Study of Utilization of Waste Paper Sludge Ash (WPSA) for Soil Stabilization

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Abstract

The potential of Waste Paper Sludge Ash (WPSA) as an additive to improve the characteristics of clayey soils for Civil Engineering applications is examined in this study. The study examine how different percentages of WPSA (5%, and 10%) affect the various index properties of soil, such as permeability, strength, and compaction. A number of laboratory tests were performed, including the Standard Proctor Test, Atterberg Limit Test, California Bearing Ratio (CBR) Test, Unconfined Compressive Strength (UCS Test), and Triaxial Compression Test with varying WPSA levels. The findings demonstrated that adding WPSA has a major impact on the compaction properties of the soil, that is an increase in optimal moisture content and a decrease in maximum dry density as the WPSA% rises. When WPSA was added, there is a decrease in the liquid limit and a rise in the plastic limit, which indicates increased soil plasticity. There is an improvement in the soil's shear strength, increased strength in unsoaked conditions with 5% WPSA. WPSA is waste from paper industry used for improving soil properties, especially for applications like foundation construction and road embankments that call for increased soil strength. Future studies might concentrate on evaluating the WPSA-treated soils' long-term performance under field circumstances.

Key words: Waste, Paper, Sludge, Ash, Soil, Stabilization, civil, engineering, etc.

Introduction

A basic component of many civil engineering applications, including pavement design, embankment construction, and foundation building, is soil. However, the strength, stability, and durability of natural soils are frequently limited, making them unsuitable for such undertakings (M.E. Bildirici, 2019). In order to get around these restrictions, soil stabilization techniques are used to enhance the soil's mechanical and physical characteristics, which improve the soil's performance during construction (Khalid.N et al, 2012). The process of enhancing or altering the properties of soil, either chemically or mechanically, to satisfy the specific needs for a project is known as soil stabilisation. Additives like bitumen, cement, and lime are frequently used in traditional stabilising techniques. However, research into alternative stabilising agents, in particular waste materials, has been spurred by the growing need for environmentally acceptable and sustainable building materials (P.J.M. Monteiro, 2017). Waste Paper Sludge Ash is an industry by-product of various industries such as paper, Textile ect. It has a High Concentration of lime, silica, and alumina—all crucial elements for enhancing soil strength (Mochizuki, Y et al ,2002). A combination of Lime, silica and Alumina makes it a good source of supplementary cementitious material which help in improving the soil's bearing capacity, compaction, and shear strength (Ankit Kumar, 2016).

Aims & Objective

With an emphasis on comprehending its impact on compaction characteristics," liquid limit, plastic limit, California Bearing Ratio (CBR), and unconfined compressive strength, this study attempts to investigate the impact of WPSA on the geotechnical features of clayey soil. Experimental studies on soil samples treated with 5% and 10% WPSA are part of the study, and the outcomes are compared to those of untreated soil" (S.A. Miller, A. Horvath,2017). It is anticipated that the results of this investigation will provide important new information regarding the viability of employing WPSA as an economical and environmentally friendly method of stabilizing soil in building projects (D. Kakasor Ismael Jaf, 2023) (P. Ismael Abdulrahman, 2023).

Materials and Methods:

- Description of the materials used: soil and WPSA sourced from Ballarpur Industries Ltd.
- Explanation of the experimental tests: Standard Proctor Test, Atterberg Limit Test, California Bearing Ratio Test, Unconfined Compressive Strength Test, and Triaxial Compression Test.

Experimental Analysis

Table 1: Observation table for standard proctor test with 0%WPSA

Sr. No.	w(%)	Ws (gm)	V(cm3)	ρB(gm/cm3)	ρD
1.	8	1708	944	1.809	1.675
2.	12	1845	944	1.954	1.835
3.	14	2021	944	2.140	1.875
4.	16	2065	944	2.188	1.885
5.	18	2022	944	2.141	1.845

