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Study to Investigate Variation of California Bearing Ratios of Soil Materials with Changes of Soaking Duration

Dr. Duwa Hamisi Chengula*

Mbeya University of Science and Technology, College of Engineering and Technology, Department of Civil Engineering. P.o.Box 131 Mbeya, Tanzania

Email: chengula@yahoo.com

Abstract

The study was conducted to investigate variation of CBR values with soaking duration. Four sample materials were used for laboratory tests which are cinder and natural pozzolan from Ituha borrow pit, clay soil from Mlimanyoka borrow pit in Mbeya region and then the three source materials were blended together to obtain a fourth sample materials. Characterizations of soil materials were conducted including maximum dry densities (MDD) and optimum moisture contents (OMC) were determined. The results for MDD and OMC for the four soil samples are 1680kg/m^3 and 13.2% for cinder, 1543kg/m^3 and 19.5% for natural pozzolan, 1524kg/m^3 and 23.4% for clay and 1642kg/m^3 and 15.6% for blended sample respectively. The variation of California bearing ratios (CBR) for four soil samples were determined. The CBR values of sample materials were determined for unsoaked samples, 4 days, 8 days and 12 days soaking duration. The results of CBR values at 95%MDD for the four samples soaked for four days are 16.5% for cinder, 23% for natural pozzolan, 4.8% for clay soils and 27.4% for the blended sample. The results indicated that there are exponential decrease of CBR values with increasing soaking duration to the residual values after fully saturation of soil sample. The high CBR values of blended sample enhanced by interlocking and friction properties of the mixtures and addition of clay which act as binder to none plastic soils. It is important to determine CBR values at longer soaking duration than 4 days whenever the soil materials are to be used in areas with high water tables and frequent rainfalls. For easy estimation of CBR values for a particular soaking time, an equation has been developed, which will reduce time for laboratory works to determine CBR values at longer soaking duration.

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* Corresponding author.

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1. Introduction

California bearing ratio (CBR) is the measure of resistance of soil materials against plunger penetration and it is described as strength of soil materials [1, 2, 7]. CBR values are soil strength measure used for design of unsealed pavement layers [1,7]. In the field of pavement design and pavement materials, CBR has become common parameter used to determine strength of granular soils for design and construction of pavement layers. The CBR values are affected by particle size distribution, particle textures and shapes, dry density and water content [8].

The CBR test is conducted on a soil sample soaked for 96 hours (4 days) in water to simulate the worst condition of the subgrade or gravel materials [2]. This is because it is difficult to guarantee that the water won't penetrate through the pavement down to the base and subgrade in the event of rains or raise by capillary action when the water table raises. The studies have indicated that all soil materials loses strengths especially shear strength when water content increases [9, 10].

Therefore, CBR value for a soaked sample is always less than CBR value for a dry sample of the same soil material and then design of the pavement layers is done by considering wet subgrade or gravel materials even though it may be dry at the time of construction [2, 11].

In this regard, if the design of pavement layers considers dry CBR values of materials, then the pavement will deteriorate with traffic load during wet seasons. Studies recommend to use minimum soaked CBR values of soil materials for design of pavement layers [1, 12, 13]. The standard specification for laboratory CBR test procedures have limited soaking duration for soil materials to be 4days (96hours) [1, 2]. It is well understood that the soaking properties differ from one type of soil to another. Some materials take longer time to reach saturation state and other material takes even shorter time. The interlocking and adhesion forces of the submerged soil materials differs with soaking duration. It is not worth to consider that the drain condition of wet soil will be achieved within four days, as some regions it rains even more than a week none stop. But also on low lands they become flooded for long time even after rainfall has stopped. Due to that the CBR values used for design of pavement layers in areas with frequent rainfall and on low lands where water table is high are relatively high. Several researchers have indicated that there are premature pavement failures in areas with high water table and frequent rain fall which is because of reduced strength of pavement materials under water [14, 15, 16].

Various properties of soil materials are affected by the moisture which includes swelling, shrinkage and load bearing capacity. There exists several factors like pavement porosity, infiltration, groundwater table elevation, or drainage that affect the moisture content which might be aided by pavement cracks. Under vehicle loads, usually deformation is noticed when subgrades are excessively wet. Soil type, moisture content, and compaction degrees affects the load bearing capacity of the soil materials [15, 16]. The subgrade is always subjected to change in its moisture content due to rainfall, capillary action, overflow or rise of water table. For an engineer, it is important to understand the change of subgrade strength due to variation of moisture content [17]. However, to carry out laboratory tests for determining strength of materials are expensive but also time consuming especially when the projects are of short duration. But also number of sets of equipment and tools and moulds are required when the testing duration are prolonged. Therefore, the design and construction costs of road projects will be high due to increasing cost of material tests and will demand large layer thicknesses or very strong materials which are expensive.

For this study, variation of CBR values with soaking duration have been studied for clay, natural pozzolan, cider materials and for blended materials. The Atterberg limits, particle size gradation and compaction parameters of the materials were also determined.

2. Investigation Procedure and Approach

2.1. Investigation procedure

The investigation for this study involved identification of source materials, locations and classification based on AASHTO classification system. Samples from three source materials available in Mbeya region were taken to laboratory for investigation. The source materials investigated are cinder, natural pozzolana and clay. Natural pozzolan and cinder materials were sourced from Ituha borrow pit and clay were excavated from Mlimanyoka borrow pit. Characterization and strength properties of source materials and for blended materials were investigated. A blended sample material is the mixture of cinder, natural pozzolan and clay materials for proportions required to fit the blended material into envelope for base material of gravel roads of low volume roads [1]. Table 2.1 indicates materials type and physical characteristics for road construction. Soils were classified according to AASHTO classification system.

Table 2.1: Classification of Soil Materials (AASHTO).

Source materials	Abbreviation	Physical properties	AASHTO Classification	% Fines	% Sand	% Gravel
Cinder	Ci	Blackish gravel	A-1-b Stone fragment, gravel and sand	1	11	88
Natural pozzolan	Po	Brownish colour soil	A-4 Silt soil	50	46	4
Clay	Cl	Reddish brown soil	A-7-6 Clayey soil	68	31	1

2.2. Investigation Approach

The sample materials were taken from the sources and the laboratory tests were conducted including particle size analysis, Atterberg limits (liquid limit, plastic limit and linear shrinkage limit), compaction tests and California bearing ratio (CBR values) tests.

The three source materials were blended together at different proportions to meet requirements of gradation envelopes of gravel base layer of low volume roads [1]. Sieve analysis tests were conducted to determine particle size gradations and percentages passing each sieve size. The gradation factors (GF) and median particle sizes (MS) determined from particle size gradation were used to obtain blending proportions of source materials since the individual materials do not lay within the specified envelope [6]. The Atterberg limits involved determination of liquid and plastic limits used to compute plasticity index. Plasticity index is used as indication of binding properties of materials. The compaction tests were conducted to determine maximum dry densities (MDD) and optimum moisture contents (OMC) of materials which are useful parameters when conducting California bearing ratio (CBR) tests. Three point CBR test for each materials were conducted and the CBR values were determined for unsoaked sample, 4 days, 8 days and 12 days of soaking duration under water. For each soaking days, CBR values at 95% MDD were considered as strength of the materials [1. 3].

