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Evaluation on the california bearing ratio of lime sludge-cement stabilized subbase course soil

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Abstract

In designing a pavement, aside from the types and properties of the surface layer (flexible or rigid), the soil properties of subgrade, subbase, and base materials are also important parameters. This research study was performed to determine the effects of lime sludge (LS) mixed with cement for use as stabilizers for road subbase course material. Laboratory tests to determine the engineering properties and California bearing ratio (CBR) were conducted on treated and untreated soil samples. There were two (2) sets of treated soil samples, Set 1: (Subbase soil + LS) added with varying percentages of lime sludge of 8, 10, 12, 14 and 16; and Set 2 (Subbase soil + LS + OPC) which contained lime sludge content of 8, 10, 12, 14 and 16 percent each coupled with 2% cement. For Mixture Set 1, laboratory test results indicated that treated samples with LS of 10%, 12%, 14% and 16% showed CBR values higher than the untreated sample. Highest CBR in this set of mixtures was recorded from the treated sample with 14% LS. Moreover, when 2% cement was added for Mixture Set 2, CBR values of subbase soil+LS mixtures increased, obtaining the highest value from the mixture with 10%LS and 2% cement. Therefore, the experimental result showed that the LS combined with cement can effectively improve the CBR value of the subbase course material.

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Introduction

Civil engineering structures are necessary infrastructures built to strengthen native terrains. The soil is the definitive base of all constructions and its geotechnical properties significantly contribute to the stability of these structures. The pavement's design takes into account the types and properties of the surface layer, its flexibility or rigidity, as well as the soil layers such as subgrade, subbase, and base materials as vital parameters. The subbase course layer is on top of the subgrade which is identified as native soil or improved compacted soil; and, the base course layer is between the surface and the subbase course layer. The subbase course layer contains assorted types of smaller rocks and fragments, sometimes with troughs or holes, compressed to produce a strong surface. It assists in distributing the wheel load to mitigate stress on the subgrade layer (Joe and Rajesh, 2015). Hence, a good quality subbase material is vital in a pavement structure.

Soil stabilization technique improves the characteristics of soil (Kowalski and Starry, 2007). It treats soil to increase its strength and durability beyond their original classification that are suited for construction (Alhassan and Mustapha, 2007). More importantly, it increases bearing capacity or reduces settlement, water permeability, or risks of liquefaction (Zorluer and Gucek, 2020). The stabilization process is categorized into two broad fields, mechanical and chemical stabilizations. Mechanical stabilization requires compaction, aggregate mixing, gradient improvement, and asphalt cement extension. On the other hand, chemical stabilization utilizes chemicals like lime, asphalt, or fly ash as compaction supports to soil. According to Guyer (2011), additives such as cement, lime, bitumen, among others, contribute to the improvement of soil in terms of strength and stiffness, and permit to reduce the design thickness of layer being stabilized. Among the chemicals applied for soil stabilization, cement is commonly used (Firoozi, *et al*., 2017). However, the construction cost of a stabilized road using cement has remained financially high because of the over-dependence on the use of manufactured additives. This is one of the reasons underdeveloped countries still struggle to make quality road networks (Alhassan and Mustapha, 2007). Also, it has been reported that Portland cement, by the nature of its chemical components, produces large quantities of CO_2 for every ton of its final product (Rubenstein, 2012). Thus, the use of available industrial waste having similar chemical composition with cement as soil stabilizer in the locale would be a good alternative means to construct stabilized roads at a possibly reduced construction cost.

Various engineering scholarly studies opined about the effectiveness of using industrial wastes as stabilizers highlighting their potential as replacements of chemicals such as cement and lime. Researchers were conducted on the by-product from paper milling and sugar milling companies called lime sludge (Chandak, 2015; Nagaraju and Kumar, 2017; Daleon and Lorenzo, 2018; Suthar and Aggarwal, 2018) and hyposludge (Usha, 2016), the by-product from rice milling company called rice husk ash (Hossain *et al*., 2018), the by-product from coal-fired thermal power plant called fly ash (Simatupang *et al*., 2020; Turan *et al*., 2020; Diallo and Unsever, 2019; Sharma and Hymavathi, 2016; Dahale *et al*., 2016) and by-products of other industrial wastes.

