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Enhancing Clayey Soil Performance with Recycled Paper Pulp and Lime Treatment

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***Abstract*— Clayey soils are commonly found in various construction and agricultural applications, presenting challenges such as poor drainage, low bearing capacity, and susceptibility to shrink-swell behavior. This study explores a sustainable approach to improve the engineering properties of clayey soil by incorporating recycled paper pulp and lime. Recycled paper pulp, a waste material from the paper industry, and lime, a widely available and cost-effective stabilizer, were combined to address the soil's limitations. The research involved laboratory experiments to investigate the effects of different proportions of recycled paper pulp and lime on the clayey soil's characteristics. This eco-friendly approach not only enhances the engineering properties of clayey soil but also contributes to the recycling of paper waste. The findings of this study have implications for sustainable construction and agriculture, offering a promising solution to address the challenges associated with clayey soils, while also promoting environmental conservation and resource utilization.**

***Keywords*— Clayey soil, paper pulp, lime treatment, soil stabilization, engineering properties, sustainable construction, agriculture.**

I. INTRODUCTION

Soil stabilization is a crucial construction technique that modifies the physical and chemical properties of soil using stabilizing agents like recycled paper pulp and lime. This approach aims to enhance the soil's load-bearing capacity, durability, and resilience against erosion and settlement. By utilizing recycled paper pulp, this method not only improves soil engineering properties but also promotes sustainability by repurposing waste from the paper industry. This eco-friendly approach strengthens the soil matrix, mitigates erosion, and ensures the long-term stability of infrastructure projects, making it an ideal solution for addressing soil-related challenges in civil engineering and construction.

II. OBJECTIVES

Soil stabilization aims to enhance the load-bearing capacity and engineering properties of clayey soils, making them suitable for construction projects. By utilizing recycled paper pulp as a stabilizer, it promotes eco-friendly practices by repurposing waste, contributing to environmental sustainability, and offering a cost-effective alternative to traditional methods. This approach also reduces the soil's plasticity, minimizing susceptibility to moisture-induced swelling and shrinking. Additionally, it boosts the shear and tensile strength of clayey soils, improving their overall stability and performance for long-lasting infrastructure solutions.

III. SCOPE OF STUDY

The goal of the study is to thoroughly investigate how lime and recycled paper pulp can improve the performance of clayey soils. It explores topics such as stabilizing soil, measuring gains in mechanical attributes and microstructure, and analyzing the advantages of employing recycled paper pulp for the environment. The study looks for the best mix ratios, assesses durability over time in different scenarios, and does cost-benefit assessments. Validation of findings will be achieved by field testing and case studies, which will also ensure compatibility with other construction materials. This comprehensive strategy seeks to give a soil stabilization technique that is both economical and sustainable, while also providing insightful information for practical construction uses.

IV. METHODOLOGY

The initial part of the project is topic selection. The next step is a site visit to gather necessary data and materials. The test sample is obtained here, which is approximately 250kg of clayey soil.

A. Methodology flow chart

a) Sample collection
b) Testing of sample without additives
c) Mixing of sample with additives
d) Testing of sample with additives
e) Comparison of results

V. MATERIALS USED

A. Clayey soil

Taliparamb's clayey soil holds water because of its tiny pore size. Waterlogging and inadequate drainage may come from this. Clayey soils can also expand and contract in response to variations in moisture, which increases the possibility of structural harm to infrastructure and structures.

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B. Lime

Lime reacts with the clay particles, causing them to bind together and become more stable. This process is called lime stabilization. Lime can help reduce the plasticity of the soil and improve its strength.

C. Recycled paper pulp

It is made from shredding of post-consumer waste paper. Recycled paper pulp helps in reducing waste and conserving natural resources while providing valuable material for various applications.

VI. LABORATORY TESTS FOR SOIL WITHOUT ADDITIVES

Several physical characteristics have been examined for Clayey soil alone in the early phases of this experimental study. These characteristics include Compaction properties (MDD and OMC), Plastic properties (Liquid limit and Plasticity index), California Bearing Ratio (CBR), Free swell index (FSI), and Unconfined Compression.

