Strength Improvement of Cement – stabilized Soil using Natural Rubber Latex for pavement base applications

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Abstract *Cement-stabilized soil, especially those with high fine contents, often exhibits brittle behavior under both flexural and compressive stress, which leads to macrocracks and microcracks in road structure and pavement. Moreover, the properties also may not be sufficient to meet the local authority specifications. Hence, in this work, Natural Rubber Latex is used in conjunction with cement to improve the properties of lateritic soil to be used in road subgrade. The samples were prepared by varying percentages of cement (5%, 10%, 15%, and 20%) by weight of soil and NRL replacement ratios (5%, 10%, 15%, and 20%) by weight of the soil. The test programme included sieve analysis, California bearing ratio (CBR) (soaked), Proctor compaction test (modified), and Atterberg Limits tests to assess the suitability of the virgin gravelly soil and the blended samples. The results showed that increase in the cement and NRL percentages up to 15% improved the CBR value (after four days of soaking) but decreased thereafter. The optimum moisture content (OMC) decreased continuously until 15% replacement of NRL and thereafter a very slight increase was observable. A similar trend was observable in the maximum dry density (MDD) as well, where it increased up to 15% and then decreased thereafter. Blended soil samples achieved CBR values of 14%, 28%, 38%, and 31%, with 5%, 10%, 15%, and 20%of cement and NRL replacements respectively, meeting the CIDA requirements. Findings suggest using an optimum proportion of 15% cement and 15% NRL mixture for optimal results in compliance with the CIDA specifications for roads in Sri Lanka.*

Keywords: *Natural rubber latex (NRL), California bearing ratio (CBR) test (Soaked), optimum moisture content (OMC), maximum dry density (MDD), Proctor compaction test (Modified), subgrade*

1 INTRODUCTION

A pavement structure is generally composed of base and subbase layers, which play an important role in the bearing capacity and serviceability of a road. This pavement structure requires high-quality soil as a construction material. Nevertheless, natural soils typically demonstrate undesirable physical and engineering characteristics, that frequently make them undesirable for road construction (Buritatun et al., 2020).

Lateritic soil is a common pavement material in the tropical region, especially in Southeast Asia. However, the virgin lateritic soil in its original state, might not meet the necessary pavement specifications to be used as a subgrade due to it's poor bearing capacity (Emmanuel et al., 2021). Hence soil stabilization technique is usually employed to enhance the properties of the natural soil, encompassing both its physical attributes and strength. This approach yields significant engineering and economic advantages. Soil stabilization is mainly used in road construction to avoid the need to remove the existing soil and replace it with new soil possessing the required properties (Firat, et al., 2020). Therefore, the objective of soil stabilization is to enhance existing soil resilience, durability, and strength (Glossop, 1968; Sabat 2012).

Conventional additives include lime, fly ash, and cement. Broadly, substantial research has been conducted on the efficacy and reliable performance of these conventional materials, as well as waste materials (palm oil fuel ash, quarry dust, waste crumb tyre, cement kiln dust, etc.,) often exploring their interaction behaviors (Arinzie et al., 2018, Firat et al., 2017, Mahmood et al., 2020, Tingle et al., 2007, Mahdi et al., 2018). The utilization of Portland cement as a stabilizer is preferred to other additives in Southeast Asia due to its cost-effectiveness and the rapid enhancement of mechanical properties, including the bearing capacity, stiffness, and strength of the soil. This approach has been extensively applied in various countries as a solution to address the scarcity of high-quality materials (Horpilbulsuk et al., 2006, Zhang and Tao, 2008). Nevertheless, the cement-stabilized soil, especially with high fine contents, exhibits brittle behavior and extremely low flexibility, which causes macro and micro-cracks when subjected to static and repeated loads (Jamsawang et al., 2015). Therefore, several studies have been conducted, with the addition of different admixtures on soil stabilized with cement and as such there has been research conducted to appraise the improvement of compacted soil cement using different rubber alternatives. The listed below are the most novel and innovative studies of rubber alternatives to enhance the properties of cement-stabilized soil.