6.	20	2005.1	944	2.124	1.770
7.	22	1957.8	944	2.074	1.700

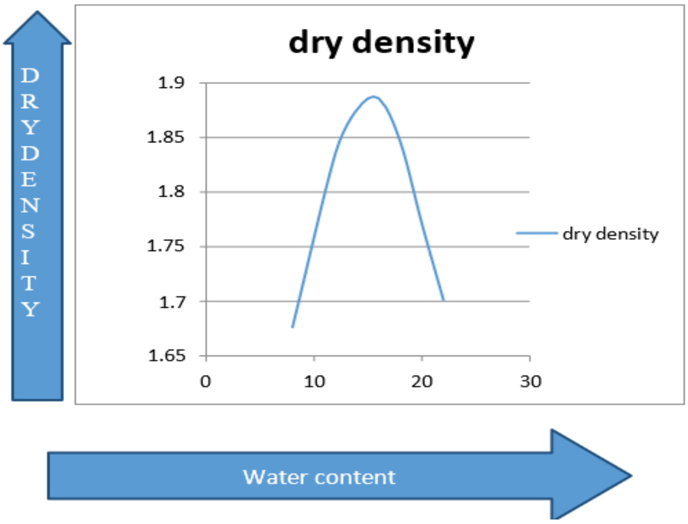

Fig 1: (Representing OMC and max. dry density at 0%WPSA)

Observation table (5% WPSA)

Table 2: (Observation table for standard proctor test with 5%WPSA)

Sr. no.	w	Ws	V	ṗ B	ṗ D
1.	12	1729	944	1.83	1.634
2.	14	1873	944	1.98	1.737
3.	16	1970	944	2.09	1.8
4.	18	2052	944	2.174	1.842
5.	20	2067	944	2.19	1.836
6.	22	2049	944	2.171	1.8
7.	24	2048.5	944	2.17	1.75
8.	26	1998.4	944	2.12	1.68

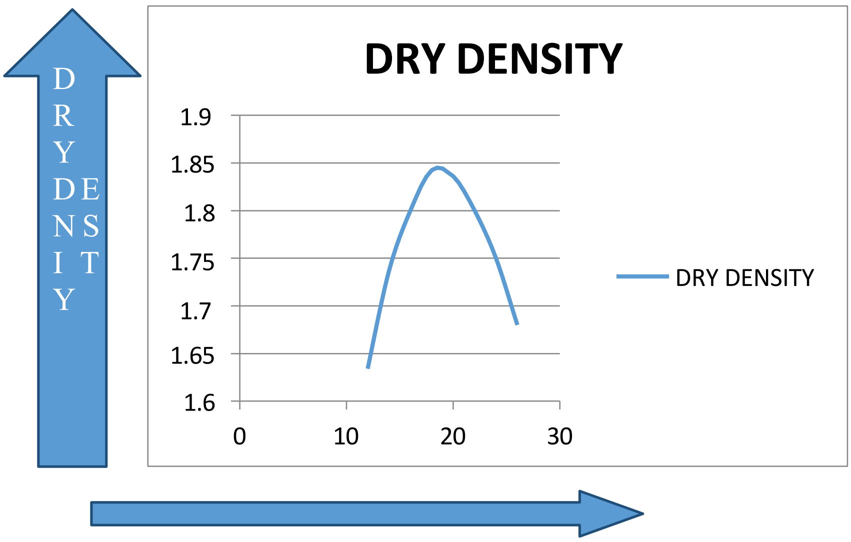

FIG 2: (Representing OMC and max. dry density at 5%WPSA)

When the weight percentage rises from 12% to 26%. While dry density varies from 1.634 gm/cm³ to 1.842 gm/cm³, bulk density begins at 1.83 gm/cm³ and progressively increases to 2.12 gm/cm³. These patterns show how variations in the weight % of the material impact the overall density characteristics (Z. Jwaida,2023).

