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Evaluation of the Effect of RAP and Lime on Geotechnical Properties of Clayey Soil

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Abstract: ***Road network plays a large role in the rapid development of the economy of a country, providing connectivity to remote areas for various transportation activities. India ranks second in the world in terms of length of road network after the United States. The major road network in the urban locality consists of bituminous pavements periodically resurfaced during maintenance. From the milling process, reclaimed asphalt pavement (RAP) is obtained. Additionally, RAP can be used for the utilization of recycled asphalt pavement (RAP) materials in subgrade soil. Reclaimed Asphalt Pavement (RAP) is being used in this case study to stabilize the subgrade soil collected from Crop Research Center (CRC), Govind Ballabh Pant University, Tanda Range, Uttarakhand (29°01'09.7"N, 79°28'55.9"E). To conduct the experimental program, a variable amount of RAP percentages viz., 5, 10, 15, and 20%, and different percentages of lime i.e., 2, 4, 6, and 8% were mixed with natural soil. Based on gradation, Standard Proctor Test (SPT), Unconfined Compressive Strength (UCS), California Bearing Ratio (CBR), and Specific gravity, the characteristics of RAP-soils with added lime were evaluated. For soil mixture including 10% RAP and 4% lime, a maximum MDD of 19.04 and a percentage increase in compaction of 11.93% was observed. OMC value was observed as 11.35%, which further decreased as RAP content increased. Due to RAP containing coarse aggregate, a higher CBR value was obtained due to the harder sample surface. For all soil mixers of 15% RAP and 4% lime, unsoaked CBR and soaked CBR values were found to be 31.39% and 18.69% respectively. Percentage increases in their respective CBR values were 868.83% and 662.86%. for every percentage of lime variation, maximum CBR was obtained at 15% RAP, and maximum CBR value for soaked CBR was obtained for soil with 15% RAP and 2% lime, whereas for unsoaked CBR, it was obtained for soil with 15% RAP and 4% lime. Maximum UCS values of 412.45 kN/m^2, 606.81 kN/m^2 and 857.62 kN/m^2 were observed on 3rd, 7th and 14th days for soil mix with 15% RAP and 4% lime, with percentage increase of 291.17%, 249.40% and 387.78% respectively. Based on the results of the study, RAP materials can be effectively used in the soil subgrade, sub-base, and base of flexible pavements, reducing the cost of construction.***

Keywords: Reclaimed Asphalt Pavement (RAP), Lime, CBR, SPT, UCS, OMC, MDD.

I. INTRODUCTION

The Indian road network is the second largest in the world, covering 5.89 million km, after the USA, which has a road network of 6.89 million km. Among the total road network of India, National Highways constitute 2.19%, State Highways represent 3.99%, District roads covered 10.17% and Rural roads 72.97%. In most cases, these roads have bituminous surfaces and require regular maintenance. Soil stability has evolved throughout time since more and more materials are being used to establish the degree upto which they can be used for required design strength. Stabilization of soil results in a reduction in permeability, compressibility, and an increase in shear strength which makes the soil more stable and increases its bearing capacity.

Reclaimed Asphalt Pavement (RAP) is a term used to describe removed or reprocessed pavement materials, which contain asphalt and aggregate. These materials are created when asphalt pavements are removed to repair, resurface to obtain subsurface utilities. National Asphalt Pavement Association estimates that 41 million tons of RAP is produced every year in the United States, so if RAP can be used as a soil stabilizing reagent, then it would be a revolutionary technology. UNdata reports that the total production of bitumen asphalt increased by 5803 tons in 2018 in India. about 50% of this asphalt was reused in hot mix asphalt plants, and the rest was disposed of in landfills when RAP is added to the soil, the grain size distribution curve is affected and RAP acts as a mechanical stabilizer.

Granular particles in RAP cause medium bearing capacity and brittleness. Therefore, lime or cement can be blended with RAP-Soil to produce a mixture that is the strength of soil increases over time and continues to increases.

Many Researcher's theory was presented to study the effect of Reclaimed Asphalt Pavement (RAP) and Lime mixed in soil for stabilization. ANOVA (Analysis of Variance) was used by Brown [1] to analyze the impact of RAP and cement composition on soil, when RAP content was increased from 0 to 100%, the Unconfined Compressive Strength decreased from 425 to 208 psi when RAP is mixed with cement, Unconfined Compressive Strength is increased from 63 to 564 psi as cement content increases from 0.0 to 2.0%. Kamel *et al.* [9] took different compositions of RAP mixed with soil and found optimum moisture content decreased with an increase in RAP content. CBR values increased with an increase in RAP content up to 50% RAP. In the study by Alhaji and Musa [10], 30% RAP- 70% soil were mixed with Black Cotton Soil in different proportions and the results indicated a maximum MDD of 2.03 mg/m3, with a maximum CBR of 35%. In the study, it was found that 40% RAP-60% BCS provided the greatest durability. After adding lime and emulsion to a soil sample mixture, Aizadeh and Modarres [13] observed that both acted independently instead of being bound together. According to Alhaji et al. [12] the soil that had been mixed with 120 % RAP had the highest Maximum Dry Density of 2.252 g/cm3. Ruknuddin et al. [15] concluded that the penetration resistance of subgrade soil can be significantly enhanced when 25% RAP was mixed with subgrade soil.

II. MATERIALS AND METHODS

The soil used in this research project was collected from Crop Research Center (CRC), Govind Ballabh Pant University, Tanda Range, Uttarakhand (29°01'09.7"N, 79°28'55.9"E) Sample was collected and sealed in plastic bags for use laboratory. The collected sample was dried in the air then pulverized to the required particle size for various tests.