Following Laboratory tests were done in accordance with IS standards to assess the physical qualities of clayey soil.

a) Liquid limit
b) Plastic limit
c) Swelling index
d) Proctor compaction test
e) Unconfined compressive test
f) California bearing ratio test

Table.1. Index properties of soil

Sl. No	Properties	values
1	Soil Type	Clayey soil with intermediate plasticity
2	Liquid Limit (LL)	40%
3	Plastic Limit (PL)	16.67%
4	Plasticity Index (PI)	23.33%
5	Free Swell Index	20%
6	Optimum Moisture Content (OMC)	12.3%
7	Maximum Dry Density (MDD)	1.62
8	Compressive Strength (Qu)	0.43 kg/cm2
9	Cohesion	0.215
10	CBR	18.24%

The test findings indicate that the soil is clayey and has weak properties. Therefore, recycled paper pulp and lime can be used to stabilize it.

VII. LABORATORY TEST OF SOIL WITH ADDITIVES

To improve clayey soil performance, lime and recycled paper pulp is added to clayey soil in varying proportions of 2%, 4%, 6%, 8%, and 10%.

Following Laboratory tests were done in accordance with IS standards to assess the physical qualities of clayey soil.

a) Liquid limit
b) Plastic limit
c) Proctor compaction test
d) Unconfined compressive test
e) California bearing ratio test

A. LIQUID LIMIT AND PLASTIC LIMIT

Liquid limit is the moisture content at which a soil changes from a plastic to a liquid state when rolled in a groove is called as liquid limit.

Plastic Limit is the moisture content at which a soil becomes plastic but can no longer be rolled into a thread is called as plastic limit.

Liquid limit and plastic limit test were carried out for soil with lime and recycled paper pulp for varying proportions of 2%, 4%, 6%, 8%, and 10%.

Table.2. Results of LL, PL and PI for Combinations of 2%

SAMPLE	LL (%)	PL (%)	PI (%)
SOIL + 2% LIME	47	16.66	30.34
SOIL+ 1% LIME +1% PAPER PULP	45	20	25
SOIL + 2% PAPER PULP	49	25	24

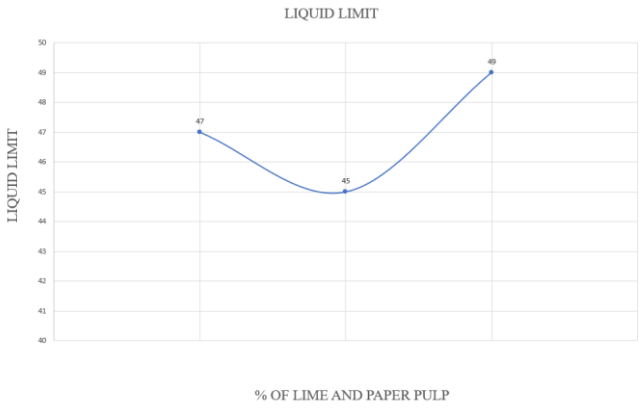

Fig.1. Effect of liquid limit on various combinations of 2% lime and recycled paper pulp

From table 2, it is observed that the lower value of liquid limit is 45% and it is considered as the optimized value for 2%, which

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corresponds to soil with 1% lime and 1% paper pulp plastic limit is 20% and plasticity index is 25%.

Table.3. Results of LL, PL and PI for Combinations of 4%

SAMPLE	LL (%)	PL (%)	PI (%)
SOIL +4% LIME	45	20	25
SOIL+ 3% LIME +1% PAPER PULP	46	23.07	22.93
SOIL + 2% LIME +2% PAPER PULP	44	28.57	19.43
SOIL +1% LIME + 3% PAPER PULP	48	25	23
SOIL + 4% PAPER PULP	54	40	14

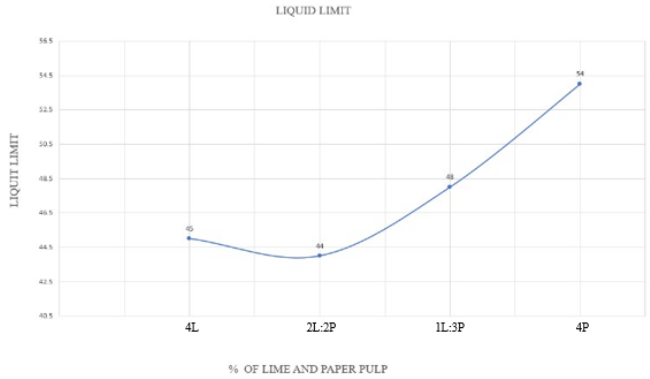

Fig.2. Effect of liquid limit on various combinations of 4% lime and recycled paper pulp.

