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Cost Comparison of Flexible Pavement on Weak Sub-Grade Soil Modified with Lime and SD

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Abstract

The effectiveness of flexible pavement is affected by the subgrade quality. The subgrade refers to a compacted layer of soil that provides sideways support to the pavement. When constructed on a weak subgrade, it negatively impacts the pavement's performance, leading to a shorter lifespan. Traditionally, the common method to stabilize a soft subgrade involves removing the weak soil and replacing it with stronger soil. However, due to the high expenses associated with soil replacement, highway agencies are exploring alternative approaches to constructing highways on soft subgrades. Soil stabilization is a commonly employed alternative in pavement construction, serving as an effective method to enhance the engineering characteristics of soil, including its strength and stability. This paper focuses on the utilization of lime and stone dust (SD) as admixtures for an efficient ground improvement technique over weak subgrade soil deposits. The California Bearing Ratio (CBR) test is conducted by making the specimens of weak subgrade by adding the variable percentages of a mixture of lime and SD. First, the soil was mixed up with lime to 12% by weight with an increment of 3% again the soil was mixed with SD with increments of 10% up to 50% by weight of soil. The study determined an optimal lime content of 3% based on the geotechnical properties of the mixture and the cost considerations of lime and the weak subgrade. Following this, SD was added to the optimized lime-weak subgrade mixture in varying increments of 10% by weight, up to a maximum of 40%. The modified mixes were then evaluated for their CBR and maximum dry density values. The CBR is increased to 15% and the total pavement thickness decreased to 725 mm for 50% SD addition with 4.89 % in cost reduction.

Keywords: *Plastic Limit; Liquid Limit; Plastic Index; California Bearing Ratio; Unconfined Compressive Strength; Pavement.*

INTRODUCTION

There is more than 2000 km of road network in Kathmandu Valley, Nepal, of which more than 500 km constitutes strategic road network. These major routes transverse the soft soil of Kathmandu Valley at various places. Some of the roads built over these deposits are affected by subgrade rutting due to the presence of soft soil deposits in these areas (Paneru, 2020). The major problem associated with soft soil subgrade is that road built over this soil requires frequent maintenance and overlay; the Department of Roads (DoR) makes huge investment annually to make the roads serviceable.

Presently the roads are built based on past experience and practices. The method of replacement is employed in soft subgrade conditions. The practice in other countries has suggested chemical stabilization are more reliable in soft subgrade condition than the replacement by capping layer (Harris *et al.*, 2006). The soil in the Kathmandu Valley, specifically the black clay referred to as *Kalomato*, consists mainly of heavy clay with clay-to-loam variations. It was formed by the deposition of fine sediments from rivers and streams into a lake, containing a significant amount of organic matter (Sakai, 2001). It is generally light to dark grey in color with a soft and compressive nature (Dahal and Zheng, 2018). The compressive nature of soft subgrade poses a challenge to highway engineers. The minimum soaked CBR value of subgrade for pavement construction must be greater than 5%, limiting the expansion below 1%. If pavement needs to be constructed over subgrade with a CBR value of less than 5%, lime or mechanical stabilization should be carried out (DoR, 2016). The soil is stabilized with various chemicals with lime being the most commonly used stabilizers in the road (Bell, 1996). Currently in Kathmandu Valley, either a capping layer of stronger material or lime stabilization (DoR, 2016) is used to overcome the problem associated with soft soil. The problem with the conventional method of replacement is that it requires the acquisition of suitable material away from the site which can increase the construction cost. Furthermore, the soil excavated to be replaced gets wasted and needs to be dumped away. At present, lime stabilization is considered an expensive solution to treat soft soil subgrade. To overcome the above problems the relatively less costly SD was mixed with lime. Certain subgrade soils, particularly clayey soils, exhibit high strength when their moisture content is low. However, as the water content surpasses the optimal value, these soils become weak and less manageable. In such cases, it is recommended to either replace the soil with high-quality fill material or employ appropriate treatment methods to improve its properties (Prusinski and Bhattacharja, 1999). The objective of chemical soil stabilization is to improve the stability of soils by increasing the size of soil particles, reducing the plasticity index, minimizing swelling-shrinking potential, and enhancing cementation. This is achieved by introducing specific chemical compounds into the soil as part of the stabilization process (Fondjo *et al.*, 2021). Apart from strength and stability soil stabilization prevents erosion and dust formation (Sen and Kashyap, 2012). A comparative study has been conducted on soil stabilization using lime and cement up to 15% conducting tests like liquid limit, plastic limit, CBR and UCS tests. The research reflected a maximum 10% substitution as beyond 10% the test values show a decreasing trend (Rai, Singh and Tiwari, 2020). The experimental study including lime and cement shows that the compressive strength at 28 days increased 2 to 6 times compared to untreated specimens. Furthermore cement relatively demonstrated higher influence on mechanical behavior as compared to lime (Sharma *et al.*, 2018). Soil modified with lime improves workability and compatibility. Soils classified according to the USCS as CH, CL, MH, ML, OH, OL, SC, SM, GC, GM, SW-SC, SP-SC, SM-SC, GW-GC, GP-GC, ML-CL, and GM-GC should be considered as potentially capable of being stabilized with lime (Firoozi *et al.*, 2017). Experimental research on subgrade modified with 2%, 4 % and 6 % of lime found that the engineering properties of soil significantly improved by the addition of lime (Singh and Res, 2015). SD in the range of 0 – 60% is used as a modifier and its effect on liquid limit (LL), plastic limit (PL), plasticity index (PI), maximum dry density (MDD), optimum moisture content (OMC), and CBR is analyzed (Dixit and Patil, 2016). The result demonstrated that 20% SD as a modifier in expansive soil improved MDD and CBR by 5% and 35% respectively, whereas OMC and Atterberg limit values were diminished which made the soil suitable for the subgrade (Bilal and Talib, 2016). In a study conducted in the Bundelkhand region of India, the stabilization of soft soil was investigated using crusher dust, a waste product. The study determined that an optimal percentage of 40% crusher dust (quarry dust) resulted in notable changes in various soil properties. Specifically, there was a decrease in the liquid limit from 54.10% to 24.2%, a reduction in swelling pressure from 103.6 KN/m^2 to 9.4 KN/m^2, an increase in shrinkage limit from 12.05% to 18.7%, an improvement in CBR value from 1.91% to 8.06%, and a slight increase in UCS value from 28.1 kN/m^2 to 30.2 kN/m^2 (Parhi and Das, 2014).

