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EFFECT OF REPLACING CRUSHED STONE IN STONE COLUMNS BY WASTE MATERIAL ON SOIL IMPROVEMENT RATIO

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Many researchers' studies have shown that stone column is the best material to use to improve the bearing capacity of clayey soils. There are millions of waste volumes resulting from daily human activities. This excess waste leads to disposal problems and also causes environmental contamination and health risks. Demolished concrete is such one waste material that is produced from building demolition in Baghdad, Iraq. This paper describes experimental work conducted at the University of Technology that was carried out to investigate the improved bearing capacity of soft clay using crushed stone, followed by replacing crushed stone with concrete waste with the same relative density and grain size. The replacement was carried using waste concrete with different percentages corresponding to 25%, 50%, 75%, and 100%. The main conclusion drawn is that the bearing capacity increased to 119% by using crushed stone column, while the bearing capacity increased to 155% by using 100% of crushed concrete waste.

Keywords: Demolition recycled concrete, Bearing capacity, Soft clay, Settlement ratio.

1 INTRODUCTION

Stone columns usually consist of compacted gravel or crushed stone arranged with specific densities. The size of a soil's grain is considered as the main parameter in a stone-column's design. Hence, the influence of a stone column was studied for performance through conducting experiments in the lab using a model of stone column embedded in a clay layer, using five reinforcement materials: stone, river and sea sand, and quarry dust. The main conclusion drawn was that stones are more effective than other materials (Dipty and Girtish 2009). Stone column is the most well-known technique for improvement of soft soil; the main principle is that replacing the soft soil with vertical columns of compacted aggregates will turn the soft soil into a compound material with higher shear strength and low compressibility (Murugesan and Rajagopal 2009). Nayak (1983) suggested that the size of the crushed stone should range from 1/6 to 1/7 diameter of the column. The mechanism and the performance of stone columns are due to the composite material, which gives a great reduction in the compressibility and at the same time gives a higher increases in the shear strength compared to the in situ soil. The surrounding soil provides the lateral confinement for the insitu stiffness of the stone coumns. The application of an applied load at the top of the stone-column causes a lateral expansion that in turn increases additional confinement for the stone column by the surrounding clay. The equilibrium state is reached, resulting in a reduction in vertical displacement (Greenwood 1970, Hughes and Withers 1974).

In general, the improvement of soft clay using stone columns is due to the following points:

1. The implication of a stiffer column material (such as stone, gravel, etc.) in soft clay.
2. The densification of surrounding soft soil during the installation of the stone column.

3. The stone column and gravel column will be as drains and accelerate the drainage of water and acelerate consolidation process of soft clay.

There are millions of waste volumes that result from daily human problems, which leads to disposal problems and also causes environmental contamination. This study analyzed whether locally available waste material could be used as filler material for a stone column.

2 MATERIALS USED

2.1 The Soil and Crushed Stone

The soils were brought from a site in Baghdad. Standard tests were performed to determine the physical properties of soil. Details are given in Table 1. The grain size distribution of soil and stone used are shown in Figures 1 and 2 respectively.

Table 1. Physical properties of the soil used.

Index properties	Index value
Liquid Limit (L.L.)	43%
Plastic Limit (P.L.)	19
Plasticity index (P.I.)	24
Specific gravity (Gs)	2.67
Gravel % $> 4.75\ mm$	3
Sand % , 0.075-4.75 mm	35
Clay % $< 0.005\ mm$	62%
D85 mm	0.018
D60 mm	0.0036
Activity	0.39
Classification (USCS)	CL

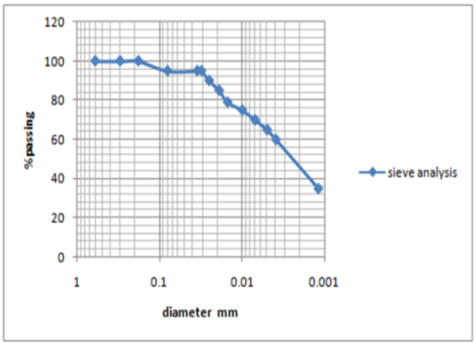

Figure 1. Grain size of soil used.

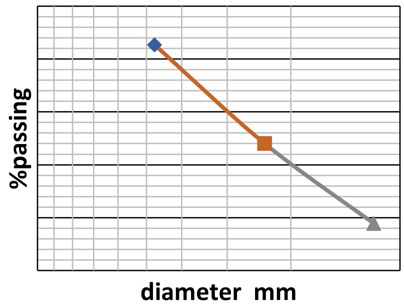

Figure 2. Grain size of crushed stone used.

