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Using recycled crushed concrete columns to stabilize fully saturated silty clay soil

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Abstract:

The object of the study is the improvement of fully saturated silty clay soil using columns of recycled crushed concrete. ASTM D 2166 - Standard Test Procedure for Unconfined Compressive Strength of Cohesive Soil is used to apply the axial load. This work aims to to examine how recycled crushed concrete affects settlement control and bearing capacity by 38%, increasing the initial soil state and reducing swelling from 14.75% to 5.66% in 7 days. The research also examined the variation in subgrade modulus and the cause of a shallow circular footing's failure on the soil where silt clay layer soil had been substituted with recycled broken concrete. The results demonstrated that combining a partly replaced column of silty clay soil and a column of recycled crushed concrete significantly preload-bearing capability. The approach may drastically alter the footing's stress displacement curve when resting on silty clay soil, reduce settlement, swelling, and shrinkage, and make the replacement soil block within the container act as a deep foundation. Consequently, a foundation supported by silty clay may change its bearing capacity failure mechanism at the top of a column constructed of recycled crushed concrete from exclusive settling to general bearing capacity failure—the use of fills with shattered concrete, whether natural or artificial, is growing. Hence, research into this material's bearing and deformation properties is essential for application areas such as road construction, soil replenishment, and embankments.

1 Introduction

A clayey soil is referred to as expansive soil if it can contract and expand due to climatic variations in moisture content. Starting density, salt concentration, clay content, clay mineral composition, soil structure, depth of soil, and initial water content are some initial parameters. Are some of the factors that heavily influence the kind of swelling of expansive soil[1]? Clayey soil movement is seen as a severe risk to structures, particularly those that are light in weight, such as one-story buildings, airports, paving roads, and footings. Climate change and common environmental elements such as severe drought occurrences, vegetation, and root water intake by trees are regarded as significant threats to the stability of civil and geotechnical engineering structures. The current research looks at how these parameters affect the structural behavior of residential structures erected on unsaturated expanding clays at the field. Since 2011, a damaged residential structure built on shrink-swell clays and exposed to root water intake by trees and changing climatic circumstances in the southwest of France has been studied [2]. While more expensive and demanding, the engineering designer wants to replace the problematic expanding soil with favorable soil qualities. Heavy equipment is also needed for the soil's extrusion, transporting, and compaction. Thus, scientists devised various strategies to improve the properties of expansive soil. Among the earliest and best-known methods for stabilizing swelling soil are chemical additives such as cement, lime, bentonite, asphalt, and fly ash[3]. Several approaches were presented to reduce the hazard of expanding soil by combining it with sand [4]. The use of lime to lessen swelling and improve the engineering qualities of expansive soil is a recent example of how materials are used to manage swelling characteristics Shahzada Omer Manzoor and Aadil Yousuf [5]. Investigated how waste tire rubber fibers impregnated with bentonite clay behaved regarding swelling and strength Bekhitia et al. [6].

On the other hand, Signes et al. The findings show swelling potentials and pressure steadily decrease when tire rubber fiber content and cement levels rise. Selvakumar and Soundara [7] used discarded expanded polystyrene (EPS) beads to create geofoam granule columns to lessen the strain and possibility of expanding soil.

One way to determine coarse-grained soil's shear strength is to establish correlations between the mechanical properties of the mixture and its finer fraction. Arezou Rasti Hamid Ranjkesh Adarmanabadi [8] has focused on this strategy for clayey-silt combinations. According to earlier research on clayey soils by Bolton [9],[10]. Bolton [2] collected considerable data on 17 clays in axisymmetric and planar strain experiments under various relative densities and confinements to examine clays' strength and dilatancy properties. It was stated that the maximum dilation angle (ψ_{max}) is a function of the critical state or constant volume friction angle (φ_{cv}), which is itself a function of soil mineralogy, and that the maximum friction angle of clay soil (φ_{max}) is a function of the critical state or constant volume friction angle. (φ_{cv}) These relationships are shown in equation (1).

$$\varphi_{max} = \phi_{CV} + 0.8\psi_{max} \quad (1)$$

To connect equation (1) for the planar strain condition to a new index (IR), Bolton [9] established relative density (D_r) in percent and adequate confining level in failure (p') in KPa.

$$I_R = D_r\left(10 - Ln\left(P'\right)\right) - 1 \quad (2)$$

$$\varphi_{max} - \varphi_{cv} = 0.8\,\psi_{max} = 5\,I_R \quad (3)$$

Every year, a large number of concrete-built historic structures are destroyed. Crushed concrete is widely accessible and may be used in various applications. This investigation used crushed concrete instead of some original soil to address swollen soil below footings. Footings are utilized below columns for crushed concrete. Moreover, it optimizes both high- and low-suction soils.