3. Results and Discussion

3.1. Characterization of Materials

The analysis of laboratory tested sample materials were mainly to investigate variations of CBR values at 95%MDD with soaking duration. However other parameters were investigated which includes particle size parameters, soil classification, Atterberg limits and compaction parameters. In order to obtain these parameters of the three source materials and one blended material, characterization and analysis of tested data were performed.

The Atterberg limits tests was for determining plasticity indices. Table 3.1 gives results of Atterberg limit tests for four soil materials. The results indicates that Ituha cinder and Ituha pozzolan are non-plastic materials and plasticity indices (PI) of Mlimanyoka clay is 28.8%.

Table 3.1: Atterberg limit data of source materials.

Source materials	Abbreviations	Liquid limit (LL) (%)	Plastic limit (PL) (%)	Plasticity index (PI) (%)	Linear shrinkage limit (SL) %
Ituha cinder	Ci	44.75	Non-plastic	Non-plastic	0
Ituha pozzolan	Po	51.00	Non-plastic	Non-plastic	0
Mlimanyoka clay	Cl	59.00	30.2	28.8	10.7

The particle size analysis tests for source materials were conducted to determine particle size gradation. The particle size distributions of source materials were used to compute grading factors (GF) and median particle sizes (MS) used for determining blending proportions of materials [6]. The grading factor "GF" and median particle size "MS" are computed using equation 3.1 and 3.2 [6]. Figure 3.1 shows particle size distribution of source materials.

$$GF = \frac{\sum_{P=0}^{100} PP_i * SS_i}{\sum_{P=0}^{100} PP_i} \qquad 3.1$$

Where: "PP_i" denotes percentage passing sieve size in mm; "SS_i" denotes sieve size for each percentage passing

$$MS = \frac{\sum_{i=0}^{n} PR_i * SS_i}{100} \quad 3.2$$

Where: "PR_i" denotes percentage retained on sieve size in mm; "SS_i" denotes sieve size for each percentage retained.

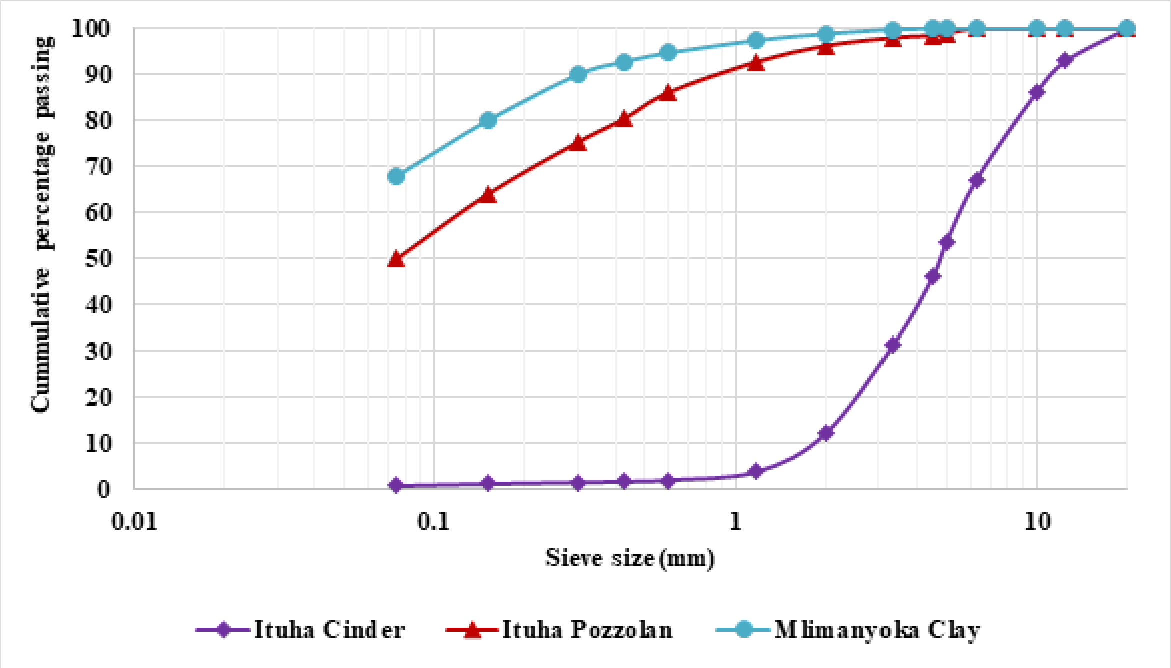

Figure 3.1: Particle Size Distribution Curves of Source Materials.

Table 3.2 shows computed gradation factors and median particle sizes for each source material and for upper and lower limit of the gradation envelopes.

Table 3.2: Particle size data, gradation factor and median particle sizes.

Blending parameters	Sample materials			Envelopes	
	Ituha cinder (Ci)	Ituha pozzolan (Po)	Mlimanyoka clay (Cl)	Uper limit (UP)	Lower limit (LL)
Grading factor (GF)	10.10	2.44	1.09	10.77	4.02
Median particle size (MS)	4.76	0.27	0.10	4.84	1.12

The three source soil materials were blended together to obtain one blended sample soil which was used to determine CBR values. The blending process were conducted in order to obtain particle size gradation curves laying within the envelope of base course gravel materials for low volume roads [6]. Equation 3.3 was used to determine proportions of cinder, clay and pozzolan to be blended [6].

$$P_A = \frac{(GF_U + GF_L - 2GF_B) + (MS_U + MS_L - 2MS_B)}{2[(GF_A + MS_A) - (GF_B + MS_B)]} \text{ and } P_B = 1 - P_A \quad 3.3$$

Where: P_A and P_B are proportions of soil material A and B in decimals respectively, GF_A and GF_B are gradation factors of soil material A and B respectively, MS_A and MS_B are the median particle sizes of soil material A and B respectively, MS_L and MS_U are the median particle sizes of lower and upper gradation envelopes respectively, GF_L and GF_U are the gradation factors of lower and upper gradation envelopes respectively.

For more than two materials the combined parameters (GF and MS) of the first blended soil materials are used to blend with the remaining soil materials [6].

Gradation curves of the new mixture blended from three source materials which are cinder, natural pozzolan and clay and the gradation envelope (lower and upper limits) of the granular materials of base layer for LVR are shown in figure 3.2. The proportions of the materials in percentages are given as numerals in front of the abbreviation of each source soil material. Uniformly distributed gradation of soil particle sizes enhances densification and friction resistance which then increases penetration resistance for CBR values.

