RESEARCH ARTICLE OPEN ACCESS

Shear Strength of Plastic Waste Mixed Soil

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Abstract:
In certain situations, the quality of soil at greater depths can be extremely poor, making it impractical to construct deep foundations. To overcome this challenge, engineers employ various soil stabilization and reinforcement techniques. The primary objective of these methods is to enhance the soil properties at the construction site, enabling it to bear loads effectively. By improving the soil's shear strength and reducing its compressibility, these techniques aim to create a stable foundation. From the experimental observations, it has been discovered that the addition of a small percentage of plastic waste to the soil can significantly enhance its strength. This newfound strength improvement due to the inclusion of plastic waste can be effectively utilized in enhancing the bearing capacity and reducing settlement issues in the design of road embankments and similar structures. Furthermore, the utilization of waste plastic materials in soil improvement offers environmental benefits by addressing the challenges associated with plastic waste disposal. The generation of solid waste is constantly increasing due to factors such as population growth, developmental activities, lifestyle changes, and socioeconomic conditions. Among the various types of waste, plastic waste constitutes a substantial portion of the total municipal solid waste (MSW). In fact, it is estimated that the country generates approximately 10 thousand tons per day (TPD) of plastic waste. Recognizing this, the recycling of plastic waste from water bottles as a reinforcing material in geotechnical and civil engineering practices is proposed. Experimental results have demonstrated a significant enhancement in soil strength when plastic waste is incorporated. This improvement arises from the increased friction between the soil and plastic waste, as well as the development of tensile stress within the plastic waste itself. Consequently, the inclusion of plastic waste not only provides a viable solution for improving soil characteristics but also serves as an environmentally conscious approach to address the challenges associated with plastic waste disposal.

Keywords: soil, stabilization, reinforcement, bearing capacity, recycling of plastic waste, shear strength.

I. INTRODUCTION:

Shear strength refers to the soil's ability to withstand deformation caused by shear stresses. When soil is subjected to compressive loads, shear stresses are generated. Shear failure of the soil occurs when these shear stresses surpass the soil's shear strength. The shear strength of soil is primarily derived from the following factors:

1) Interlocking of soil particles: Soil particles can interlock with each other, providing resistance against shear deformation.

2) Frictional resistance: Individual soil particles exhibit frictional resistance, which can involve sliding friction, rolling friction, or a combination of both. This frictional resistance contributes to the shear strength of the soil.

3) Cohesion or adhesion: Soil particles may possess cohesion or adhesion, which refers to the bonding forces between them. These cohesive or adhesive forces contribute to the overall shear strength of the soil.

So, the shear strength of soil depends on the interlocking of particles, the frictional resistance between them, and the cohesion or adhesion present among the soil particles.

The shear strength of cohesionless soil, such as granular soils like sand, arises mainly from the interlocking of particles and the friction between them. In contrast, cohesive soils like clays gain shear strength from a combination of friction and cohesion properties. It is worth noting that the majority of soils found in nature possess a blend of cohesionless and cohesive characteristics, allowing them to display both frictional and cohesive qualities. Gaining a comprehensive understanding of soil shear strength is a challenging endeavor due to its dependence on numerous variables. Soil exhibits significant variations in shear strength across a wide range of field conditions and can possess distinct qualities from one site or region to another. Consequently, developing a universally standardized tabulation of soil shear strength in codes of practice is impractical. Furthermore, accurate interpretation of laboratory test results and their effective application to real-world field circumstances necessitate a high level of expertise and experience.

The objective of the current study is twofold: to enhance the shear strength properties of a specific weak soil and simultaneously address the issue of plastic disposal. Research indicates that global plastic consumption reached approximately 10 to 15 million tons in 2007, with an observed annual growth rate of 20%. On average, each person worldwide utilizes around 20 kilograms of plastic annually, while in India, the per-person consumption is approximately 1 to 2 kilograms per year. However, recycling rates for plastic bottles, as highlighted by ECO PET (2007), remain considerably low. Additionally, Watershed reports that the United States of America (USA) consumes 1500 bottles per second.