Meghana and Veerendra (2022) investigated the potential of using styrene butadiene rubber (SBR), a synthetic rubber, as a stabilizer to enhance the characteristics of expansive clay subgrade. Researchers conducted the Standard Proctor Compaction Test and California Bearing Ratio Test on soil samples mixed with different percentages of SBR. The findings indicated that the addition of SBR up to 12% resulted in favourable outcomes. The Optimum Moisture Content (OMC) of soil decreased while the Maximum Dry Density (MDD) increased, suggesting improved stability. Compared to untreated soil, the use of SBR significantly enhanced the California Bearing Ratio (CBR) values. At 2.5mm penetration, the CBR values increased by 6.5 times, 7.2 times, 8.0 times, and 9.18 times for soil stabilized with 3%, 6%, 9%, and 12% SBR, respectively. These findings indicate that SBR can effectively serve as a stabilizer for enhancing the properties of expansive clay subgrade.

Juliana, et al., (2020) evaluated the effectiveness of using crumb rubber for stabilizing subgrade soil. Crumb rubber, known for its lightweight and strong shear strength, was investigated as a solution for reducing pollution and improper tyre disposal. The study involved altering subgrade soil with varying percentages (2%, 4%, 6%, and 8%) of crumb rubber. CBR tests were conducted on unsoaked and soaked soil mixtures from a landslide area in Malaysia. All mixtures met the subgrade requirements set by the Public Construction Department Malaysia (JKR) for road construction, with the 4% crumb rubber mixture showing the highest CBR values. The presence of crumb rubber improved the subgrade soil's CBR values, with the 4% mixture proving the most effective. Thus, the study recommends using 4% crumb rubber for subgrade soil stabilization.

Kererat, et al., (2022) investigated the potential use of a novel road base material composed of bottom ash blended with Portland cement and para-rubber latex. Various mixtures were tested, and the findings revealed that the optimal ratios of bottom ash to Ordinary Portland Cement were 95:5% and 93:7%, each with 6% para rubber latex content. These mixtures exhibited excellent performance in terms of unconfined compressive strength, skid resistance, and wet/dry durability. Compaction tests highlighted that 6% and 8% para rubber latex content yielded the best maximum dry density results. The study also indicated that fine bottom ash outperformed its coarse counterpart in terms of strength. Moisture presence decreased the unconfined specimen strength as anticipated. Most importantly, these mixtures satisfied the requirements for both light and heavy traffic scenarios, showcasing the potential for substituting traditional road-based materials with this innovative combination.

A study carried out by Buritatun, et al., (2020) to enhance the mechanical strength of cement-stabilized soil using NRL for pavement base by replacing varying percentages of cement with NRL. The optimum NRL replacement ratios providing the optimum unconfined compressive strength (UCS) and Flexural strength (FS) were found at 20%, 15%, and 10% for 3%, 5%, and 7% cement contents, respectively. At the optimum NRL replacement ratio, the UCS was improved up to 30%, 21%, and 18% for 3%, 5%, and 7% cement contents while, FS was improved up to 78%, 40%, and 29% for 3%, 5%, and 7% cement contents. However, excessive NRL replacement hindered compactability and delayed cement hydration, leading to diminished strength. This research suggests that NRL could serve as a sustainable alternative to synthetic latexes for boosting the mechanical strength of soil-cement mixes, particularly for pavement-based applications. They also reported that NRL as an additive could improve the compressive and flexural strengths, cracking problems, and premature pavement distress, due to the cyclic wet and dry seasons of cement-stabilized pavement base material.

As can be seen from the results of previous research findings, NRL is a viable substitute for cement-stabilized soils for improving its properties. Hence, it is worthwhile to investigate the applicability of NRL to cement-stabilized lateritic soil subbases. NRL is a biopolymer from the Hevea brasiliensis tree. The raw state of NRL consists of polymer content (cis-1,4- polyisoprene) and water. The solid polymer content consists of approximately 94% rubber hydrocarbon and 6% non-rubber substances, such as phospholipids, and protein (Buritatum, 2020). Natural rubber is obtained by tapping the tree's bark; the rubber latex is found inside cells that are created by plant metabolic processes. The milky-looking, viscous liquid that drips from the tree is actually a colloidal dispersion of polyisoprene molecules in water.

To the best of the authors' knowledge, there has been no research undertaken to date on the usage of NRL in pavement geotechnics to assess the NRL enhancement applicability to the laterite soil of Sri Lanka and the compliance of the local authority guidelines (CIDA, 2007). The outcome of this research will result in the promotion of NRL utilization as a sustainable additive in cement-stabilized pavement base/subbase courses for Sri Lankan lateritic soils. In this study, lateritic soil was mixed with NRL and cement to assess whether the properties of the subgrade soil could be improved. It is also to note that NRL utilization in soil stabilization does not cause negative environmental impacts because NRL is a plant-based product, devoid of chemical hazards and petroleum components. A series of laboratory tests were carried out on gravelly soils blended with cement and NRL to evaluate the MDD, OMC (NRL and water), Atterberg limits, and CBR to assess whether NRL in conjunction with cement stabilization for lateritic soils of Sri Lanka would comply with the Institute for Construction Industry Development Authority (CIDA, 2007) guidelines.

