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Use of Construction and Demolition Waste Material for Soil Stabilization

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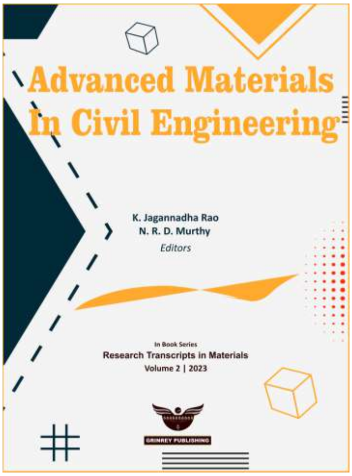

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Abstract

Soil stabilization is the method of modifying and improving soil engineering properties. Properly stabilized soil exhibit better bearing capability, shear strength, density and lower permeability, plasticity and shrink-swell characteristics. Soft and expansive soil is grave threat to the existence and safety of the structures constructed over and underneath it. The availability of a suitable stabilizer, which can modify and strengthen the characteristics of weak soil, is vital for the safety and longevity of the structures. It is essential to use such a stabilizer which is cheap, easily available and environment-friendly. Construction and demolition (C&D) debris are solid wastes accessible at construction sites at nominal cost. This study mainly investigates the changes in the soil behaviour, precisely the strength characteristics, on mixing the C&D wastes by replacing the original soil with 5%, 10%, 15% and 20% of the C&D debris respectively. The results demonstrated that up to certain extent the strength characteristics improved. The C&D debris utilization can help in environmental protection and prevention of land and water pollution, which can contribute towards the goal of sustainable development.

1. Introduction

Soil is a combination of minerals, dead and living organisms, air and water. Due to significant interaction of these four components, soil is rendered as an essential natural resource. Soil stabilization is the process of boosting the characteristics of the soil in order to improve its strength, stability, bearing capacity etc. by the amalgamation of some suitable additives in the original soil. If a weak soil stratum is discovered during construction, the normal practice is to replace it with other good quality soil with a desirable bearing capacity. By soil stabilization, the characteristics of local accessible soil may be boosted, and the enriched soil can be used successfully as subgrade material without replacing the local soil. The expense of replenishing weak soil is more than the cost of the subgrade or foundation improvement with proper stabilizer. Proper soil stabilization techniques can effectively increase the strength characteristics of the soil to the required level. In this study an effort has been made to use the debris, available at local construction sites, as soil stabilizers to ameliorate the soil properties and stabilize the locally available soil for the construction of buildings and other concrete and RCC structures over it without the fear of structural failure due to settlement of the foundation soil.

