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Strength Improvement Of Soft Soil By Supplementing Waste Paper Sludge Ash

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Abstract — Study is carried out to investigate the improvements in the properties of expansive soil by using Waste Paper Sludge ash as a stabilizing agent in varying percentages. The aim of this study is to modify the expansive soil using waste paper sludge into a stabilized soil to make it an asset for construction of various structures. Soil sample was supplemented with different percentage of waste paper sludge ash i.e. at 2%, 5%, 7%, 10%, 15% and 20% by weight and various laboratory tests were conducted to investigate the modified properties of the soil. Tests such as plastic limit, liquid limit, shrinkage limit, standard proctor compaction, unconfined compressive strength test and California bearing ratio test (soaked and unsoaked condition) were conducted on the modified soil sample i.e. expansive soil mixed with Waste Paper Sludge at different proportions. As an outcome of the study, it was observed that addition of Waste Paper Sludge as stabilizing agent reduces the liquid limit value, plastic limit value and enhance the shrinkage limit value up to 20%. The proctor test result indicates that with the increase in waste paper sludge content there was an increase in the optimum moisture content and reduction in the maximum dry density. Laboratory experiments results depicted that the 7% is the optimum percentage of waste paper sludge addition in the soil for obtaining higher strength. Furthermore, California bearing ratio (soaked and unsoaked) values improved with percentage increase in Waste Paper Sludge. The optimum value of Waste Paper Sludge for obtaining better California Bearing Ratio value is 10%.

Keywords— Waste Paper sludge Ash, Optimum Moisture Content, Maximum Dry Density, Liquid Limit, Plastic Limit, Shrinkage Limit, California bearing ratio Value.

I. INTRODUCTION

Soil stabilization is the process of enhancing soil properties i.e. to reduce volumetric changes and increase strength parameters. Techniques for soil stabilization includes light & heavy compaction process, dewatering or by adding suitable waste material. There are several industrial waste materials that can be used individually or mixed in combination with one another, to achieve soil stabilization. This study is based on adding waste paper sludge in soil at different percentages. Sludge from waste paper treatment plant is a major environmental problem. Estimation depicts about millions of tons of paper sludge is being generated from various paper industries in India resulting into health issues and environmental hazards. WPS is an outcome of the de-inking and repulsing of waste papers. The major process of recycling and disposal routes for paper sludge are land dumping as agricultural fertilizer, incineration at the paper mill, converting into paper sludge ash or disposal by land filling. This study verifies the possibility of using WPS for soil enhancement schemes for geotechnical applications. The clayey soil used in this study was collected from GGV campus near new IT building at an approximate depth between 1m and 2m from ground surface. The soil, which significantly shows considerable sign of agony accompanied by strength detainment during rainy seasons caused due to their expansive nature and shrinkage during summer. Expansive soils depict high plasticity and compressibility when they are saturated. Though these types of soil have high strength in dry state but they become soft after saturation. Filling up water into voids spaces, leads to the process of softening causing reduction in shear strength and degrading the bearing capacity of the soil. Constructions in dry seasons causes differential settlement which is caused because of expansion of soils during wet seasons. Obstruction in swelling in the foundation soil causes swell pressure, making the structure unstable. To rectify the instability of the soil, stabilization is required prior to any construction over the soft soil. Treatments are classified into two groups, (1) soil modification and (2) soil stabilization. Soil stabilization is the process of blending and adding suitable materials with unstable soil to improve properties of the soil & making it an appropriate construction material. The process includes the mixing of soils to economically available mineral admixtures that may enhance the gradation, texture, plasticity, and strength. WPS is used as a admixture to improve the engineering property of soil. The proportions of waste paper sludge used along with the soils in the study are 2%, 5%, 7%, 10%, 15% and 20%. For determining the effect of WPS on soil, following tests were conducted on the soil samples mixed at different proportions of WPS. The liquid limit and the plastic limit tests were conducted as per IS 2720 (Part V) - 1985 [18]. The shrinkage limit test was conducted as per IS 2720 (Part VI) - 1972[19]. Light/Standard Proctor compaction test of soil was carried out as per IS 2720 (Part VII) - 1980[20]. Unconfined compressive strength tests were conducted at OMC as per IS 2720 (Part X) - 1991[21] and the CBR test (soaked and unsoaked) was conducted as per IS 2720 (Part XVI) -1979[22].