2 CIDA (2007) SPECIFICATIONS

The following road construction specifications have been outlined by the CIDA. These specifications ensure the quality and performance of the constructed road.

Table 1 CIDA specifications ensure the quality and performance of the constructed road (2007)

Property	Requirement	Standard
CBR Value (four days soaked)	> 15%	BS1377 Part 4
Liquid Limit	< 50%	BS 1377 Part 2 - 1990
Plastic Index	< 25%	BS 1377 Part 2 - 1990
Optimum Moisture Content (OMC)	10% to 20%	BS 1377 Test 13
Maximum Dry Density (MDD)	> 1.65g/cm^3	BS 1377 Test 13
Gradation Requirements	Upper and Lower limit of gradation curves are given in Fig. 1.	BS1377: 1990, Part 2

These specifications collectively ensure the appropriate composition, strength, and performance of the road construction project.

3 MATERIALS AND METHODOLOGY

3.1 Materials

Soil samples

The materials used in this research were lateritic soil, Natural Rubber Latex, and Ordinary Portland Cement. A lateritic soil sample was collected from Ambanpola, Sri Lanka (7°54'56.8"N, 80°14'31.7"E).

Natural Rubber Latex

NRL was obtained from the Rubber Research Institute – Polgahawela (Polgahawela Substation). Table 2 depicts the properties of NRL.

Insee Sanstha Portland Composite Cement (SLS 1697:2021) with strength class 12.5 N/R which is commonly used in the stabilization of pavement materials, was selected to stabilize the soil. Table 3 depicts the physical and chemical properties of Portland Composite cement.

Table 2 Properties of Natural Rubber Latex (Dananjaya et al., 2022).

Properties	Value
Sludge content (%wt.)	2.46
Coagulum content (%wt.)	0.024
Specific gravity (Gs)	0.96
pH	8
MST value (seconds)	800
Alkalinity % (w/w)	0.7
VFA number	0.1
Proteinaceous substances %	1.2
KOH number	0.70
Mechanical stability, min, seconds	650

Table 3 Physical & Chemical Properties of Insee Sanstha Portland Composite Cement

Property	SLS 1697:2021 Requirement	Insee Sanstha Portland Composite Cement Average
	PHYSICAL PROPERTIES	
Compressive Strength (2 days)	≥ 10 N/mm^2	≥ 20 N/mm^2
Compressive Strength (28 days)	42.5 - 62.5 N/mm^2	> 52 N/mm^2
Initial Setting Time	≥ 60 minutes	130 - 150 minutes
Fineness	Not Specified in Standard	400 - 420 m^2/kg
Soundness	< 10 mm	< 1 mm
Relative Density	Not Specified in Standard	2.96
	CHEMICAL PROPERTIES	
SO_3	≤ 3.0 %	< 2.8 %
Chloride	≤ 0.1 %	< 0.05 %
LOI	Not Specified in Standard	< 3.0 %

3.2 Sample Preparation

Cement and rubber latex were mixed with lateritic soil in the following proportions in weight percentages as depicted in Table 2.

Table 4 Mix proportions of lateritic soil, cement, and natural rubber latex

Lateritic soil %	Cement %	NRL %
100	0	0
90	5	5
80	10	10
70	15	15
60	20	20

3.3 Experimental Procedure

Sieve Analysis test (BS1377: 1990, Part 2), California bearing ratio (CBR) test (Soaked) (BS 1377 Part 4), Proctor compaction test (Modified) (BS 1377 Test 13), Atterberg Limits test (BS 1377 Part 2 - 1990) were conducted according to the standard specifications to evaluate the suitability of the virgin material and blended sample. The results obtained were compared with those of CIDA guidelines to see whether they comply with the local road authority guidelines applicable to rural roads of Sri Lanka.

4 RESULTS AND DISCUSSION

4.1 Results of Virgin Gravel Soil

The Sieve Analysis test, California bearing ratio (CBR) test (four-day Soaked), Proctor compaction test (Modified), and Atterberg Limit tests were carried out on the virgin sample. The grain size distribution is depicted in Fig. 1. According to the Unified Soil Classification system, soil was categorized as Silty gravel (GM). Lower and Upper limits of curves specified in CIDA guidelines are depicted in Fig. 1.