For this study, cinder material was blended with clay materials and the ratios obtained are 67% for cinder and 33% for clay soil. Then cinder materials was blended with natural pozzolan and the ratios obtained are 63% for cinder and 37% for natural pozzolan. The two blends were blended together to determine the combined ratios for the three materials. In this regards the blended ratios for cinder materials was 64%, for natural pozzolan was 27% and for clay was 9%.

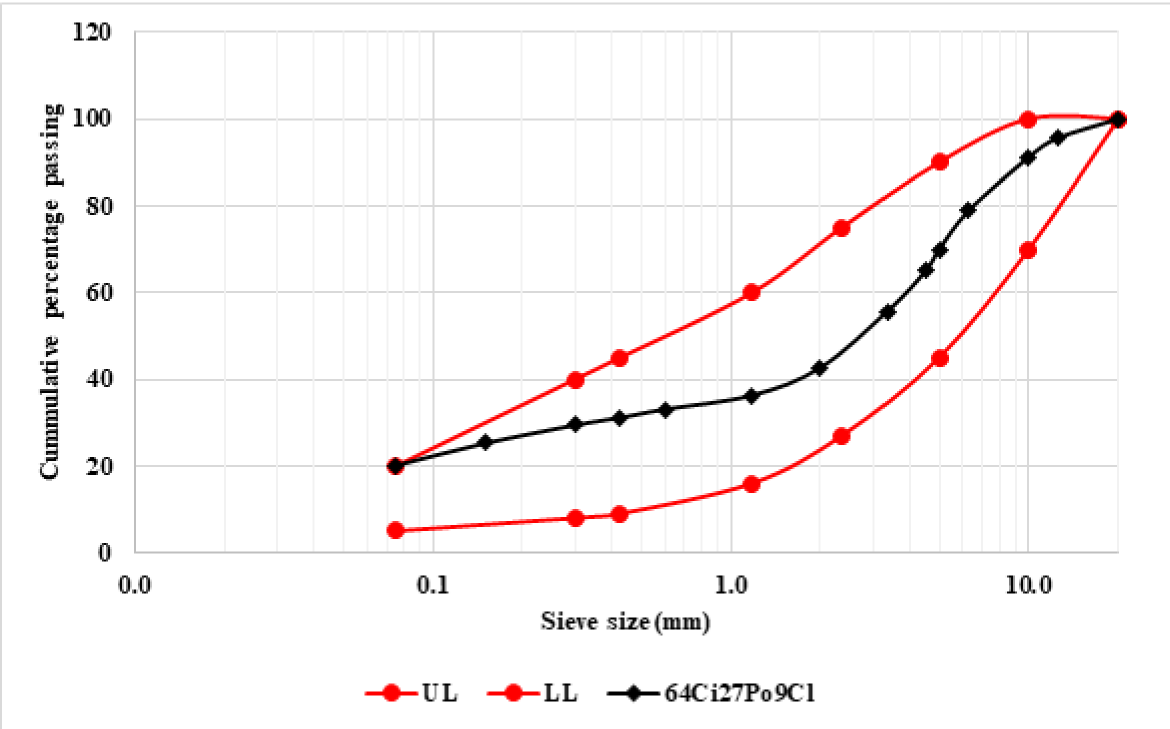

Figure 3.2: Particle Size Distribution Curves of Blended Materials.

Compaction test and three points California bearing ratio tests were conducted for source materials and for the blended in order to determine variations of CBR values of soil material at 95%MDD.

3.2. Compaction and California Bearing Ration (CBR) of Materials

The compaction tests for all four samples were conducted using modified BS heavy proctor test to determine maximum dry densities (MDD) and optimum moisture contents (OMC) [2]. The results for maximum dry densities and optimum moisture contents obtained for cinder are 1680kg/m^3 and 13.2%, for natural pozzolan are 1543kg/m^3 and 19.5%, for clay are 1524kg/m^3 and 23.4% and for blended sample are 1642kg/m^3 and 15.6% respectively. Figure 3. 3 shows the compaction curves of four soil materials where by the turning points of the curves indicates their maximum dry densities and optimum moisture contents. The three point California bearing ratio tests for four soil materials were conducted using modified BS heavy density to determine CBR values at 95%MDD [1, 2, 3]. The materials were mixed and compacted at optimum moisture contents and soaked in water for 0 day, 4 days, 8 days and 12 days and penetrated to read resisting shearing forces for each plunger penetration depth. The average CBR values are calculated from the forces obtained at 2.5mm and 5.0mm plunger penetration depths [2, 4].

For three point CBR tests of the sample materials, three different compaction efforts and layer thickness of the same material are used. The materials in the first mould is compacted using 4.5kg pistol weight, 62 blows for 5 layers, the materials in the second mould is compacted using 4.5kg pistol weight, 30 blows for 5 layers and the materials in the third mould is compacted using 2.5kg pistol weight, 62 blows for 3 layers. The three point CBR test is conducted to determine variation of material strength with degree of compaction.

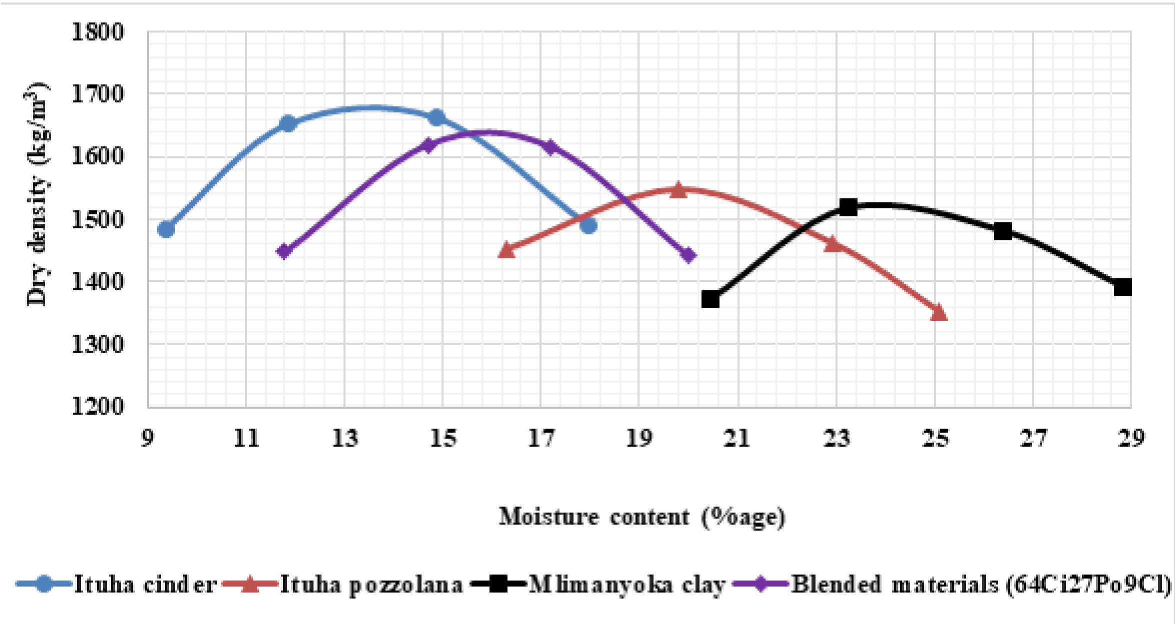

Figure 3.3: Compaction Curves of Soil Materials.