From table 3, it is observed that the lower value of liquid limit is 44% and it is considered as the optimized value for 4%, which corresponds to soil with 2% lime and 2% paper pulp plastic limit is 28.57% and plasticity index is 19.43%.

Table.4. Results of LL, PL and PI for Combinations of 6%

SAMPLE	LL (%)	PL (%)	PI (%)
SOIL +6% LIME	43	18.75	24.25
SOIL+ 5% LIME + 1% PAPER PULP	46	21.42	24.58
SOIL + 4% LIME + 2% PAPER PULP	44	27.27	16.73
SOIL +3% LIME + 3% PAPER PULP	40	17.64	22.36
SOIL + 2% LIME + 4% PAPER PULP	41	30	11
SOIL + 1% LIME + 5% PAPER PULP	45	33.33	11.66
SOIL + 6% PAPER PULP	47	40	7

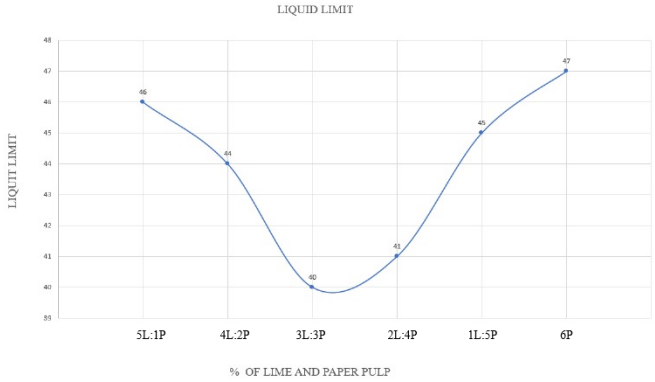

Fig.3. Effect of liquid limit on various combinations of 6% lime and recycled paper pulp

From table 4, it is observed that the lower value of liquid limit is 40% and it is considered as the optimized value for 6%, which corresponds to soil with 3% lime and 3% paper pulp plastic limit is 17.64% and plasticity index is 22.36%.

Table.5. Results of LL, PL and PI for Combinations of 8%

SAMPLE	LL (%)	PL (%)	PI (%)
SOIL +8% LIME	40	17.64	22.35
SOIL+ 7% LIME +1% PAPER PULP	42	22.22	19.78
SOIL + 6% LIME +2% PAPER PULP	41	23.07	17.93
SOIL +5% LIME + 3% PAPER PULP	39	25	14
SOIL +4% LIME + 4% PAPER PULP	38	14.28	23.72
SOIL+ 3% LIME +5% PAPER PULP	43	28.57	14.53
SOIL+ 2% LIME +6% PAPER PULP	46	38.46	7.53
SOIL+ 1% LIME +7% PAPER PULP	50	26.66	23.32
SOIL+ 8% PAPER PULP	58	50	8

From table 5, it is observed that the lower value of liquid limit is 38% and it is considered as the optimized value for 8%, which corresponds to soil with 4% lime and 4% paper pulp plastic limit is 14.28% and plasticity index is 23.72.

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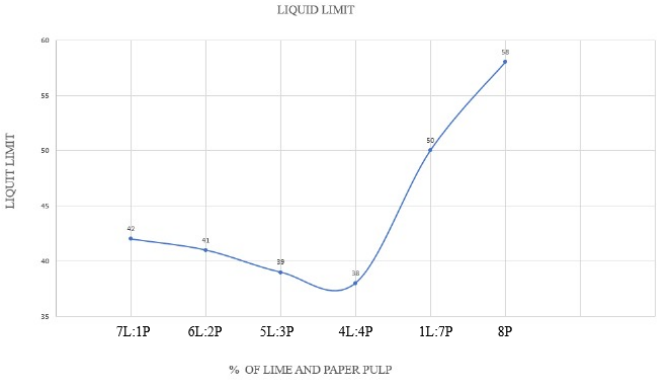