2.2 Recycled Concrete

Concrete is one of the most widely used construction materials in the world, so the use of waste concrete can minimize the environmental impact and slow the huge consumption of natural resources utilized for different applications (Hansen and Narud 1983). The recycled concrete used was brought from demolished buildings in the Baghdad area in Iraq. There is no available data on the age of the buildings; however, the construction of most old buildings in that region took place 20–40 years ago. Large amounts of construction debris were brought to the Laboratory and broken by laborers into pieces with a size less than 50 mm. The stone was crushed into pieces and then sieved. The particle size distribution of recycled concrete is similar to the particle size distribution of normal stone.

3 PREPARATION OF MODEL TEST

3.1 Soil Bed Preparation

The work conducted on soil with Cu = 16 kPa. To achieve the desired consistancy, the soils were dried, mixed with water, and kept inside tightened polythene bags for two days to get uniform moisture content. After that, the soil was placed in a steel container, 300 x 300 x 350 mm, in five layers; each layer was leveled using the wooden tamper, then the leveled layer was tamped gently with a wooden hammer of 3 kg, having dimensions of 300 x 350 mm, to remove any entrapped air. The soil bed preparation is shown in Figure 3.

Figure 3. Process of preparation of bed of soil.

3.2 Installation of Crushed Stone Column

The construction of the stone column started directly after the preparations of the soil bed. The depth of the stone column was chosen corresponding to L/d=6. A pipe (PVC) with an external diameter of 50 mm was pushed down the bed to a required depth. A hand auger was used to remove the soil inside the pipe and the PVC pipe was removed with care. The stone was charged into the hole in five layers and compacted to achieve a density of (15.6 kN/m^3). After that, the pipe was slowly raised. Figure 4 shows the process of stone column installation while Figure 5 shows the loading process using 60 x 60 x 6 mm steel footing.

4 MODEL TEST RESULT OF TREATED AND UNTREATED SOIL

In this study, the model tests are classified into the following categories.

1. The first test is a footing placed on the soft saturated soil bed without treatment.
2. The second test is a footing placed on the soft saturated bed with the stone column.
3. The third test replaced the crushed stone with waste concrete using the following percentages:
   a. Using 75% crushed stone and 25% waste concrete.
   b. Using 50% crushed stone and 50% waste concrete.
   c. Using 25% crushed stone and 75% waste concrete.
   d. Using 100% waste concrete.

For all model tests, and as proposed by Terzaghi (1947), the ultimate pressure is defined as the stress required to cause settlement corresponding to 10% of the footing width.

4.1 Bearing Improvement Ratio Versus Settlement Ratio

The improvement ratio of bearing capacity can be calculated by using the Eq. (1):

$$\text{Improvement in bearing capacity} = \frac{q_{\text{treated}}}{q_{\text{untreated}}} \qquad (1)$$

Figure 4. Stone column installation.

Figure 5. Loading process.

4.2 Settlement Reduction Ratio Versus Bearing Ratio

The settlement can be calculated by using the Eq. (2):

$$\text{Settlement reduction ratio} = \frac{S_{\text{treated}}}{S_{\text{untreated}}} \qquad (2)$$

Figure 6 represents the relationship between the bearings ratios plotted against the settlement ratios for treated and untreated soil using crushed stone only. The results show that there is an increase in bearing capacity ratio for soil improved with a stone column compared with untreated soil. The increment approaches 119% using crushed stone columns.

Figure 7 illustrated the bearing ratios and the settlement ratios for treated and untreated clay soil using crushed stone and replacing the crushed stone with a different percent of concrete waste. The values of the increase in bearing capacity by using different percent of waste concrete are summarized in Table 2. It is clearly shown that the maximum improvement ratio was achieved by using 100% waste concrete. It can be ascertained that by inserting crushed stone, or by replacing the stone column with waste material, an increase in bearing capacity can result. That should not be considered as just a replacement operation, but that it can influence both material properties and state of stresses in treated soil mass (Guetif *et al.* 2007). Table 2 shows that using concrete waste causes an improvement in the bearing capacity, and that concrete waste obtained from the construction waste has the potential to be used in the stone column. With 100% crushed concrete used to replace crushed stone resulted in a 155% increase in bearing capacity; this resulted from the good properties of waste concrete and the powerful bonding between old mortar and low porosity. Using crushed concrete from demolition waste instead of natural materials like crushed stone on the large scale may make a significant contribution to preserving natural resources and to the reduction of the demolition waste (Karin *et al.* 2003).