1.1 Various materials used for improvement of soil engineering properties

Diamond and Kinter, (1965) have assessed the mechanism of soil-lime stabilization meticulously. They have found that there was a key reaction between the lime and soil which helped in binding the soil particles through the synthesis of strong water insoluble gel [1]. The ASTM Standards on Soil Stabilization (1992) has recommended changing the grain size physically which includes the particle size distribution of soil. The mixing of additives and soil particles could hold the soil grains in a tough bond, therefore producing enriched soil compared to mechanical and physical methods [2]. Hardjito and Rangan (2005) conducted detailed research on the synthesis and use of locally available fly ash (ASTM Class F) based geopolymer concrete. They used the same technique and equipment, used to make ordinary Portland cement (OPC) concrete, to make geopolymer concrete. They found that the density, elasticity modulus, Poisson’s ratio, stress-strain and indirect tensile strength of the geopolymer concrete were equivalent to OPC concrete [3]. Olaniyan et al., (2011) observed that the soil improvement by physical and mechanical means could be achieved by dwindling the void ratio by compaction and by using fibrous and geomaterials as non-biodegradable reinforcements [4]. Manso et al., (2013) observed noteworthy enhancement in mechanical properties and compressive strength, when clays were assorted with ladle furnace slag. The compressive strength for clay was superior since it kept growing as from day three onwards. For the smectite group, the compressive strength increased at 28 days but the outcome was analogous with clay and lime mix except at 90 days where the results improved [5]. Anand Kumar et al., (2014) strived for construction of roads in places having poor soil quality using demolished brick waste (DBW) as soil stabilizer. They resolved that 40% is the ideal DBW content which has to be added to cohesive soil for proper stabilization. The maximum dry density (MDD) value improved for the soil stabilized using DBW content. They found that MDD of 1.954 gm/cc was obtained when 40% DBW content was mixed with the virgin soil sample. They also found that the CBR value was highest when 40% DBW was mixed with soil and the Unconfined compressive strength value showed around 100% increment when the virgin soil sample was mixed with DBW at ratio of 60:40 [6]. Kerni et al., (2015) critically reviewed the role of various methods and techniques in soil stabilization. They concluded that different wastes like wood ash, fly ash, rice husk ash etc. were being utilized as soil stabilizers but the C&D waste was not being utilized for soil stabilization. They also suggested that there was a need for utilization of C&D wastes of buildings for soil stabilization. The C&D wastes could help in reduction of hazardous environmental impacts of the waste [7]. Jain and Chawda, (2016) worked on the stabilization of clayey soil by utilizing damaged concrete debris. They observed the MDD and the CBR value improved and the OMC reduced with the surge in damaged concrete percentage in the mixture. They concluded that the demolished concrete could act similar to lime and cement in enhancing the characteristics of clayey soil. It was also observed that there was a reduction in the cost of construction and hazardous environmental impacts [8]. Kumar and Rathod, (2018) reviewed several literatures and finally suggested the usage of C&D debris to curb detrimental effect of wastes on environment and enhance soil properties. They also suggested the use of polypropene as an economical material with high strength, longevity and non-biodegradability which in turn could improve soil properties leading to soil stabilization [9]. Bhat and Gupta, (2018) examined and analyzed the various sorts of researches on the use of C&D waste in pavement subgrade. They suggested that use of C&D waste for improving sub-grade properties. They observed that coarser aggregates were used but finer were escaped which could be utilized for enhancing density of the soil [10]. Silva et al., (2019), Ding et al., (2020) involved aggregates from debris in construction application and highway subgrade filling respectively [11-12]. Bagriacik, (2021) mixed alkali-activated demolition waste with sandy soil and observed enhancement of soil properties including bearing capacity [13]. Islam et al., (2022) amalgamated recycled mortar powder with clayey soil in different proportions and found improvised consolidation settlement of soil [14]. Xue et al., (2023) mixed recycled sand obtained from debris for modifying strength of pavement subgrades and observed positive results [15].

Several research works have been done using demolished waste fines and waste fibrous materials separately for improving the soil quality. The C&D debris can improve the soil characteristics and enhance the vital soil engineering properties like bearing capacity, compressive strength and shear strength. According to Centre for Science and Environment, India produces millions of tonnes of C&D debris annually but has a recycling capacity of only about 1.3 percent of the debris generated daily and remaining 98.7 percent of the debris remains unused creating a pile of solid waste which poses a serious hindrance in the process of solid waste management. So it is vital to use the C&D debris properly for enhancement of soil properties and utilization of solid waste.

2. Methodology and Experimentation

Soil is the most essential part of the foundations and pavement structures which provides base and support to the structures and pavement from the bottom. The various properties of the soil are very important for the longevity and durability of the structures built over it. In the current study the soil sample was taken from a location close to Dr. B. C. Roy Engineering College. The soil sample was extracted at depth of 1.5 metre form the ground level. About 40 kg of the soil sample was collected in a gunny bag, the soil sample was thoroughly pulverized in a large tray to break lumps and put into oven at 110°C for entire day to expel all the moisture present in the soil. After placing out of the oven, the soil sample was air dried and then the sample was thoroughly analyzed for the index properties and various strength parameters in the departmental soil lab. The various index properties of soil like grain size distribution using various IS Sieves (4.75 mm to 0.075 mm), Liquid Limit (W_L), Plastic Limit(W_P), Plasticity Index (PI), moisture content (w), Specific Gravity (G), Maximum Dry Density (MDD), Optimum Moisture Content (OMC) and the strength parameters tests like Direct Shear Test (DST), Unconfined Compressive Strength (UCS) test, California Bearing Ratio (CBR) test (Both in soaked, unsoaked conditions) have been thoroughly tested in the soil lab. Then about 30 kg of C&D waste was obtained from a nearby construction site in a plastic bag. The C&D waste debris was also thoroughly pulverized in a large tray using a wide rammer, sieved through 4.75 mm and 0.150 mm sieves (4.75 mm passing and retained on 0.150 mm) and oven dried at 110°C for full day. Then the original soil sample was replaced by 5%, 10%, 15% and 20% of debris and the change in strength of mixed soil was thoroughly tested using DST, UCS and CBR (Soaked and Unsoaked) tests. The various strength test results for the mixed soil was compared with the virgin soil sample to find out what sort of change takes place in the strength characteristics of the soil sample after having mixed the C&D wastes.