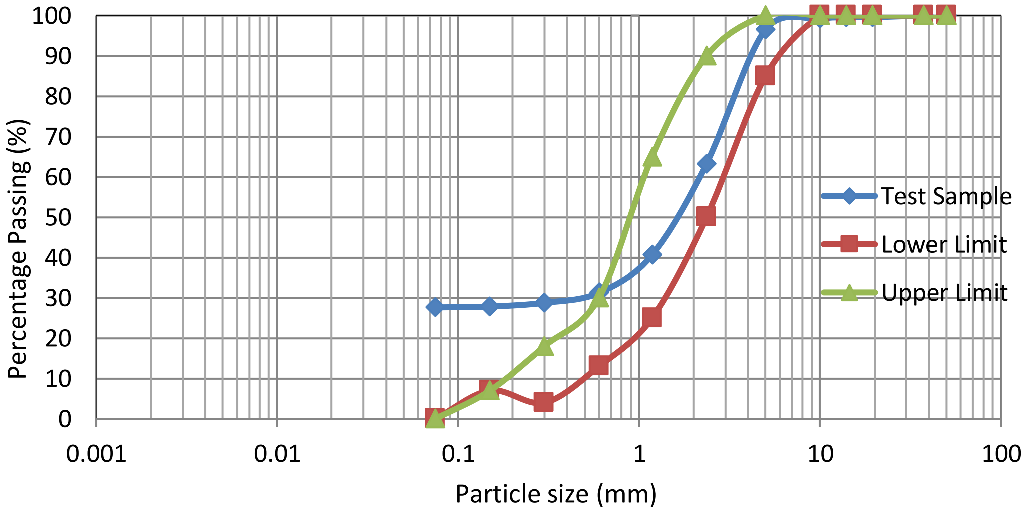

Fig. 1. Particle Size Distribution curve of lateritic soil

Figure 2 shows the Atterberg Limits Test graph of the initial lateritic soil sample. Accordingly, the Liquid limit (LL) for virgin sample is 53.9 %.

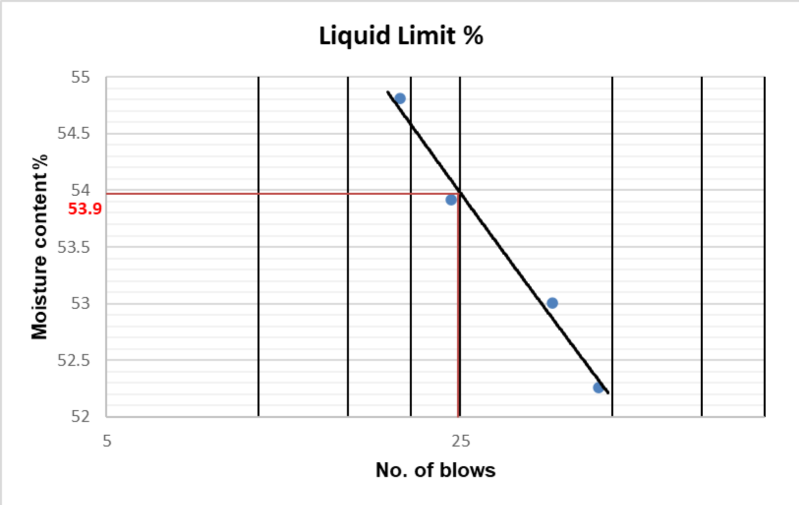

Fig. 2. Liquid Limit Test curve of lateritic soil sample

Fig. 3 shows the Modified Proctor Compaction test. Accordingly, the maximum dry density and optimum moisture content for the virgin lateritic soil sample is 1.72 g/cm³ and 18.10 %.