RAP used in this research paper was collected from Bakhpur, Udham Singh Nagar, Uttarakhand 243201 (28°54'39.8"N, 79°33'11.1"E). RAP was dried and crushed into small particles so that it can pass through 20 mm Indian standard sieve before being used in the study.

Sieve size	Percent Finer After Crushing
40 mm	100%
25 mm	84%
20 mm	70%
16 mm	40%
12.5 mm	16%
10 mm	10%

Table 1: Percentage finer of RAP

Lime was purchased from the local market of Rudrapur, Udham Singh Nagar, Uttarakhand had a brand name "Dehraduni Special Chuna". The proportion of lime used in this research paper was 2%, 4%, 6%, and 8%.

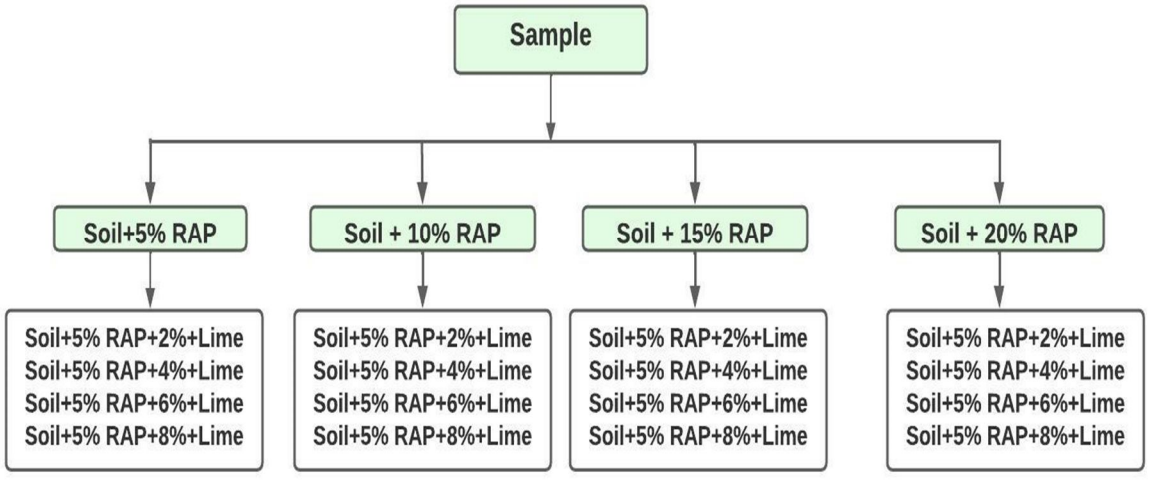

Fig. 1 Sample preparation of soil mixed RAP and lime

III. CONDUCTED TESTS

The tests were carried out in 2 phases. In the first phase, geotechnical soil properties were studied by conducting laboratory experiments. In the second phase, soil with four different RAP compositions i.e., 5%, 10%, 15%, and 20% was mixed with different lime percentage content i.e., 2%, 4%, 6%, and 8% were mixed and various tests were conducted on it.

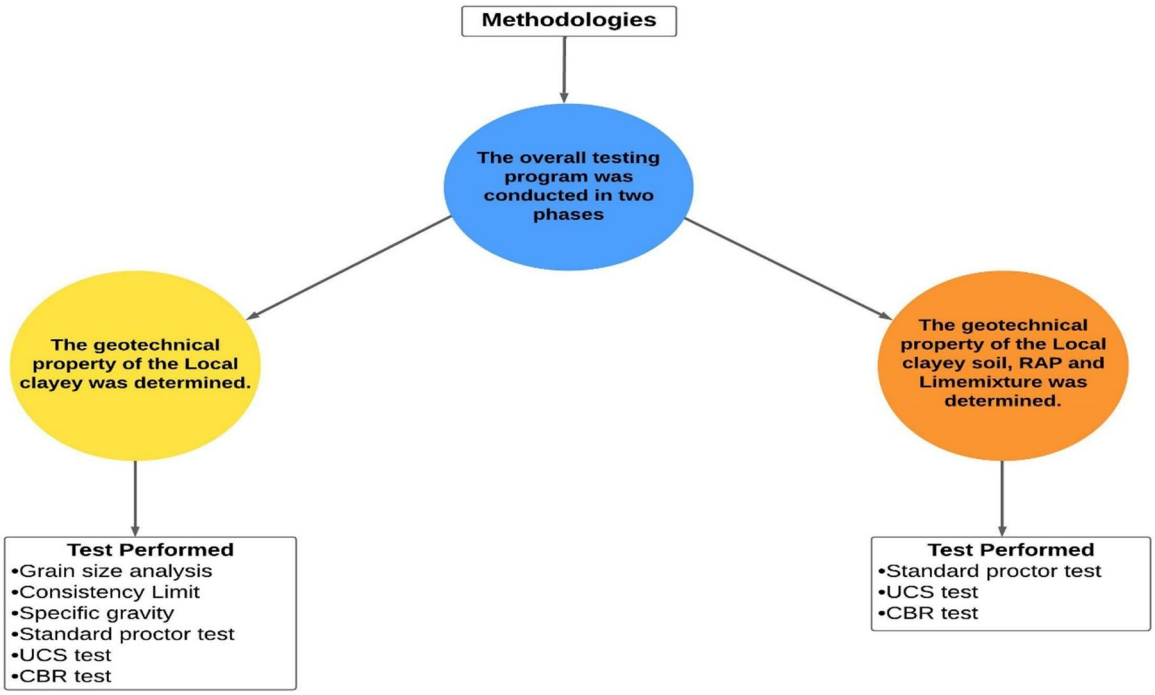

Fig. 2 Methodology adopted in investigation

A. Standard Proctor Test

Standard Proctor Test (SPT) is a laboratory method performed as per IS:2720 (Part VII)-1980 to determine Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) at which soil become most compacted. This test comes under the category of the penetration test.