II. LITERATURE REVIEW:

The research conducted by S. A. Naeini and S. M. Sadjadi in 2008 focused on the utilization of waste polymer materials as reinforcement in clayey soils with varying plasticity indices. The study involved randomly incorporating plastic fibers into the soil at different weight percentages (0%, 1%, 2%, 3%, and 4%). To evaluate the effectiveness of waste plastic fibers for soil reinforcement, Behzad Kalantari, Bujang B.K. Huat, and Arun Prasad conducted CBR (California Bearing Ratio) experiments in 2010. Additionally, Consoli et al. proposed a field application in 2003, suggesting the use of fiber-reinforced cemented sand to enhance the bearing capacity of spread foundations on weak residual soil layers.

Consoli et al. (2004) conducted triaxial compression tests on cemented and uncemented sand reinforced with various types of fibers to examine their effects on failure mode, ultimate deviator stress, ductility, and energy absorption capacity. The inclusion of fibers was found to change the failure mode from brittle to ductile. Other studies focused on using tire shreds as reinforcing elements (Hataf and Rahimi, 2006; Yoona et al., 2008), with Hataf and Rahimi (2006) conducting laboratory tests on a model of shallow footing resting on reinforced sand using tire shreds as reinforcement. The addition of fibers significantly reduced the seepage velocity of the soil, thereby enhancing the piping resistance. Sivakumar Babu and Chouksey (2010) proposed a constitutive model based on critical state concepts to obtain the stress-strain response of coir fiber-reinforced soil as a function of fiber content.

The literature review highlights the limited availability of studies on the use of waste plastic water bottles. Mixing soil with plastic waste is expected to result in a behavior similar to fiber-reinforced soil. Patented procedures for utilizing fiber-reinforced soil in the field, as suggested by Freed (1988), are also available. To encourage large-scale recycling of plastic waste in geotechnical applications where bulk utilization of waste materials is possible, this study presents experimental results on the stress-strain response of soil mixed with plastic waste.

III. MATERIALS AND METHODS

SOIL :

For the current study, the red soil samples were collected from various locations in the hilly region of Karwar, Uttar Kannada District Karnataka. Red soils are typically derived from sedimentary rocks and are characterized by their distinctive red color, which is indicative of high iron content, often in the form of iron oxide. The presence of iron oxide can be attributed to either the parent material or the prolonged process of intense weathering. Red soil is the predominant soil type found in Karwar and its surrounding areas, as well as in various other regions across the country.

Soil Sample Used for Test

To explore the impact of incorporating plastic mixed waste into the red soil, a direct shear test was conducted while varying the percentage of plastic waste. The red soil was obtained from a borrow area and subsequently sieved through a 425 μ sieve. Table 1 presents the fundamental characteristics of the red soil.

Properties of Red Soil Sample

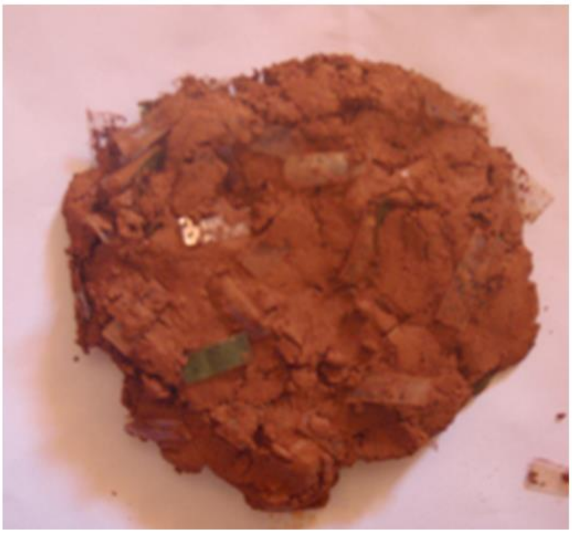
Properties	Values
Liquid limit (%)	46.5%
Plastic limit (%)	30%
Optimum moisture content (%)	15.28%
Specific gravity	2.30
Maximum dry density	1.64 g/cc
Silt +clay size (%)	45.1%

The soil exhibited a liquid limit of 46.5% and a plastic limit of 30%. The tests were carried out at an optimum water content of 15.28% and a maximum dry density of 1.64 g/cc, which were determined through standard Proctor tests.