Table 2. The change in bearing capacity by using crushed stone and different percent of waste concrete.

Type of calculation	Bearing Ratio	Bearing Capacity (kPa)	% increase in Bearing Capacity
Clay only	---	3.1	---
Stone Column	2.2	6.8	119
75% Stone and 25% waste concrete	1.42	4.4	42
50% Stone and 50% waste concrete	1.55	4.8	55
25% Stone and 75% waste concrete	2.52	7.8	152
100 concrete waste	2.55	7.9	155

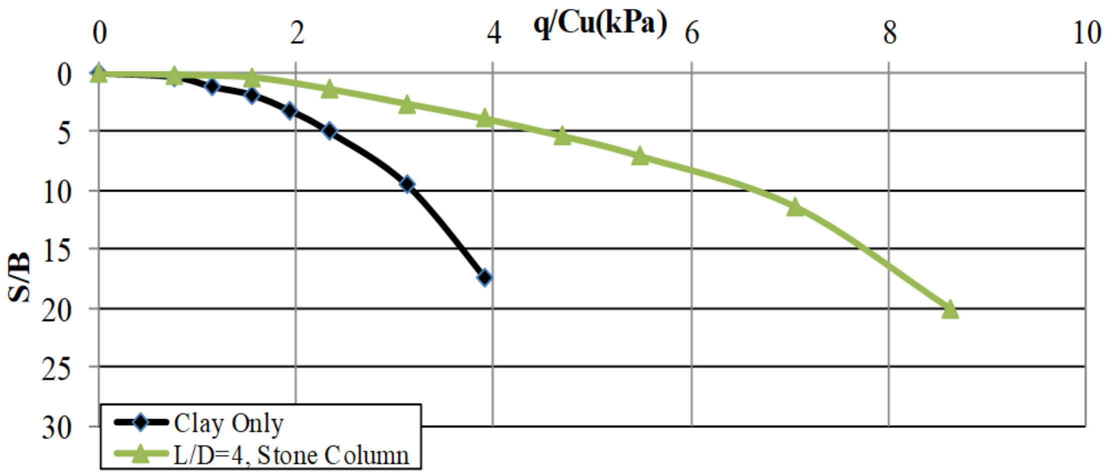

Figure 6. Bearing -- Settlement ratio for model tests for treated and untreated soft clay.

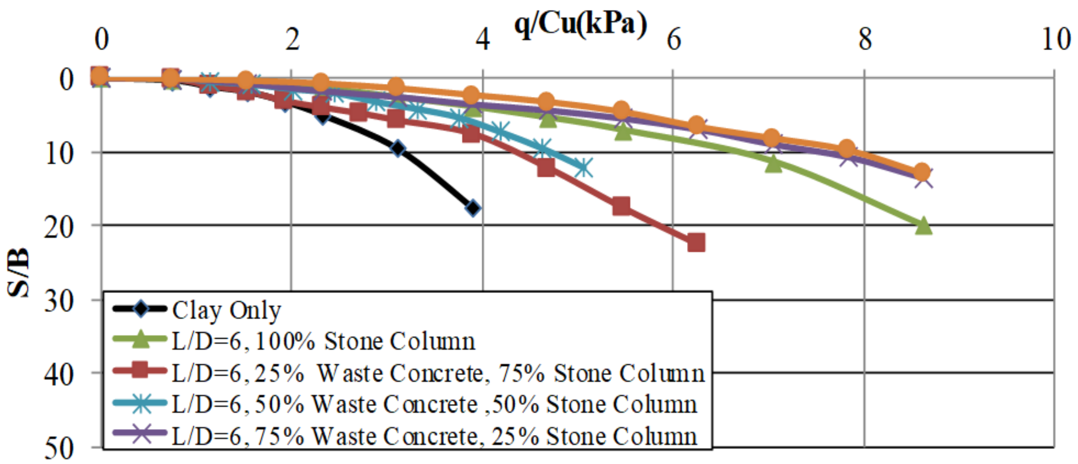

Figure 7. Bearing – Settlement ratio for model test using stone only and replacing the stone with different percentages of concrete.

5 CONCLUSIONS

The study was conducted to analyze whether locally available materials could be used as filler material for stone columns. The following results were obtained:

1. Among the different percentages of replacement tested, using 100% crushed concrete, the bearing capacity increased by approximately 155% while using the stone only caused an increase in bearing capacity of only 117.7%.
2. We recommend that using 100% crushed concrete is quite suitable for soft soil improvement.
3. In conclusion, recycling waste demolition in stone column production may assist resolve a vital environmental problem.

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