Fig. 3 Standard proctor test mould

External energy is provided to the soil sample using rammer blows and it reduces the voids between the soil particle, resulting in an increased density of the soil, shear strength and bearing capacity, and reduction in settlement and permeability of the soil. SPT is an instantaneous phenomenon and soil is always taken in a partially saturated state while the densification is mainly due to a reduction in the volume of air voids in the soil at a given water content.

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B. Unconfined Compressive Strength test

As per IS:2720 (Part X)-1991, the Unconfined Compressive Strength (UCS) test is used to determine the sample strength, it is the maximum axial compressive stress that a soil can withstand under zero confining pressure i.e.,σ_3=0.

Fig. 3 UCS sample and test machine

Initial length and diameter of the sample were measured to obtain the UCS results on soil, soil + RAP, and Soil + RAP + lime at OMC of the respective samples. In this test, a cylindrical soil sample with zero lateral support is tested to failure under compression at a constant rate of strain i.e., 1.5 mm/min, and load readings were taken for particular values of the deformation dial gauge.

C. California Bearing Ratio test

California Bearing Ratio (CBR) is the ratio expressed in percentage of force per unit area to penetrate a soil sample with a standard circular plunger having a diameter of 50 mm at the rate of 1.25 mm/min to that required for equivalent penetration in standard material. The ratio is generally determined for penetration of 2.5-mm and 5-mm. Standard load corresponding to 2.5-mm and 5-mm penetration are given in Table.

Penetration of plunger in sample (mm)	Standard load (kg)
2.5	1370
5.0	2055

Table 2 CBR standard load corresponding to 2.5mm and 5mmpenetration

CBR test helps to find the strength of subgrade soil of pavement and roads.

Fig. 4 CBR Soaked sample and CBR machine

CBR test is performed as per IS:2720 (Part XVI)-1987 in soaked and unsoaked conditions. As moisture content can decrease the strength of soil thus CBR test is performed in soaked condition, in soaked condition sample is kept in a fully saturated condition, typically subgrade. unsoaked value of CBR represents the sample strength in an unsaturated state, usually for well-drained road base materials.

IV. RESULTS ANALYSIS AND DISCUSSIONS

A. Geotechnical Parameters of Soil

Firstly, the soil was pulverized and then oven-dried at a temperature of 105°C to 110°C for 24 hrs. After that tests were performed on soil and Table 1 presents the results of the tests on the clayey soil.

Parameters	Results
Grain size distribution: Clay size fraction (%) Silt size fraction (%) Sand size fraction (%) Soil type as per IS: 1498-1970	 15.65 65.99 18.36 CL
Liquid Limit (%)	25.03
Plastic Limit (%)	13.89
Plasticity Index (%)	11.14
Specific Gravity	2.63
Maximum dry density, MDD (kN/m^3)	17.01
Optimum moisture content, OMC (%)	16.30
California bearing ratio value (CBR): Unsoaked (%) Soaked (%)	 3.24 2.45
Unconfined compressive strength (kN/m^2): a. 3 Days b. 7 Days c. 14 Days	 105.44 173.67 175.82

Table 3 Geotechnical properties of soil

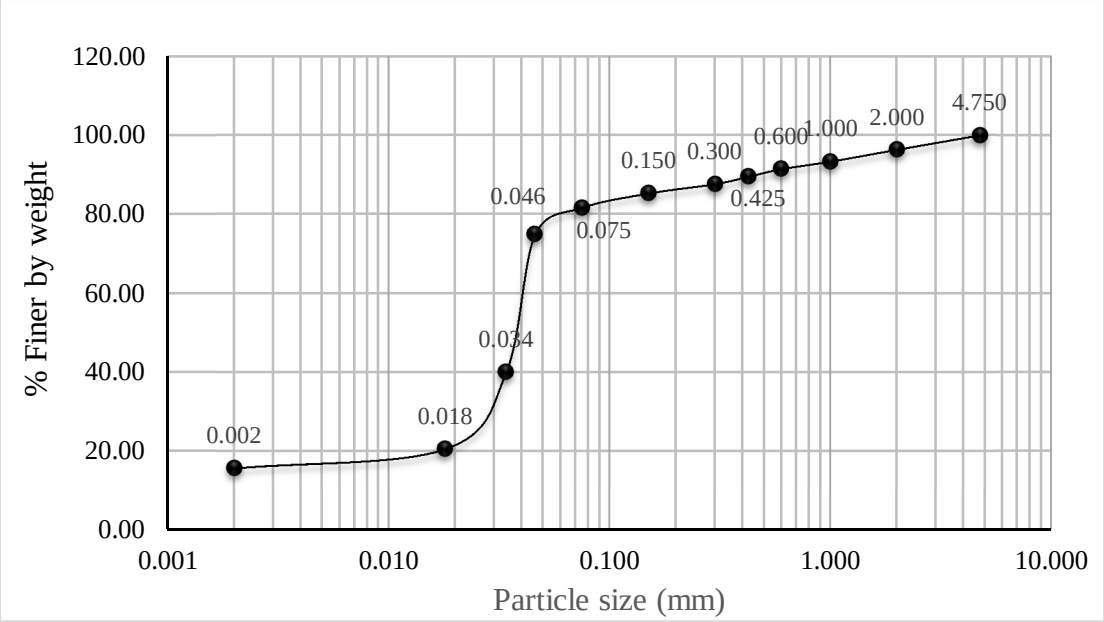

Fig. 5 Grain size distribution curve of soil

B. Geotechnical Parameters Soil Mixed with Reclaimed Asphalt Pavement (RAP) and lime:

1) Standard Proctor Test Results: The results of the experiments are tabulated in Table 4. The variation of the maximum dry density (MDD) of clayey soil with RAP and lime is as shown in Figure 6. From Table 4, it was observed that the maximum of Maximum Dry Density (MDD) of all mixes was obtained at soil mixes with 10% RAP and 4% lime. Percentage increase in compaction of soil mixes with 10% RAP and 4% lime was calculated as 11.93%.

