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The Behavior of Soft Clay Treated with Waste Concrete Column

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***Abstract*— This study considering the waste concrete and crushed stone materials is basic material in constructing stone columns. A series of model test were run to determine the effectiveness of a single and group of stone and waste concrete columns in strengthening the soft clay. Factors such as, shape of supported footing, Stone column's diameter and spacing were studied. The existence of a single stone column under a footing causes the B_r to be increased by 19% and reduces the S_r by 50%. waste concrete column of (D=25 mm) causes the load carrying capacity of a footing to be increased by 25% over that of crushed stone column while it is increased by (45-65)% for (D=32 mm). Thus, waste concrete approved to be more effective and economical than crushed stones for constructing stone columns.**

Keywords—Stone Column; Soil; Waste Concrete

I. INTRODUCTION

Geotechnical design and implementation of engineering structures on soft soils are accompanied with substantial difficulties. Such soils suffer from poor engineering properties like low bearing capacity, excessive total and differential settlement, lateral spreading.

Ground improvement techniques can be adopted to provide a suitable and safe solution for the structures constructed on such difficult soils. Among several techniques for strengthening the ground conditions, the use of stone columns is frequently implemented in thick soft soil deposits, besides it is considered as a simple and economic method to support the compressible soils [1],[2],[3],[4],[5],[6], and [7].

Several researchers reported that the improvement of soft soil by stone columns is related to three factors. First is the replacement of the weak soil by a stiffer column material. Second is the densification of the surrounding soft soil during the installation of stone column. Third is the acceleration of the consolidation process, i.e. working as a vertical drains.

II. RELATED STUDIES

The influence of stone columns in strengthening soft soil was experimentally investigated by several researches. Hughes and Whithers [8] showed that the pattern of the vertical and radial deformation within the single stone column demonstrated that the bulging is limited to a depth of four times the diameter of stone column. Al-Mosawe et al. [9] concluded through a series of test model that treated soil reaches its ultimate bearing capacity at a vertical displacement of (60%) of the column diameter. Moreover, the most effective parameters are the diameter of the column and undrained shear strength of the soil. Ambily & Gandhi [10] investigated the effect of different parameters such as, spacing between the columns, undrained shear strength of the clay, angle of internal friction of the stone on the behavior of stone column. The stiffness improvement was found to be independent on the shear strength of the clay and depends mainly on column spacing and the friction angle of the stone. They also showed that columns arranged with spacing more than 3 times the diameter of the column does not give any significant improvement. Dipty and Girish [11] studied the influence of column material through laboratory experiments on model stone columns installed in clay. Five reinforcement materials were studied: stones, gravel, river sand, sea sand and quarry dust. It was found that stones are the most effective stone column material. The objective of this study is to investigate the effect of using waste concrete and crushed stone materials on the behavior of stone column constructed in soft soil.

III. TEST PROGRAM

A laboratory test was conducted on 26 models to investigate the behavior of stone column embedded in soft clay. Several variables were used during this work including:

- Material of column: two types of granular materials were used for the preparation of the columns, crushed gravel and waste concrete.
- Loading type and condition: the loads were applied incrementally until the rate of settlement (dial gauges reading) became 1.25mm/hr according to ASTM D 3689 – 90. Static loads were continuously applied until they reach the failure point. The failure point is corresponding to the settlement ratio (s/b) equal to (58-60) % [8], [9].

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- Spacing between stone columns: three spacing ratios (spacing/diameter = S/D) were used in this study, S/D=3, 3.5 and 4.
- Two diameters of column (D) were studied; D=25 and 32 mm. Footing's dimensions were assessed and manufactured based on the diameter and number of columns as shown in Figure (1). Each footing has two faces; the first was designed to assess the column print and location on the soil surface. The second is a smooth face required during the load application.

Table (1) summarized the testing program adoted for this study.