The results of CBR values at 95%MDD for the four soil samples for four days of soaking in water are 16.5% for cinder, 23% for natural pozzolan, 4.8% for clay soils and 27.4% for 64Ci27Po9Cl blended sample. The high CBR value was indicated for the blended sample due high densification properties and friction resistance of well graded materials and low CBR value is for clay materials which is due to high soaking rate compared to other soils used for this study, which have similar observation with other study [4]. Figure 3.4 shows variations of CBR values at 95%MDD with soaking durations for the four soil materials.

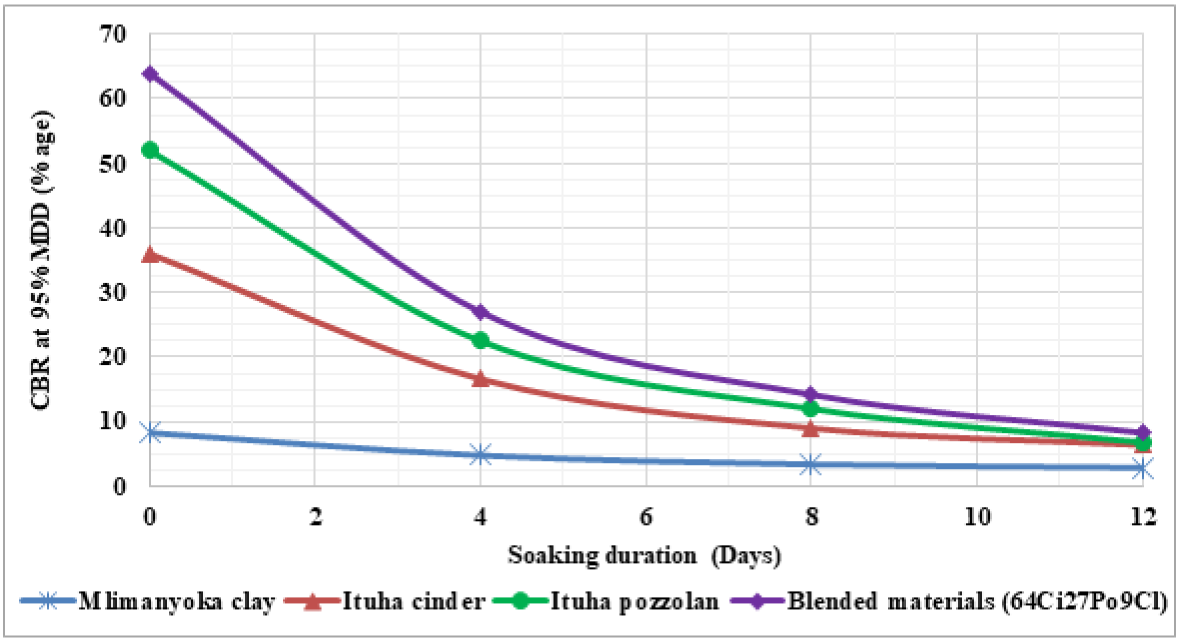

Figure 3.4: Variation of CBR of soil samples at 95%MDD with soaking days.

It has been investigated that CBR values of soil materials decrease exponentially with increasing soaking duration (refer figure 3.4), which is similar to other studies [5, 17]. Regardless of compaction efforts but also CBR values are the function of packing density and friction resistance and soaking potential of soil materials. The testing procedures to determine CBR values of soil materials are time consuming because the results should wait the materials to be soaked for 4 days in water but also it is expensive especially when the sample materials are many to be tested. In case the project is large and it is required to be completed within short time then the process of materials testing becomes more tedious, many sets of tools and equipment are needed and cost of project increases. In order to reduce testing duration, processes and projects costs, this study has developed a model to estimate CBR value at a particular soaking time provided unsoaked CBR value at 95%MDD is determined. Equation 3.4 can be used to estimate CBR value of soil material for particular soaking duration. However, estimated CBR values from the equation can be affected by soaking potential of particular material type which requires further investigation.

$$CBR = \left[\boldsymbol{e}^{\left(e^{-0.0585T} ln\sqrt{A}\right)}\right]^2 \qquad 3.4$$

Where: CBR - is a California bearing ratio at 95%MDD for particular soaking time, “A” is a CBR at zero day soaking time and “T” is a soaking duration of a sample soil in days.

The estimation equation of CBR value at a particular soaking duration will assist researchers, engineers, scientists and project planners to reduce time for execution of the projects and costs of the projects.

4. Conclusion and Recommendation

The strength resistance and durability of gravel pavement layer materials are affected by vehicle loads and repetitions. The strength of pavement materials are much deteriorated when the soil materials get soaked by moisture for long time. The strength of soil materials measured in terms of CBR values are reduced exponentially with increased soaking durations. Characterization and determination of CBR values of cinder, natural pozzolan, clay and blended soil materials were conducted under laboratory condition.

The results from data analysis indicated that the maximum dry densities (MDD) and optimum moisture content (OMC) are1680kg/m3 and 13.2% for cinder, 1543kg/m3 and 19.5% for natural pozzolan, 1524kg/m3 and 23.4% for clay and 1642kg/m3 and 15.6% for blended materials. The CBR values at 4 days soaking duration are 16.5% for cinder, 23% for natural pozzolan, 4.8% for clay soils and 27.4% for 64Ci27Po9Cl blended sample.

From this study it has been investigated that the increase in CBR values of sample materials does not depend very much on the maximum dry density of the material. The interlocking and friction properties of blended samples and addition of clay which act as binder to the coarse grain particles has much impact to CBR values. The decrease in CBR values with increasing soaking duration of sample materials is mainly contributed by materials soaking potential. For the case that the soil materials are to be used in low land areas and on area with high frequent rainfall, it is recommended to determined design CBR values at longer soaking days. For this study an equation to estimate CBR values for a particular soaking time have been developed, the equation uses unsoaked CBR and time required to estimate the soaked CBR value.