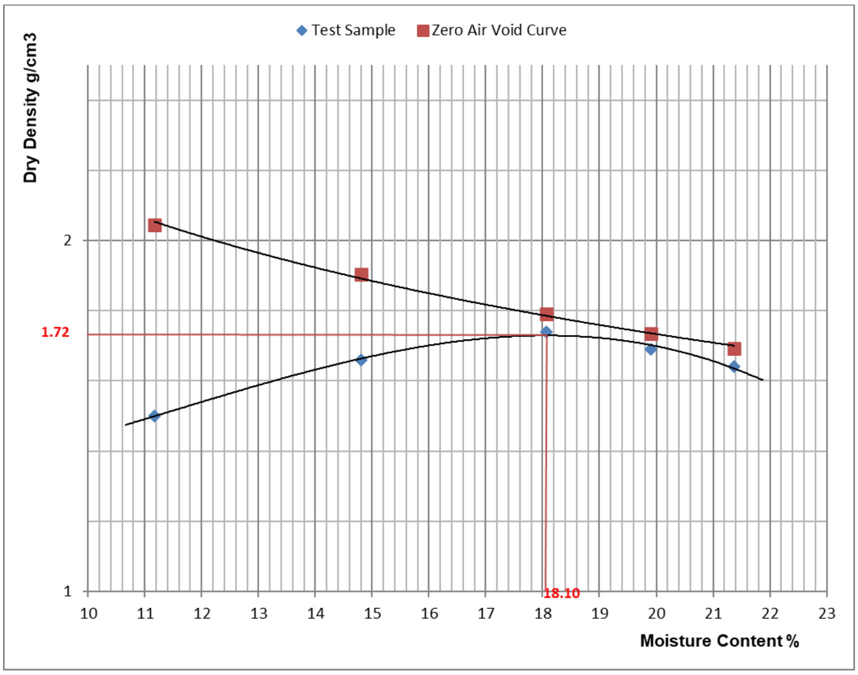

Fig. 3. Variation of Dry Density with moisture content of virgin lateritic soil

Fig. 4 shows the variation of Load against the Penetration of the CBR test for the virgin lateritic soil.

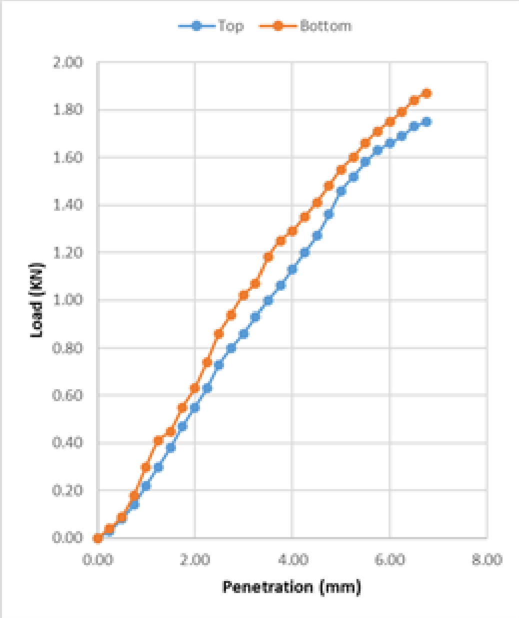

Fig. 4. Variation of Load (kN) with Penetration (mm) of CBR test for the virgin lateritic soil sample

The basic and engineering properties of virgin soil are summarized in Table 5 and were compared with the CIDA (2007) for base and subbase materials. According to the standard of CIDA (2007) the virgin lateritic soil did not meet the minimum requirements of Liquid limit and CBR as can be seen from Table 5.

Table 5 Summary of the test results of virgin gravel soil sample

PARAMETERS	CIDA REQUIREMENTS	RESULTS	ACCEPTABILITY
Liquid limit (LL)	<50%	53.9 %	Not Accepted
Plasticity index (PI)	< 25%	16 %	Satisfied
Laboratory M.D.D of soil	>1.69g/cm³	1.72 g/cm³	Satisfied
Laboratory O.M.C of soil	10 – 20 %	18.10 %	Satisfied
CBR (Four Days Soaked)	> 15%	8 %	Not Accepted
Soil description	Silty gravel (GM)		

4.2 Blended Soil Sample

4.2.1 Compaction Characteristics

Figure 5 illustrates the variation of OMC with that of cement and NRL percentages. According to Figure 5, when increasing the cement and NRL %, OMC decreases up to 13.5% and thereafter a very slight increase is observable. The reduction of moisture content is due to the fact that Natural Rubber Latex (NRL) increases soil cohesion and necessitates less water for maximum compaction (Meghana and Raja, 2022). NRL composition is as per the Table 2.

