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Evaluating the effect of using shredded waste tire in the stone columns as an improvement technique

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HIGHLIGHTS

- Utilizing tire wastes in geotechnical applications is a reasonable way to reduce stockpiles of disposed tires.
- Shredded waste tires can be used as a partial substitution for stone column materials.
- Using long planar shape tire shreds improves the axial bearing capacity of stone column by 30%.
- Results lead to reusing tire waste, improvement in stone columns performance and a decrease in construction costs.

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ABSTRACT

In this paper, shredded waste tires are used as a substitution for gravel materials and their effect on stone column's behavior is investigated. An experimental study is carried out on three sizes of tire shreds, including "Fine tire", "Medium tire", and "large tire". The medium-sized tire shred has the same size as the gravel materials and the other sizes are selected smaller and larger. Thirteen series of large scale direct shear, large oedometer, and constant head permeability tests are carried out in three different volumetric mixture proportions of gravel and tire shreds. The results of the large scale direct shear box and large oedometer tests show an increase in the loading capacity of stone columns for 20% of tire content, however, for tire mixing ratios greater than 20%, the loading capacity of stone column is reduced. Furthermore, 20% of medium-sized tire shreds enhances the loading capacity by 30% and 15%, respectively, with no significant change in permeability. Therefore, it is concluded that the best performance of gravel tire shred admixture is achieved by the medium-sized tire shreds. Eventually, utilizing tire shred as partial replacement for gravel materials is an economic way to enhance the loading capacity of stone columns and also to solve environmental problems.

1. Introduction

The aim of this study is to use tire shreds and tire crumbs as an alternative material for stone column construction. Tire waste disposal is an environmental issue in the industrialized countries around the globe. The huge amount of stockpiles of tire waste and consequent environmental problems of their disposal, increased the necessity of investigating new applications for these waste materials. Due to the unique properties of tire such as low density, high strength, hydrophobic nature, and high frictional strength, it has gain interest as a valuable engineering resource [1]. Geotechnical engineering has a great potential to reutilize tire wastes and take advantage of their characteristics in order to prevent environmental problems. Tire shreds have been successfully used for road embankment [2], improvement of slope stability [3], drainage layer and etc.

A great deal of research has put forth effort to investigate new applications of tire wastes. According to Rao and Dutta's [4], the CU triaxial test results of sand and tire shreds mixtures with 20% tire content sustains higher stress values compared to pure sand. Tuncan's [5] studied tire-sand mixtures and showed that adding tire shreds to asphaltic concrete leads to a reduction in cracks expansion. Foose et al. [6] reported a friction angle of 30° in a 305 mm direct shear test for tire shreds with the size of 50–150 mm. Vinot et al. [7] reported a 3°–6° increase in the friction angle value and the optimum tire content was estimated to be%30. Utilizing tire wastes for soil improvement is another application of these waste material in geotechnical engineering. Among soil improvement techniques, stone column is one of the most

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Nomenclature

σ_{ro}	Total in situ lateral stress (initial)	G_s	Specific gravity of gravel
E_c	Elastic modulus of the soil	V_d	Direct shear box volume (total volume)
C	Undrained shear strength	V_t	Tire content volume as a fraction of total volume
ϑ	Poisson's Ratio	V_s	Gravel volume as a fraction of total volume.
D_r	Relative density	LL	Liquid Limit
$\gamma_{dmatrix}$	Matrix density	PL	Plastic Limit
γ_{dmin}	Minimum density of gravel	PI	Plastic Index
γ_{dmax}	Maximum density of gravel	D10	Effective grain size
G_L	Specific gravity of tire content	D50	Medium grain size

well-known and cost effective techniques. Stone column improves the strength and deformation capacities of the soft soil by acting as a reinforcement and a drainage element [8]. This technique is suitable for flexible structures such as road embankments and storage tanks and is mostly installed on loose sand or soft marine clay [9]. Many researches studied the load transfer mechanism of stone columns [10–13]. Some researches have investigated stone columns as liquefaction countermeasures through field experiments [14–17] and numerical studies [8,18]. Hughes and Withers [11] estimated the ultimate loading capacity considering bulging failure for a single column and using elastic-plastic theory. Many studies investigated methods to enhance stone column stiffness through encasing [19–23] or inserting nails or steel bars [24,25]. Ayothiraman et al. [26] investigated tire shreds as an alternative material for stone columns. They replaced 20%, 40%, and 60% of gravel with tire chips. It was observed that replacing 20% of gravels in stone column with tire chips leads to the highest axial bearing capacity.

In this study, a series of large scale direct shear box tests are carried out to investigate the effects of adding tire shreds on mechanical properties and deformation of stone columns. For this purpose, three sizes of tire shreds including "Fine tire", "Medium tire", and "large tire" are considered to investigate the influence of tire size. Furthermore, tire contents of 20%, 40%, and 60% are selected to study the effects of different mixing ratios. Specimens are placed in a large Oedometer with the stone column in the center and the soft soil surrounding the stone column. Finally, by using the constant head test method, the permeability of each tire-gravel mixture is calculated.