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Appendices

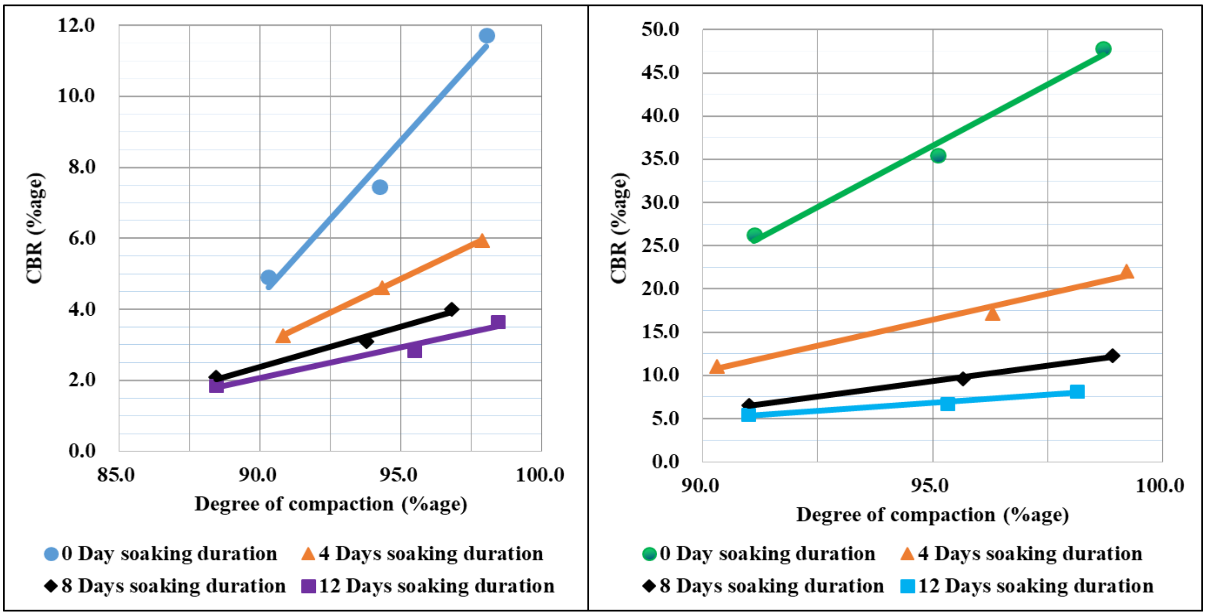

Figure A1: Three points CBR values for Mlimanyoka clay (left) and Ituha cinder (right).

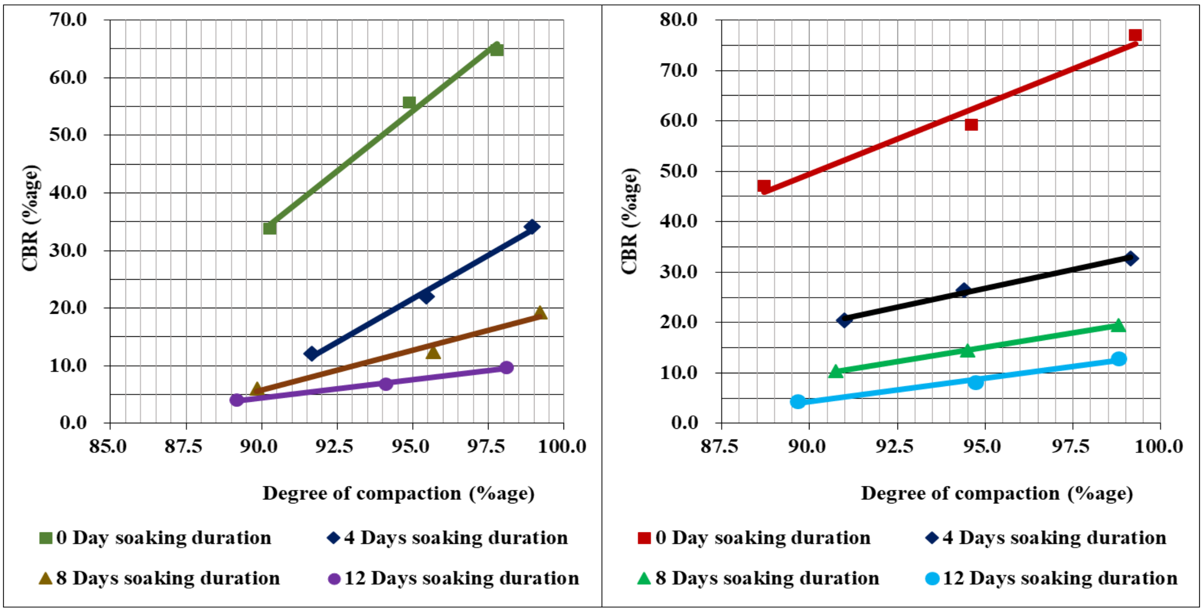

Figure A2: Three points CBR values for Ituha pozzolan (left) and Blended samples (64Ci27Po9Cl) (right).

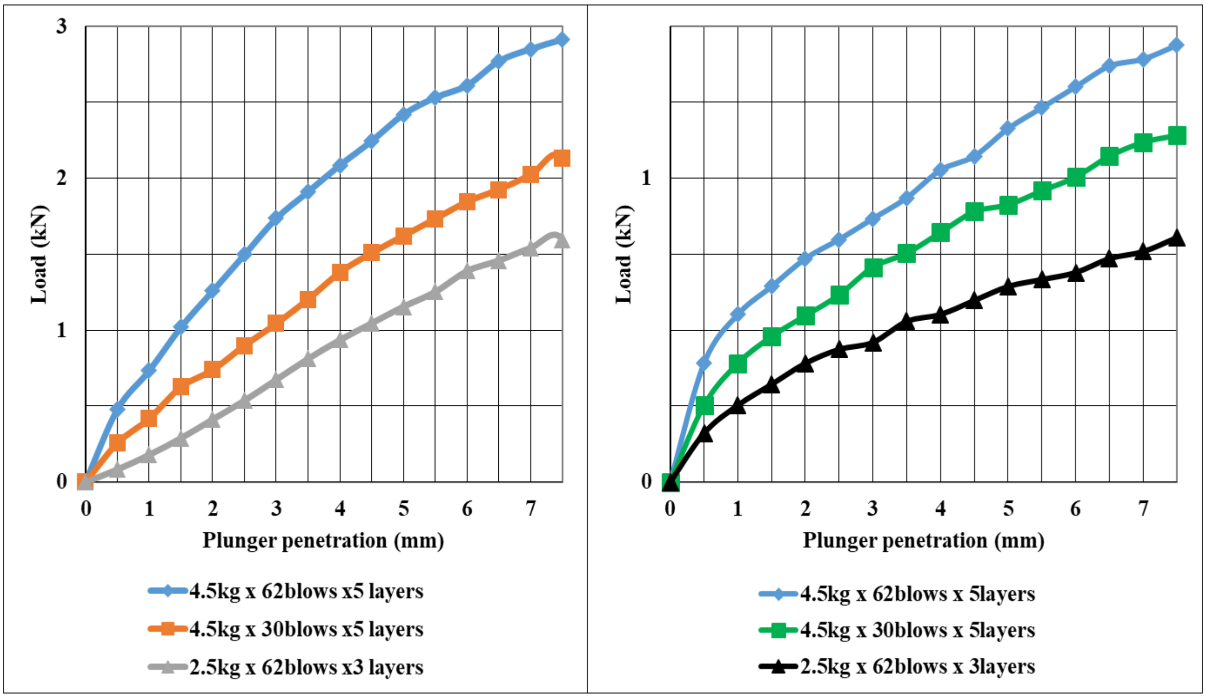

Figure B1: Penetration resistance of Mlimanyoka clay for 0 day soaking time (left) and 4 days soaking time (right).