Observation table (10% WPSA)

Table 3: (Observation table for standard proctor test with 10%WPSA)

Sr.no.	w	Ws	V	ρ̇ B	ρ̇ D
1.	12	1774	944	1.88	1.675
2.	16	1960	944	2.076	1.789
3.	20	2034	944	2.154	1.795
4.	24	1959	944	2.075	1.673

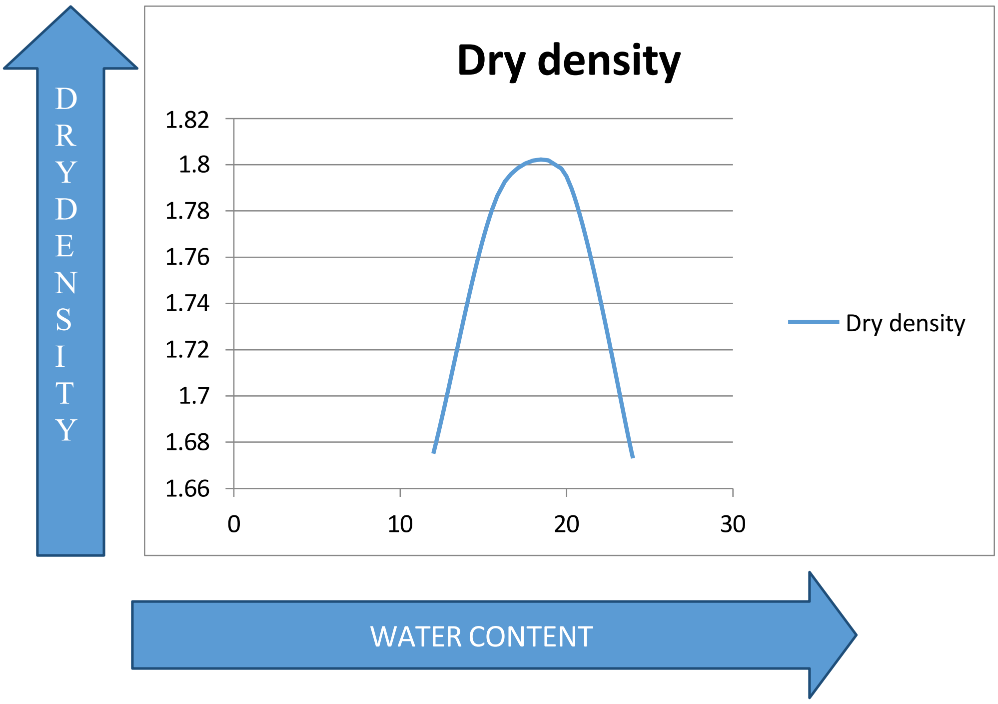

Fig 3: (Representing OMC and max. dry density at 10%WPSA)

While dry density (ρ̇D) varies between 1.675 gm/cm³ and 1.795 gm/cm³, bulk density (ρ̇B) increases from 1.88 gm/cm³ to 2.154 gm/cm³ when the weight percentage climbs from 12% to 24%. Both a general rise and considerable variety are evident in the increases in bulk and dry densities, which indicate how the weight % of the material affects its density properties (A. Dulaimi, 2023).

Table 4: (Observations for liquid limit at different numbers of blows)

S.no.	No. of Blows	Water Content(%)
1	60	40
2	30	45
3	25	46.56
4	14	50

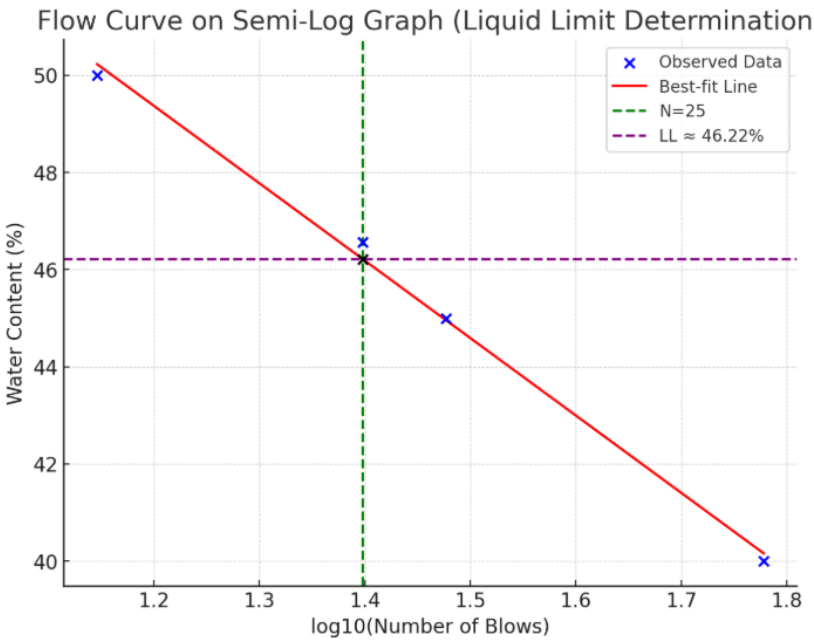

Fig.4.9

Fig 4 : (water content at 25 number of blows)