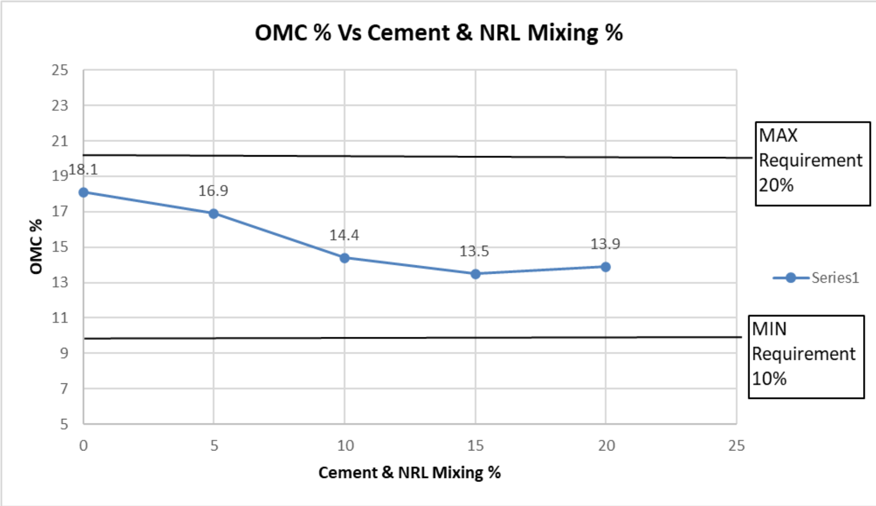

Fig. 5. Variation of OMC with cement and NRL mixing percentages

Figure 6 illustrates the variation of MDD with that of cement and NRL mixing percentages. According to Figure 6, when increasing the cement and NRL %, MDD increases up to 15% and decreases thereafter.

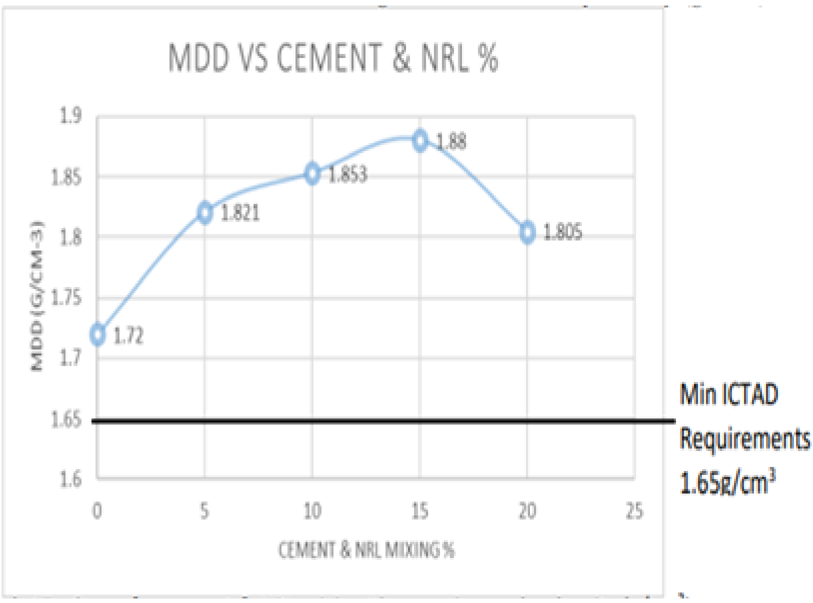

Fig. 6. Variation of MDD with cement and NRL mixing %

According to the test values, the virgin lateritic soil sample produced an MDD value of 1.72 g/cm^3 at OMC of 17.60%. When increasing the cement and NRL mixing percentage, OMC decreases. The OMC of lateritic soil is lowered by adding more cement and NRL, as these additives increase soil cohesion and density and necessitate less water for maximum compaction. The OMC is lowered by this densification procedure (Meghana and Raja, 2022). When increasing the cement and NRL mixing percentage, maximum dry density (MDD) increases up to 15% and decreases thereafter. The initial increase in MDD is due to the addition of cement and NRL to gravel soil, which enhances the cohesion and strength of the soil, resulting in a denser and more compacted soil structure. This increased cohesion and density lead to a higher MDD as the soil particles are packed more closely, reducing the air voids. However, an increase in the percentage of cement and NRL beyond the optimal point, cause an excess of these binding agents. This excess can hinder the compaction process, making it more difficult to achieve the same level of compaction compared to the optimal mixture. In addition, excessive cement content can lead to the formation of clumps or agglomerations in the soil, reducing its workability and causing a decrease in MDD (Meghana and Raja, 2022). According to the CIDA requirement, the MDD is 1.65g/cm³ and OMC should lie between 10% – 20%. The obtained MDD values are 1.821g/cm³, 1.853g/cm³, 1.880g/cm³, and 1.805g/cm³ and OMC values are 16.9%, 14.4%, 13.5%, and 13.9% for blended soil samples. Hence all the blended samples comply with the requirements specified by CIDA.