Table 1 Summary of the test program

Test no.	Dimensions		Area ratio Ar%	No. of column	Spacing Diameter S/D	Col. Material
	Footing (B*L) cm	Col. Diameter (D) cm				
1	7.5*7.5	----	0	----	----	----
2	9.6*9.6	----	0	----	----	----
3	17.5*17.5	----	0	----	----	----
4	17.5*7.5	----	0	----	----	----
5	5*5	2.5	19.635	1	----	Gravel
6	6.25*6.25	2.5	12.566	1	----	Gravel
7	7.5*7.5	2.5	8.7277	1	----	Gravel
8	7.5*17.5	2.5	7.4799	2	4	Gravel
9	7.5*17.5	2.5	7.4799	2	3	Gravel
10	17.5*17.5	2. 5	6.4114	4	4	Gravel
11	6.4*6.4	3.2	19.635	1	----	Gravel
12	8*8	3.2	12.566	1	----	Gravel
13	9.6*9.6	3.2	8.7277	1	----	Gravel
14	22.4*9.6	3.2	7.4799	2	4	Gravel
15	22.4*22.4	3.2	6.4114	4	4	Gravel
16	5*5	2.5	19.635	1	----	Waste conc.
17	6.25*6.25	2.5	12.566	1	----	Waste conc.
18	7.5*7.5	2.5	8.7277	1	----	Waste conc.
19	7.5*17.5	2.5	7.4799	2	4	Waste conc.
20	7.5*17.5	2.5	7.4799	2	3	Waste conc.
21	17.5*17.5	2. 5	6.4114	4	4	Waste conc.
22	6.4*6.4	3.2	19.635	1	----	Waste conc.
23	8*8	3.2	12.566	1	----	Waste conc.
24	9.6*9.6	3.2	8.7277	1	----	Waste conc.
25	22.4*9.6	3.2	7.4799	2	4	Waste conc.
26	22.4*22.4	3.2	6.4114	4	4	Waste conc.

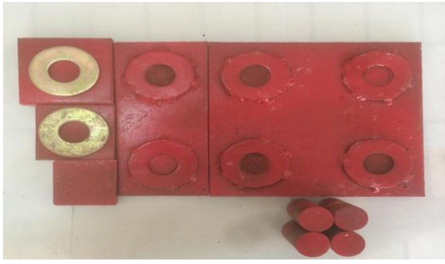

Figure 1. Different types of footings of shaft diameters (D=25 and 32 mm).

IV. Material Properties

A. Kaolinite

Kaolinite clay used to prepare the soil bed was submitted to routine laboratory tests .The physical properties results are shown in Table (2). The particles size distribution of the clay is shown in Figure (2). According to the unified soil classification system (UCSC), the soil is classified as a low plasticity clay (CL).

Table 2. Physical properties of Kaolinite

Physical properties	Index value	Standards
Specific gravity (G_s)	2.58	ASTM: D 854
Liquid Limit (L.L. %)	34	ASTM: D 4318
Plastic Limit (P.L. %)	21	ASTM: D 4318
Plasticity Index (P.I. %)	13	
Maximum dry unit weight (kN/m^3)	16.57	ASTM: D698
Optimum moisture content (%)	17.65	ASTM: D698
Soil Classification (USCS*)	CL	ASTM: D2487

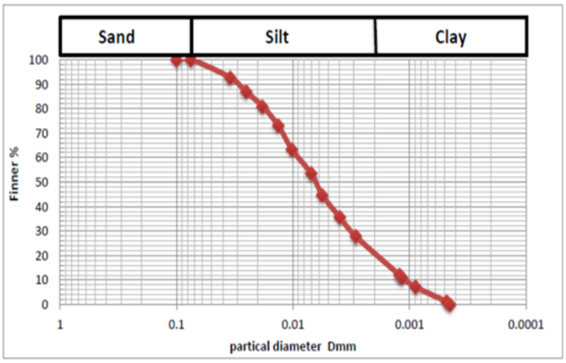

Figure (2). Grain size distribution of Kaoline

B. Crushed Stone

The crushed stone used in this study was brought from the crushed stone factory. Routine laboratory tests were done to investigate the properties of this material. A sieve analysis was conducted to achieve the limitation's requirement provides that the lower limit of gravel sizes 1/9 from the diameter of stone column while the higher limit was 1/7 for the crushed stone [12]. Table (3) shows the result of tests conducted on the crushed stone