II. Objectives of the study

- To study the engineering behaviors and geotechnical properties of soil blended with various proportions of the waste paper sludge ash.
- To determine an optimum dose of the supplementary material i.e. Waste Paper Sludge ash for development in strength of soft soil

III. Related Studies

Jwaida et al. (2024) [1] concluded that the PSA (paper Sludge ash) can be an efficient soil stabilizer, imparting improvement in strength and reduction in erosion tendency. Supplementing of paper sludge ash can improve soil structure, specifically for clayey soils, enhancing its water absorption as well as plasticity properties.

Tabassum et.al. (2022) [2] stated with early strength development, strength reduction was caused by crumbling effect that may have significant influence. However, for PSAS-treated soils with slow strength development, effectively adjust the water content of the sludge ash supplemented soils during primary curing before compaction.

Akshatha et al. (2022) [3] stabilized lateritic soil by replacement of soil with waste paper sludge at 0%, 2%, 4%, 6%, 8% and 10%. Conclusion drawn from the study states Strength and stiffness of soil increases with increase in replacement of WPS and at the same time the loss of ductile or cohesive nature of the soil will occur. The increase in the CBR value is because of the pozzolanic reaction and the cementation process of WPS.

Baloochi et al. (2020) [4] concluded using WPFA causes expansion in stabilized soil, but a delay time of 30 min, after mixing the material with water and then compacting it, can decrease the expansion. ll the results obtained in this study have shown that WPFA is a suitable material for use as a binder for soil stabilization while reducing its optimum water content, adding a proper delay time, and taking into consideration WPFA's expansive behaviour at the moment of its use.

Bawa & Bawa (2017) [5] studied development of strength in soft soil stabilized with waste paper sludge. Study proposed as when soil is treated with Waste Paper Sludge an increase in Optimum moisture content and decrease in maximum dry density is observed. The results from the UCS test for soil for varying proportions such as 2, 4,5,6,7 and 10 percentages WPS increased to better strength. UCS at 7 days & 28 days gives optimum results at a dry density of 1.5g/cc and 22% OMC.

Kumar & Gupta (2016) [6] conducted work related to the strength development of soil using Waste Paper Sludge (WPS). Investigation depicted that dry density is decreasing with increasing percentage of Waste Paper Sludge (WPS) mixes to soil from 17.06 KN/m2 and 14.97 KN/m2. Optimum moisture content enhanced from 16.0 % to 25.0 % with increment in the percentage of waste paper sludge (WPS) in the soil. With increment of Waste Paper Sludge (WPS) in soil, the unconfined compression strength enhanced up to optimum dose. The Optimum percentage of Waste Paper Sludge (WPS) mixed to soil was found 6 % after conducting a series of laboratory test.

Dhakar & Jain. (2016) [7] studied the effect of waste paper sludge on clayey soil. It is concluded that WPS admixture increases the unconfined compressive strength changes from 10 kg/ mm^2 to 35 kg/ mm^2 and CBR value from 3.1% to 4.82 %. Due to increase in CBR, value thickness of pavement decreases from 12 inches to 8.5 inches.

Teja et.al (2016) [8] focused his study on improvement of properties of highly swelling soil by using Waste Paper Sludge. They concluded that the liquid limit has been reduced to 34.3% when treated with Waste Paper Sludge compared with untreated soil. Plastic limit has been reduced to 22.48% when treated with Waste Paper Sludge compared with untreated soil. Plasticity index was reduced by 11.82% when treated with Waste Paper Sludge. Differential swelling index decreased by 6% when supplemented with Waste Paper Sludge. The dry density peaked to 1.92 g/cc when modified with Waste Paper Sludge.