2. Experimental program

2.1. Materials

2.1.1. Shredded tire and stone column gravel materials

The shredded tire used in this study is provided by Azar-Sum Company. Three sizes of tire shreds are selected, including granular "Fine", planar "Medium", and cubic "large". Tire shreds are graded using standard sieves and their corresponding categories are shown in Fig. 1. Edincliler et al. [27] classified tire waste products with respect to their size and processing technique into four categories: tire chips, tire shreds, tire buffings, and tire crumb. According to Edincliler et al. [27], shape and processing technique of the tire influences the mechanical properties of the soil-tire mixtures. In this study, fine tire is classified as tire crumb and medium and large tires are classified as tire chips with no wire. Specifications of rubber used in this study is shown in Table 1.

ASTM D854[28] is used to determine the specific gravity of fine tire shreds. On the other hand, ASTM C127[29] is used for determining the specific gravity of gravel and the other sizes of tire shreds. The specific gravity of tire shred and gravel are 1.1 and 2.65, respectively. Note that gravel is graded similar to medium tire.

2.1.2. Soil

Stone column is one of the improvement methods for fine clayey soils. The stone materials act as the reinforced element and drainage system in the fine soil. According to Fig. 2, in this research, a fine clayey surrounding soil is selected to model the stone column behavior. ASTM D422 [30] and D4318 [31] are used to determine the physical properties of the soft soil, including the particle size distribution, Atterberg Limit, and plasticity index (PI). The properties of the soil and particle size distribution are presented in Table 2 and Fig. 3.

2.2. Sample preparation

For the sake of convenience, mixtures of tire shreds and gravel are hereinafter referred to as a combination of the tire size, gravel, and the percentage of tire volume. Each sample is named with three symbols, XGZ where X represents the size of tire content, G represents gravel in the mixture and Z represents tire content percentage. For example, FG20 refers to a mixture with %20 of fine tire shreds content, while G00 refers to a mixture without any shredded tire. Manufactured samples and percentage of tire volume for each sample are given in Table 3. In this study, tire contents of 20%, 40%, and 60%, are selected based on the study conducted by Ayothiraman et al. [26]. In samples preparation process, gravel and tire contents are selected in a manner to obtain a target relative density of 75% for all samples. For each mixture, the minimum and the maximum densities are calculated in accordance with ASTM D4253 [32], D4254 [33]. To estimate the weight of stone aggregates and tire content, Eqs. 1–3 are used. In Eq. (1), matrix density is assumed in order to obtain the desired relative density.

$$D_r = \left(\frac{\gamma_{dmatrix} - \gamma_{dmin}}{\gamma_{dmax} - \gamma_{dmin}}\right)\left(\frac{\gamma_{dmax}}{\gamma_{dmatrix}}\right) \tag{1}$$

$$\gamma_{dm} = \frac{W_s}{V_t - V_l\frac{G_l}{G_s}} = \frac{W_s}{B \times L \times h - V_l\frac{G_l}{G_s}} \tag{2}$$

$$W_l = \left(R\frac{G_L}{G_S}\right)W_s \tag{3}$$

Where, D_r is the relative density and $\gamma_{dmatrix}$ denotes the matrix density. γ_{dmin} and γ_{dmax} refer to the minimum and maximum density of gravel, respectively. G_L and G_s, represent the specific gravity of tire and gravel, respectively. In addition, V_t is the direct shear box volume (total volume) and V_l is the tire content volume as a fraction of the total volume.

2.3. Tests

2.3.1. Direct shear test

The gravel-shredded tire mixtures with tire contents of 0%, 20%, 40%, and 60% with three sizes of tire shreds are manufactured and their shear resistance are determined using direct shear test. Large-scale direct shear device with the dimensions of 30 cm × 30 cm × 15 cm is used to evaluate the shear strength of gravel-shredded tire mixtures. This testing machine facilitates testing the larger sample particles of shredded tire according to ASTM D3080 [34]. Fig. 4, shows the test setup including large direct shear test apparatus, LVDTs, computer, and data logger system that are used in this research.

Compaction of the mixtures is conducted by using a plastic hammer to hit the steel plate placed on top of the specimen until it reaches the target unit weight. Direct shear test are carried out using normal stresses of 20, 50, and 100 kPa. Note that the vertical deformation of the specimen is recorded by using an LVDT, installed on the top of the upper shear box. Furthermore, a shear rate of 2 mm/min is selected according to ASTM D3080 [34]. The test is stopped when the shear force becomes constant or the shear displacement reaches 30 mm or 10 percent horizontal strain is obtained.

2.3.2. Bearing capacity test

In this investigation, a large oedometer testing device with the diameter of 500 mm is used to evaluate the bearing capacity of gravel-shredded tire mixture. This device is designed and constructed in Geo-Environmental laboratory of Iran