3. Results and Discussion

The various index and the strength characteristics of the original soil were examined and the results have been recorded in Table 1:

Table 1. Various index and strength properties of the original soil sample

Soil Properties		Results
Coefficient of Uniformity		5.5
Coefficient of Curvature		1.01
IS Classification soil type		Well Graded Soil
Specific Gravity (G)		2.36
Moisture Content (w)		14.715%
W_L		29%
W_P		12.82%
PI		16.18%
Compaction Test	OMC	19%
	MDD, (kg/cm^3)	1.79
DST for original soil	Angle of Friction (Φ)	24°
	Cohesion (C) in kg/cm^2	0.284
UCS Test for original soil	Unconfined Compressive strength, qu Shear strength, S = qu/2	0.834 kg/cm^2 0.417 kg/cm^2
Unsoaked CBR value for original soil	At 2.5 mm	5.5
	At 5.0 mm	7.5
Soaked CBR value for original soil	At 2.5 mm	6.0
	At 5.0 mm	7.5

3.1 Direct Shear Test (DST) results for various percentage of C&D debris in the soil sample

Table 2 clearly depicts the value of shear stress at various percentages of C&D debris mixed with original soil.

Table 2. Comparison of Shear Stress for various % of C&D debris mixed with original soil

Normal Stress	Shear Stress (original soil)	Shear Stress (5% of C&D waste mixed)	Shear Stress(10% of C&D waste mixed)	Shear Stress(15% of C&D waste mixed)	Shear Stress(20% of C&D waste mixed)
0.5	0.045	0.060	0.192	0.156	0.151
1.0	0.065	0.085	0.267	0.247	0.222
1.5	0.080	0.116	0.389	0.338	0.303

Table 3 shows cohesion values for various percentages of C&D debris mixed with original soil.

Table 3. Value of Cohesion, C (kg/cm^2) for various % of C&D debris mixed with original soil

Percentage C&D mixed with original soil	Cohesion, C (kg/cm^2)
0%	0.284
5%	0.310
10%	0.590
15%	0.847
20%	0.185

Figure 1 depicts cohesion values at various percentages of C&D debris mixed with original soil.

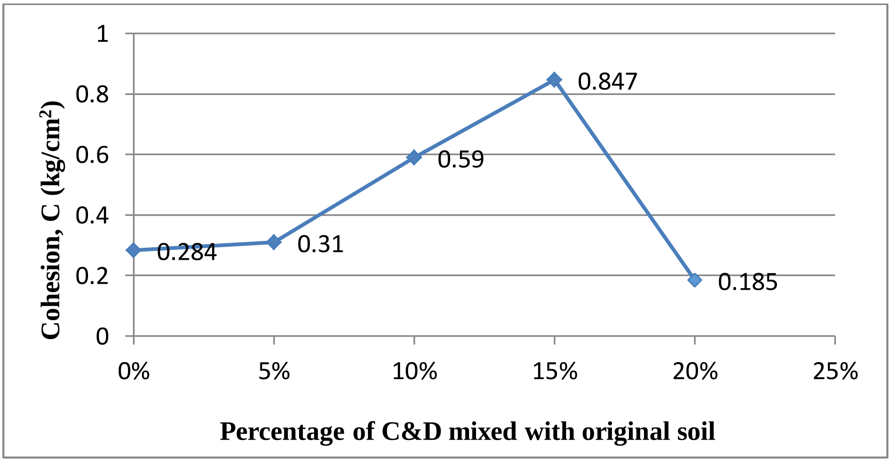

Fig. 1. Value of cohesion (C) for various % of C&D debris mixed with original soil

Table 4 shows angle of friction (Φ°) for various percentages of C&D debris mixed with original soil.

Table 4. Value of angle of friction for various % of C&D debris mixed with original soil

Percentage C&D debris mixed with original soil	Value of Angle of friction (Φ°)
0%	24°
5%	32°
10%	28°
15%	23°
20%	21°

Figure 2 depicts angle of friction at various percentages of C&D debris mixed with original soil.