Talukdar (2015) [9] detailed the effect of Waste Paper Sludge in three different Clay soils. The study includes determination of Atterberg limits, compaction abilities, and swelling properties of three types of expansive soil samples. Compaction Characteristics, Strength Characteristics and CBR values were analyzed for soil treated with (0%, 5%, 10%, and 15%) of Waste paper sludge and decrease in plasticity index, maximum dry density, and increase in OMC, CBR values were observed in Soil treated with Lime Sludge. It increases the CBR values with addition of lime mud in all types of soil samples. At 15%addition of lime sludge, the increase in CBR is 19.76% for S1 for soil S2 and S3 the increase is 23.90% and 9.33% respectively.

Elias (2015) [10] investigated the aftermath of waste paper sludge on plasticity, swell index, compaction, unconfined compressive strength and CBR value of soft clayey soil. Compressive strength was increased by adding 5% WPS about 314 KN/m2 to 496 KN/m2 and 284 KN/m2 to 590 KN/m2 of 7 days 28 days curing period respectively. Furthermore, UCS values increased 107.9% by using 5% of WPS in 28 days curing.

Anupam et.al (2013) [11] studied the efficiency of WPS, in increasing the load bearing capacity of medium compressible clay soil underlying a road to be constructed. The admixtures were mixed with the soil at 5 percent equal intervals up to 35% replacing the soil by part. Shrinkage limit, OMC and CBR increased and MDD decreased with addition of these admixtures and cured for 3-28 days. The author concluded that WPS was a more efficient admixture to stabilize expansive soil and suggested to perform intensive laboratory study to validate the results.

Norazlan et.al (2012) [12] presented the effect of WPS on unconfined compressive strength and California bearing ratio of sandy clay soil. WPSA consist of 62.39% CaO, 23.25% of SiO_2 and 5.26% of Al2O3. It is concluded that increase in WPSA content improves unconfined compressive strength content about 2 times by the addition of 10% WPSA. Blending of 10% WPSA in the soil increased the CBR value about 1.5 times in unsoaked condition and 3.6 times in soaked condition as compared to unaltered soil sample.

Horace and Thomas (1996) [13] studied the effect of WPS on the liquid limit, plastic limit and plasticity index of loose soil and concluded that the liquid limit, plastic limit is decreasing with percentage increase in WPS in soil by weight.

IV. METHODOLOGY

The methodology opted to accomplish the objectives of the research work is described below. The strength properties of the soil get enhanced with the addition of Waste Paper Sludge Ash. Following test were performed to determine the change in the physical properties & geotechnical properties of the soil.

A. Materials

The materials for the investigation were clayey soil collected from GGV campus near new IT building at an approximate depth between 1m and 2m from ground surface and Waste Paper Sludge collected from Madhya Bharat Papers Ltd, champa, Chhattisgarh. Clayey soil being the major construction material used in this study& Waste paper sludge (WPS) was used as soil stabilizing agent.

1) Soil: Clay soil collected from Guru Ghasidas Vishwavidyalaya campus, near new IT building was used. Following geotechnical properties were obtained on testing the soil sample.

TABLE I OBSERVED GEOTECHNICAL PROPERTIES OF SOIL SAMPLE

S. No.	Geotechnical Properties of Soil		
	Parameters		Results
1.	Soil type		CH
2.	Plastic limit (%)		28.6%
3.	Liquid limit (%)		56.5%
4.	Shrinkage limit (%)		19.18
5.	Plasticity index (%)		27.9%
6.	Specific gravity (G)		2.62
7.	Maximum dry density (KN/m^3)		17.1 KN/m^3
8.	Optimum moisture content (%)		15.8%
9.	Unconfined compressive strength (KN/m^2)		255.27
10.	California bearing ratio (%)	Unsoaked condition	2.30%
		Soaked condition	1.14 %

2) Waste paper sludge: Waste Paper Sludge (WPS) is a waste material collected from the Paper Industry. WPS becomes a useful material that can be used as soil stabilizing agent. The paper sludge for the study was collected from a recycled paper Madhya Bharat Papers Ltd, Champa, Chhattisgarh. The oven dried sludge for the soil stabilization behaves a clay-like material consisting of short fibers, ink and other impurities. Freshly collected sludge samples will be essentially odourless and there will not be any distinct odours. Following properties were examined as detailed in Table II.