The general objective of this study is to perform a comparative study of strength enhancement and cost analysis of flexible pavement on weak soil modified with lime and SD in combination.

MATERIALS AND METHODS

To achieve the objective of the study, the study area is selected in Madhyapur Thimi-5 Paachagaal, Bhaktapur Nepal. The sampling point starts from Thimi police station located in Purano Bato to a distance of 1 km length. The soil sample, lime and SD stabilizers were collected using standard methods of sampling conforming IS 2720 part one. The soft soil sample at a depth of 0.5 to 0.6m was collected in the wet state. Table 1 shows the tests that are carried out on the soil sample.

Table 1: Tests on soil sample

SN	Name of Test	Test Procedure
1	Specific Gravity	IS 2720 (Part 3)
2	Liquid Limit	IS 2720 (Part 5)
3	Plastic Limit	IS 2720 (Part 5)
4	Free Swell Index	IS 2720 (Part 40)
5	Wet Sieve Analysis	IS 2720 (Part 4)
6	Standard Proctor Compaction	IS 2720 (Part 7)-1980
7	California Bearing Ratio	IS 2720 (Part 16)-1987

Lime is one of the additives used in this study that is commercially known as hydrated lime ($Ca(OH)_2$). The required lime in this study was purchased from the local market. The product specification of the lime is shown in Table 2.

Table 2: Physical Properties of Lime

S.N.	Requirement	Physical Properties of Lime
1	No. 30 mesh (600 µm), max.%	0.05
2	No. 200 mesh (75 µm), max %	No Value Assigned
3	Pits or Pops	Not applicable unless No. 30 Mesh>0.5% then one
4	Plasticity	200 within 30 minutes
5	Water retention, min. %	85 within 30 minutes

The SD used in this study is procured from a local stone crusher plant. The gradation of SD was done in the laboratory; other physical characteristics of SD were not carried out in the laboratory.