This study concludes that crushed concrete can enhance saturated clay soil's bearing capacity, swelling, and shrinkage. The quantity and kind of the most effective input factors were assessed for optimal results, and sensitivity analysis of crushed concrete was performed based on its anticipated ultimate bearing capacity. Using crushed concrete columns to improve the properties of saturated clay soil is more effective than other methods because it increases the layer thickness and the soil's internal friction coefficient (φ). Instead of crushed concrete columns, previous studies focused on using crushed concrete layers to improve soil properties. In addition to the environmental and economic characteristics that separate this technology from prior ways, it allows for recycling environmentally acceptable structural parts at meager costs.

2 Methods and Materials

2.1 Characterization of recycled broken concrete

The concrete was mixed in this investigation at a 1:2:4 (cement: sand: aggregate) ratio. The substance was crushed and put through a sieve with a 9.51mm diameter that is used to enhance the soil characteristics due to the effectiveness of these sizes in stabilizing clay soil and in proportion to the size of the model being tested.

2.2 Soil Characterization

In this research, a saturated silty clay soil was employed from Al-kut City in Iraq. The following typical tests are performed to identify the mechanical and physical properties of the soil.

2.3 Identification tests

1. Specific Gravity Test (Gs): The ASTM D-854-00 Standard is used to assess the specific gravity of the soil in question. Table (1) displays the results.

2. Grain Size Distribution Test: The main test procedure for particle-size analysis of soils is (ASTM) D 422 - 01 Standard Test Method for Sieve Analysis (ASTM 2001). The selected grain size distribution is shown in Table (1).

3. Maximum and Minimum Index Density Tests: The maximum and minimum index density tests were carried out generally following ASTM D 4253-00, "Standard Test Method for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table," and ASTM D 4254-00, "Standard Test Method for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density."

Table 1. Physical and chemical characteristics of the natural soil.

Property	Value	Specifications
Grain size analysis		ASTM D422-01
Sand	3.5%	
Silt	31.5 %	
Clay	65%	
Effective size		
D10	0.14 mm	
D30	0.24 mm	
D60	0.27 mm	
Coefficient of uniformity, Cu	1.98	
Coefficient of curvature, Cc	1.60	
Classification (USCS)		
Specific gravity, Gs	2.68	ASTM D854- 00
Dry unit weights		ASTM D4253-00
Maximum dry unit weight, γd (max)	17.3 KN/m3	
Minimum dry unit weight, γd (min)	14.1 KN/m3	
Void ratio		
Maximum void ratio, emax	0.82	
Minimum void ratio, emin	0.55	
Atterberg limit		ASTM D4318-00
Liquid limit (figure 1)	46.4 %	
Plastic limit	32.8 %	

2.3.1 A Formulation for Model Setup

These components make up the model;

Steel container: All model tests were conducted in a steel container with the following measurements: 300 mm x 300 mm x 400 mm (figure 1). It is constructed of five pieces of steel plate joined by welding (base and four sides). The container's components are all stainless steel plates with a 3 mm thickness. The container is reinforced to prevent lateral distortion as the soil bed is prepared during the test. The tank's measurements were selected to provide completely mobilized pressure inside the soil medium throughout the loading test.

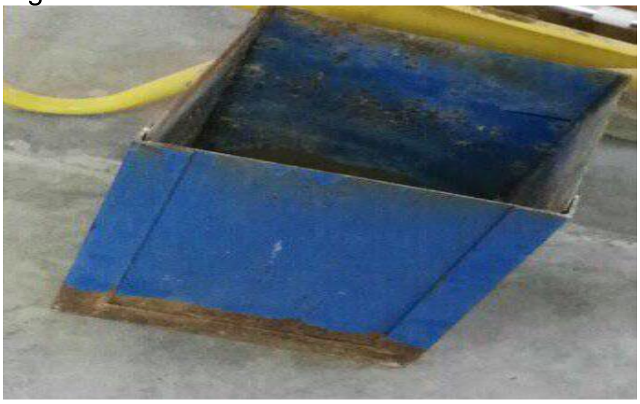

Fig. 1 - Steel container

Axial loading system (UC Test Device) Standard Unconfined Compression System: ASTM D 2166 - Standard Test Procedure for Unconfined Compressive Strength of Cohesive Soil Figure (4) is used to apply the axial load.