PLASTIC REINFORCEMENT

For the test, discarded plastic Polyethylene terephthalate (PET) water bottles were cut into pieces and utilized. Polyethylene terephthalate (PET) is the polymer commonly employed in the production of plastic bottles. It has a molecular formula of $(C_{10}H_8O_4)$ n, and its solubility in water is negligible, with less than 0.4 percent solubility. The melting point of polyethylene terephthalate ranges from 473°F to 500°F (245°C to 260°C). It is not compatible with strong oxidizing agents or strongly alkaline materials. The degree of polymerization of polyethylene terephthalate may vary depending on the specific product. Plastic water bottle waste, in the form of chips, was utilized as the reinforcing material. The dimensions of the plastic chips were 8 mm in length, 4 mm in width, and 0.1 mm thick. The specific gravity of the plastic waste was assumed to be 1.4 gm/cc, and the permissible tensile load was set at 350N, as indicated by Shivkumarbabu (2012).

Plastic Waste Chips of Pet Bottles



Plastic Waste Mixed Soil

SAMPLE PREPARATION

The procedure involved in the experiment consisted of several steps. Initially, dry soil of a predetermined weight was mixed with the necessary amount of water and placed in desiccators to reach an equilibrium state. The moist soil was then removed from the desiccators, and a specific weight of plastic waste, expressed as a percentage of the dry weight of the soil, was uniformly distributed and mixed throughout the soil. The mixture of plastic waste and soil was then placed in a plastic container to allow for moisture content equilibration. The entire mixture was compacted by filling it into a compaction mold and applying static compaction. Subsequently, specimens were obtained from the compacted mixture for strength testing.

Figure 4.2 displays the plastic waste chips used in the experiment, while Figure 4.3 showcases the soil mixed with plastic waste. Various percentages of plastic waste (0%, 1%, and 1.5% by dry weight of soil) were mixed with the soil, and tests were conducted accordingly.

IV. EXPERIMENTAL METHODS

Direct Shear Test: The direct shear test is an enduring method for assessing the strength properties of soils. Its purpose is to determine key shear strength parameters, namely cohesion (c) and angle of internal friction (ϕ). By plotting shear stress against horizontal displacement, the maximum shear stress can be determined at a specific vertical confining stress. Multiple experiments are conducted with varying vertical confining stresses, resulting in a plot of maximum shear stresses (τ) against vertical (normal) confining stresses (σ) for each test. This plot enables the approximation of a straight-line Mohr-Coulomb failure envelope curve. The angle between the resulting straight line and the horizontal axis represents the angle of shearing resistance (ϕ), while the point where the line intercepts the vertical axis corresponds to the cohesion intercept (c).