Lime sludge produced from the lime calcining process is an industrial by-product from paper and sugar-milling companies. It is identified as one of the prospective soil stabilizer substitute to lime. Limestone and lime sludge have the same composition except that the latter is found to be smoother. In the study conducted by (Daleon and Lorenzo, 2018), the lime sludge from BUSCO Sugar Milling Co. Inc. contained similar chemical compounds with Portland cement. A major proportion of lime sludge such as Silicon Dioxide (SiO_2), Aluminum Oxide (Al_2O_3) and Calcium Oxide (CaO), is the same as the major compounds evident in cement. Thus, this study examined the potential of the sugar mill's by-product as soil stabilizer in order to improve the engineering properties of road subbase/base material.

Materials and method

The researchers have randomly picked a locally available source of subbase course soil based on the recommendation by the Department of Public Works and Highway (DPWH). There was no particular parameter set on the selection of soil sample for this study. In the actual construction, the materials used for this pavement layer is usually blended and modified to meet DPWH standards.

Collection and Preparation of Soil Sample

Soil samples were excavated and hauled from the site and placed in appropriate containers to preserve the moisture. The soil samples were carefully stored in the zip lock then were placed inside a sack and delivered to Allied Materials Testing Laboratories for the physical, index, and mechanical tests in accordance with the American Society of Testing and Material (ASTM) standard. The tests included sieve analysis (ASTM D6913: Standard Test Methods for Particle-Size Distribution of Soils Using Sieve Analysis), Atterberg limits (ASTM D4318: Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils), compaction test (ASTM D1557: Standard Test Methods for Laboratory Compaction Characteristics of Soil using Modified Effort), and CBR test (ASTM D1883: Standard Test Method for CBR of Laboratory-Compacted Soils). The obtained values for Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) from compaction test were used for the CBR test.

Grain Size Analysis of the untreated soil

The distribution of different grain sizes affects the engineering properties of soil. Grain size analysis provides the grain size distribution and is a requirement in classifying the soil. It is performed to determine the proportion of different sizes in the untreated soil. One technique of the test is the mechanical or sieve analysis which is used to determine the distribution of the coarser, larger-sized grains of soil. ASTM D6913: Standard Test Methods for Particle-Size Distribution of Soils Using Sieve Analysis was used in this study. Sieve analysis was conducted at Allied Materials Testing Laboratories. The sieves used were #4, #8, #16, #40, #60, #100 and #200 sieves. Prior to sifting, the mass of each sieve was determined. The retained mass of soil per sieve was determined by weighing the retained soil. The equivalent percent passing per sieve was computed by subtracting the cumulative mass of the sieve considered to the total mass of the soil samples and were divided by the total mass.

Atterberg Limits and Soil Classification of the untreated soil

The plastic limit is defined as the minimum moisture content at which the soil can be readily moulded without breaking or crumbling. Plasticity Index indicates compressibility; high P.I. means a high degree of compressibility of the soil. It is also related to permeability, where, the higher the P.I. is, the lower is the permeability. The liquid limit is defined as the lowest moisture content at which the soil will flow upon the application of a very small shearing force. The liquid limit gives a certain measure of the shearing resistance of a soil when mixed with water. It is the measure of a potential cohesion which in turn depends upon the total size of the contract areas, or the fineness and shape of the grains. The finer and flatter the grains, the greater will be the total contact area between the grains, and the higher amount of water that could be taken in to coat the grains. The limit tests and plasticity index are widely used to control the characteristics of soil which are to be incorporated in roadways. ASTM D4318 Standard Test Methods for Liquid Limit, Plastic Limit and Plasticity Index of Soils were the basis for this test. The results were plotted in the Liquid Limit Chart. The moisture content corresponding to twenty-five blows determined the Liquid Limit of the Soil. For the Plastic Limit of the soil, the water content at which the soil can no longer be deformed by rolling into 3.2 mm diameter threads was determined. An average of three trials was done to determine the Plastic Limit of the soils. The Plasticity Index was computed by subtracting the Plastic Limit value from the Liquid Limit value.