S.No	Sample Type	OMC (%)	MDD (kN/m^3)	% Increase in Compaction (%)
1	Natural Soil	16.3	17.01	
2	Soil + 5% RAP	13.44	18.17	6.82
3	Soil + 5% RAP + 2% Lime	11.72	18.46	8.52
4	Soil + 5% RAP + 4% Lime	11.45	18.2	7.00
5	Soil + 5% RAP + 6% Lime	11.3	18.13	6.58
6	Soil + 5% RAP + 8% Lime	11.5	17.41	2.35
7	Soil + 10% RAP	10.8	18.96	11.46
8	Soil + 10% RAP + 2% Lime	10.67	18.35	7.88
9	Soil + 10% RAP + 4% Lime	11.35	19.04	11.93
10	Soil + 10% RAP + 6% Lime	10.45	18.16	6.76
11	Soil + 10% RAP + 8% Lime	10.2	18.78	10.41
12	Soil + 15% RAP	9.5	18.85	10.82
13	Soil + 15% RAP + 2% Lime	9.23	18.4	8.17
14	Soil + 15% RAP + 4% Lime	9.55	18.47	8.58
15	Soil + 15% RAP + 6% Lime	10.49	18.35	7.88
16	Soil + 15% RAP + 8% Lime	11.25	18.72	10.05
17	Soil + 20% RAP	11.3	18.519	8.87
18	Soil + 20% RAP + 2% Lime	11.6	18.72	10.05
19	Soil + 20% RAP + 4% Lime	11.72	18.46	8.52
20	Soil + 20% RAP + 6% Lime	12.95	18.36	7.94
21	Soil + 20% RAP + 8% Lime	13.14	18.58	9.23

Table 4 OMC and MDD values of soil and various mixes

From fig. 6, it was observed that Maximum Dry Density (MDD) for 0% lime, 4% lime, and 8% lime increased with increasing RAP content till 10% RAP, afterward a decreasing trend of MDD was observed while for lime content 2%, it was observed that curve has U shaped. For lime content of 6%, it was observed that with increasing in RAP content maximum dry density of the mixes increased.

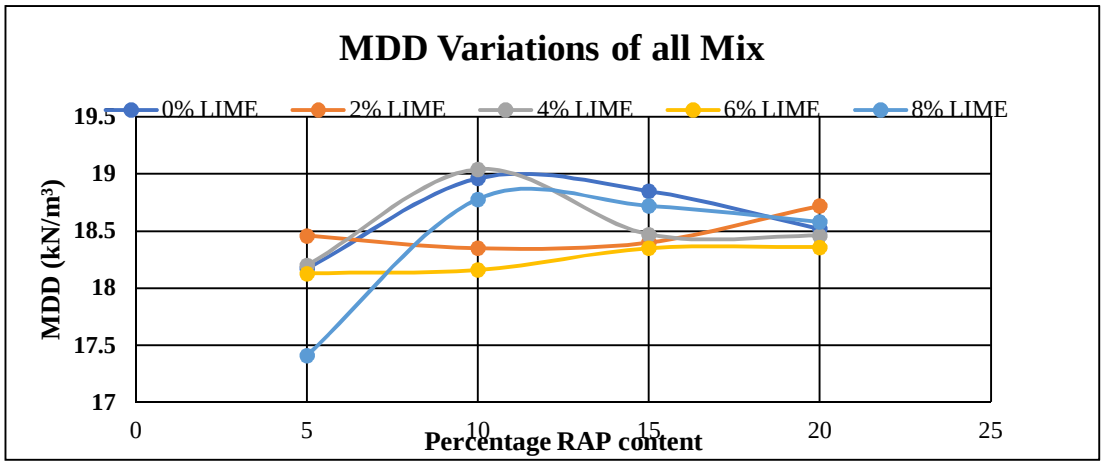

Fig. 6 variation of the maximum dry density (MDD) of clayey soil with RAP and lime

2) *Unconfined Compressive Strength Results:* Unconfined Compressive Strength (UCS) was performed on various mixes of soil, Reclaimed Asphalt Pavement (RAP), and lime content with varying proportions. The results obtained after UCS of each mix have been summarized in Table 5. From Table 5, it was observed that the maximum UCS value of all mixes obtained at soil mixes with 15% RAP and 4% lime for the 3rd, 7th, and 14th day.