Proving Ring: The employed proving ring has a 50 KN capacity and a sensitive 0.001mm dill gauge (4).

Preparation of the soil bed: The soil was prepared by removing a specific amount of soil and weighing it with a potted balance; we used soil weighing 43 kg to obtain the obtained unit weight figure (2). Next, water was added to the model until completely submerged to obtain a fully saturated soil with a degree of saturation (S=1).

Fig. 2 - Soil sample

Loading Test: The model is tested with a standard load and moving at a speed of 1 millimeter per second. The results are displayed in Table (2) below.

2.3.2 Testing Procedures

First, we weigh the soil and compact it in a container. Next, we calculate the water content and add it to the soil's first precipitation without adding recycled crushed concrete. Finally, we looked at using a test column by setting it up in the center of a bucket of recycled crushed concrete that had passed a sieve with a diameter of 9.51 mm (3).

Fig. 3 - Column of crushed concrete

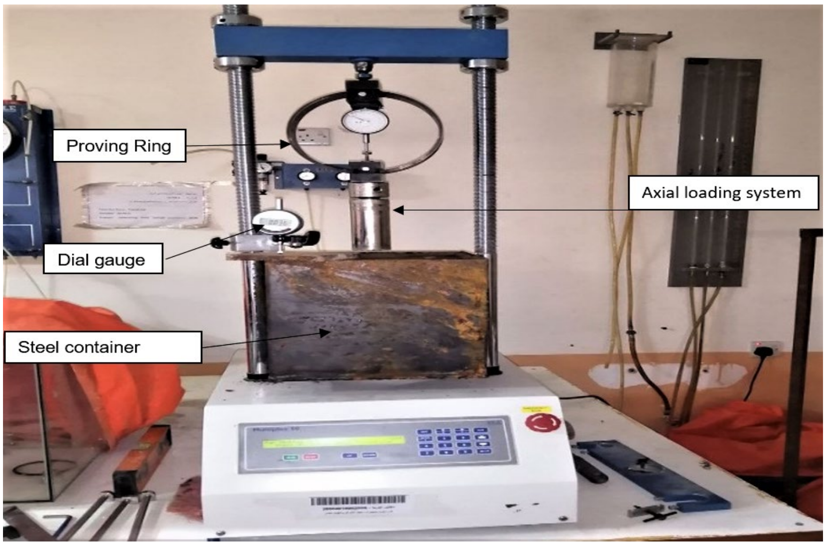

Fig. 4 - (UC) Standard Unconfined Compression System

3 Results and Discussion

This study presents the conclusions of model tests conducted to determine the capacity of models using recycled crushed concrete columns. Selection of Failure Criterion: Several criteria have been put forward to establish the failure load of the foundations and piles. According to Fellenius 2009 [11], some of these requirements are as follows:

1. Terzaghi suggested (1947) that according to the criteria used in this study, failure is defined as a load that causes a displacement of 10% of the model footing width or pile diameter.
2. De Beer's idea from 1968 [12] (as reported by Winterkorn and Fang, 1975) [13] :After charting the load-settlement relationship in a log-log plot, the bearing capacity is measured at the intersection of two interesting straight lines with different slopes. This breakpoint represents the failure state.
3. The tangent proposal, where failure is defined as the point at which two tangents to load-settlement curves connect. The first tangent is to the curve's upper, flatter component, and the second is to the curve's lower, flatter portion [14].
4. The Chin-Kondner technique, proposed in 1970, assumes that the load-settlement curve takes a hyperbolic form as the failure load approaches. Every load value is divided by its matching settlement value, and the resultant value is displayed against the settlement. Since the plotted values lie on a straight line, the Chin failure load is determined by the inverse of the slope of this line [15].
5. Davisson's idea from 1972 [16]: The movement that surpasses the elastic compression of the pile by a value of 0.15 inch (4 mm) plus a factor equal to the diameter of the pile divided by 120 is what is referred to as the failure load [17].
6. Decourt's technique from 1999 [18] is number six; each load's related settlement is divided by each load, and the resulting number is then contrasted with the applied load. To compare the value to the applied load, it divides each load by its corresponding settlement [19]. The line is determined using linear regression over the apparent line [20]. According to Decourt, the location where this line crosses the load axis is known as the ultimate load.