Collection and Preparation of Lime Sludge and Cement

The sugar-mill lime sludge was collected from BUSCO Sugar Milling Company at Butong, Quezon, Bukidnon. The lime sludge was air-dried and oven-dried to be easily pounded into a finer grain. Type 1 Portland cement, available in the local market, was used as well.

Preparation of Treated Sample

The proportion of the mixtures was based on the minimum standard set by the DPWH and the best percentages recommended in other studies. Variation of mixes is presented in Table 1. As stipulated in the DPWH Blue Book (2013), the amount of cement to be added to the soil-aggregate should fall within the range 6 – 10 mass percent of the dry soil. Hence, in this study, cement was initially added at 2%, 4%, 6%, 8% and 10% on the dry soil to discover results beyond the standard set for cement addition. However, the results showed that when the samples were subjected to CBR test, only the mixture containing 2% cement can be penetrated by the CBR piston to obtain readings. All other mixtures with higher percentages of cement can no longer be penetrated by the CBR piston resulting to the unavailability of readings in the samples. With this, the researchers decided to use an amount of 2% cement as a constant variable incorporated in the varying percentages of lime sludge to be added to the subbase course material.

On the other hand, an annotation of the conclusions from earlier studies conducted by Chandak & Babu (2015), Suthar & Aggarwal (2018) and Daleon & Lorenzo (2018) on the utilization of lime sludge as soil stabilizer, indicates that the best results were observed from mixtures with 6% to 10% lime sludge addition. In this study, the amount of lime sludge added was within 8% to 16% for the three set of mixtures to obtain a wider set of test results. The samples were indexed based on the percentage amount of lime sludge and cement added to the soil, e.i. 08LS2C, 10LS2C and 12LS2C.

Table 1. Computation of materials for treated samples.

Sample ID	Mixture	Soil (grams)	OMC (%)	LS (grams)	Cement (grams)	Water (mL)
Untreated	100% Soil +0% LS + 0% Cement	6,000	8.3	0	0	335.80
Treated soil samples						
SET 1: Subbase soil + LS						
08LS	100% Soil +8% LS	6,000	8.3	468.02	0	362.67
10LS	100% Soil +10% LS	6,000	8.3	585.02	0	369.38
12LS	100% Soil +12% LS	6,000	8.3	702.03	0	376.10
14LS	100% Soil +14% LS	6,000	8.3	819.03	0	382.82
16LS	100% Soil +16% LS	6,000	8.3	936.04	0	389.53
SET 2: Subbase soil + LS + OPC						
08LS2C	100% Soil +8%LS + 2% Cement	6,000	8.3	468.02	117.00	369.38
10LS2C	100% Soil +10%LS + 2% Cement	6,000	8.3	585.02	117.00	376.10
12LS2C	100% Soil +12%LS + 2% Cement	6,000	8.3	702.03	117.00	382.81
14LS2C	100% Soil +14%LS + 2% Cement	6,000	8.3	819.03	117.00	389.53
16LS2C	100% Soil +16%LS + 2% Cement	6,000	8.3	936.04	117.00	396.25

After obtaining the necessary amount of additive and soil to be mixed, the soil mixture was subjected to compaction and CBR tests in accordance to the objectives of the study.

Compaction Test

Compaction of soil mass involves the application of energy and the addition of water as lubricant. It results in the reduction of pore spaces and increases the density by the rearrangement of particle grains. Thus, the mass becomes more stable and impermeable which are desirable characteristics of foundations. The compaction of fills in various engineering operations is very important. A properly compacted fill would not settle very much even after the loads are imposed. Therefore, the detrimental effects of settlement on the structures are minimized. Maximum stability is attained by compaction. Structures built on a stable fill are both safe and economical. Compaction also makes fill impervious; thus, it reduces the detrimental effects of infiltrating surface water. ASTM D 1557- Standard Test Methods for the Laboratory Compaction Characteristics of Soil Using Modified Effort was the method used in this test. In the Modified Proctor Test, the soil is compacted by a 10 lb rammer falling a distance of one and a half foot into a soil filled six-inch diameter mold. The mold is filled with five equal layers of soil, and each layer is subjected to 56 drops of the rammer. The compactive effort is the amount of mechanical energy that is applied to the soil mass.