The relationship between the number of blows and water content for the given soil sample was plotted on a semi-logarithmic graph, where the logarithm of the number of blows was taken on the x-axis and the corresponding water content on the y-axis . The plotted points were fitted with a straight line, known as the flow curve, which represents the variation of water content with respect to the logarithmic scale of blows (I. Ignjatović, 2017). From this curve, the liquid limit of the soil is determined as the water content corresponding to 25 blows. In this test, the flow curve intersects the vertical line at log10(25), and the corresponding water content was found to be approximately 46.2%. This indicates that the soil requires about 46% water content to achieve a state where it changes from plastic to liquid behavior (Z. Sas, 2017). The obtained result is consistent with the natural soil characteristics observed in fine-grained soils, where the liquid limit typically lies within the range of 30–60%, confirming the validity of the test and the plotted flow curve.

The result of test are represented in form of a curve knows as flow curve from which water content corresponding to 25 no. of blows is 46.56

Table 5: (Observations for liquid limit at different numbers of blows)

Sr. No.	No. of Blows	Water Content(%)
1	40	35
2	25	42.5
3	20	45
4	16	47.5
5	9	55

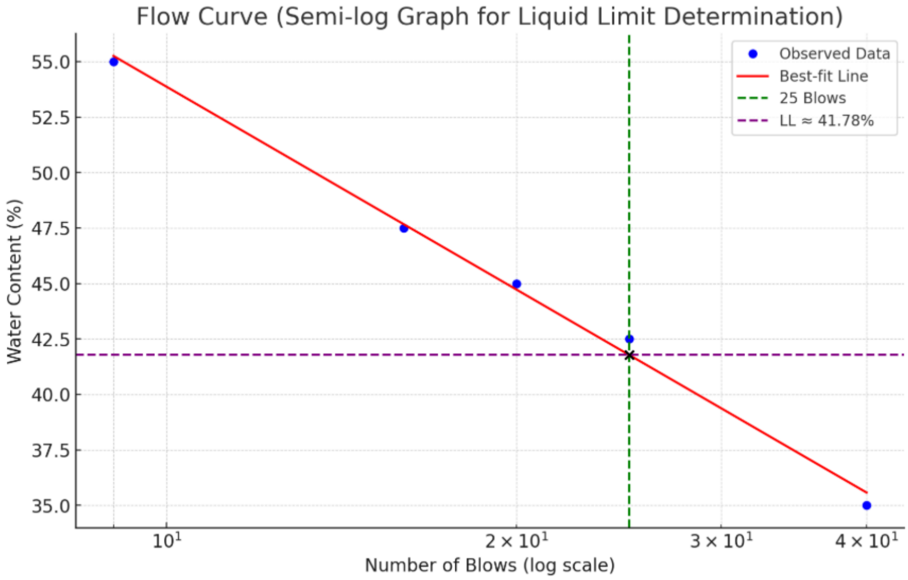

Fig 5 : No of blows and water content at 5% WPSA

The graph represents the flow curve plotted between the logarithm of the number of blows and the corresponding water content for the given soil sample. The observed data points have been plotted on semi-logarithmic graph paper and a straight line has been drawn through them, known as the flow curve. From this flow curve, the liquid limit of the soil was determined by drawing a vertical line at 25 blows and locating the corresponding water content (A.A. Shubbar, 2020). The water content obtained at this point was found to be approximately 41.8%, which is taken as the liquid limit of the soil. This value indicates the water content at which the soil changes from a plastic state to a liquid state. The result lies within the typical range of liquid limit values for fine-grained soils, thereby confirming the correctness of the experimental procedure and observations (M. Sadique 2020).