3.1 Impact of the gravel column on bearing capacity

Tests on crushed concrete are conducted to choose a reference value of loading to determine the gravel column's impact on the load capacity figure (5).

Table 2 represents time–load–settlement results for both naturally saturated and treated soil with recycled materials of a crushed column under accelerating axial force.

Table 2. An axial loading test results for both natural and treated soil

Natural saturated soil			Soil with Recycled crushed concrete column		
Time (min)	Load(N)	Settlement (mm)	Time(min)	Load(N)	Settlement (mm)
0	0	0	0	0	0
0.1	11	0.4	0.1	15	0.146
0.2	23	0.63	0.2	21	0.421
0.3	44	0.867	0.3	30	0.645
0.4	56	1.214	0.4	31	0.845
0.5	50	1.307	0.5	38	1.098
1	57	1.513	1	45	1.346
1.1	60	1.699	1.1	50	1.593
1.2	62	1.916	1.2	58	1.817
1.3	68	2.175	1.3	61	2.035
1.4	70	2.365	1.4	66	2.279
1.5	70	2.602	1.5	64	2.437
2	76	2.846	2	70	2.699
2.1	79	3.094	2.1	80	2.995
2.2	80	3.311	2.2	80	3.142

2.3	80	3.533	2.3	90	3.409
2.4	86	3.814	2.4	91	3.661
2.5	89	4.046	2.5	94	3.929
3	90	4.241	3	100	4.123
3.1	90	4.481	3.1	100	4.298
3.2	90	4.759	3.2	109	4.555
3.3	92	4.959	3.3	111	4.871
3.4	91	5.218	3.4	113	5.016
3.5	90	5.437	3.5	116	5.252
4	89	5.696	4	116	5.469
4.1	92	5.947	4.1	123	5.707
4.2	92	6.161	4.2	130	5.952
4.3	94	6.352	4.3	133	6.175
4.4	95	6.441	4.4	134	6.356
4.5	95	6.578	4.5	140	6.54
5	110	6.818	5	145	6.904
5.1	111	7.019	5.1	150	7.197
5.2	110	7.259	5.2	141	7.197
5.3	110	7.495	5.3	150	7.541
5.4	110	7.802	5.4	160	7.819
5.5	118	8.012	5.5	160	7.976
6	118	8.245	6	161	8.209
6.1	118	8.378	6.1	164	8.484
6.2	120	8.695	6.2	170	8.673
6.3	120	8.974	6.3	172	8.919
6.4	130	9.168	6.4	169	9.111
6.5	120	9.38	6.5	172	9.373
7	120	9.826	7	181	9.643
7.1	130	9.904	7.1	182	9.846
7.2	130	10.012	7.2	183	10.063