California Bearing Ratio Test

The California Bearing ratio is the ratio of force per unit area required to penetrate a soil mass with a circular plunger of 50mm diameter at the rate of 1.25mm/min. This test is used to evaluate the strength of subgrade, subbase, and base course materials for use in the design of road and airfield pavements. ASTM D1883 - Standard Test Method for CBR (California Bearing Ratio) of Laboratory Compacted Soils was used in this test. Three molds were filled with five equal layers of soil, and each layer was subjected to sixty-five drops of the rammer for each of the mold. The amount of water added in each mold was computed using the formula of volume-density relationship as shown in Equation 2, while the weight of stabilizers, Lime Sludge and OPC, are shown in Equations 3 and 4, respectively. As to the soaking process for the CBR test, the soil samples were soaked for four (4) days in a curing tank filled with water to simulate actual conditions in the field before penetrated by the CBR machine. The amount of water for the CBR test was computed using the formula based on the volume-density relationship as given in Equation 1. The hydroscopic moisture content (HMC) is the in-situ moisture content of the soil which was obtained by oven-drying the soil samples for 24 hours at 100+10oC. The OMC is the moisture content at which the maximum dry density is obtained from the compaction test.

$$Weight\ of\ Water = \left(\frac{Weight\ of\ soil}{1+\frac{HMC}{100}}\right) x \left(\frac{OMC-HMC}{100}\right) \quad \text{(Eq'n. 1)}$$

$$Weight\ of\ Water = \left[\left(\frac{Weight\ of\ soil}{1+\frac{HMC}{100}}\right) + Weight\ of\ Lime\ Sludge + + Weight\ of\ OPC\right] x \left(\frac{OMC-HMC}{100}\right) \quad \text{(Eq'n. 2)}$$

$$Weight\ of\ Lime\ Sludge = \left(\frac{Weight\ of\ soil}{1+\frac{HMC}{100}}\ x\ Percentage\ of\ Lime\ SLudge\right) \quad \text{(Eq'n. 3)}$$

$$Weight\ of\ OPC = \left(\frac{Weight\ of\ soil}{1+\frac{HMC}{100}}\ x\ Percentage\ of\ OPC\right) \quad \text{(Eq'n. 4)}$$

After compaction, the specimens were then soaked in a tank for four days. At the end of the period, the specimens were removed from the tank and water was drained. As seen in Fig. 1, the specimens were placed under the penetration piston and a surcharge load of 10 lb was placed. The load was applied, and the penetration load values were noted. The graph between the penetration (mm) and the penetration load (kN) was drawn and the value of CBR was computed.

Fig. 1. California Bearing Ratio Test.

Results and Discussion

Sieve Analysis, Atterberg's Limit Test and Soil Classification

Based on the sieve analysis result, the soil sample consisted of 40% gravel, 50% sand and 10% clay. This means the untreated subbase contains dominantly of sand and gravel and very little of clay. This material has passed the grading requirements for percent passing based on the DPWH Blue Book 2013. The actual moisture content of the soil sample was 3.25%. The soil exhibited non-plastic values based on the Atterberg limit values as shown in Table 2. Non-plastic soil could be considered as non-cohesive soil which do not form clods or stick together due to a lack of cohesion. Non-cohesive soils could also be referred to as cohesionless or granular soils. Considering the soil classification system of the American Association of State Highways and Transportation Official

(AASHTO), the soil was found to be under A-1-a subgroup. Further, the soil was classified as silty sands or sand silt mixture according to USCS Classification. The material passed the DPWH requirements for Item 200- Aggregate Subbase Course based on its physical and index property values.

Table 2. Summary of physical and index properties of the untreated subbase.

Property	Quantity
Gravel, %	40.00
Sand, %	50.00
Clay, %	10.00
Liquid Limit, %	
Plastic Limit, %	Non-Plastic
Plasticity Index, %	
AASHTO Classification	A-1-a
USCS Classification	SM

Compaction and California Bearing Ratio Tests

The Modified Proctor Compaction Test Method was used to arrive at the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of the untreated soil. Table 3 displays the summary of the test results for Compaction Test and California Bearing Ratio Test for the untreated soil. The CBR Value of 29.86% by the untreated subbase course obtained from the CBR test conducted barely met the requirement of 30% CBR soaked value for Item 200 – Aggregate Subbase Course as stated in the DPWH Blue Book of 2013. Hence, the engineering properties of the material could still be improved to become suitable for construction use.