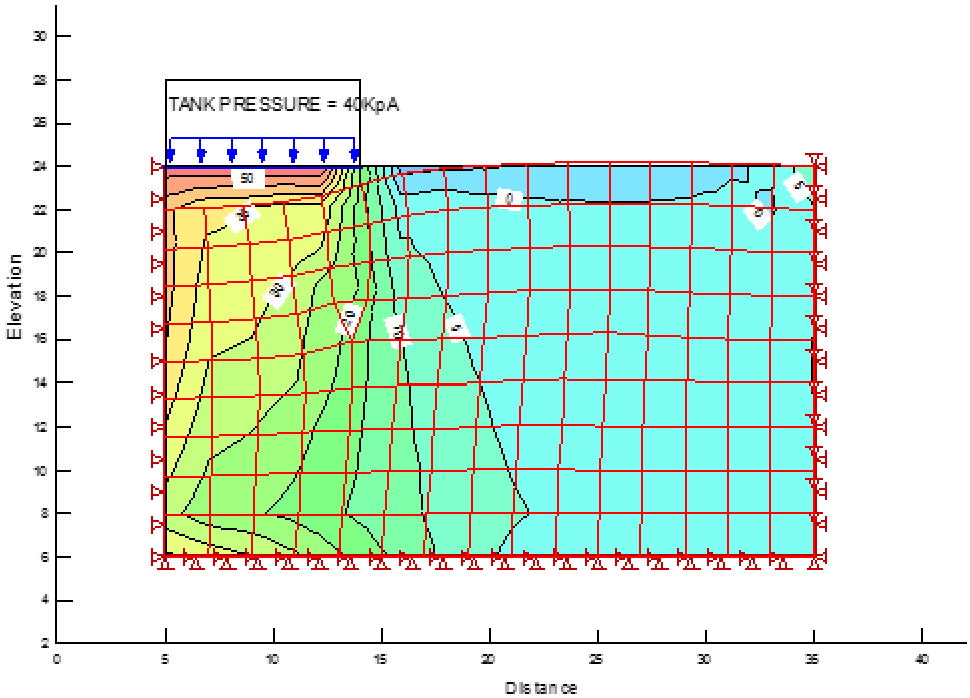
The experimental setup for the tests followed the guidelines outlined in IS 2720 (Part XIII)-1986 and utilized a box shear apparatus. Shear tests were conducted on soil samples reinforced with varying percentages of plastic waste using a direct shear test apparatus. The shear strength of the reinforced soil mixture, influenced by factors such as initial conditions, soil types, and plastic waste content, was evaluated. To maintain consistency, all specimens were subjected to identical initial conditions in terms of dry density and water content. The apparatus employed for the tests consisted of a brass box divided horizontally at the midpoint of the soil sample, which was held in place between metal grilles and porous stones.

Direct Shear Test Apparatus

The figure illustrates the application of a constant vertical load to the sample. Simultaneously, a gradually increasing horizontal load is applied to the lower section of the box until the sample undergoes shear failure. The shear load at failure is divided by the cross-sectional area of the sample to determine the ultimate shearing strength. The applied vertical stress (σ) is calculated by dividing the vertical load by the sample's area. To ensure reliability, the test can be repeated with additional samples sharing the same initial conditions as the first sample. Each sample is tested under different vertical loads, while the horizontal load is applied at a consistent rate of strain. The lower half of the box is mounted on rollers, which are driven forward at a uniform pace by a motorized gearing arrangement. The upper half of the box interacts with a steel proving ring, and the resulting deformation is displayed on a dial gauge indicating the shearing force. For the measurement of volume change during consolidation and shearing, another dial gauge is employed to monitor the vertical movement of the top platen. Additionally, the horizontal displacement of the bottom of the box can be measured using another dial gauge, although it is not visible in the figure.

V. RESULTS AND DISCUSSIONS

A mathematical soil model with axisymmetry measuring 30 meters in length and 20 meters in height was constructed and analyzed. The model was subjected to a tank pressure of 40 kPa applied at its center. Initially, the model consisted solely of pure soil, without any waste plastic content. Subsequently, plastic waste was gradually added to the model in increments of 0.5%, 1%, 1.5%, and 2%. It was noted that the inclusion of plastic waste enhanced the shear strength and settlement characteristics. However, at 2% plastic waste content, the model exhibited diminished results.



Soil Model

OBSERVATIONS, TABULATION, AND CALCULATIONS FOR PLAIN SOIL

Shear Stress and Shear Strain Calculation for Plain Red Soil at σ = 0.5 Kg/cm²

Elapsed Time sec	Shear		Shear Strain	Shear Force		Corrected area,	Shear Stress
	Div	mm		Div	N		
0	0	0	0.0000	0	0.000	3600.00	0.0000
30	25	0.25	0.0042	6	18.126	3595.00	0.0050
60	69	0.69	0.0115	13	39.273	3586.20	0.0110
90	110	1.1	0.0183	16	48.336	3578.00	0.0135
120	142	1.42	0.0237	19	57.399	3571.60	0.0161
150	202	2.02	0.0337	21	63.441	3559.60	0.0178
180	236	2.36	0.0393	22.5	67.973	3552.80	0.0191
210	266	2.66	0.0443	22	66.462	3546.80	0.0187
240	301	3.01	0.0502	20	60.420	3539.80	0.0171
270	343	3.43	0.0572	18	54.378	3531.40	0.0154