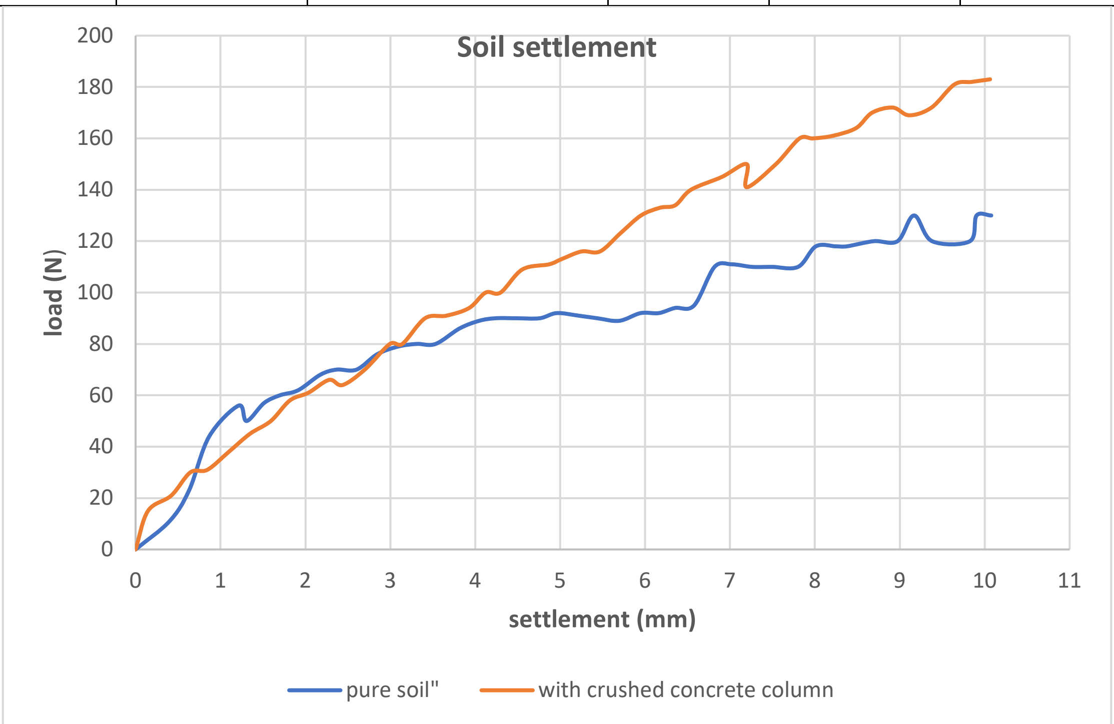

Fig. 5 - Soil settlement

Impact of the crushed concrete columns on bearing capacity: This section looks at how employing recycled crushed concrete columns affects the maximum load capacity for the clay soil model figure (5).

The use of recycled crushed concrete columns enhanced ultimate bearing capacity and reduced settling for clay soils, as shown in the figure.

3.2 The impact of aggregate size on swelling-shrinkage characteristics

Tables 3 and 6 show the outcomes of tests on swelling and shrinkage conducted on expansive soils with various aggregate sizes. According to the previously established definitions, swelling and shrinkage are stated in terms of the linear swelling ratio (LSWR) and the linear shrinkage ratio (LSHR). The ratio of the increase in specimen height to the starting height is known as the LSWR, and the ratio of the increment in specimen height to the initial height is known as the LSHR. Table 3 and Figure 6 show how the LSWR varies with immersion time. As shown in Table 3, every LSWR value for specimens treated with a concentration of 9 g/cm3 of crushed concrete aggregate is lower than the corresponding value for untreated specimens simultaneously. Figure 6 shows that, in every case, the biggest surge in LSWR occurs during the first 30 min and that, after 5 hours, the LSWR data exhibit a rather steady value. The LSWR at seven days is chosen as the end value to study the impact of aggregate size on swelling ratio.

The impact of aggregate size on LSWR and LSHR is seen in Figures 7 and 8, respectively. According to Figure 7, the LSWR of treated and untreated soils rises when aggregate sizes exceed 1 mm. In terms of aggregate size, LSHR data shows the opposite tendency. Regarding the shrinkage test findings in Table 3, the LSHR of treated specimens with crushed concrete aggregate is less than that of untreated specimens. The LSHR of treated samples with aggregate sizes of 0.5–1, 1-2, 2-4, and 4–9 mm is 56.48%.

Table 3. The linear swelling ratio of specimens with different crushed concrete sizes

Time	Treated soil 9 (g/cm^3)				Untreated
	0.5–1 mm	1–2 mm	2-4 mm	4–9 mm	Natural clay soil
0	0.00%	0.00%	0.00%	0.00%	0.00%
5 min	2.06%	1.46%	3.00%	3.11%	4.10%
10 min	3.23%	2.53%	5.09%	5.19%	8.00%
15 min	4.05%	3.35%	5.88%	6.00%	10.30%
20 min	4.98%	4.22%	6.72%	6.85%	12.30%
30 min	5.47%	4.71%	7.27%	7.40%	13.90%
1 hour	5.95%	4.96%	7.50%	7.93%	14.10%
3 hours	6.40%	5.12%	7.67%	8.32%	14.24%
5 hours	6.53%	5.45%	7.75%	8.45%	14.28%
7 hours	6.60%	5.50%	7.77%	8.54%	14.31%
9 hours	6.65%	5.54%	7.80%	8.60%	14.33%
12hours	6.70%	5.58%	7.83%	8.64%	14.42%
1 day	6.78%	5.63%	7.86%	8.68%	14.55%
2 days	6.83%	5.64%	7.88%	8.70%	14.59%
3 days	6.87%	5.65%	7.89%	8.71%	14.62%
4 days	6.88%	5.65%	7.90%	8.72%	14.65%
5 days	6.89%	5.66%	7.91%	8.73%	14.68%
6 days	6.90%	5.66%	7.92%	8.74%	14.74%
7 days	6.92%	5.66%	7.92%	8.74%	14.75%