CBR and UCS tests were performed on selected virgin soil, soil mixed with lime, soil mixed with SD and soil mixed with lime and SD. The modified Proctor tests were performed on soil samples alone as well as their mixes with an increasing percentage of lime by weight (3, 6, 9 and 12 percent) of soil, and SD with (20, 30, 40 and 50 percent). The MDD was plotted to obtain the optimum percentage of lime and SD and lime with SD mixed with the soil. In total, fifty-six samples were prepared to study the fluctuation in CBR values. Soaked CBR tests were carried out for the following combinations:

- Natural soft soil with no additives.
- Natural soft soil modified with lime (+3%, +6%, +9%, +12%)
- Natural soft soil modified with SD (+20%, +30%, +40%, +50%)
- Natural soft soil modified with optimum lime with SD (+20%, +30%, +40%)

For the CBR values more than 5% the composition of pavement course was evaluated for different lime and SD combinations. From the design table of the Guideline for the Design of Flexible Pavements (GFPD-2014 (2nd Ed., 2021) the pavement composition for maximum design traffic of 250 million standard axles (msa) considering future upgrading for various values of CBR was taken to evaluate the overall required thickness of pavement. The variation of thickness was evaluated based on the required thickness of pavement for various combinations of lime and SD.

The quantity of materials and cost per unit area for pavement structure was analyzed based on norms of rate analysis for road and bridge work and Bhaktapur district rate. The rate analysis was carried out for the computed pavement composition and variation of cost per unit area was evaluated for different combinations of additives.

RESULTS and DISCUSSIONS

Sieve analysis and hydrometer tests were performed on the clay soil sample, and the results are presented in Figure 1. The figure indicates that the soil is classified as fine-grained since more than 30% of the soil fraction passes through sieve No. 200 (0.0075 mm).

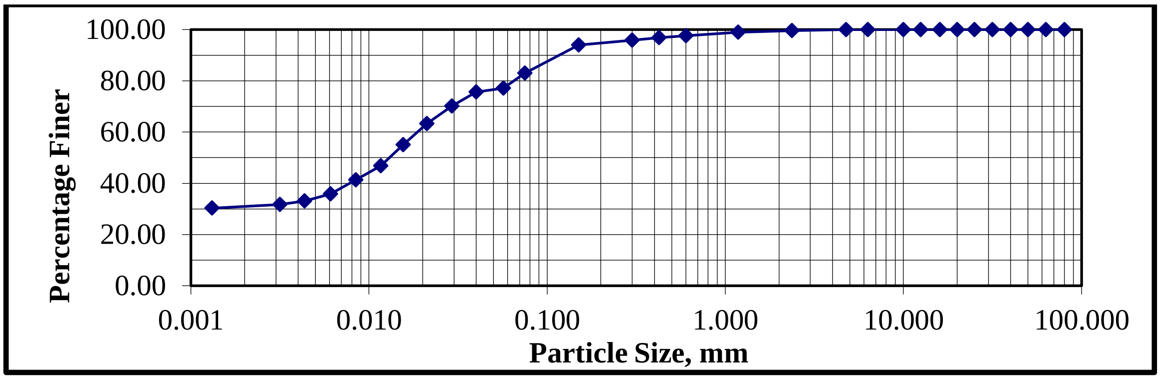

Figure 1: Soil Particle Gradation Curve

The elevated fine content suggests that the soil may consist of clay or silt. According to the AASHTO classification system, the soil falls within the range of A-4 to A-7 soils. Upon further analysis, it is determined to be an A-4 soil since the liquid limit and plastic index are both below 41 and 10, respectively, as indicated in Table 3. Soils in this group are classified as silty soil with a group index of 10, and they are generally considered fair subgrade material.

Table 3: Classification of soil sample

Sample Number	Passing ASTM Sieve # 200, %	LL, %	PL, %	PI, %	Classification	
					AASHTO	USC
S-1	83	34	26.41	7.59	A-4(10)	ML

The moisture density relationship was determined using modified Proctor compaction test for different compositions of soil with lime and SD.