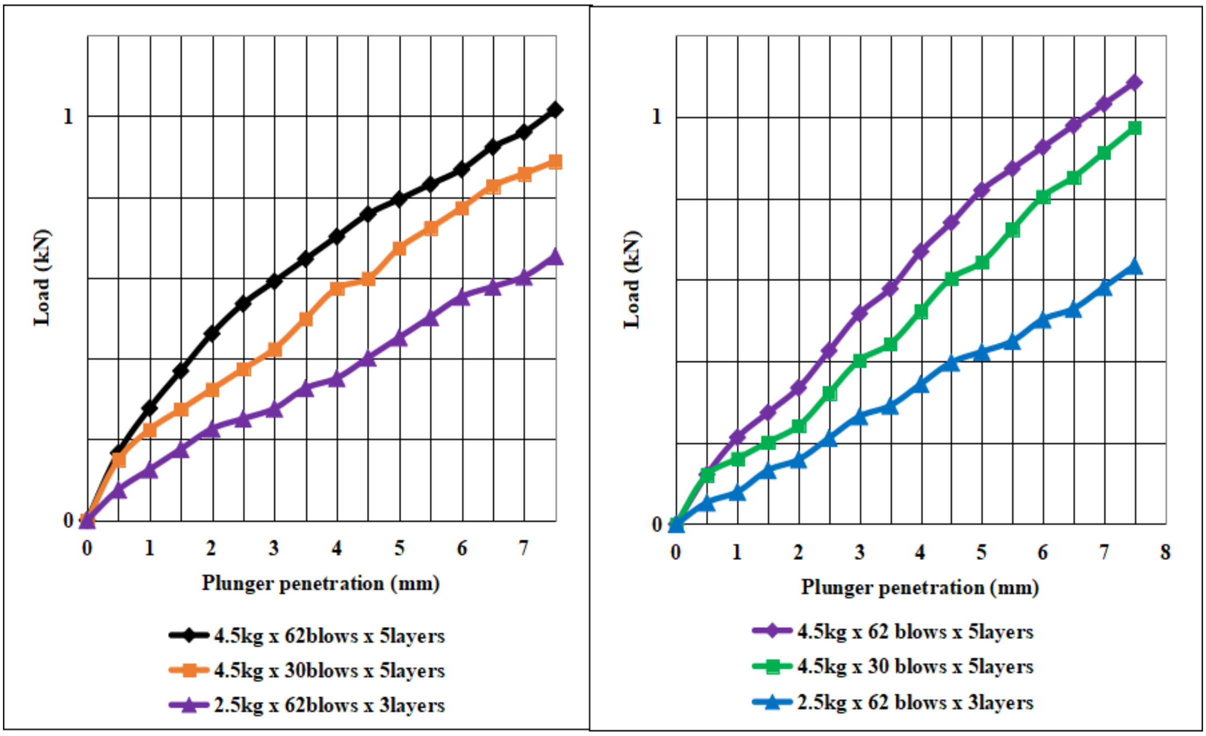

Figure B2: Penetration resistance of Mlimanyoka clay for 8 days soaking time (left) and 12 days soaking time (right).

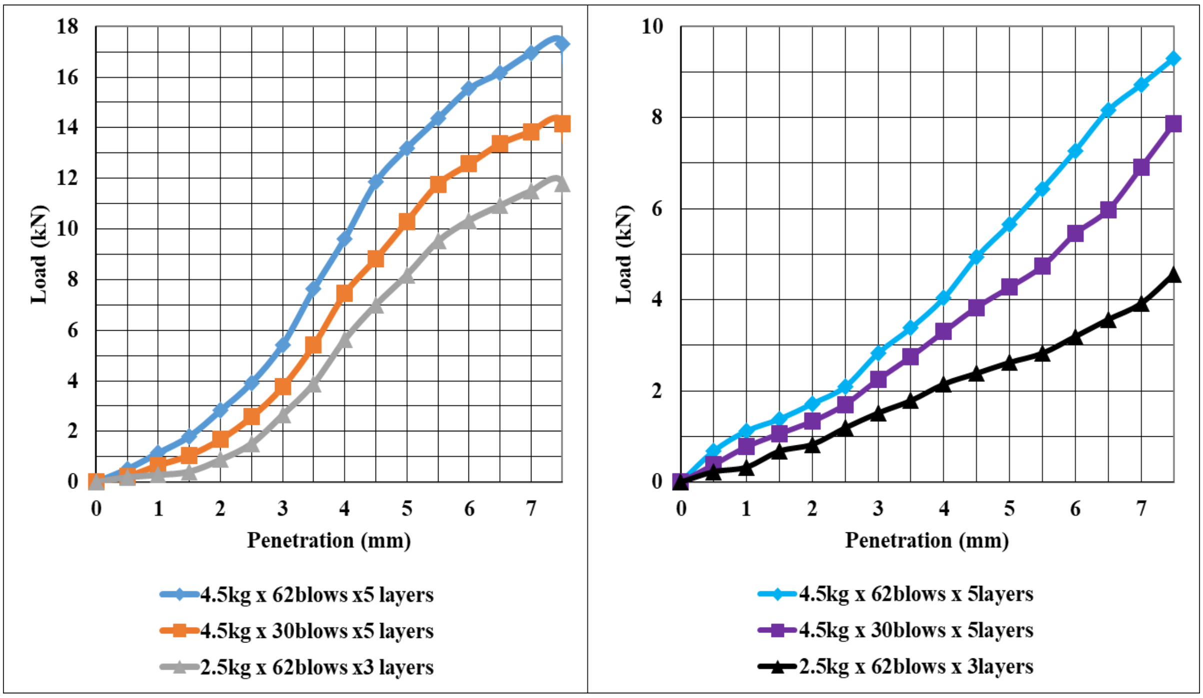

Figure B3: Penetration resistance of Ituha cinder for 0 day soaking time (left) and 4 days soaking time (right).