Table 4. The linear shrinkage ratio of specimens with different aggregate sizes

Aggregate sizes (mm)	Linear shrinkage ratio (%)	
	Untreated	6 (g/cm^3)
0.5–1 mm	3.187	1.800
1–2 mm	2.895	1.279
2-4 mm	2.316	1.150
4–9 mm	2.044	0.930

Among the untreated, 44.18%, 49.65%, and 45.50% were untreated. Figure 8 illustrates how the LSHR of treated and untreated specimens declined as aggregate size increased. In all soils, it has been shown that the relative declines in LSWR and LSHR are more than 40%. In soil specimens with aggregate sizes between 0.5 and 1 mm, their corresponding maximum values (55.11% for LSWR and 55.82% for LSHR) are found.

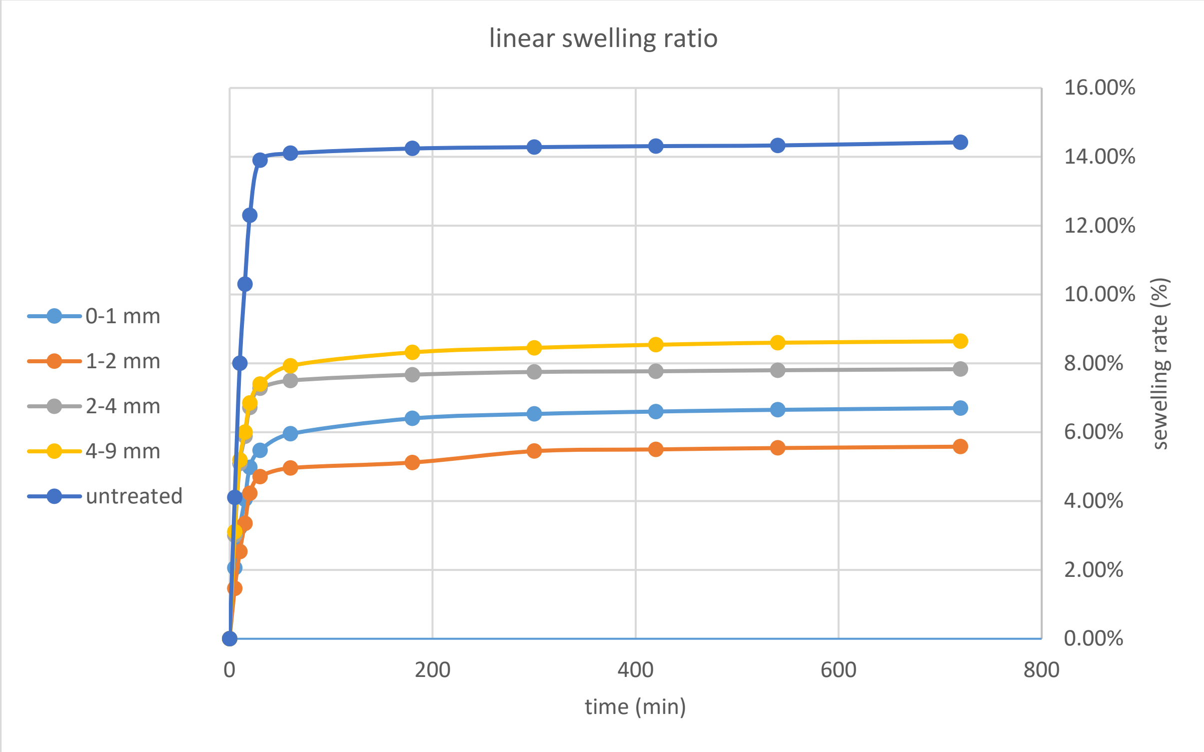

Fig. 6 - Variation of linear swelling ratio with immersed time

3.3 Impact of Concentration of Crushed Concrete Aggregate on Swelling-Shrinkage Properties

Tables 5 and 6 show the impact of aggregate concentration on the swelling and shrinkage characteristics of soils with 0.5 to 1 mm aggregate sizes. As shown, the values of the LSWR and LSHR drop as the aggregate concentration rises. Figures 7 and 6 show the changes in LSWR and LSHR with aggregate concentration. They demonstrate how aggregate concentration is a key factor in regulating the swelling-shrinking characteristics of soils. The LSWR drops from 12.61% to 1.85% and the LSHR from 2.9% to 0.87% compared to the results between the untreated and treated specimens at a concentration of 9 g/cm3, respectively.

Table 5. The linear swelling ratio of specimens with different concentrations of crushed concrete

Concentration (g/cm^3)	0	1.5	3	4.5	6	9
Aggregate sizes	0.5–9 mm	0.5–9 mm	0.5–9 mm	0.5–9 mm	0.5–9 mm	0.5–9 mm
The swelling ratio of 7 d (%)	12.61	7.81	5.66	3.65	2.33	1.85

Table 6. The linear shrinkage ratio of specimens with different concentrations of crushed concrete

Concentration (g/cm^3)	0	1.5	3	4.5	6	9
Aggregate sizes	0.5–9 mm	0.5–9 mm	0.5–9 mm	0.5–9 mm	0.5–9 mm	0.5–9mm
Linear shrinkage ratio (%)	2.895	1.697	1.279	1.067	0.913	0.872