TABLE II PROPERTIES OF WASTE PAPER SLUDGE

S. No.	Parameters	Results
1.	Moisture content (%)	83.54
2.	Specific gravity (G)	1.36

B. Experimental programme

Experimental tests include laboratory soil test such like liquid limit, plastic limit, shrinkage limit, standard proctor test, unconfined compressive strength test and California bearing ratio test (soaked and unsoaked) is performed as per Indian standard procedure. Plastic limit test: Plastic limit is the water content corresponding to an arbitrary limit between the plastic and semi- solid state of consistency of the soil. It is the minimum water content of the soil at which it will initiate to crumble when rolled into a thread of approximately 3 mm diameter. Plastic limit (PL) was obtained by thread rolling method as per IS 2720 (Part V) -1985[18]. The soils are then classified according to ISSCS. Soil is found to be clay of high compressibility (CH). The crumble state of soil is shown in fig.1

Fig. 1 Soil Sample of Plastic Limit Test

1) Liquid limit test: The consistency is largely related with the amount of water content of soil and mostly used for fine-grained soils. Liquid limit is the water quantity of soil corresponding to arbitrary limit defining liquid and plastic state of soil. It is the Least water content at which soil maintains its liquidity but also possess some shearing strength against flowing. Liquid limit (LL) was determined by using “Cassegrande apparatus” as per IS 2720 (Part V) -1985[18]. The liquid limit test is shown fig.2.

Fig. 2 Liquid limit apparatus during testing

2) Shrinkage limit test: Shrinkage limit is water content corresponding to Atterberg limit between the solid state and semi- solid state. A state when decrease in moisture content of soil does not lead to change in volume of soil mass. This moisture content is called shrinkage limit. It is lowest water content at which soil can still be in saturated condition. Shrinkage limit test is conducted as per IS 2720 (Part VI)-1972[19]. The shrinkage limit test is shown in fig 3.

Fig.3 Shrinkage limit test apparatus& sample

3) Standard Proctor compaction test: The standard proctor test is used to determine optimum moisture content and maximum dry density of soil in the laboratory. The test was performed in a cylindrical mould of 1000 ml capacity using a rammer of weight 2.6 kg with 310 mm height of free

fall. In this method the soil filled into the mould in three layers and each layer compacted by 25 number of blows from a 2.6 kg hammer weight with fall of 310 mm. The process is repeated for different soil sample to determine optimum moisture content and maximum dry density. The plot between dry density and water content is drawn on graph to find out optimum moisture content and maximum dry density. 'Standard Proctor Test' is conducted as per IS 2720 (Part VII)-1980[20] to perform experiment. The standard proctor test sample is shown in fig 4.

Fig.4 Standard compaction test sample

4) Unconfined compressive strength test: An unconfined compression test is a special case of triaxial test in which no confined pressure is given to soil. For conducting this test, preparation of sample is done with dynamic compaction on re moulded specimen at Proctors maximum dry density and optimum water content as per light compaction method. The compressive load required to fail the UCS sample is called Unconfined Compressive Strength of soil. 'Unconfined Compressive Strength Test' is conducted as per IS 2720 (Part X)-1991[21] to perform experiment. The unconfined compression test is shown in fig 5.

Fig.5 UCS apparatus during testing of soil specimen

5) California bearing ratio test: CBR test denotes a major of resistance to penetration of soil or another pavement material. The principle behind this test is causing a cylindrical plunger of 50 mm diameter to penetrate into the subgrade soil or other pavement material at the rate of 1.5 mm per minute. The load required for 2.5 mm and 5.0 mm penetration of the plunger into the soil or material tested are recorded. Generally, the CBR value at 2.5 mm penetration is higher than that at 5.0 mm is reported as CBR value in percentage, if CBR value at 5 mm penetration is higher then test to be repeated. If the test gives similar result, the higher is reported as CBR value of soil or material. For conducting this test specimen is prepared as by dynamic compaction on remolded specimen using Proctors maximum dry density and OMC. The CBR value is obtained as per IS 2720 (Part XVI) -1979[22] in both the soaked and unsoaked condition. The California bearing ratio test is shown in figure 6.