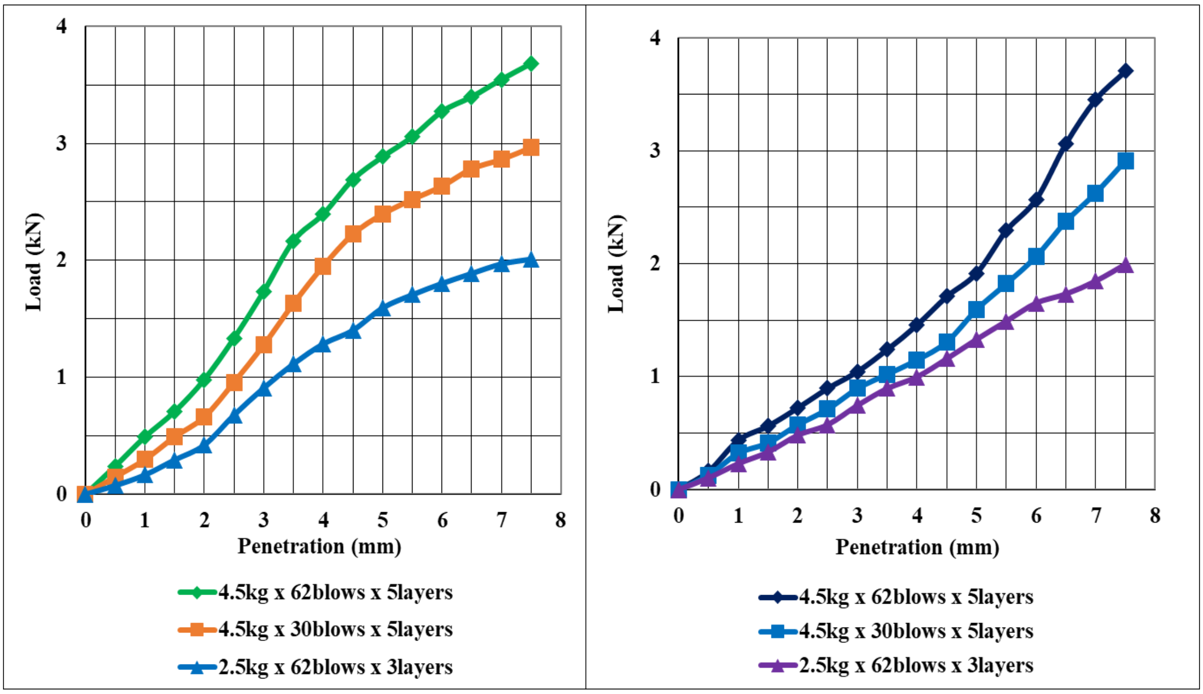

Figure B4: Penetration resistance of Ituha cinder for 8 days soaking time (left) and 12 days soaking time (right).

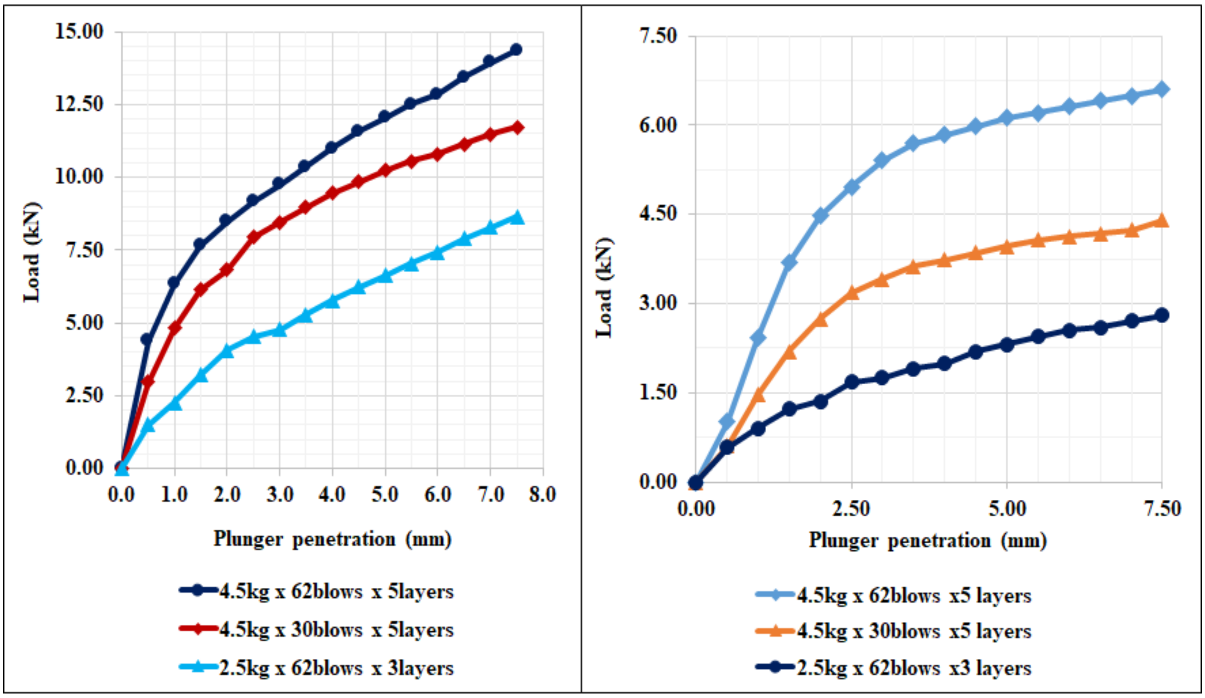

Figure B5: Penetration resistance of Ituha pozzolan for 0 day soaking time (left) and 4days soaking time (right).