4.2.2 CBR Test Results

The CBR test was conducted to determine the bearing value and, thus to evaluate the strength of road subgrade and subbase for pavement thickness design. In this study, CBR tests of four-day soaked have been conducted. The penetration test was carried out at the top and bottom parts of the CBR samples. Figure 7 illustrates the variation of CBR value with that of cement and NRL mixing percentages. According to the test values, the virgin lateritic soil sample CBR (four-day soaked) value is 8%. It is observable that when increasing the cement and NRL %, the CBR value (four days soaked) increases up to 38% and decreases thereafter.

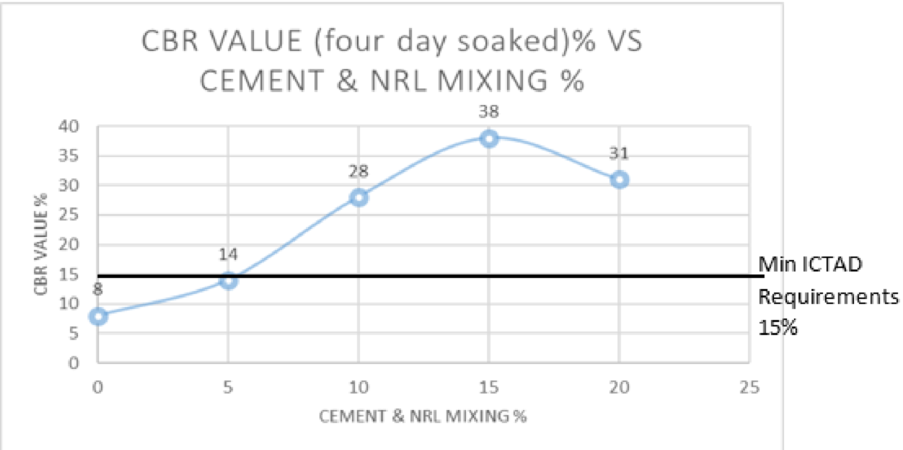

Fig. 7. Variation of CBR value (four-day soaked) with cement and NRL mixing %

The reason for this variation can be explained as follows. The initial increase in CBR value is because when cement and NRL are added to lateritic soil, these enhance the cohesion and strength of the soil, resulting in better compaction and increased CBR values. The binding agents improve the load-bearing capacity and resistance against deformation. Therefore, the initial increase in CBR value is possible. The cause of the decrease in CBR value, beyond the optimal point, would be an excessive amount of cement and NRL leading to problems such as clumping, reduced workability, and decreased compaction efficiency (Juliana et al., 2020). These issues can diminish the load-bearing capacity of soil, causing a decline in the CBR value. According to the CIDA requirement, CBR (four-day soaked) should not be less than 15%. Attained CBR (four-day soaked) values are 14%, 28%, 38%, and 31% for blended soil samples. Hence, a CBR value of 14% (which is less than 15%) does not fulfill the ICTAD requirements. However, the 10%, 15%, and 20% samples did comply with the CBR requirement.

4.2.3 Atterberg Limit Test Results

Figure 8 illustrates the variation of Atterberg limits with cement and NRL mixing percentages. The liquid limit, plastic limit, and plasticity index for the virgin gravel soil sample were 53.9%, 37.6%, and 16.4% respectively. When increasing cement and NRL mixing percentages (5%, 10%, 15%, 20%) it was observed a decline in the liquid limit, plastic limit, and plastic index. Increasing the cement and NRL content in lateritic soil can decrease liquid limit, plasticity limit, and plasticity index due to reduced water absorption and increased binding, resulting in a stiffer and less plastic material although cohesion increases with the additives (Hoy et al., 2023).

