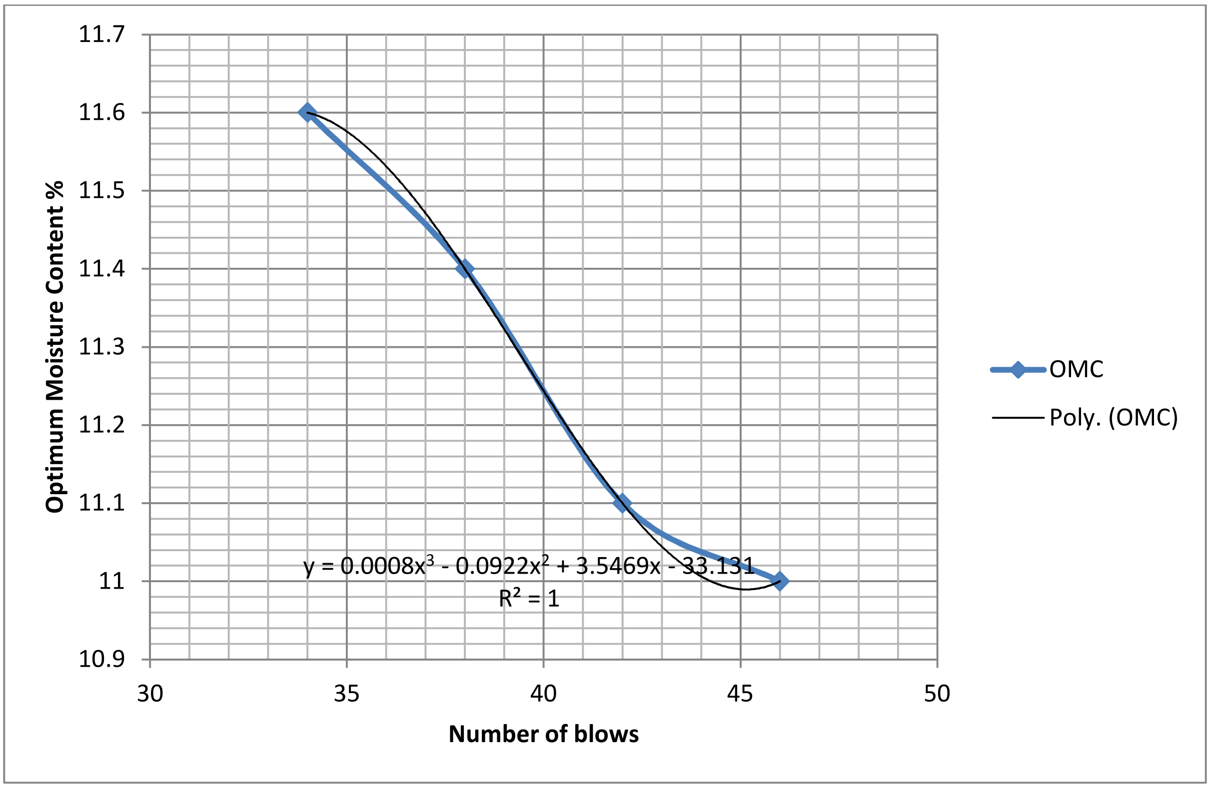

Figure 9; OMC/Number of blows curve for the five layers.

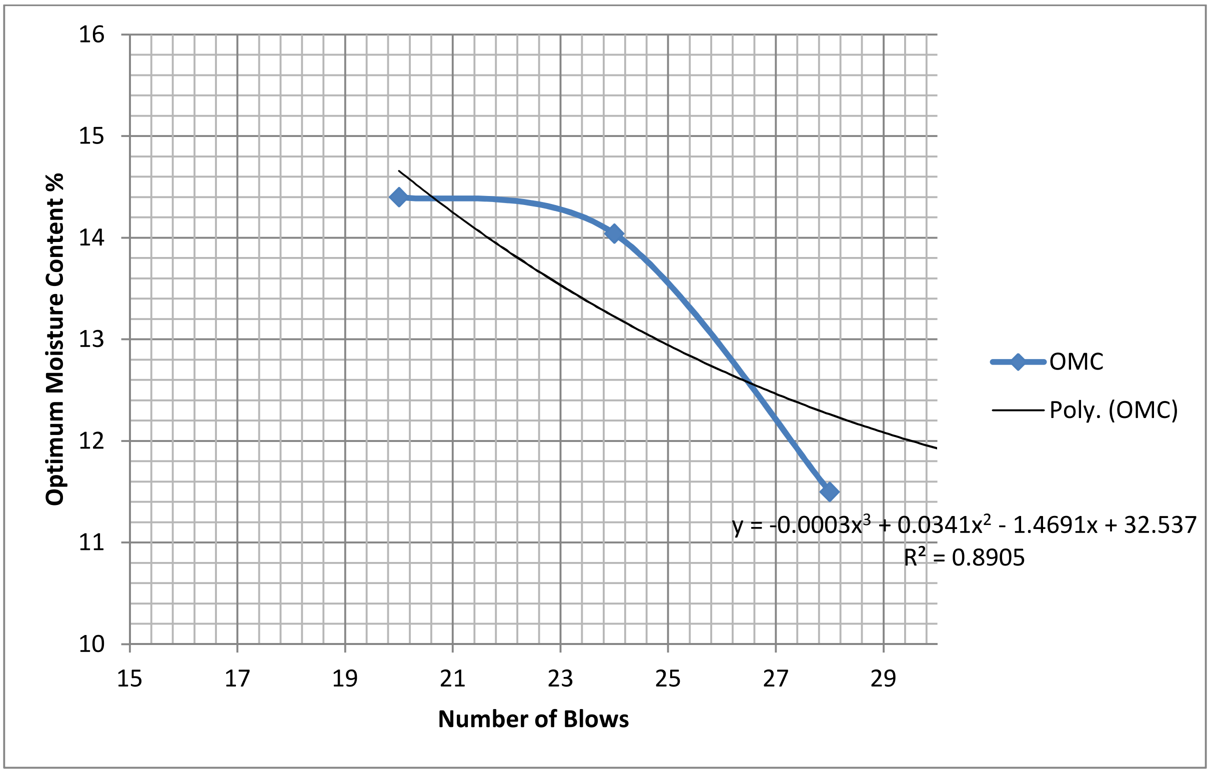

Figure 10; OMC/Number of blows curve for the three layers.

4.0; CONCLUSION

In this study, a minicompactor was calibrated with the equivalent blow approach. The study revealed that increase in compactive efforts leads to increase maximum dry density and decrease in the Optimum Moisture Content. The fact that compacting at three layer, 22 blows and 27 blows yielded equivalent MDD and OMC as the RBSL and BSL respectively, while compacting at 5 layers 42 blows and 46 blows yielded equivalent MDD and OMC as the WAS and BSH respectively, the minicompactor was thus calibrated. With the high coefficient of determination from the statistical data model fitted to the experimental data, it was concluded that these estimated number of blows would yield the same compaction as the standard methods for which they were recommended.

The outcome of this calibration study shows that it is very quintessential to practically calibrate any new equipment before they are put in use in the laboratory as speculations and assumptions may not be realistic.

5.0; Further Research

Further studies would be necessarily conducted with lateritic soils from other locations and other soil materials to further strengthen the estimates made by this study. This calibration approach can also be adopted in the calibration of other minicompactors apart from the model calibrated as part of this study.

The authors also propose a further investigation into the implications of the compactive efforts of these minicompactor on the validity of soil laboratory experiments.

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