Fig.4. Effect of liquid limit on various combinations of 8% lime and recycled paper pulp

Table.6. Results of LL, PL and PI for combinations of 10%

SAMPLE	LL (%)	PL (%)	PI (%)
SOIL +10% LIME	62	30	32
SOIL+ 9% LIME +1% PAPER PULP	54	28.57	25.43
SOIL + 8% LIME +2% PAPER PULP	52	25	27
SOIL +7% LIME + 3% PAPER PULP	51	27.27	23.73
SOIL +6% LIME + 4% PAPER PULP	48	20	28
SOIL +5% LIME + 5% PAPER PULP	49	18.75	30.25
SOIL +4% LIME + 6% PAPER PULP	50	30	20
SOIL +3% LIME + 7% PAPER PULP	53	33.33	19.67
SOIL +2% LIME + 8% PAPER PULP	56	40	16
SOIL +1% LIME + 9% PAPER PULP	60	45.55	14.55
SOIL + 10% PAPER PULP	65	54.54	10.45

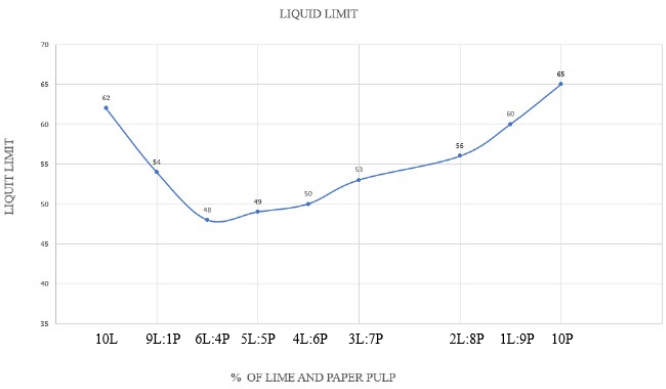

Fig.5. Effect of liquid limit on various combinations of 10% lime and recycled paper pulp

From table 6, it is observed that the lower value of liquid limit is 48% and it is considered as the optimized value for 10%, which corresponds to soil with 6% lime and 4% paper pulp plastic limit is 20% and plasticity index is 28%.

B. PROCTOR COMPACTION TEST

The Proctor compaction test is a standardized laboratory test used to determine the optimal moisture content and maximum dry density of a soil or aggregate sample. It helps in assessing the compaction characteristics of a material, which is crucial in construction and civil engineering to ensure the stability and strength of compacted soils.

Table.7. Results of Proctor Compaction Test for various combination of additives

%	SAMPLE	MDD (Kg/cm3)	OMC (%)
2%	SOIL+1%LIME+1% PAPER PULP	1.74	15
4%	SOIL+2%LIME+2% PAPER PULP	1.71	16.66
6%	SOIL+3%LIME+3% PAPER PULP	1.35	23
8%	SOIL+4%LIME+4% PAPER PULP	1.8	16.67
10%	SOIL+6%LIME+4% PAPER PULP	1.3	27

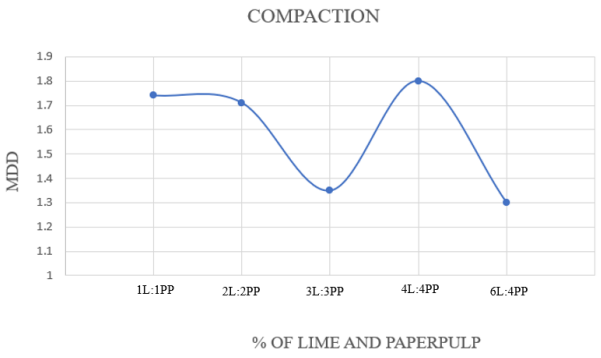

Fig.6. Effect of compaction on various combinations of lime and recycled paper pulp

From table 7, it is observed that the higher value of maximum dry density is 1.8 Kg/cm3 and it is considered as the optimized value for compaction, which corresponds to soil with 4% lime and 4% paper pulp plastic with optimum moisture content of 16.68%.