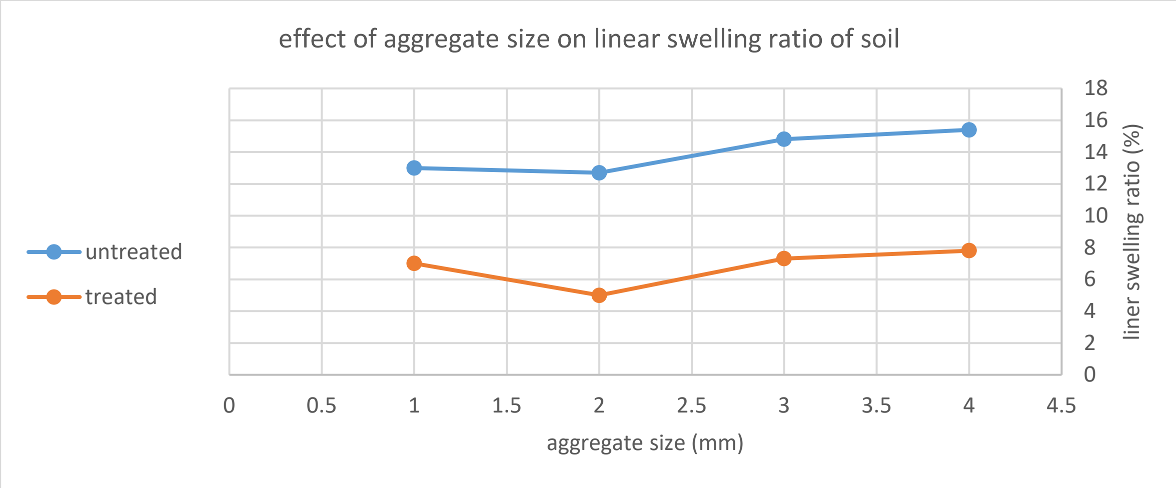

Fig. 7 - Effect of aggregate size on the linear swelling ratio of soils

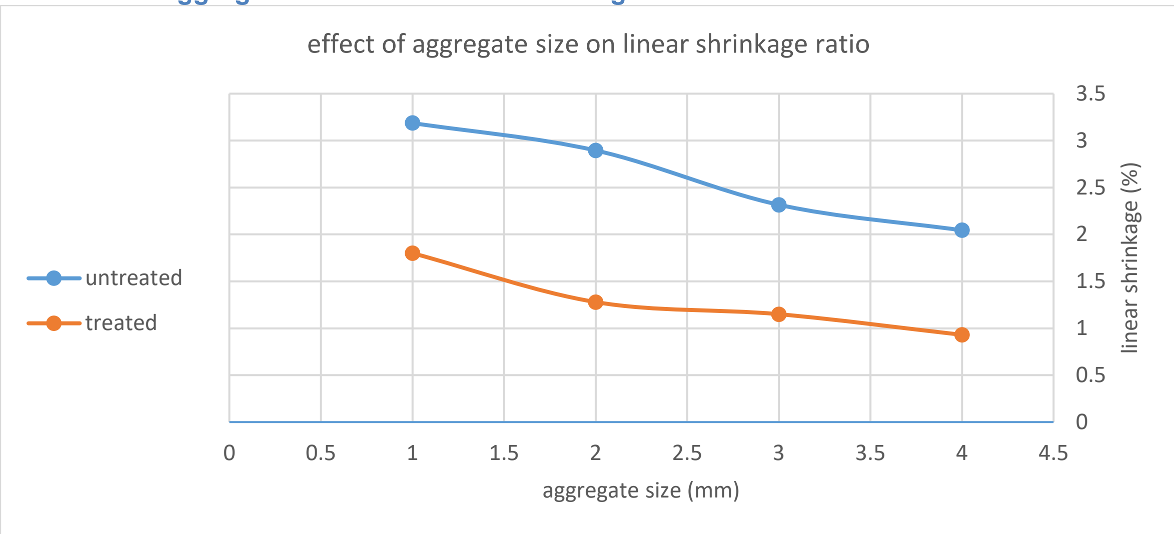

Fig. 8 - Effect of aggregate size on linear shrinkage ratio of soils

4 Conclusions

The primary objectives of this research are to improve the characteristics of saturated silty clay soils, increase their load-bearing capacity, and decrease the rate of swelling and shrinkage subsidence. Recycling crushed concrete has been successfully used to increase bearing capacity and lower settlement.

In this work, the ultimate bearing capacity, swelling, and shrinkage limitations of silty clay soil were calculated using the outcomes of a laboratory test method. The quantity and type of the most effective input factors were assessed to get the best results, and a sensitivity analysis was done to determine the impact of the crushed concrete parameters following the results for estimating the final bearing capacity. The study shows:

1. The observed increase in bearing capacity was determined to be 38% higher compared to the start condition of the soil. The performance of the crushed concrete columns was superior to that of the natural soil due to a reduced occurrence of settling.
2. The vertical expansion (swelling) gradually decreased as more columns of crushed concrete were installed. The vertical rise was often slowed down by adding columns made of crushed concrete, both with and without a footing.