S.No	SAMPLE	UCS-3 Days (kN/m^2)	UCS-7 Days (kN/m^2)	UCS-14 Days (kN/m^2)
1	Natural Soil	105.44	173.67	175.82
2	Soil + 5% RAP	178.02	240.17	323.37
3	Soil + 5% RAP + 2% Lime	195.65	253.97	341.62
4	Soil + 5% RAP + 4% Lime	292.44	388.29	512.35
5	Soil + 5% RAP + 6% Lime	279.55	364.16	491.86
6	Soil + 5% RAP + 8% Lime	265.57	348.07	476
7	Soil + 10% RAP	233.36	306.97	452.49
8	Soil + 10% RAP + 2% Lime	297.18	318.76	548.31
9	Soil + 10% RAP + 4% Lime	320.09	412.84	653.62
10	Soil + 10% RAP + 6% Lime	295.22	403.56	622.46
11	Soil + 10% RAP + 8% Lime	282.66	389.07	598.03
12	Soil + 15% RAP	280.77	457.94	730.5
13	Soil + 15% RAP + 2% Lime	353.22	530.91	818.62
14	Soil + 15% RAP + 4% Lime	412.45	606.81	857.62
15	Soil + 15% RAP + 6% Lime	396.47	478.43	787.54
16	Soil + 15% RAP + 8% Lime	379.88	453.82	761.24
17	Soil + 20% RAP	267.59	327.74	458.02
18	Soil + 20% RAP + 2% Lime	339.15	347.85	498.44
19	Soil + 20% RAP + 4% Lime	387.92	415.35	534.27
20	Soil + 20% RAP + 6% Lime	340.53	353.45	507.95
21	Soil + 20% RAP + 8% Lime	305.78	349.75	484.65