C. Waste concrete

Waste concrete is a small grain product which result from crushing the concrete cubes and used as an alternative material for the crushed stone. These wastes were sieved in order to get a uniform size used in the crushed (gravel) stone size, and to

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achieve the same requirements used for crushed stone, i.e. the lower limit of gravel size is 1/9 of the diameter of stone column and the higher limit is 1/7,[12].
Several measurements were done to make a comparison between the gravel and waste concrete to find the equivalent density of the waste concrete. The equivalent dry density of the waste concrete that used in the test was 12 kN/m^3. The properties of the waste concrete are also shown in Table (3).

Table 3. The properties of gravel and waste concrete

Physical properties	Index value		Standards
	crushed stone	Waste concrete	
Maximum dry unit weight γ_{dmax}(kN/m^3)	16.86	12.6	ASTM D4253
Minimum dry unit weight γ_{dmin} (kN/m^3)	14.85	11.5	ASTM D4254
Specific gravity (G_s)	2.694	2.594	ASTM D854
Friction angle	41.62	54.077	ASTM D3080
Coefficient of curvature (C_u)	0.9	1.38	
Coefficient of gradation (C_c)	1.16	0.83	

D. Steel Boxes

Two steel boxes of dimensions (50*50*50) cm and (32*32*40) cm were made for the purpose of this program of tests. The depth and width of steel box were designed to achieve the specification requirement that limited the depth of the clay layer is (the length of column + 4 times the diameter of column) and the width of clay layer must be (the diameter of stone column + 4 times the diameter to the each edge),[8].

E. Loading Frames

A movable loading frame was manufactured to support a load of 300 kg. This frame was made from a square steel pipe (section area =5*5 cm) of a thickness 3mm and fixed to the box by steel bolts as shown in figure (3).

Figure (3). Large box with the frame loading

V. PREPARATION THE SOIL BED

After the assessment of the soil properties, the following steps can be adopted for the preparing the soil bed in the model box.
1. The clay was mixed gradually for 15 min with the amount of water required to achieve a water content (24-26) %.

2. A sand layer was first furnished at the bottom of the steel box to provide a drainage path for the water in the clay. The thickness of sand layers were (5 and 15) cm under clay layers of (40, and 30) cm respectively.

3. The soft clay was gradually spreaded inside the box with a layer of 5 cm thickness. Each layer was compacted by 15 blows using a special hammer of 20 kg in weight.
The soil was placed inside the box in 6 layers for column diameter D = 25mm, and in 8 layers for column diameter D = 32mm.

4. As the soil bed reaches the required level, a total weight of (480 kg) was applied at the soil surface in four equal increments to simulate the consolidation process. Each increment (120 kg) was left for 1 day while the last one left for 3 days, so the total consolidation time was 6 days.

VI. TEST PROCEDURE

The test procedure for both cyclic and static load on stone column and boring the hole as follow:
1- Remove the applied load at the soil surface that used for the consolidation process.

2- An electrical vane shear apparatus was inserted inside the soil body at three to four different places. The vane was pushed to a depth of 6.5 cm when using stone column or waste concrete column with diameter 25 mm while the depth of vane reached 8 cm (half depth of the column) for a diameter of 32 mm.

3- After assessing the location of columns and footing, the soil was bored with a hand auger to the required depth. The depths of boring were 12.5 cm and 16 cm for diameter of columns 25mm and 32mm respectively. The hole is then filled with crushed stone or waste concrete materials in five equal layers. Each layer was compacted by 10 blows to reach the desired density.

4- After leveling the soil surface, the footing was located at the projected area mentioned in point 3 above.

7- The frame was fixed and two or four dial gauges were inserted depending on the footing's dimensions used in each test. The stone columns were then loaded until the end of the test.