Table 6: (Observations for load at different displacements)

S.no.	Displacement	Load
1	0	0
2	0.44	0.1
3	2.19	0.3
4	3.94	0.42
5	5.69	0.52
6	7.94	0.63
7	9.69	0.68
8	11.94	0.7

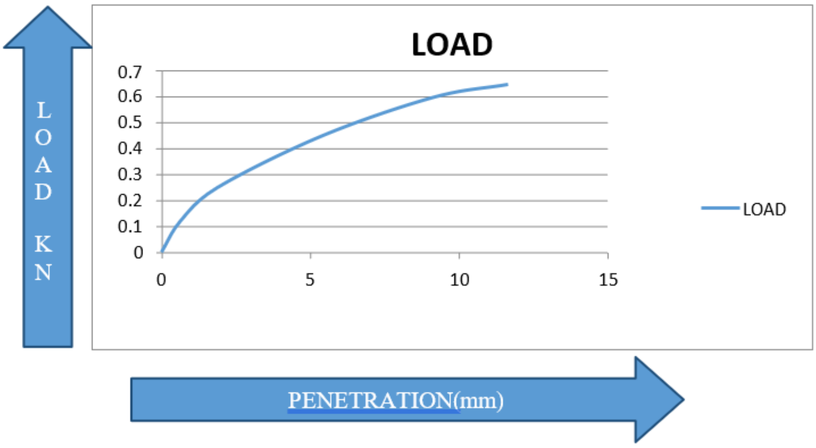

Fig 6: (load at different penetration for 0% WPSA unsoaked condition)

The above table presents the observations of load corresponding to different displacement values recorded during the test. Initially, both load and displacement were zero, and with the gradual application of load, the displacement increased in a nearly proportional manner. The plotted graph of load versus displacement shows a rising trend, indicating that as displacement increases, the load carried by the specimen also increases. At lower displacement levels (up to about 4 mm), the relationship appears approximately linear, suggesting elastic behavior of the material. Beyond this region, the curve starts to flatten, showing that the rate of load increase reduces with further displacement, which reflects the transition from elastic to plastic behavior. The maximum load attained during the test was about 0.7 kN at a displacement of nearly 12 mm, after which no significant increase in load was observed. This graph thus demonstrates the typical load-displacement characteristics of the tested specimen and helps in understanding its strength and deformation properties.

Table7 : (Penetration for soaked and unsoaked condition at diff % of WPSA)

Penetration	**0%**	**5%**	**10%**
Unsoaked			
2.5mm	2.34	3.06	2.48
5 mm	2.046	2.941	2.33
Soaked			
2.5 mm	2.08	2.19	3.06
5 mm	1.95	2.04	2.5

ISSN PRINT 2319 1775 Online 2320 7876
 Journal UGC CARE Listed (Group-I) Volume 12, Issue 01 2023

Fig. 7 (% age of WPSA change in soaked and unsoaked condition)

The data shows the variation of California Bearing Ratio (CBR) values at different penetrations under both unsoaked and soaked conditions for soil samples with 0%, 5%, and 10% additives. For the unsoaked condition, at 2.5 mm penetration, the CBR values increased from 2.34% (0%) to 3.06% (5%), before slightly reducing to 2.48% (10%). Similarly, at 5 mm penetration, the values followed the same pattern, rising from 2.046% to 2.941% and then decreasing to 2.33%. This indicates that a 5% additive provides maximum strength in the unsoaked state. CBR value for the soaked condition, at 2.5 mm penetration was 2.08%, 2.19%, and 3.06% for 0%, 5%, and 10% additive respectively, while CBR values at 5 mm penetration are 1.95%, 2.04%, and 2.5%. Maximum improvement was seen at an additive content of 10%, which suggests that the soil exhibits better resistance under soaked conditions at higher additive content. Overall, the results show that unsoaked samples performed best with 5% addition,

Results and Discussion:

The experimental studies on the utilisation of "Waste Paper Sludge Ash (WPSA)" as a soil stabilisation addition resulted in an enhancement of the geotechnical properties of clayey soils. The compaction properties resulted in a change in OMC and MDD with the addition of 5% and 10%. Results of the Standard Proctor Test state that the optimum moisture content (OMC) rose while the maximum dry density (MDD) declined as the WPSA content rose. These results imply that WPSA changes the internal structure of soil as a result of the chemical reactions between the soil's clay particles and cementitious material present in WPSA, such as lime, silica, and alumina (C. Herath, 2020). Adding WPSA improved the flexibility of and decreased susceptibility to shrink and swell, more it more durable for application building. The Liquid Limit is decreased, and the plastic limit is increased. The addition of 5% WPSA shows greater strength in the unsoaked condition addition of 10% WPSA shows greater strength for the soaked condition in the California Bearing Ratio Test. This increase in bearing capacity of soil resulted in more construction of more load-bearing structures as well as the development of a strong composite for subgrade and base courses in road building (C. Gunasekara, 2020). These results were also supported by the Unconfined Compressive Strength (UCS) and Triaxial Compression tests, which showed that the addition of WPSA, especially at the 5% concentration, increased the soil's shear strength. This suggests that WPSA improves the soil's structural stability, which makes it a good substitute for conventional soil stabilizers like lime and cement. The general improvement in soil characteristics, such as strength, compaction, and plasticity, indicates that WPSA may be a practical and environmentally responsible way to stabilize soil in civil engineering projects, particularly in subgrade construction, foundation work, and road embankments.

Conclusion

According to findings from the experiment, Waste Paper Sludge Ash (WPSA) was found to be a sustainable and effective substance for the enhancement of soils' geotechnical characteristics. The results of the experiments showed that WPSA considerably improved soil compaction, plasticity, and shear strength even at lower percentages (5% and 10%). Significantly, the findings of the CBR, UCS, and Triaxial Compression tests verified that WPSA-treated soils had better strength properties than untreated soils, which made them a more sustainable choice than conventional methods of soil improvement useful for foundations and road embankments. In addition to increasing the strength and index properties of soil, WPSA offers a more sustainable alternative of traditional stabilizers like cement and lime. Additionally, because WPSA is a waste product of the paper and textile industry, it is a sustainable solution that helps to mitigate industrial waste and encourage material recycling (P.-M. Zhan, 2020). The results supplemented that that WPSA may be a great substitute for conventional stabilizers, especially in areas where improving soil qualities without the negative environmental effects of existing products is desired (Z.-H. He, 2020).

Future Scope

Even though the current study demonstrated that Waste Paper Sludge Ash (WPSA) has potential to improve soil properties, a lot of other application directions can be explored to optimise usage of WPSA in Civil engineering purposes.

- **Long-Term Durability:**

Long-term durability test to incorporate the impact of various environmental factors should be studied. Usage of WPAS for soils in problematic areas such as sandy and slaty soil should also be explored to evaluate how WPAS-treated soils are effective in different environmental circumstances such as rainfall, salt attack and temperature variability. (M.E. Bildirici, 2019).

- **Combination with Other Additives:**

The synergy between WPSA with other waste materials or stabilizing agents also be be investigated in more detail. For example, the development of even more effective and economical soil stabilizing methods may result from the coupling of WPSA with bio-waste or industrial by-products (S.A. Miller, 2017).

- **Field-Scale Applications:**

Results from these experiments should be implemented on Large-scale infrastructure projects like highways, embankments, and foundations (Ismael Abdulrahman, 2019). To find the ideal proportion for diverse uses, studies should look into how different WPSA concentrations affect distinct soil types and geographical areas.

- **Environmental Impact and Sustainability Assessment:**

WPSA should be evaluated based on its environmental and sustainability assessment on this ecosystem. Carbon footprint of applying WPSA to conventional stabilisers and assessing any possible leaching or soil contamination. Furthermore, life cycle assessments may be used to measure the environmental advantages of stabilising soil with WPSA (A. Dulaimi, 2023).

- **Economic Viability:**

More research should be done on the viability of employing WPSA as a stabilizer in major civil engineering projects (Z. Sas, 2017). Decision-makers in the construction sector would benefit greatly from a cost-benefit analysis that contrasts WPSA with traditional stabilizers like cement and lime while accounting for transportation expenses, material availability, and environmental impacts.

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