Table 3. Summary of Compaction Test and CBR Test Results of the untreated subbase course.

Mixture ID	Tests	Result
Untreated	Maximum Dry Density (Kg/cu.m.)	2182
	Optimum Moisture Content (%)	8.3
	California Bearing Ratio (%)	29.86

Compaction behaviour of untreated and treated subbase course

Table 4 presents the Maximum Dry Densities (MDD) and Optimum Moisture Contents (OMC) of both the untreated and the treated (set 2) soil samples. The MDD for the untreated soil was 2182kg/m³ with optimum moisture content (OMC) of 8.3%. Among the treated soil samples, the highest MDD of 2295kg/ m³ with OMC of 9.00% was recorded from the mixture with sample ID 10LS2C, and the lowest MDD of 2242kg/ m³ with OMC of 6.80 was recorded by the mixture with sample ID 16LS2C. Fig. 2 portrays the moisture-density relation graphs of both the untreated and treated subbase soil. As observed, the highest compaction values were given by the mixture with 10% LS + 2% cement. On the other hand, the lowest compaction values were demonstrated by the untreated subbase.

Table 4. MDD and OMC of each Mixture.

Sample ID	Mixture	MDD (Kg/m^3)	OMC (%)
Untreated	100% Soil + 0% Lime Sludge + 0% Cement	2182	8.30
Treated			
SET 2: Subbase soil + LS + OPC			
08LS2C	100% Soil+ 8% Lime Sludge + 2% Cement	2253	7.25
10LS2C	100% Soil + 10% Lime Sludge + 2% Cement	2295	9.00
12LS2C	100% Soil + 12% Lime Sludge + 2% Cement	2250	7.50
14LS2C	100% Soil + 14% Lime Sludge + 2% Cement	2247	7.00
16LS2C	100% Soil+ 16% Lime Sludge + 2% Cement	2242	6.80

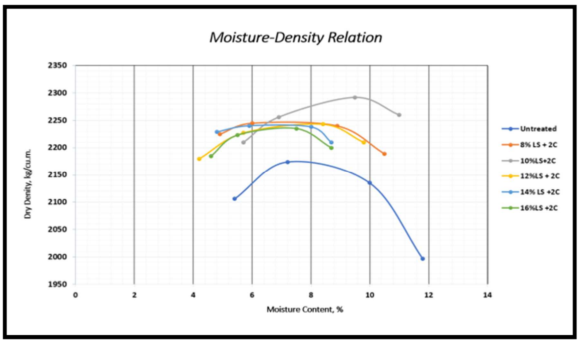

Fig. 2. Moisture-Density Relation.

Fig. 3 illustrates the variation of MDD with different percentage of lime sludge. Addition of 8% lime sludge with 2% cement to soil increases the MDD to 2,253kg/m³, continued to increase and reached its highest MDD of 2,295kg/m³ with the addition of 10% lime sludge with 2% cement. Further, an increase in the amount of lime sludge to 12%, 14% and 16% all paired with 2% cement decreased the MDD but appeared to have higher value compared to the untreated soil. Similar results of increased MDD were also observed by Deng *et al.* (2014). They claimed that the results could be ascribed to either sludge clod formation or sludge filling pores between soil particles. As a result, there were smaller pores between soil and sludge particles. Additionally, cement could also increase the size of the flocculated mass. The incorporation of 2% cement into the mix resulted in greater density, resulting in the flocs repositioning, hence showing denser compacts.