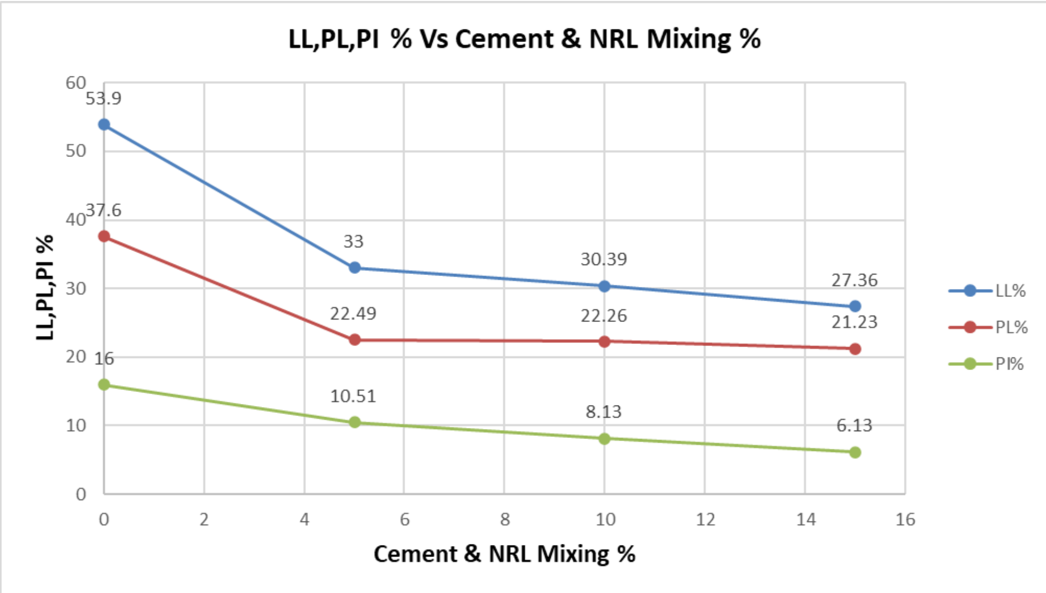

Fig. 8. Variation of Liquid limit, Plasticity Limit & Plasticity Index with cement and NRL mixing %

The summary of test results of the Atterberg limits test, California bearing ratio (CBR) test (four-day Soaked), and Proctor compaction test (Modified) of blended samples are given in Table 6.

Table 6 - Summary of the laboratory test results for the blended soil sample

PROPERTY	RESULTS				
	PROCTOR COMPACTION TEST (MODIFIED)		CALIFORNIA BEARING RATIO (FOUR-DAY SOAKED)	ATTERBERG LIMIT TEST RESULTS	
	M.D.D (g/cm³)	O.M.C	CBR Value (FOUR DAY SOAKED)	LIQUID LIMIT %	PLASTICITY INDEX %
ICTAD requirements	>1.65g/cm3	10 – 20 %	> 15%	< 50%	< 25%
5% C & NRL	1.821 (satisfied)	16.9% (satisfied)	14% (Not satisfied)	33% (satisfied)	10.51% (satisfied)
10% C & NRL	1.853 (satisfied)	14.4% (satisfied)	28% (satisfied)	30.39% (satisfied)	8.13% (satisfied)
15% C & NRL	1.880 (satisfied)	13.5% (satisfied)	38% (satisfied)	27.36% (satisfied)	6.13% (satisfied)
20% C & NRL	1.805 (satisfied)	13.9% (satisfied)	31% (satisfied)	———	———

5 CONCLUSIONS AND RECOMMENDATIONS

This study assessed whether cement and NRL are viable admixtures for the stabilization of gravelly soil to be used in subgrade and sub-base. The results indicate that with increasing the cement and NRL mixing percentage, CBR value (four days soaked) increases up to 15% and decreases afterwards, and with increasing the cement and NRL mixing percentage, the optimum moisture content (OMC) decreases, and maximum dry density (MDD) increases up to 15% and decreases thereafter. The CBR (four-day soaked) values are 14%, 28%, 38%, and 31% for blended soil samples. However, the CBR value of 14% does not fulfill the CIDA requirements. The Atterberg limits of all the blended samples did comply with the CIDA specifications. It can be seen from Table 6, that the percentages of 10% cement and NRL as well as the percentages of 15% cement and NRL do comply with the standards stipulated in the CIDA guidelines. According to Sani et al., (2019), most importantly, the soil subgrade should have sufficient strength to support the structure that is constructed over it. The strength of the soil to be used as subgrade for road pavement is assessed in terms of CBR value. Hence, from these two percentages, 15% cement and NRL can be recommended based on the higher dry density and CBR values compared to the 10% cement and NRL mixing. However, 10% also is a viable option considering the plasticity as lower plasticity hinders better compaction. Therefore, from the results so obtained, it can be recommended an optimum percentage of 15% cement and NRL for the improvement of lateritic soils to be used as subgrades of Sri Lankan roads. The outcome of this research will promote the usage of NRL and cement as sustainable stabilizing agents for improving the properties of lateritic soils for pavement bases and subbases.

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