Fig.6 CBR and swelling apparatus

V. RESULTS & DISCUSSION

A series of laboratory tests were performed to determine the basic engineering properties of soil such like liquid limit, Plastic limit, shrinkage limit, standard compaction test, unconfined compressive stress test and California bearing ratio (soaked and un-soaked condition) based on recommendations of standards with addition of WPS as 2%, 5%, 7%, 10%, 15%and 20% in the soil. The observations were recorded and the results are obtained.

A. Plastic limit: This section provides the illustration of estimation of plastic limit of the soil with addition of WPS in different percentage as 2%, 5%, 7%, 10%, 15% and 20%. The value of plastic limit of the soil without WPS is more than the plastic limit of the soil with WPS. The addition of WPS lowers the plastic limit of the soil is as follows.

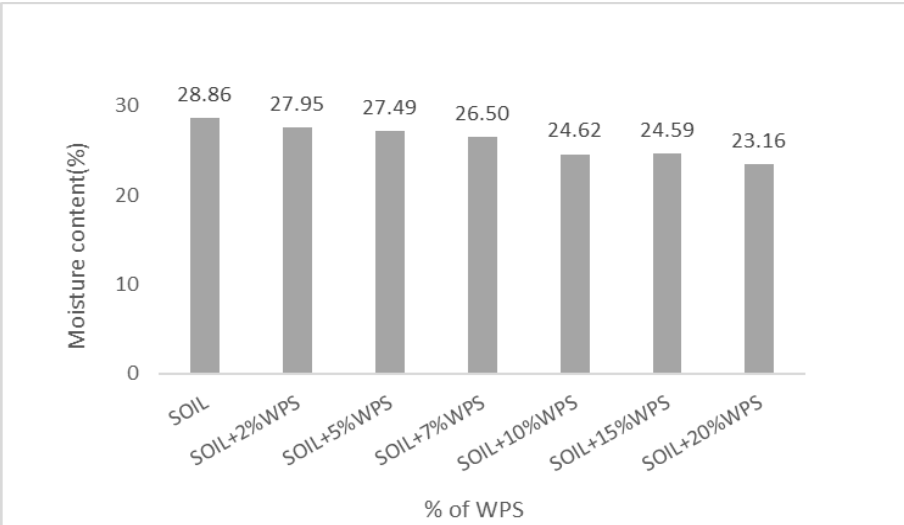

Fig.7 Variation of plastic limit with WPS

B. Liquid limit: This section provides the illustration of estimation of liquid limit of the soil with addition of WPS in different percentage as 2 %, 5%, 7%, 10%, 15% and 20%. The value of liquid limit of the soil without WPS is more than the liquid limit of the soil with WPS as shown in the table. The addition of WPS lowers the liquid limit of the soil presented in tables and figures.

TABLE III PLASTIC LIMIT (%) WITH WPS

S. No.	Soil mix	No. of blows	Water content (%)
1.	Soil	25	56.50
2.	Soil+2% WPS	25	53.50
3.	Soil+5% WPS	25	50.50
4.	Soil+7% WPS	25	48.00
5.	Soil+10% WPS	25	43.50