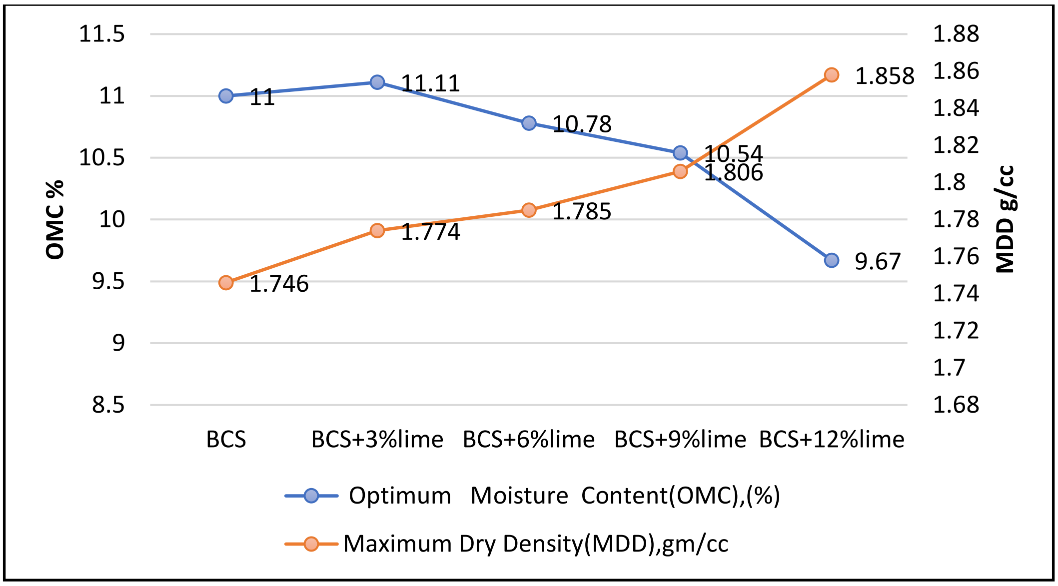

Figure 2: Variation of OMC and MDD with Lime

There was a decrease in OMC with the addition of lime. It is evident from Figure 2 that the OMC changes from 11% to 9.67% and shows a declining trend with the addition of lime from 0% to 12% with the peak value at 3%. The MDD varies from 1.746 to 1.858 and revealed an increasing trend with the peak value at 12%. Lime plays a role in coagulating, aggregating, or flocculating soil particles resulting in greater workability with enhanced strength and stiffness.

As shown in Figure 3, the reason for an increase in MDD of soil by the addition of SD is due to better rearrangement of soil particles with an increasing percentage of SD. Replacement of clay with higher specific gravity non-plastic SD improves the binding capacity. With increasing percentage of SD OMC was found to decrease because of reduction in clay content of soil which has less attraction for water.