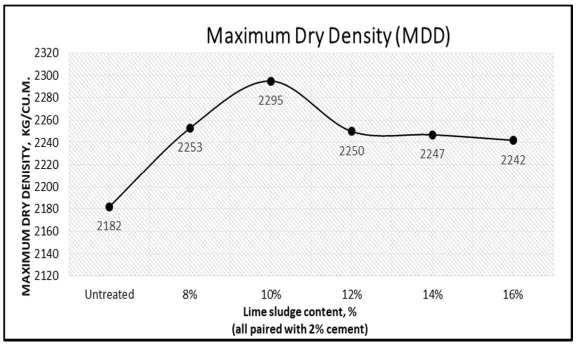

Fig. 3. Variation of MDD of lime sludge-cement stabilized subbase course.

Fig. 4 illuminates the variation of OMC with different percentages of lime sludge. A fluctuating increase and decrease of OMC were observed between the addition of 8% and 12% lime sludge. OMC decreased to 7.25% with the addition of 8% lime sludge with 2% cement and with the addition of 10% lime sludge with 2% cement, it increased to 9% obtaining the level for the MDD value. As the amount of lime sludge continued to increase, the OMC values further decreased lower than that of the untreated soil. This occurrence could be due to the combination of Al_2O_3 and CaO being reactive with water. According to Withee (2006), as this mixture reacts with water, it reduces the overall amount of moisture in the soil.

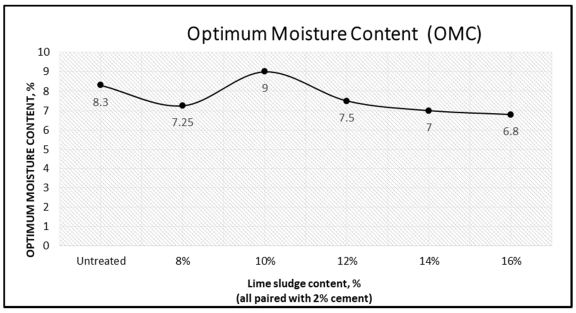

Fig. 4. Variation of OMC of lime sludge-cement stabilized subbase course.

CBR Values of untreated and treated subbase course

Table 5 shows the CBR value of the untreated subbase course at 29.86%. Among the mixtures added with lime sludge, the addition of 10% gave the highest CBR value at 42. 83%, while the lowest CBR Value of 28.9% was obtained from the mixture added with 8% lime sludge. When 2% cement was added to Soil-LS mixture, the highest CBR value obtained was 225.85% from the mixture with sample ID 10LS2C, and the lowest CBR Value was given by the mixture with sample ID 16LS2C.

Fig. 5 presents the variation of soaked CBR with different percentages of lime sludge contents in Soil-LS mixture and in Soil-LS-Cement mixture. Considering the Soil-LS mixture, it could be observed that the CBR value decreased to 28.90% with the addition of 8% lime sludge, found to be lower than the untreated soil. Coban (2017) observed similar results in his study on the use of lime sludge as soil stabilizer. He said, this is because the lower lime sludge content did not respond as effectively in flocculation, the CBR value barely changed, and higher lime sludge contents were required to achieve this. Moreover, this decrease in CBR value was also observed by Daleon & Lorenzo (2018) which, which according to them, could be ascribed to thixotropic characteristic of soil, where in it temporarily losses its strength and recover when allowed to settle.

Table 5. CBR values of untreated and treated samples.

Sample ID	Mixture	CBR Value (%)
Untreated	100% Soil + 0% Lime Sludge + 0% Cement	29.86
Treated Soil Samples		
SET 1: Subbase + LS		
08LS	100% Soil + 8% Lime Sludge	28.9
10LS	100% Soil + 10% Lime Sludge	29.2
12LS	100% Soil + 12% Lime Sludge	36.99
14LS	100% Soil + 14% Lime Sludge	42.83
16LS	100% Soil + 16% Lime Sludge	32.50
SET 2: Subbase + LS + OPC		
08LS2C	100% Soil + 8% Lime Sludge + 2% Cement	198.59
10LS2C	100% Soil + 10% Lime Sludge + 2% Cement	225.85
12LS2C	100% Soil + 12% Lime Sludge + 2% Cement	81.77
14LS2C	100% Soil + 14% Lime Sludge + 2% Cement	56.46
16LS2C	100% Soil + 16% Lime Sludge + 2% Cement	52.57

It could also be observed that the CBR value of 36.99% obtained by the soil sample added with 12% have already passed the minimum requirement of

30% soaked CBR Value for Item 200 – Aggregate Subbase Course as stipulated in the DPWH Blue Book which means that this mixture could already be considered for adaptation depending the on the pavement design parameters.