6.	Soil+15% WPS	25	41.50
7.	Soil+20% WPS	25	34.00

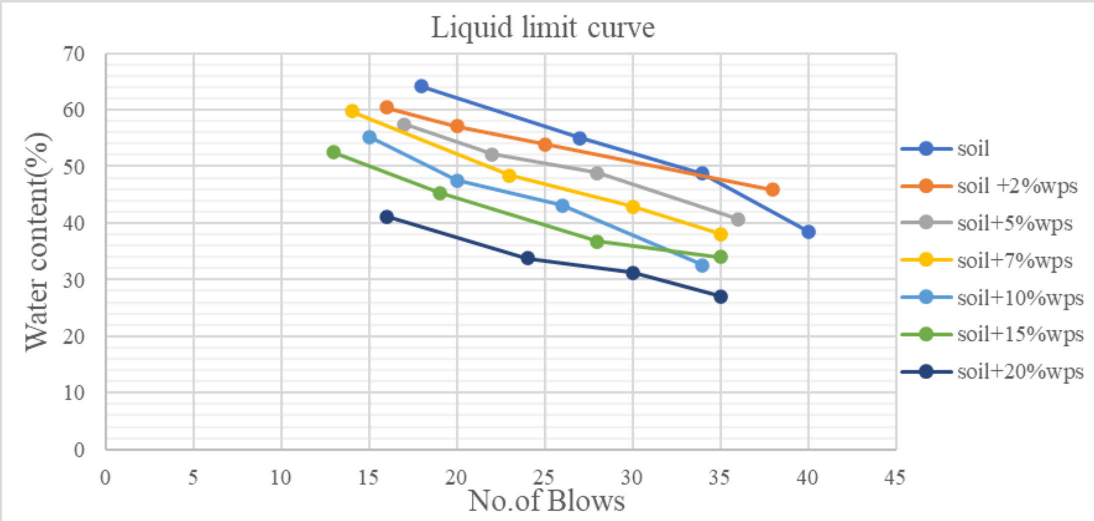

Fig.8 Change in liquid limit characteristics of soil with WPS

C. Soil classification as per ISSCS system: The Indian Standard Classification System (ISCS) classify that the fine-grained soil has been subdivided into three groups, low plasticity, medium plasticity, and high plasticity when the liquid limit is less than 35%, 35% to 50% and greater than 50% respectively

TABLE IV PLASTIC LIMIT (%) WITH WPS

WPS%	**0%**	**2%**	**5%**	**7%**	**10%**	**15%**	**20%**
Liquid limit (%)	56.5	53.5	50.5	48.0	43.5	41.5	34.0
Plastic limit (%)	28.86	27.95	27.49	26.50	24.62	24.59	23.16
Plasticity index (%)	27.64	25.55	23.01	21.50	18.88	16.91	10.84

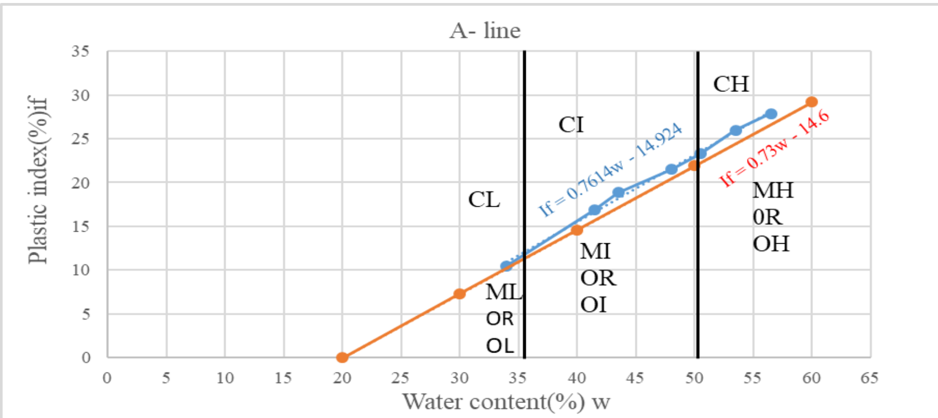

Fig.9 Plasticity chart

TABLE V SOIL CHARACTERISTICS ACCORDING TO A-LINE

S. No.	**Soil mix**	**Soil characteristics**
1.	soil	CH
2.	soil+2%wps	CH
3.	soil+5%wps	CH

4.	soil+7%wps	CI
5.	soil+10%wps	CI
6.	soil+15%wps	CI
7.	soil+20%wps	CL

D. Shrinkage limit test: This section provides the illustration of shrinkage limit of soil and soil with different percentage of WPS as 2 %, 5%, 7%, 10%, 15% and 20%. The value of shrinkage limit of soil without WPS is less than the shrinkage limit of soil with WPS as shown in below tables. The addition of WPS in soil increases the shrinkage limit (SL) of soil is presented figure below.