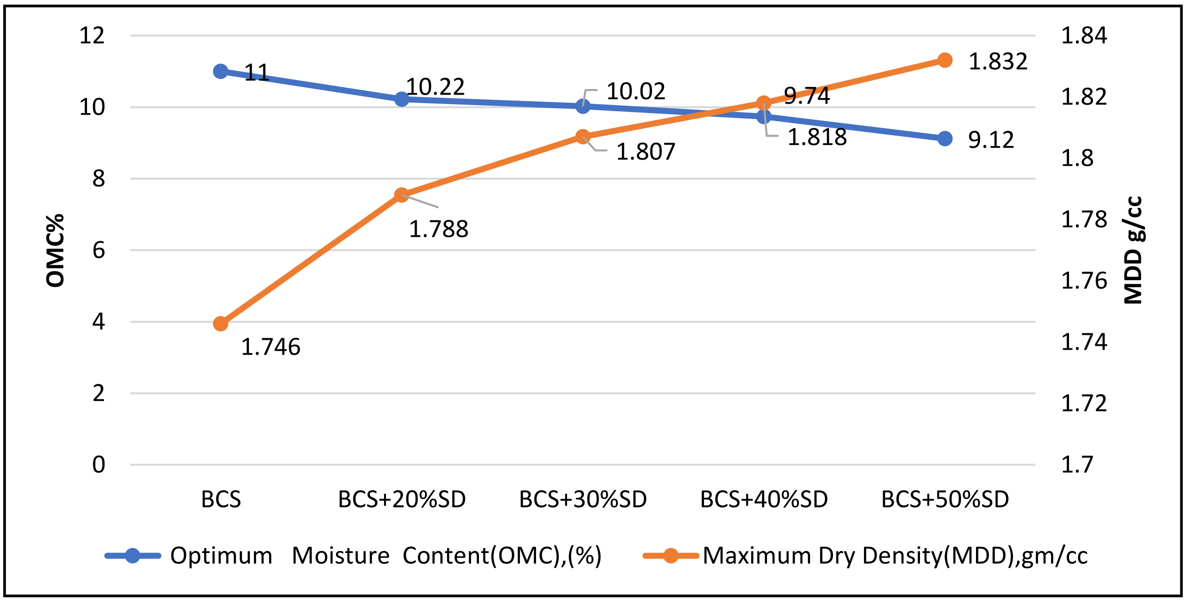

Figure 3: Variation of OMC and MDD with SD

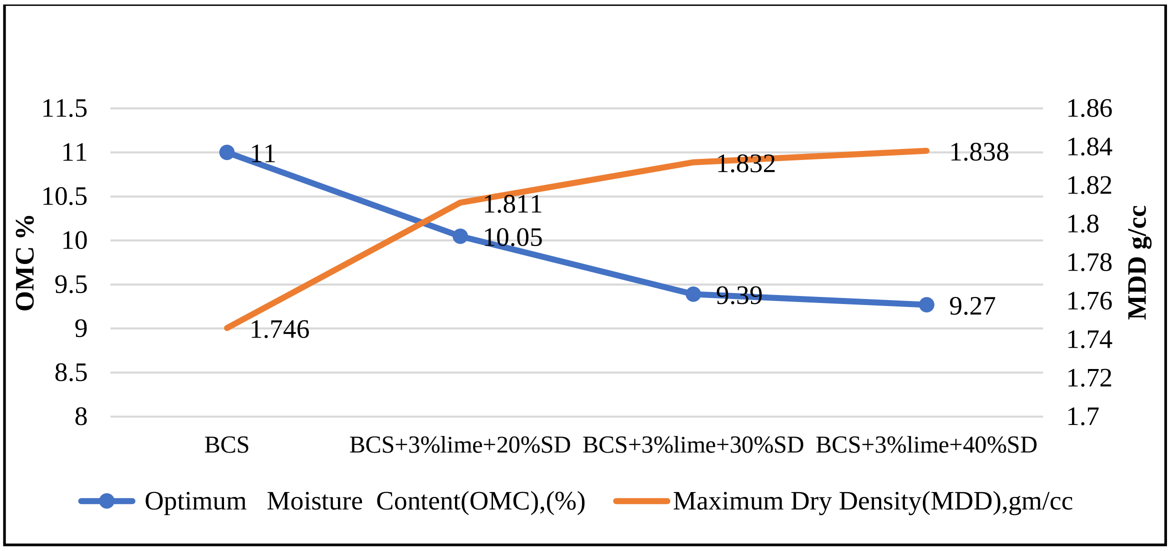

Figure 4: Variation of OMC and MDD with Lime and SD

However to study the combined effect of lime and SD on the soil samples laboratory tests were conducted with varying percentages of SD with 3% lime content. The rationale for fixing 3% lime is that lime is more expensive than SD. The graph in Figure 4 indicates that there is a rising trend of MDD and a declining trend of OMC with the increase in SD.

To understand the consequence of lime and SD on the strength of weak sub soil, CBR test has been performed on soil with 3%, 6%, 9% and 12% lime, soil with 20%, 30%, 40% and 50% SD and soil with 3% lime and 20%, 30% and 40% SD. As represented in Figure 5, the CBR values of the soil samples without additive is only 4% which do not meet the requirement of a minimum of 5% as mentioned in the SSRBW whereas CBR values is in increasing trend with the addition of additives and meet the specifications.

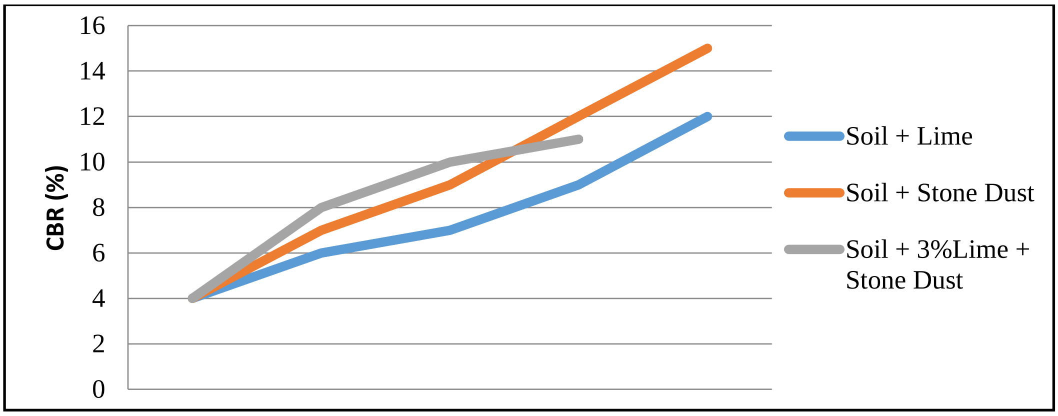

Figure 5: Variation of CBR with Different Composition of Additives

In order to find the variation of pavement cost based on the CBR values obtained for different compositions of additives cost analysis was done based on the district rate of Bhaktapur. The thickness of corresponding pavement layers was evaluated on the basis of the design of flexible pavement guidelines with a maximum traffic of 250 msa. The maximum pavement thickness of 845 mm was observed for soil modified with 3% lime whereas the minimum pavement thickness of 740 mm was obtained for three compositions viz soil modified with 12% lime, soil modified with 40% SD and soil modified with 3% lime and 40% SD.