Shear Stress and Shear Strain Calculation for Plain Red Soil at σ = 1.0 Kg/cm^2

Elapsed Time sec	Shear		Shear Strain	Shear Force		Corrected area,	Shear Stress
	Div	mm		Div	N		
0	0	0	0.0000	0	0	3600.00	0.00000
30	20	0.2	0.0033	7.5	22.658	3596.00	0.00630
60	60	0.6	0.0100	13	39.273	3588.00	0.01095
90	97	0.97	0.0162	19	57.399	3580.60	0.01603
120	150	1.5	0.0250	24	72.504	3570.00	0.02031
150	214	2.14	0.0357	26	78.546	3557.20	0.02208
180	257	2.57	0.0428	27.5	83.078	3548.60	0.02341
210	293	2.93	0.0488	26	78.546	3541.40	0.02218
240	328	3.28	0.0547	25	75.525	3534.40	0.02137
270	341	3.41	0.0568	24.5	74.015	3531.80	0.02096
300	367	3.67	0.0612	23	69.483	3526.60	0.01970
330	388	3.88	0.0647	22.5	67.973	3522.40	0.01930

Shear Stress and Shear Strain Calculation for Plain Red Soil at σ = 1.5 Kg/cm^2

Elapsed Time sec	Shear		Shear Strain	Shear Force		Corrected area,	Shear Stress
	Div	mm		Div	N		
0	0	0	0.0000	0	0	3600.00	0.00000
30	24	0.24	0.0040	6	18.126	3595.20	0.00504
60	60	0.6	0.0100	16	48.336	3588.00	0.01347
90	100	1	0.0167	23	69.483	3580.00	0.01941
120	145	1.45	0.0242	26	78.546	3571.00	0.02200
150	180	1.8	0.0300	29	87.609	3564.00	0.02458
180	217	2.17	0.0362	32	96.672	3556.60	0.02718
210	260	2.6	0.0433	33	99.693	3548.00	0.02810
240	300	3	0.0500	32	96.672	3540.00	0.02731
270	352	3.52	0.0587	31	93.651	3529.60	0.02653
300	405	4.05	0.0675	30	90.630	3519.00	0.02575
330	450	4.5	0.0750	30	90.630	3510.00	0.02582
360	485	4.85	0.0808	29	87.609	3503.00	0.02501

Shear Stress and Shear Strain Calculation for Soil+1% Plastic Waste at σ = 0.5 Kg/cm^2

Elapsed Time sec	Shear		Shear Strain	Shear Force		Corrected area,	Shear Stress
	Div	mm		Div	N		
0	0	0	0.0000	0	0	3600.00	0.00000
30	31	0.31	0.0052	8	24.1680	3593.80	0.00672
60	65	0.65	0.0108	12	36.2520	3587.00	0.01011
90	110	1.1	0.0183	19	57.3990	3578.00	0.01604
120	156	1.56	0.0260	22	66.4620	3568.80	0.01862
150	190	1.9	0.0317	23	69.4830	3562.00	0.01951
180	234	2.34	0.0390	24	72.5040	3553.20	0.02041
210	278	2.78	0.0463	25	75.5250	3544.40	0.02131
240	320	3.2	0.0533	25	75.5250	3536.00	0.02136
270	361	3.61	0.0602	23	69.4830	3527.80	0.01970
300	423	4.23	0.0705	20	60.42	3515.4	0.0172
330	451	4.51	0.0752	20	60.42	3509.8	0.0172
330	492	4.92	0.082	20	60.42	3501.6	0.0173