Table 5 UCS Values of Soil and various Mixes

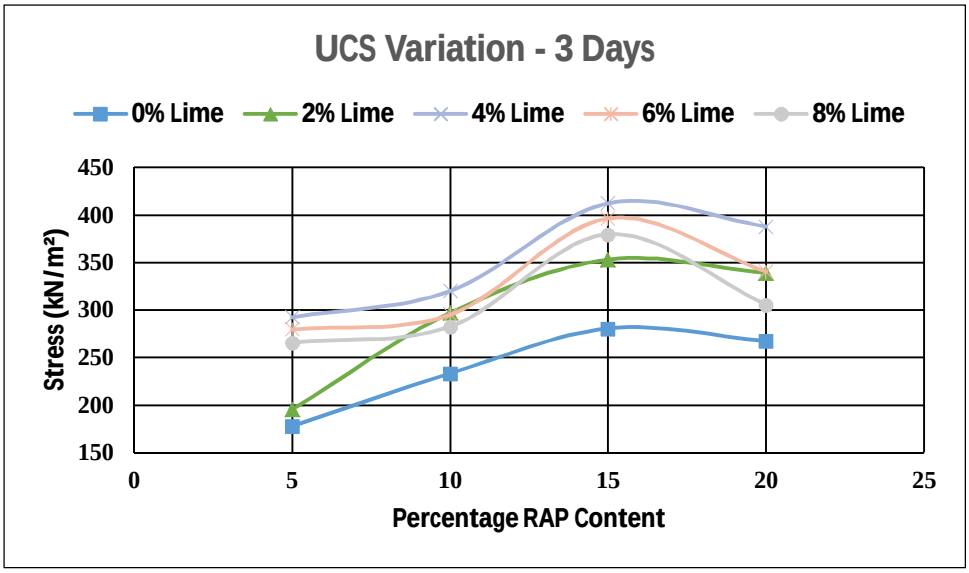

Fig. 7 UCS variation of the mix- 3 days

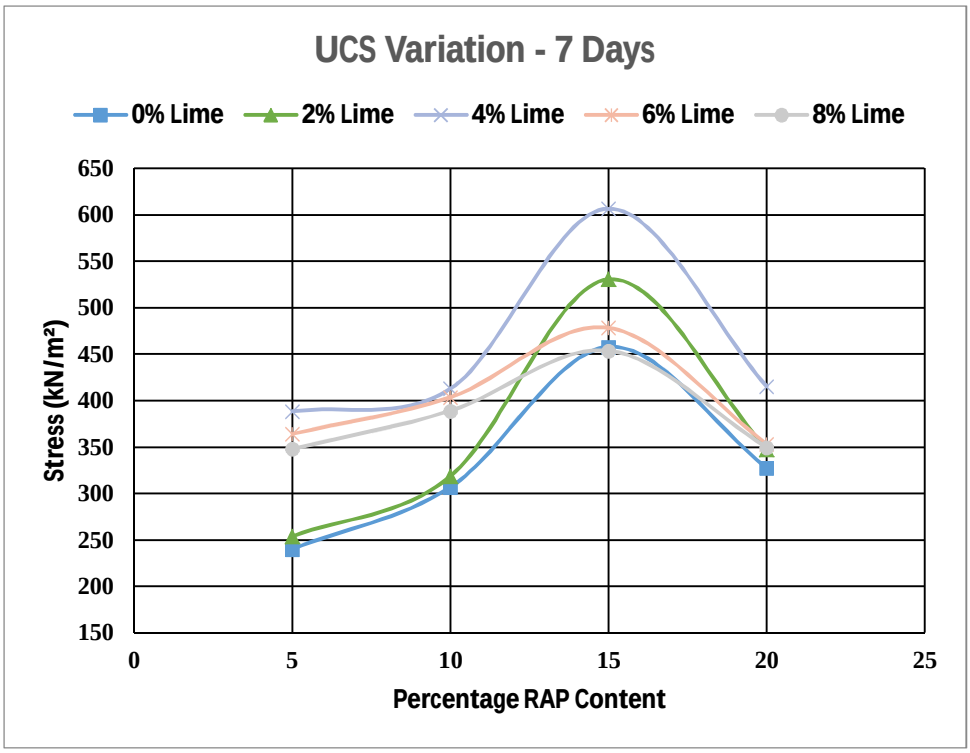

Fig. 8 UCS variation of the mix- 7 days

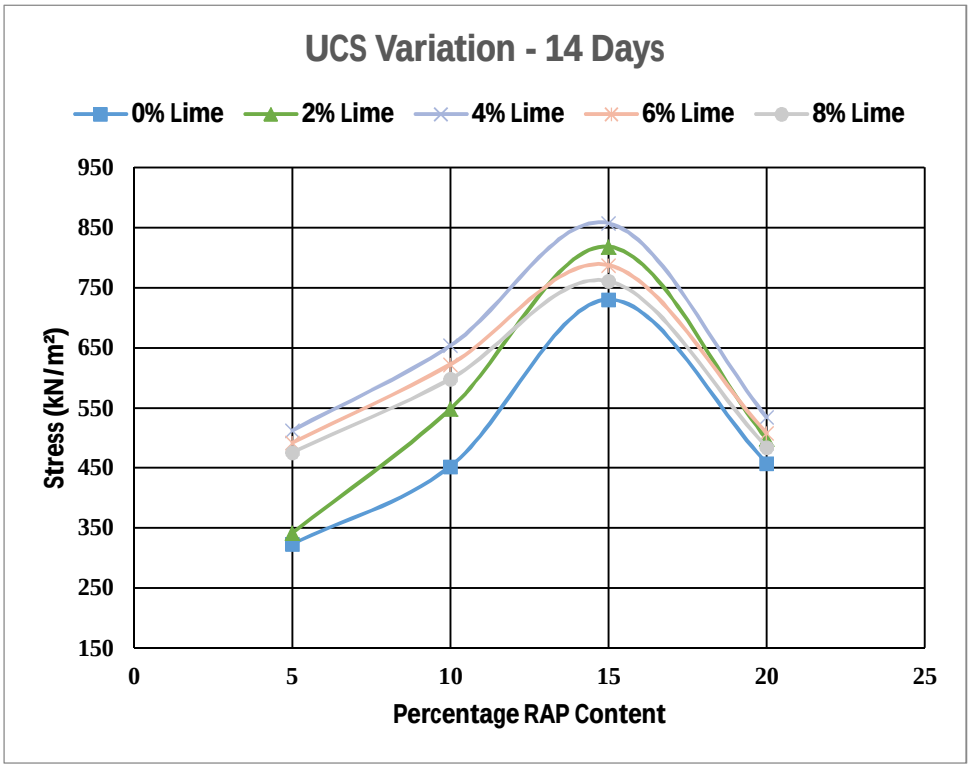

Fig. 9 UCS variation of mix- 14 days

From fig. (7-9), it is observed that the maximum value of stress was obtained at 15% RAP for every lime variation for the 3rd day, 7th day and 14th day of testing.

3) California Bearing Ratio Test

The results obtained after the CBR of each mix have been summarized in Table 6.

S.No	Sample Type	CBR (%) Unsoaked	CBR (%) Soaked	% Increase in Unsoaked CBR	% Increase in Soaked CBR
1	Natural Soil	3.24	2.45		
2	Soil + 5%RAP	7.85	4.11	142.28	67.76
3	Soil + 5%RAP+2% Lime	8.6	4.48	165.43	82.86
4	Soil + 5%RAP+4% Lime	10.46	6.73	222.84	174.69
5	Soil + 5%RAP+6% Lime	12.33	8.22	280.56	235.51
6	Soil + 5%RAP+8% Lime	13.83	9.34	326.85	281.22
7	Soil + 10%RAP	15.7	10.84	384.57	342.45
8	Soil + 10%RAP+2% Lime	18.31	12.71	465.12	418.78
9	Soil + 10%RAP+4% Lime	18.69	13.08	476.85	433.88
10	Soil + 10%RAP+6% Lime	20.93	15.7	545.99	540.82
11	Soil + 10%RAP+8% Lime	20.55	16.44	534.26	571.02
12	Soil + 15%RAP	23.54	18.31	626.54	647.35
13	Soil + 15%RAP+2% Lime	26.91	19.06	730.56	677.96
14	Soil + 15%RAP+4% Lime	31.39	18.69	868.83	662.86
15	Soil + 15%RAP+6% Lime	24.67	16.82	661.42	586.53
16	Soil + 15%RAP+8% Lime	19.43	14.95	499.69	510.20
17	Soil + 20%RAP	17.56	10.46	441.98	326.94
18	Soil + 20%RAP+2% Lime	15.32	7.47	372.84	204.90
19	Soil + 20%RAP+4% Lime	13.45	7.1	315.12	189.80
20	Soil + 20%RAP+6% Lime	11.21	4.86	245.99	98.37
21	Soil + 20%RAP+8% Lime	9.34	4.48	188.27	82.86

Table 6 UCS values of soil and various mixes

From Table 6, it was observed that the maximum CBR value of all mixes obtained at soil mixes with 15% RAP and 4% lime for unsoaked CBR while for soaked CBR, maximum CBR was obtained at 15% RAP and 2% lime. Percentage increase in CBR value of soil mixes with 15% RAP and 4% lime were calculated as 732.63% and 527.18% for unsoaked CBR and soaked CBR respectively.