The minimum cost is NRs. 5726.81 for soil + 50% SD and the maximum cost is NRs. 7106.78 for soil + 3% lime. As explained above the pavement with 50% SD addition was selected because it exhibited more CBR 15% value as compared to lesser values of CBR of other categories. Figure 6 shows the graphical variation of cost per square meter of flexible pavement modified with lime and SD.

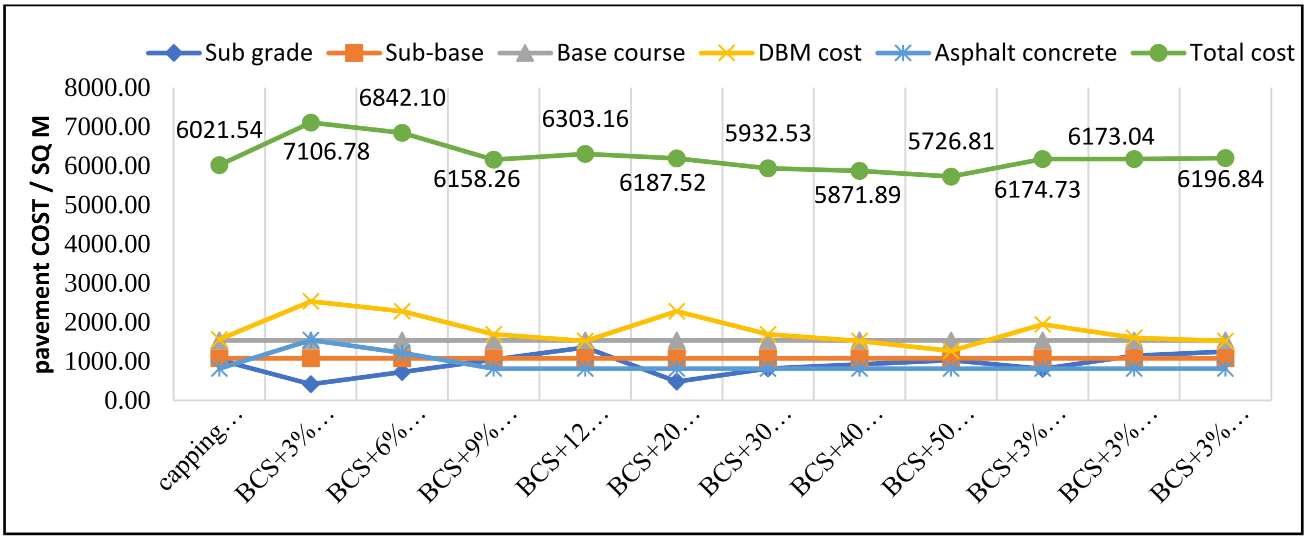

Figure 6: Variation of Pavement Cost with Pavement Components

CONCLUSIONS

This study aimed to find the variation in the cost of pavement in which weak subgrade soil was modified with lime and SD. From the results and discussion, it can be concluded that:

I. The weak subgrade is identified as ML soil (Inorganic silts with none to low plasticity) with LL, PL, PI, OMC and MDD as 34, 26.41, 7.59, 11.15% and 1.76 g/cc respectively. The dry density varied from 1.788 to 1.832 with a maximum value at 50% SD addition.

II. The experimentally obtained soaked CBR values showed continuous rising trend with maximum value as 12 for 12% lime addition which is 3 times greater compared with 4% value for soil whereas maximum value as 15% for 50% addition of SD which was 275% more compared with 0% addition of SD.

III. The maximum and minimum pavement cost was RS 77106.78 and RS 5726.81 for 3% lime and 50% SD addition respectively.

IV. The local weak soil can be improvised for highway construction as the geotechnical properties were improved for 250 msa design traffic.

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