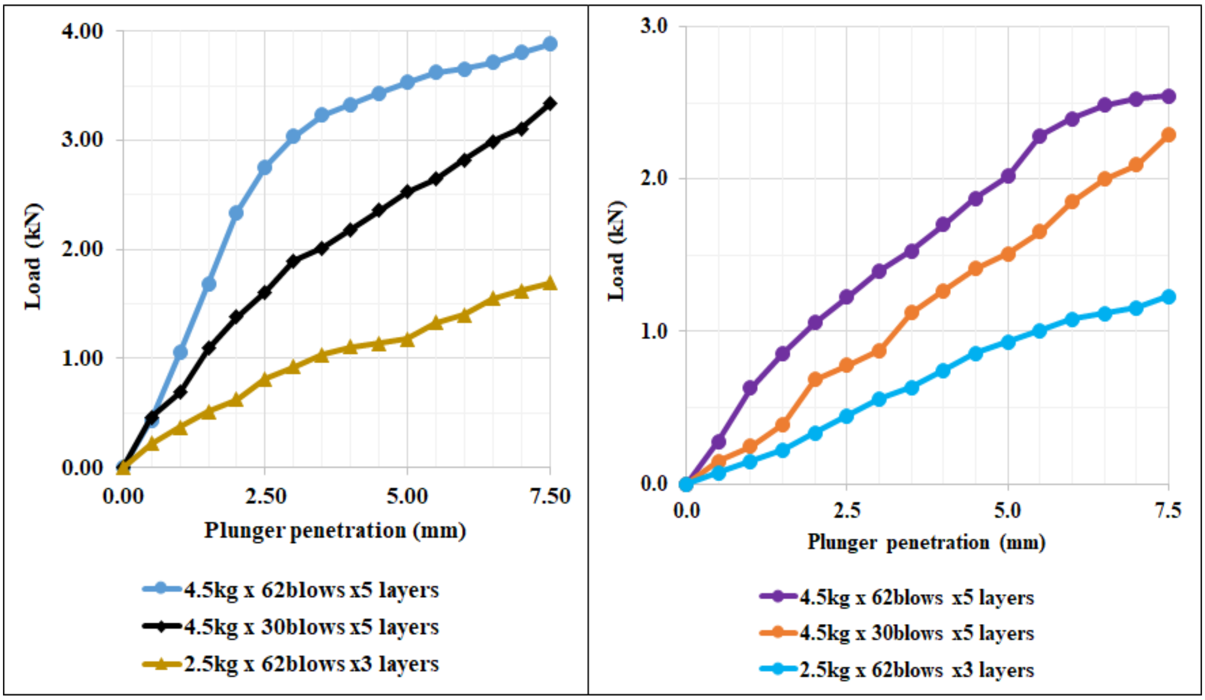

Figure B6: Penetration resistance of Ituha pozzolan for 8days soaking time (left) and 12days soaking time (right).

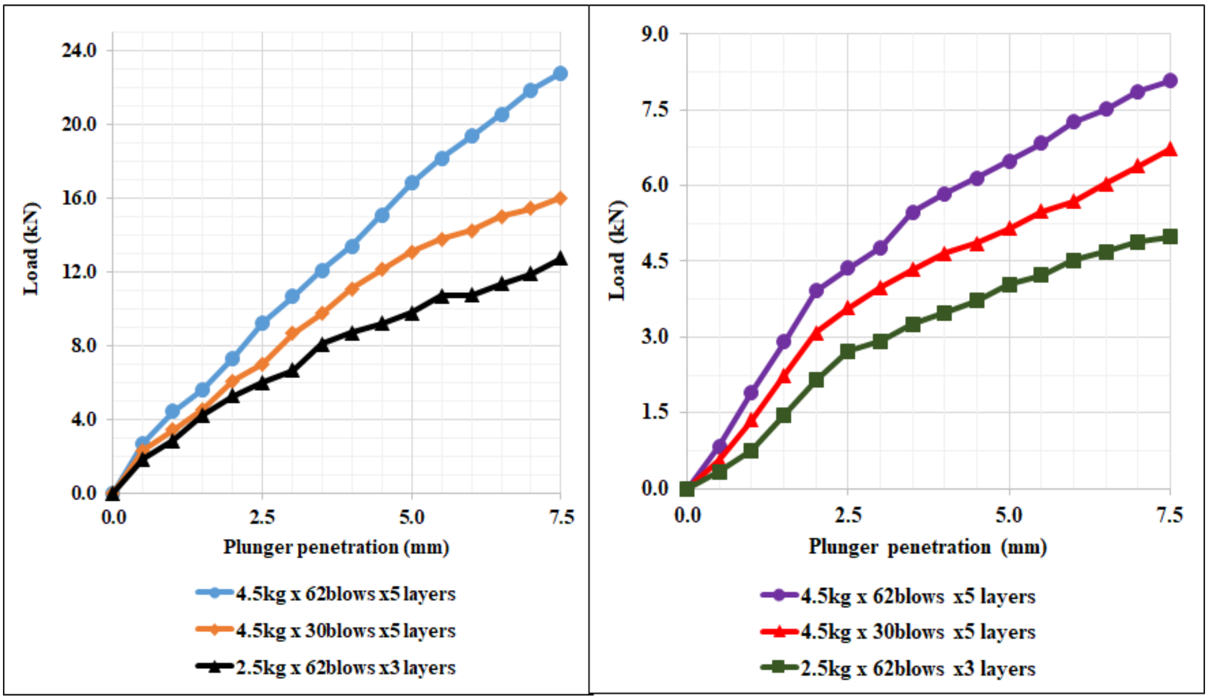

Figure B7: Penetration resistance of 64Ci27Po9Cl for 0 day soaking time (left) and 4 days soaking time (right).

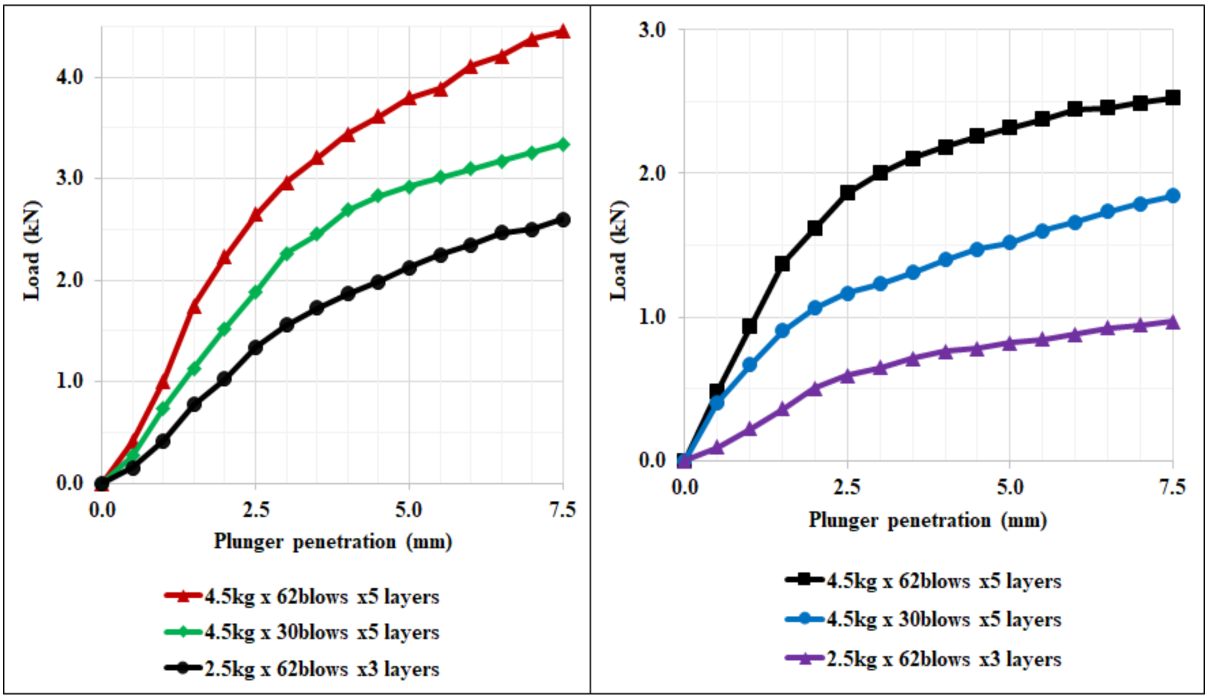

Figure B8: Penetration resistance of 64Ci27Po9Cl for 8 days soaking time (left) and 12 days soaking time (right).