VII. ANALYSIS OF THE EXPERIMENTAL RESULTS

The analysis of results of model tests is presented here regarding to the bearing ratio versus the settlement ratio. These two parameters are defined in the equations below:
Bearing ratio ; $B_r = q / cu$ …………………. (1)

Where q = applied stress (kN/m2) and cu = undrained shear strength of soil (kN/m2)

Settlement ratio ; $S_r = s / b$ …………………. (2)

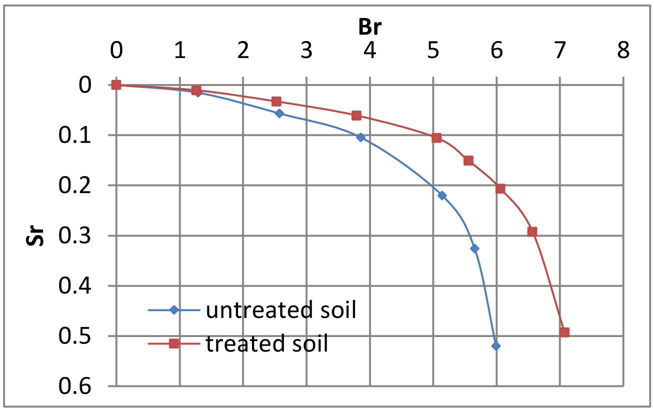
Where s = settlement (cm) and b= width of the footing (cm).
Another parameter was considered here to evaluate the effect of the stone column in increasing the bearing capacity of soft soil and decreasing the settlement. This parameter is the bearing improvement ratios which is defined as

$I_r = B_{rt}/ B_{r\ unt}$ ……………..……… (3)

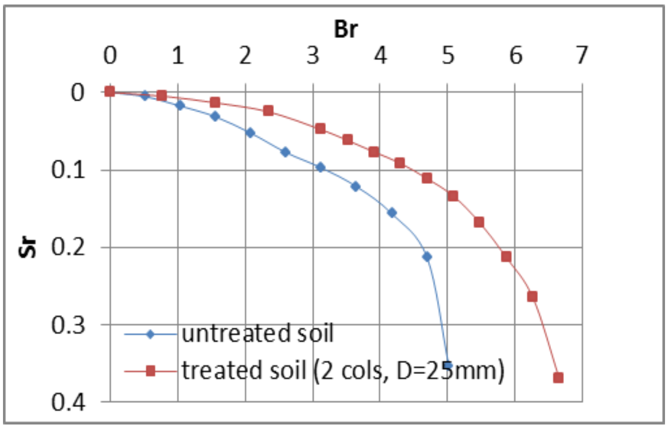
Where B_{rt} = bearing ratio of soil treated with stone column and Brunt= the bearing ratio of the untreated soil.

VIII. Soil treated with crushed stone column

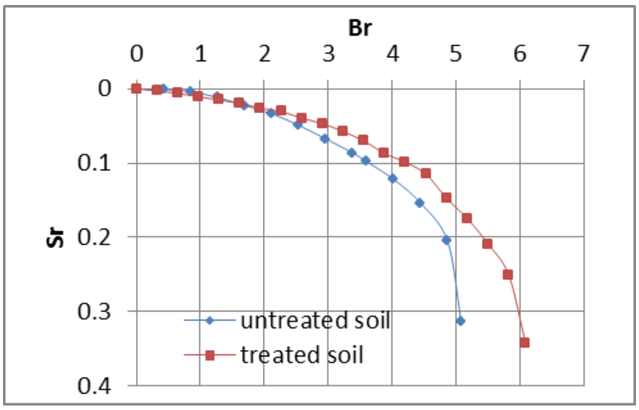
Figure (4) shows the effect of number of stone columns (D=25 mm) on the B_r vs S_r relations. The existence of a single stone column under a footing causes the B_r to be increased by 19% and reduces the S_r by 50%. A lesser effect for the stone columns is noticed with increasing their number.



A (single column, A_r=19.535%)



B (2 columns, A_r=7.4998% S/D=4)



C (4 columns, A_r=6.4114%, S/D=4)

Figure 4. B_r vs S_r for untreated and treated soil with crushed stone column (D=25 mm)

The effect of spacing ratio (S/D) on the bearing ratio B_r is shown in figure (5), where S is the spacing between stone columns and D is the column's diameter. Reducing the spacing between stone columns leads to increase the resistance of treated soil. The passive earth pressure generated from the bulging of stone columns increases the soil strength and reduces the lateral deformation under an applied load. The optimum ratio seems to be (S/D=3) which is compatible with Ambily and Gandhi [10].