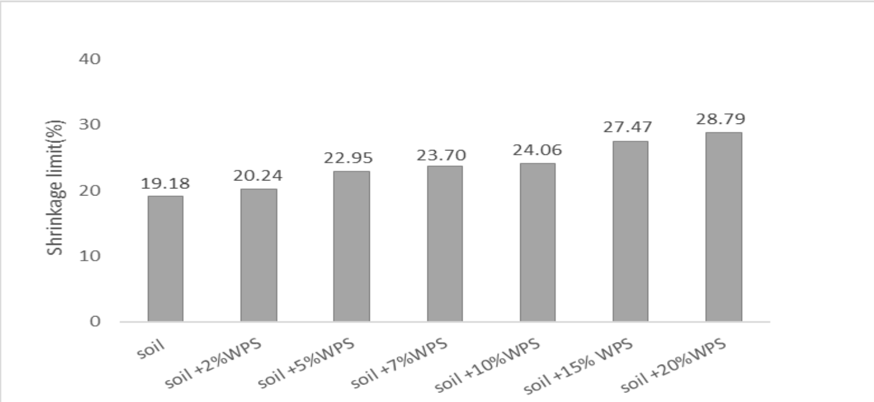

Fig.10 Variation of shrinkage limit

E. Standard Proctor compaction test: This section provides the illustration of estimation of maximum dry density and optimum water content and relation between them of the soil with addition of WPS in different percentage as 2%, 5%, 7%, 10%, 15% and 20%. The value of maximum dry density of the soil without WPS is more than the maximum dry Density of the soil with WPS and Optimum water content without WPS less than Optimum water content of the soil as shown in the table and relationship graph also shown

TABLE VI CHANGE IN COMPACTION CHARACTERISTICS OF SOIL WITH WPS

Soil mix.	OMC (%)	DRY DENSITY γ_d (KN/m^3)
Soil	15.8	17.1
Soil+2%WPS	17.6	17.0
Soil+5%WPS	18.2	16.7
Soil+7%WPS	20.1	16.6
Soil+10%WPS	20.6	16.4
Soil+15%WPS	21.6	16.3
Soil+20%WPS	23.9	16.2

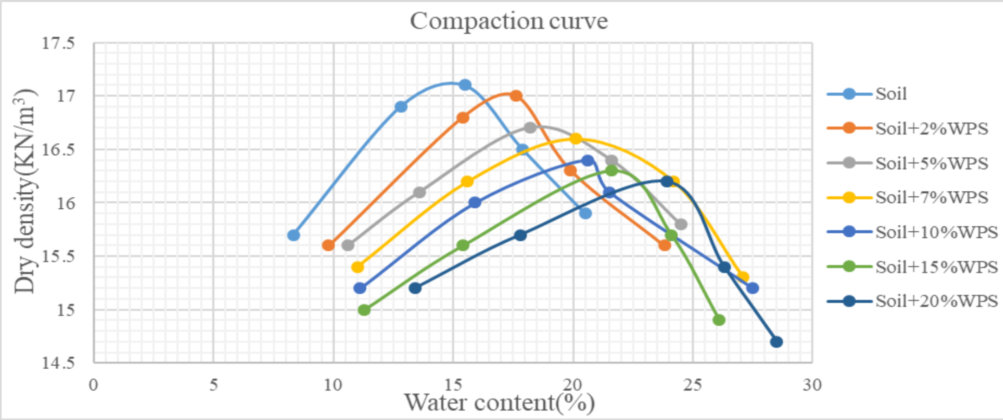

Fig.11 Variation in compaction curve

F. Unconfined compressive strength: This section provides the illustration of estimation of unconfined compressive strength of the soil for below mentioned days with addition of WPS in different percentage as 2%, 5%, 7%, 10%, 15%, and 20% be presented in table and figure. For unconfined compressive strength of soil with different percentage of WPS was tested for 0, 3,7,14 and 28 days. From this test, we found that the maximum strength is obtained at 7% of WPS.