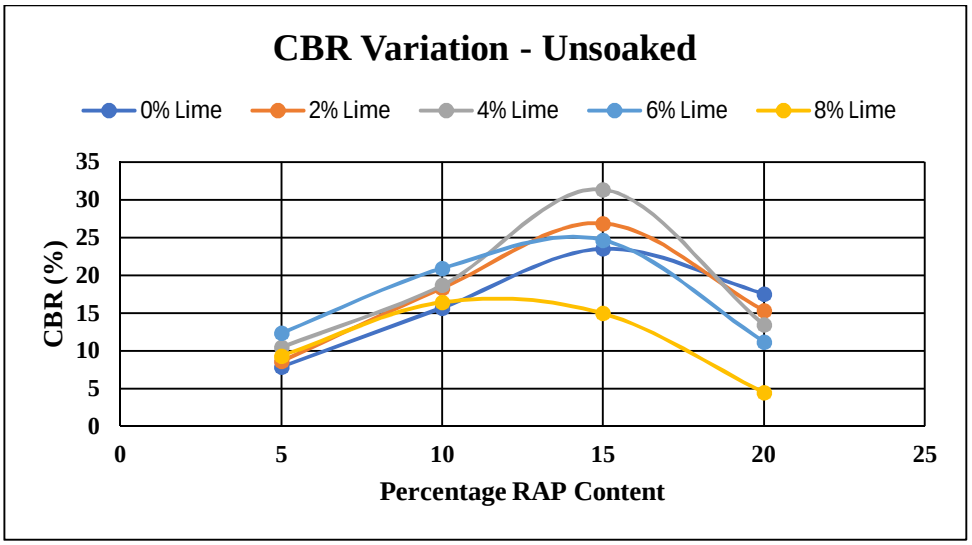

Fig. 10 Unsoaked CBR variation of the mix

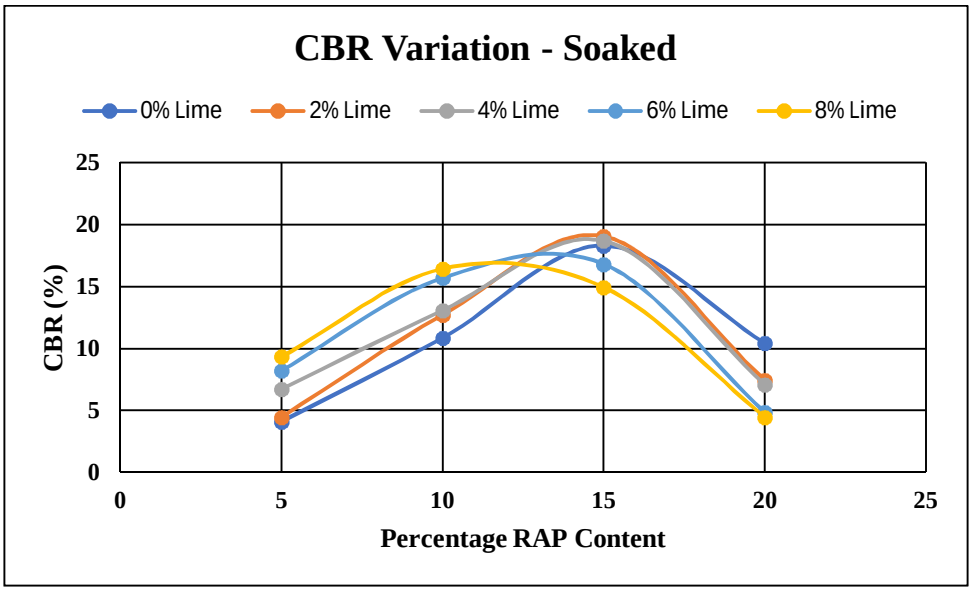

Fig. 11 Soaked CBR variation of the mix

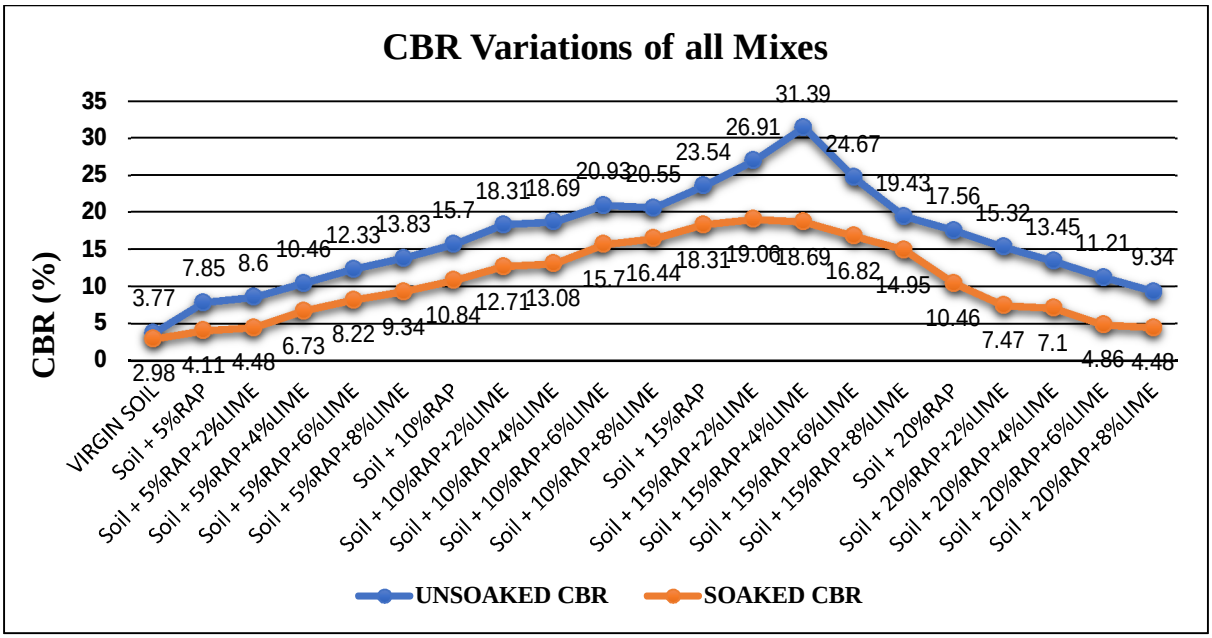

Fig. 12 Variation trend of CBR

From Fig. 12, the inverted U-shaped trend for both soaked and unsoaked conditions was observed. Maximum CBR value was obtained for the unsoaked condition at 15% RAP and 4% lime with a 732.62% in percentage increase in CBR, while for the soaked condition maximum CBR was obtained at 15% RAP and 2% lime with 539.60% in percentage increase in CBR.