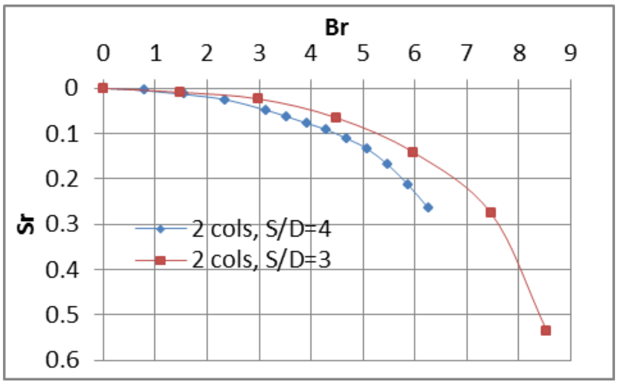


Figure 5. B_r vs S_r for soil treated with crushed stone column of different spacing ratios (D=25 mm)

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Figures (6) and (7) show the effect of area ratio on strength of treated soils. The area ratio is defined

$A_r = A_s / A$ ……………………. (4)

Where A_s = area of stone column, A = total area of the unit cell (A_s +A soil).

It is evident that increasing the area ratio leads to increase B_r and reduce S_r which is agreed with Madhav et al., [13]. A substantial improvement in the soft soil characteristics is noticed as the A_r = 19.63% at which the B_r is increased by 40% and S_r is decreased by 27%. Increasing the column's diameter causes a larger improvement as shown in figure (7) which is compatible with Al-Mosawe et al., [9].

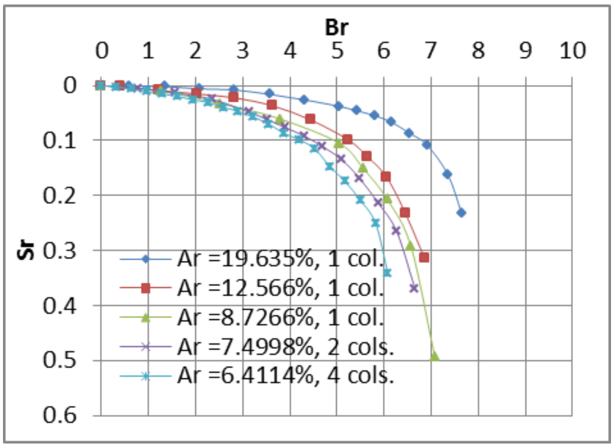

Figure 6. B_r vs S_r for soil treated with crushed stone column of different area ratios (D=25 mm)

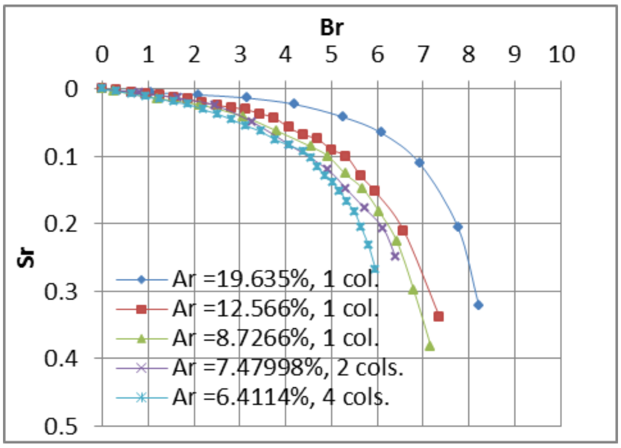

Figure 7. Br vs S_r for soil treated with crushed stone column of different area ratios (D=32 mm)

X. SOIL TREATED WITH WASTE CONCRETE COLUMN

Figures (8) and (9) show the effect of using waste concrete column under a footing. A significant improvement in load carrying capacity is noticed with using waste concrete instead of crushed stone in replacing a soil column.