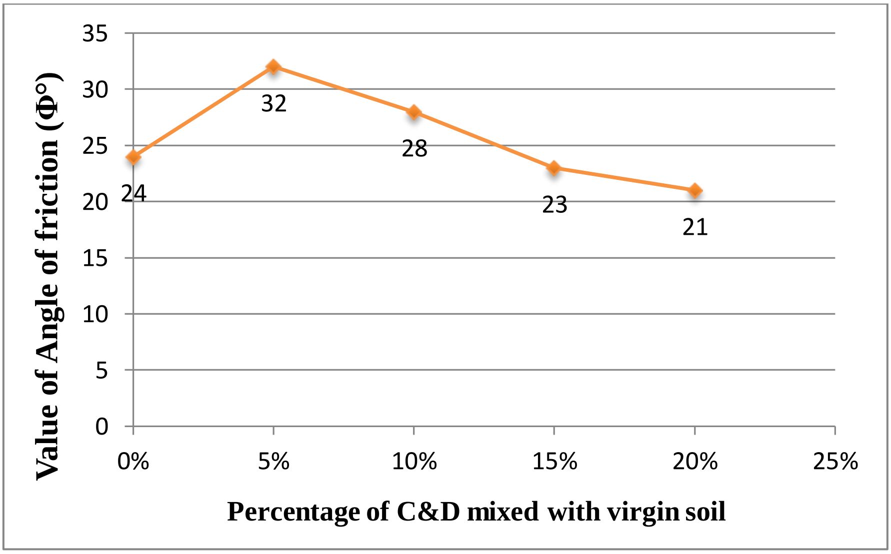

Fig. 2. Value of angle of friction (Φ°) at various % of C&D debris mixed with original soil

3.2. UCS Test results for various percentage of C&D debris mixed with original soil

Table 5 shows average compressive strength for various percentages of C&D debris mixed with original soil

Table 5. Average Compressive Strength (kg/cm^2) for various % of C&D debris mixed with original soil

Percentage C&D debris mixed with original soil	Average Compressive Strength (kg/cm^2)
0%	0.834
5%	0.769
10%	0.688
15%	0.671
20%	0.664

Figure 3 depicts average compressive strength at various percentages of C&D debris mixed with original soil.

3.3. Results obtained for the Soaked and Unsoaked samples during CBR Test for various % of C&D debris mixed with the soil sample

Table 6 shows CBR value for soaked samples at 2.5 mm & 5.0 mm penetration for various percentages of C&D debris mixed with original soil.

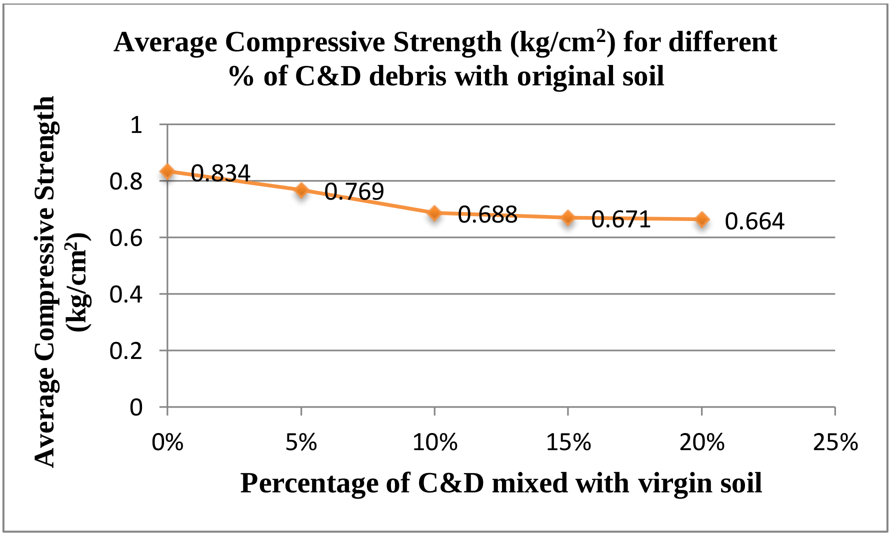

Fig. 3. Value of average compressive strength at various percentages of C&D debris mixed with original soil

Table 6. CBR value for soaked samples at 2.5 mm & 5.0 mm penetration for various % of C&D debris mixed with the soil

CBR Penetration	**100 % Soil**	**95% Soil+ 5% C&D debris**	**90% Soil+ 10% C&D debris**	**85% Soil+ 15% C&D debris**	**80% Soil+ 20% C&D debris**
CBR Penetration at 2.5 mm	6	4	6	7	4
CBR Penetration at 5.0 mm	7.5	5.5	7	8	5.5

Table 7 shows CBR value for unsoaked samples at 2.5 mm & 5.0 mm penetration for various percentages of C&D debris mixed with original soil.