V. CONCLUSIONS

Based on the results of the study and experimental investigation, the following conclusions have been drawn,

1) For soil with RAP and lime, maximum of maximum dry density for all mixes achieved at soil mix with 10% RAP and 4% lime was 19.04.

2) Percentage increase in compaction of soil mix with 10% RAP and 4% lime was calculated as 11.93%.

3) Maximum CBR value for all mixes obtained at soil mix with 15% RAP and 4% lime for unsoaked and soaked CBR.

4) For every percentage of lime variation it was found that, maximum CBR value was obtained at 15% RAP.
5) RAP contains coarse aggregates therefore, higher CBR value obtained due to the harder surface of the sample.
6) It had been observed that RAP has a higher content of fines due to the degradation of material during grinding and crushing operations, RAP can be easily applied for the purpose of soil stabilization to increase the CBR value therefore the thickness of the road surface will decrease which will lead to a reduction in construction costs.
7) Maximum UCS value for all mixes obtained at soil mix with 15% RAP and 4% lime for 3rd, 7th and 14th day.
8) As RAP content starts to increase after 15%, the Unconfined Compressive Strength (UCS) decreases. As RAP does not hold plastic nature to stick to the soil particles together. Henceforth, friction leads to decrease of large amount of content between Soil and RAP.

VI. ACKNOWLEDGMENT

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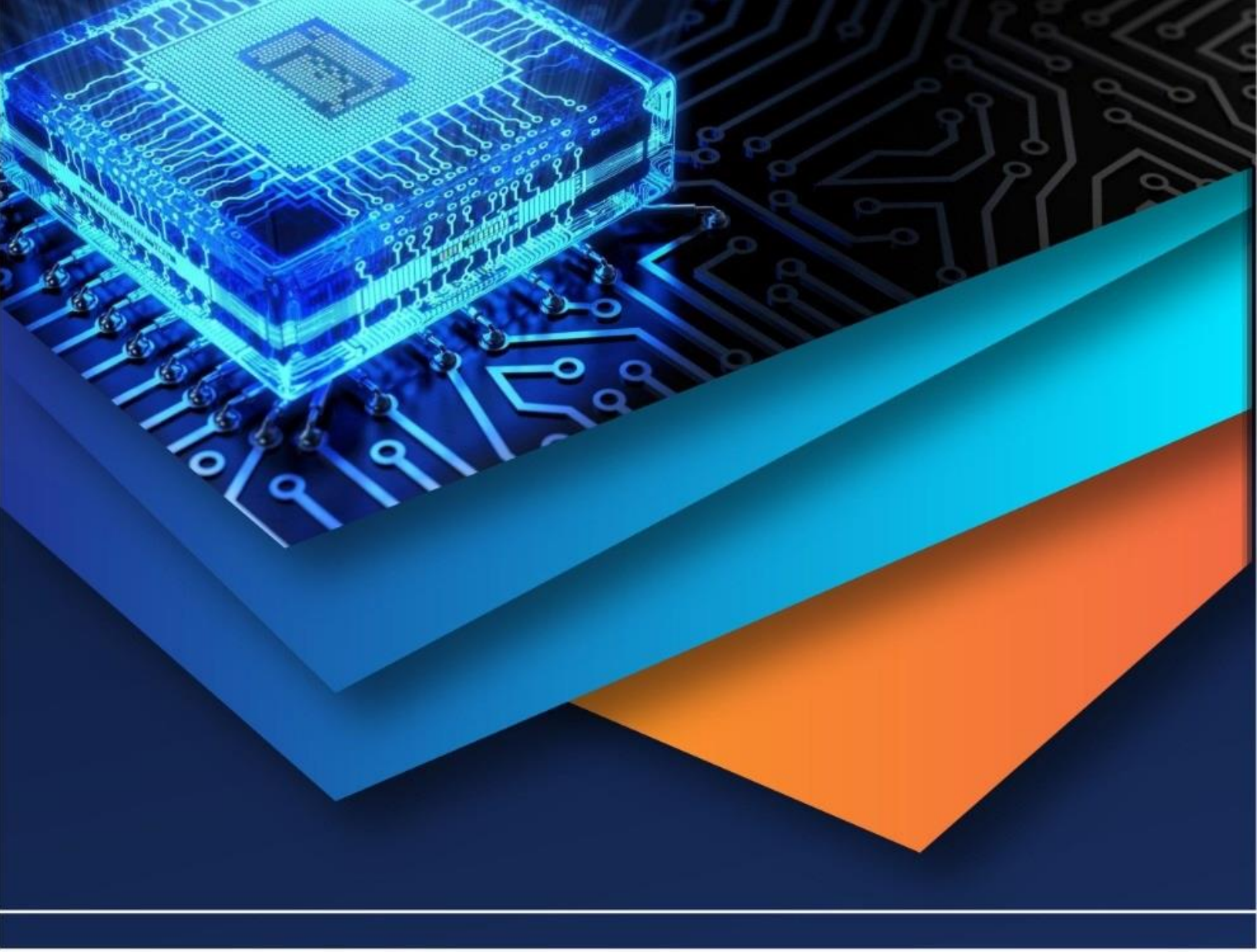

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