3. Increased column thickness of crushed concrete slowed soil's vertical growth (swelling) with low initial water content. Crushed concrete columns are more effective in reducing vertical swelling than soil with high initial water content. The proportional reduction in LSWR and LSHR of specimens at various aggregate concentrations. All studied specimens' LSWR and LSHR decrease, and as the aggregate concentration rises, so do their relative decline ratios for both LSWR and LSHR.

4. The relative LSWR reduction for specimens treated with the aggregate concentrations of 1.5 g/cm3, 3 g/cm3, 4.5 g/cm3, 6 g/cm3, and 9 g/cm3 is correspondingly 38.07%, 55.11%, 71.05%, 81.52%, and 85.33%. The relative LSHR reductions of the specimens at the various concentrations are, in order, 41.38%, 55.82%, 63.14%, 68.46%, and 69.88%. These findings suggest that aggregate may effectively reduce the expansion and contraction of expansive soils. Vertical enlargement kept expanding over time.
5. Crushed concrete aggregate helps reduce soil shrinkage and swelling that is less than 5 mm. The impact on the swelling-shrinkage properties of the clayey soil under study is significantly influenced by both the soil aggregate classes and aggregate concentration.
6. Testing for swelling and shrinking shows that soil swelling mainly occurs 5 hours after submerging water.
7. The linear swelling ratios (LSWR) of treated soil exhibit a reduction with an increase in aggregate size, particularly for aggregates smaller than 1 mm.

The study results suggest that using crushed concrete as a soil stabilizer has the potential to effectively manage the volumetric changes of expansive soil in practical problems soil stabilization projects.

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