Figures (10) and (11) show that the maximum bearing improvement ratios (I_r) appears at S_r ranges from 0.05 to 0.07 irrespective of the column's diameter.

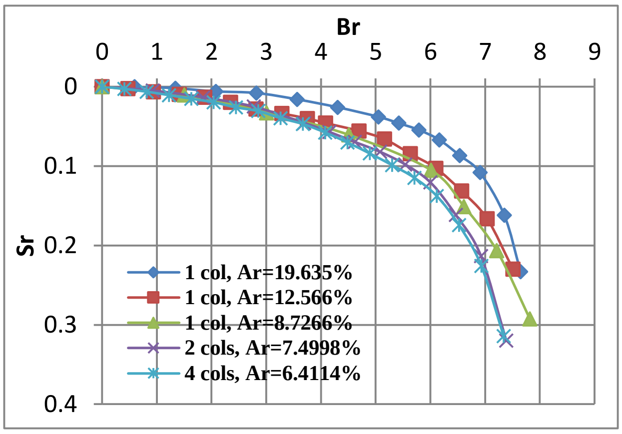

Figure 8. B_r vs S_r treated soil with waste concrete column for different area ratios (D=25 mm)

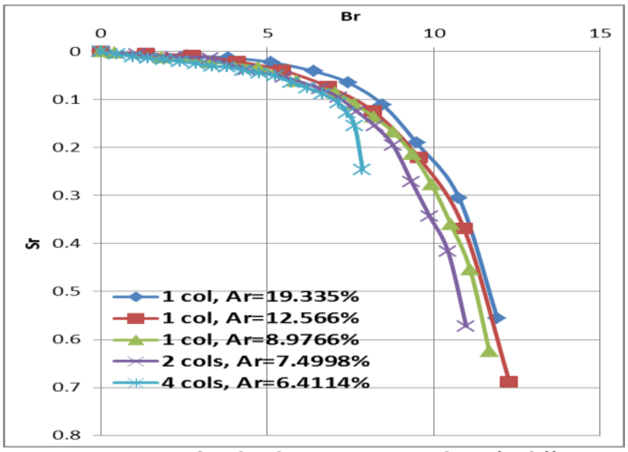

Figure 9. Br vs S_r treated soil with waste concrete column for different area ratios (D=32 mm)

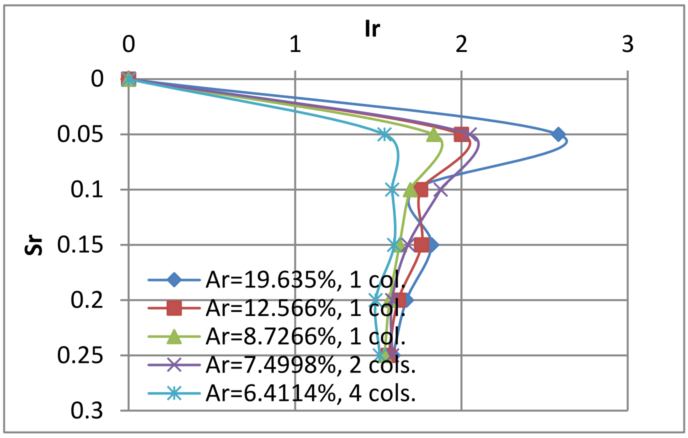

Figure 10. I_r vs S_r for soil treated with crushed stone column of different area ratios (D=25mm)

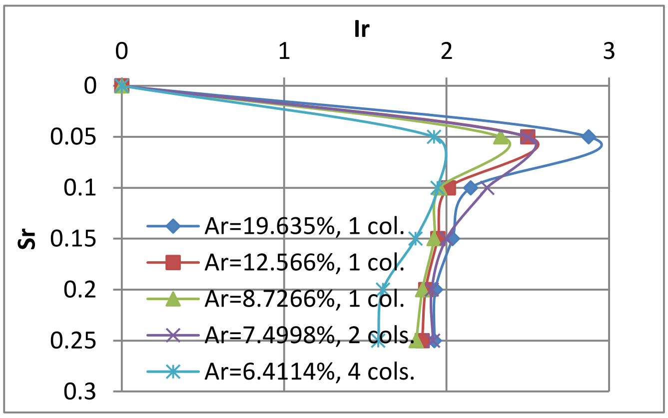

Figure 11. I_r vs S_r for soil treated with crushed stone column of different area ratios (D=32 mm)

XI. Comparison between Stone and Waste Concrete Column

Figures (12) and (13) show the I_r vs S_r for these two materials in improving soft soil.