Table 7. CBR value for unsoaked samples at 2.5 mm & 5.0 mm for various % of C&D debris mixed with the soil

CBR Penetration	**100 % Soil**	**95% Soil + 5% C&D debris**	**90% Soil + 10% C&D debris**	**85% Soil + 15% C&D debris**	**80% Soil + 20% C&D debris**
CBR Penetration at 2.5 mm	5.5	7.5	6	5.5	5
CBR Penetration at 5.0 mm	7.5	10	8	7.5	7

During the initial index properties tests on the original soil sample it was found that the soil was well graded soil with good proportion of particles of different sizes. The Uniformity Coefficient was observed as 5.5 and the Coefficient of Curvature was observed as 1.01. The water content (w) of the original soil sample was 14.715%, W_L was about 29%, W_P was about 12.82%, the PI was about 16.18%, and G was about 2.36.

The MDD value was 1.79 kg/cm^3 at an OMC of 19%. So beyond this there will not be any increment in the soil strength with further addition of water.

After completing the UCS test and gradually substituting the soil by 5%, 10%, 15% and 20% respectively of the C&D debris, it was seen that the compressive strength of the mixed soil samples deteriorated with further escalation of C&D debris. As a result, it can be said that the compressive strength of soil decreases as more C&D debris are mixed with soil sample.

The DST was performed initially with the virgin soil and then the C&D debris was mixed in increasing order by replacing the virgin soil with 5%, 10%, 15% and 20% respectively. The value of shear stress of original soil at different values of the normal stress was found to be 0.045, 0.065, and 0.080 respectively. After replacing the original soil sample with 5%, 10%, 15% and 20% of the C&D debris, it was found that value of shear strength increased till 10% of replacement of soil with the waste but the strength started dropping gradually after that point. The value of cohesion (C, in kg/cm^2) was found to be highest (0.847 kg/cm^2) at 15% replacement of the soil sample but the value dropped beyond that point. The value of the angle of friction (Φ°) was found highest (32°) at 5% replacement of the soil with C&D debris but the value decreased with further addition.

The CBR test was initially done with the original soil at both soaked and unsoaked conditions. Then the soil was replaced consecutively by 5%, 10%, 15% and 20% of C&D debris and the test was repeated under soaked and unsoaked conditions. It was realized that under soaked conditions the CBR at 2.5 mm penetration initially decreased for the 5% replacement of soil with the waste but the CBR value then increased for 10% and 15% replacement of soil with the waste but the value then dropped finally at 20% replacement of soil with the C&D debris. It was also observed that in soaked condition the CBR value at 5 mm decreased for the 5% and 10% replacement but the value then increased at 15% of replacement of soil with the waste and ultimately declined again at 20% of replacement of soil with the C&D debris.

4. Conclusion

So overall from the present study it can be concluded that the soil stabilization using C&D debris, in terms of shear strength, compressive strength and subgrade strength, was satisfactory and some of the results obtained for a few tests were very encouraging. For example the results of DST, CBR test were good enough to encourage usage of C&D debris for the stabilization of soil. The C&D debris is a significant contributor to landfill waste. By repurposing these materials for soil stabilization, they are diverted from landfills, helping to reduce the strain on limited landfill capacity and minimizing the associated environmental hazards. The C&D debris usage will be an effective tool for solid waste management, as it leads to proper use of the debris and also help in maintaining cleanliness and cater towards the goal of sustainable development for the betterment of the future generation.

Nomenclature

Φ	:	Angle of friction
C&D	:	Construction & Demolition
G	:	Specific Gravity
w	:	Moisture Content
MDD	:	Maximum Dry Density
OMC	:	Optimum Moisture Content
DBW	:	Demolished Brick Waste
DST	:	Direct Shear Test
UCS	:	Unconfined Compressive Strength
CBR	:	California Bearing Ratio
W_L	:	Liquid Limit
W_P	:	Plastic Limit
IS	:	Indian Standard

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