TABLE VII CHANGE IN COMPACTION CHARACTERISTICS OF SOIL WITH WPS

Curing days	UCS (KN/m²) with WPS (%)						
	0%	2%	5%	7%	10%	15%	20%
0	255.27	274.44	294.48	307.70	296.11	279.06	266.41
3	259.98	278.09	313.93	333.96	310.37	290.11	267.39
7	262.21	284.36	316.81	346.80	325.92	296.74	275.26
14	263.24	285.25	353.24	368.32	329.00	320.36	290.18
28	266.71	301.34	386.71	411.83	340.47	322.90	295.54

G. California bearing ratio test (Unsoaked & Soaked soil sample): This section provides the illustration of estimation of California bearing ratio value of soil and soil with different percentage of WPS as 2%, 5%, 7%, 10%, 15% and 20% be presented in below tables and figures. The California bearing ratio value of soil without addition of WPS is less than California ratio value of soil with addition of WPS. The optimum value of WPS is obtained as 10%.

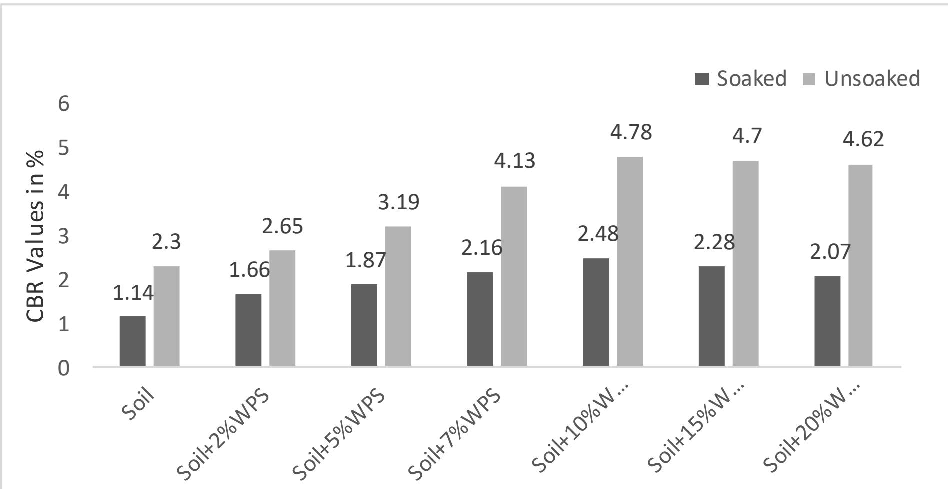

Fig.12 CBR Values of different soil mix

VI. CONCLUSIONS

1. Waste paper sludge has been successfully used as the stabilizing agent on strength development of soft soil.
2. With increment in addition of waste paper sludge by different percentages by weight of the soil, liquid limit, plastic limit, and plasticity index was reducing continuously with minimum value of 23.16%, 34%, & 10.84% respectively at 20% addition of WPS, hence enhancing the soil property.
3. On addition of waste paper sludge by different percentages of weight of the soil, there is an increment in the shrinkage limit value with maximum limit of 28.79% at 20% addition of WPS, hence reducing the shrinkage and swelling in the soil thus making soil more stable.
4. The addition of waste paper sludge by percentage weight in the soil reduces the compressibility of the soil.
5. With addition of with waste paper sludge by percentage of weight, a boost in Optimum Moisture Content with lowering Maximum Dry Density is observed thus enabling the soil to entrap more amount of moisture
6. Unconfined Compressive Strength of soil with addition of waste paper sludge increases to better strength. Unconfined Compressive Strength at 28 days gave better results. The optimum value of WPS is obtained as 7 % with better Unconfined Compressive Strength for different durations of curing.
7. With addition of waste paper sludge in the soil in specified percentage California Bearing Ratio value tends to increase and the optimum value of addition of Waste Paper Sludge is obtained as 10 % with better California Bearing Ratio value of 4.78% & 2.48% for unsoaked and soaked condition respectively as compared to unmodified soil.

Hence it can be concluded that addition of WPS in soil proves to be an efficient solution for stabilization and strength development of soft soils.

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