Shear Stress and Shear Strain Calculation for Soil+1% Plastic Waste at σ = 1.0 Kg/cm^2

Elapsed Time sec	Shear		Shear Strain	Shear Force		Corrected area,	Shear Stress
	Div	mm		Div	N		
0	0	0	0.0000	0	0	3600.00	0.00000
30	23	0.23	0.0038	7.5	22.6575	3595.40	0.00630
60	63	0.63	0.0105	15	45.3150	3587.40	0.01263

90	101	1.01	0.0168	18	54.3780	3579.80	0.01519
120	139	1.39	0.0232	24	72.5040	3572.20	0.02030
150	180	1.8	0.0300	28.5	86.0985	3564.00	0.02416
180	241	2.41	0.0402	32	96.6720	3551.80	0.02722
210	287	2.87	0.0478	33	99.6930	3542.60	0.02814
240	345	3.45	0.0575	30.5	92.1405	3531.00	0.02609
270	417	4.17	0.0695	28	84.5880	3516.60	0.02405
300	466	4.66	0.0777	26	78.5460	3506.80	0.02240
330	496	4.96	0.0827	24	72.504	3500.8	0.0207

Shear Stress and Shear Strain Calculation For Soil+1% Plastic Waste at σ = 1.5 Kg/cm^2

Elapsed Time sec	Shear		Shear Strain	Shear Force		Corrected area, A=Ao(1	Shear Stress N/mm^2
	Div	mm		Div	N		
0	0	0	0.0000	0	0	3600.00	0.00000
30	21	0.21	0.0035	7	21.1470	3595.80	0.00588
60	64	0.64	0.0107	16	48.3360	3587.20	0.01347
90	99	0.99	0.0165	22	66.4620	3580.20	0.01856
120	147	1.47	0.0245	27	81.5670	3570.60	0.02284
150	193	1.93	0.0322	36	108.7560	3561.40	0.03054
180	239	2.39	0.0398	38	114.7980	3552.20	0.03232
210	282	2.82	0.0470	40	120.8400	3543.60	0.03410
240	321	3.21	0.0535	39	117.8190	3535.80	0.03332
270	369	3.69	0.0615	35	105.7350	3526.20	0.02999
300	409	4.09	0.0682	35	105.7350	3518.20	0.03005
330	462	4.62	0.0770	33	99.6930	3507.60	0.02842
360	506	5.06	0.0843	32	96.6720	3498.80	0.02763

Shear Stress and Shear Strain Calculation For Soil+1.5% Plastic Waste At σ = 0.5 Kg/cm^2

Elapsed Time sec	Shear		Shear Strain	Shear Force		Corrected area,	Shear Stress
	Div	mm		Div	N		
0	0	0	0.0000	0	0	3600.00	0.00000
30	31	0.31	0.0052	7	21.147	3593.80	0.00588
60	81	0.81	0.0135	14	42.294	3583.80	0.01180
90	115	1.15	0.0192	17	51.357	3577.00	0.01436
120	145	1.45	0.0242	20	60.42	3571.00	0.01692
150	187	1.87	0.0312	24	72.504	3562.60	0.02035
180	223	2.23	0.0372	26	78.546	3555.40	0.02209
210	297	2.97	0.0495	27	81.567	3540.60	0.02304
240	360	3.6	0.0600	27.5	83.0775	3528.00	0.02355
270	401	4.01	0.0668	27	81.567	3519.80	0.02317
300	465	4.65	0.0775	25	75.525	3507.00	0.02154

Shear Stress and Shear Strain Calculation for Soil+1.5% Plastic Waste at σ = 1.0 Kg/cm^2

Elapsed Time sec	Shear		Shear Strain	Shear Force		Corrected area,	Shear Stress
	Div	mm		Div	N		
0	0	0	0.0000	0	0	3600.00	0.00000
30	27	0.27	0.0045	6	18.126	3594.60	0.00504
60	69	0.69	0.0115	13	39.273	3586.20	0.01095
90	125	1.25	0.0208	18	54.378	3575.00	0.01521
120	150	1.5	0.0250	24	72.504	3570.00	0.02031
150	190	1.9	0.0317	28	84.588	3562.00	0.02375
180	225	2.25	0.0375	31	93.651	3555.00	0.02634
210	280	2.8	0.0467	36	108.756	3544.00	0.03069
240	341	3.41	0.0568	36	108.756	3531.80	0.03079