The bearing improvement ratio (I_r) here is defined as the bearing ratio for soil treated with waste concrete column to that treated with crushed stone column which is finally equal to **(q_{waste}/ q_{stone})**. It is obvious from figure (12) that the waste concrete column of (D=25 mm) causes the load carrying capacity of a footing to be increased by 25% over that of crushed stone column while it is increased by (45-65)% for (D=32 mm) as shown in figure (13).

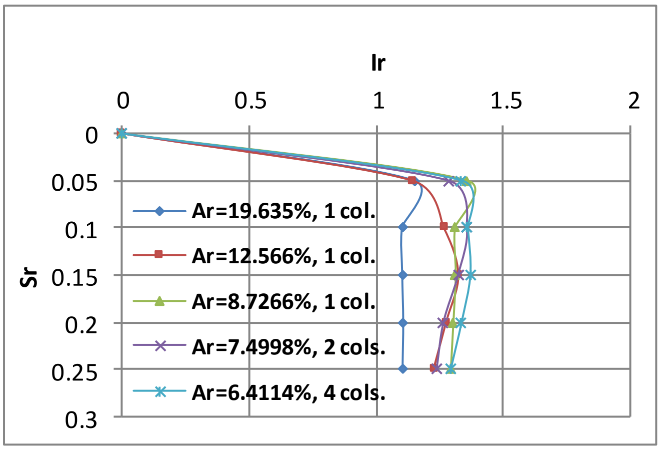

Figure 12. (**q_{waste}/ q_{stone}**) vs S_r for soil treated with crushed stone column of different area ratios (D=25 mm)

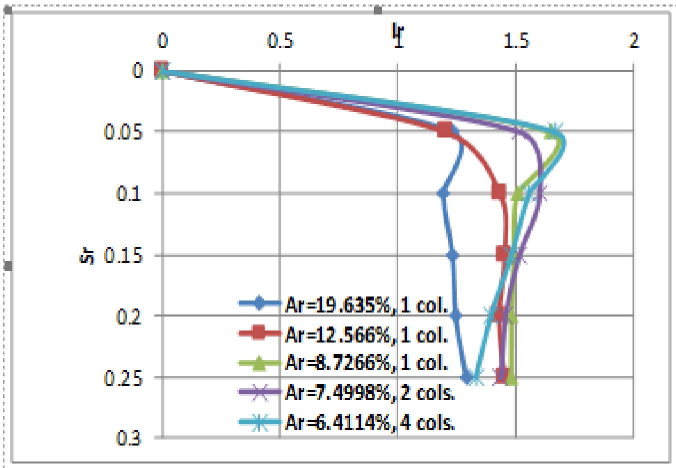

Figure 13. (**q_{waste}/ q_{stone}**) vs S_r for soil treated with crushed stone column of different area ratios (D=32 mm)

From the experimental work and reliability analysis carried out, the following points have been concluded:

[1] Stone columns cause a considerable improvement in the load deformation characteristics of soft clay.

[2] The existence of a single stone column under a footing causes the B_r to be increased by 19% and reduces the S_r by 50%.

[3] Reducing the spacing between stone columns leads to increase the resistance of treated soil.

[4] A substantial improvement in the soft soil characteristics is noticed as the Ar = 19.63% at which the B_r is increased by 40% and S_r is decreased by 27%.

[5] waste concrete column of (D=25 mm) causes the load carrying capacity of a footing to be increased by 25% over that of crushed stone column while it is increased by (45-65)% for (D=32 mm).

[6] Waste concrete approved to be more effective and economical than crushed stones for constructing stone columns.

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