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C. UNCONFINED COMPRESSIVE TEST

The unconfined compression test is a laboratory test to measure the compressive strength of soils or cohesive materials without lateral confinement. It is a way to assess how the material responds to axial loading.

Table.8. Results of Unconfined Compressive Test for various combination of additives

%	SAMPLE	COMPRESSIVE STRENGTH (Kg/cm2)	COHESION
2%	SOIL+1%LIME + 1% PAPER PULP	0.24	0.12
4%	SOIL+2%LIME +2% PAPER PULP	0.35	0.175
6%	SOIL+3%LIME +3% PAPER PULP	0.29	0.145
8%	SOIL+4%LIME +4% PAPER PULP	0.8	0.4
10 %	SOIL+6%LIME +4% PAPER PULP	0.6	0.3

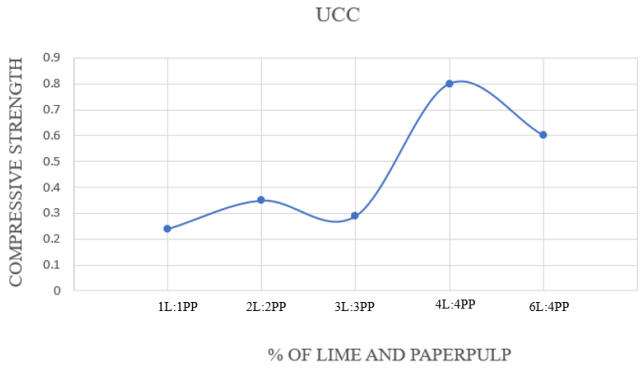

Fig.7. Effect of Unconfined Compressive Strength on various combinations of lime and recycled paper pulp

From table 8, it is observed that the higher value of compressive strength is 0.8 Kg/cm2 and it is considered as the optimized value for unconfined compressive test, which corresponds to soil with 4% lime and 4% paper pulp.

D. CALIFORNIA BEARING RATIO TEST

CBR stands for "California Bearing Ratio," and it is a standardized penetration test used to evaluate the mechanical strength of subgrade soils and base courses for road and pavement construction. The test involves measuring the load-bearing capacity of a soil sample by comparing its penetration resistance to that of a standard material.

Table.9. Results of California Bearing Ratio Test for various combination of additives

PENETRATION OF PLUNGER (mm)	PROVING RING READING (mm)	LOAD (Kg)
0.5	6	35.47
1	19	112.33
1.5	30	177.37
2	38	224.66
2.5	47	277.87
3	54	319.26
4	65	384.3
5	74	437.51
7.5	86	508.46
10	92	543.93
12.5	100	591.23

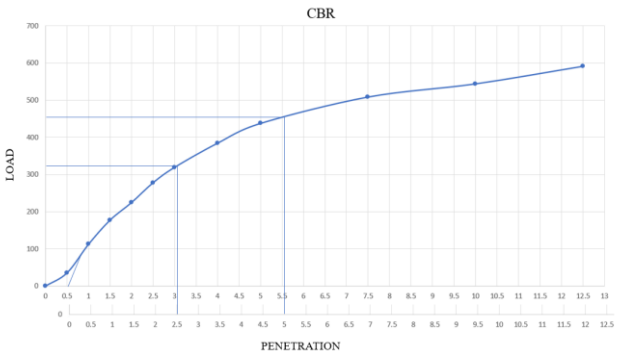

Fig.8. Load v|s Penetration graph of clayey soil treated with 8% lime and recycled paper pulp

Here the obtained value of CBR after stabilisation with additives is 23.3% which is greater than obtained value of soil. Therefore, can be used for construction purposes and as soil subgrade.

VIII. CONCLUSION

The experimental study allows for the drawing of the following conclusions: The test specimen containing a combination of 4% lime and 4% recycled paper pulp has a CBR value of 23.3% which is greater than the test specimen without additives. The compressive strength of soil containing a combination of 4% lime and 4% recycled paper pulp is 0.8 kg/cm2. The compressive strength of soil without additive is 0.43 kg/cm2. Therefore, we can conclude that there is an increase in compressive strength of soil after treatment with lime and recycled paper pulp.

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