270	400	4	0.0667	34	102.714	3520.00	0.02918
300	465	4.65	0.0775	30	90.63	3507.00	0.02584

Shear Stress and Shear Strain Calculation for Soil+1.5% Plastic Waste at $\sigma = 1.5$ Kg/cm^2

Elapsed Time sec	Shear		Shear Strain	Shear Force		Corrected area,	Shear Stress
	Div	mm		Div	N		
0	0	0	0.0000	0	0	3600.00	0.00000
30	30	0.3	0.0050	8	24.168	3594.00	0.00672
60	56	0.56	0.0093	15	45.315	3588.80	0.01263
90	80	0.8	0.0133	22	66.462	3584.00	0.01854
120	138	1.38	0.0230	29	87.609	3572.40	0.02452
150	183	1.83	0.0305	32	96.672	3563.40	0.02713
180	216	2.16	0.0360	34	102.714	3556.80	0.02888
210	241	2.41	0.0402	37	111.777	3551.80	0.03147
240	260	2.6	0.0433	38	114.798	3548.00	0.03236
270	320	3.2	0.0533	41	123.861	3536.00	0.03503
300	378	3.78	0.0630	40	120.84	3524.40	0.03429
330	441	4.41	0.0735	39	117.819	3511.80	0.03355
360	468	4.68	0.0780	38	114.798	3506.40	0.03274

DIRECT SHEAR TEST

The test is performed by subjecting the specimen to a horizontal shear load until it either fails or reaches a longitudinal displacement of 20 percent, whichever comes first. Throughout the test, the shear load readings indicated by the proving ring assembly and the corresponding longitudinal displacements are recorded at 30-second intervals until the specimen fails. The test is repeated three times using different normal stresses, specifically 0.5 Kg/cm^2, 1.0 Kg/cm^2, and 1.5 Kg/cm^2. The resulting observations are tabulated as follows.

Shear Strength Parameters

S.No.	Plastic waste content (%)	Friction angle (ϕ)	Cohesion (kPa)
1	0	33^o	14.64
2	1	40^o	16.12
3	1.5	40^o 30’	17.59
4	2	31^o	12.78

From the above table it was observed that incorporating 1% plastic waste resulted in a 10.11% increase in cohesion (c) and a 21.21% increase in frictional resistance (ϕ). Similarly, using 1.5% plastic waste led to a 21.15% increase in cohesion (c) and a 22.73% increase in frictional resistance (ϕ). This increase in strength can be attributed to the confinement effect, which enhances the cohesion and friction of the plain soil. Additionally, the presence of plastic waste fibers reduces the likelihood of soil particle slippage.

VI. CONCLUSIONS:

- The findings demonstrate a significant increase in shear strength when incorporating plastic waste from water bottles as reinforcing material in geotechnical and civil engineering practices. Therefore, the recycling of plastic waste is proposed as a viable solution.
- The experimental results clearly indicate a noteworthy enhancement in soil strength through the inclusion of plastic waste. This improvement can be attributed to the increased friction between the soil and plastic waste, as well as the development of tensile stress within the plastic waste.
- The test results reveal that as the percentage of plastic waste increases, the deviator stress at failure also increases. However, it becomes challenging to prepare specimens with a plastic waste content exceeding 1.0%.
- Despite this limitation, the observed improvement in strength response is significant enough to consider the technique of incorporating plastic waste in soil as a potential approach for enhancing bearing capacity and reducing settlement in ground improvement projects.
- Additionally, the utilization of plastic waste as reinforcing material in soil not only contributes to improved soil performance but also aids in the recycling of plastic bottles, presenting an

environmentally beneficial solution.

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