Moreover, soaked CBR value amplified along with the increased amount of lime sludge from 8% to 14% obtaining the highest CBR value at 14% lime sludge addition equal to 42.83%. This increase in CBR value compared with the untreated soil was a result of the pozzolan reaction between alumina and silica of cement and lime sludge with water. According to Little (1995), pozzolan reactions started when hydroxyl ion increased from the lime lead to a pH rise in the soil's water, with which the silicate and the aluminum sheets may start to dissolve. An increase on the CBR values of soils treated with lime sludge was also observed by Daleon and Lorenzo (2018) in their study on the treatment of clay soil with sugar-mill lime sludge. They explained that, as silica and/or alumina are released, they can be combined with calcium to form hydrates of calcium silicate and/or calcium aluminum, which can be used to cement the soils together. After reaching its peak value, the CBR value decreased as the amount of lime sludge was further increased to 16%. This may be attributed to carbonation reactions which happen due to the presence of excess lime that reduces the bearing capacity of the soil.

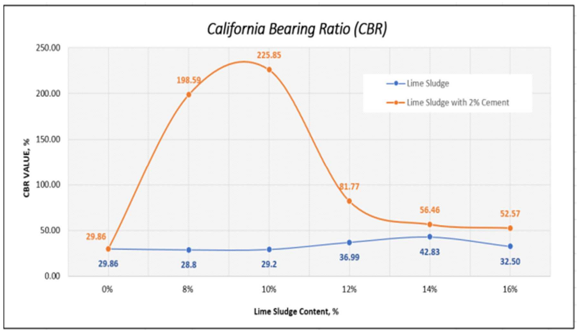

Fig. 5. Variation of CBR Value of stabilized subbase course.

On the other hand, although the CBR increased along with lime sludge content for both types of mixtures, the increase was more evident in Soil-LS mixture with 2% cement added. For example, at 8% lime sludge content, the CBR increased from 28.9% to 198.59% and in 10% lime sludge content, the CBR increased from 29.2% to 225.85% when 2% cement was added, showing a staggering improvement of 687.16% and 773.46%, respectively. This increase brought by cement addition was also observed by Phanikumar and Raju (2020) in their study on the strength characteristics of an expansive clay stabilized with lime sludge and cement. They explained that the rise in CBR was caused by the cement interacting with leachates arising from the lime sludge, thus mitigating hydration reactions in the soil matrix and resulting in the formation of ettringite.

Further increase of lime sludge content to 12%, 14% and 16% coupled with 2% cement reduced the CBR value of Soil-LS-cement mixture, however, these values are found to be higher than that of the untreated soil, hence, these mixtures can still be perceived as efficient. This decrease in the CBR values may be attributed to carbonation reactions which happens due to the presence of excess lime to react with insufficient silica alumina present in cement. This excess lime reduced the bearing capacity of the soil.

Conclusion

Based on the above findings, the following conclusions are made:

1. The untreated subbase soil consisted of 40% Gravel, 50% Sand and 10% Clay. It was also found to be non-plastic and was classified to be under soil group A-1-a using AASHTO soil classification and to be SM type of soil using the USCS Soil Classification system. MDD of untreated subbase is 2182kg/cu.m at OMC of 8.3%. CBR value of untreated soil was 29.86%. This material has passed the specifications stipulated in the DPWH Blue Book for Item 200 except for the CBR Value which has to be at least 30%.
2. As the amount of lime sludge increases, the MDD of lime sludge-cement stabilized subbase course increases. The highest MDD of 2,295kg/m^3 was recorded from the mixture added with 10% lime sludge + 2% cement.

3. CBR values of Soil-LS mixtures increases as the amount of lime sludge increases. Maximum CBR value of 42.83% was recorded from the mixture containing 14% lime sludge.
4. CBR values of Soil-LS mixture added with 2% cement increases as the amount of lime sludge increases obtaining its peak value of 225.85% from the mixture with 10% lime sludge + 2% cement.

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