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Fine-grained sand reinforced with granulated tire chips

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Abstract--Ideology of Utilizing waste tires as a material to reinforce sand has been developed recently. Waste tire properties such as flexibility, tensile strength and durability are suitable to use them in engineering applications. Alsodifficulties like fire hazard, environmental contamination occurred by waste tires are the other reasons to explore a way to reuse them in a beneficial manner. Soil used in this study is Babolsar (North of Iran) fine-grained sand. This paper aims to investigate effects of granulated tire chips with sizes in the ranges of 4 to 9 mm on the bearing capacity of sand. For this, a series of model footing tests were conducted on the reinforced sand at relative density of 55%. Sand was reinforced with different tire chips contents 5, 6,7,8,10 and15% by weight.Highest bearing capacity ratio (Ratio of bearing capacity reinforced sand to unreinforced sand) was attained 1.56 with tire chips content of 10% that this amount of tire chips named optimum percentage of tire chips. Stress – settlement graphs showed decrease in settlement of footing by using tire chips that lowest settlement was happened in optimum percentage of tire chips.To investigate the optimum reinforced depth for sand containing optimum tire chips, a few tests were done. Result indicated optimum reinforced depth is 1B (B is the footing width).

Keywords*: Tire chips, Model footing test, Bearing capacity*

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1 Introduction

Nowadays, by increase in population and development of vehicles, censuses indicate higher amount of waste tires. Increase in quantity of waste tires correlate with environmental hazards so for using them in civil engineering applications, studies have been done to investigate different characteristics of tire chips.

Shear behavior of sand – rubber chips mixture with dimensions between 12.5-50 mm were studied for the first time by Ahmed [1] in different lateral pressures in triaxial test. Effects of grain size distribution, density method, contend of rubber-chips, lateral pressures were investigated. Results showed confine pressures and weight ratios of rubber-chips are effective parameters to the shear strength of mixtures containing sand and tire chips. Among the axial test done in this research,Ahmed found optimum tire chips content in 35% rubber-chips by volume.

Based on triaxial test, Zorenberg et al. [16] conducted triaxial shear tests on the mixtures having rectangular tire chips. The highest shear strength occurred under low confining pressure in 35% rubber-chips by weight. Like Zorenberg, Rao and Dutt [15] investigated effect of rectangular tire chips on sand characteristics. They found tire chips have length to width ratio of 2 with content of 20% by weight cause the highest increase in shear strength of sand.

Mahmood Ghazavi and MasoudAmelSakhi[9] determined optimum size of rectangular rubber – chips with width of 2, 3, 4 cm having various length for each width. Three weight percent of rubber-chips15%, 30%, 50% were used in the shear direct tests. In this research, sand and tire chips were blended to achieve uniform mixture. Specimens compacted in three layers to reach a specified density. Samples in direct shear test were sheared under three normal stress of 9.8, 39.2, 98.1 kpa. It was observed by increasing in amount of tire chips, shear strength increases. Mohr-Coulomb envelope were nonlinear and whatever percentage of rubber-chips increases, nonlinear behavior of Mohr-Coulomb envelope becomes more clear. In this study optimum lengths for rubber-chips having width of 2, 3, 4 cm were gotten 10, 12, 8 cm respectively.

Also Christ and Park [6] and Marto et al. [13] investigated shear behavior of sand reinforced with tire chips by conducting direct shear tests. They concluded use of tire chips as a reinforcement material causes improvement in tensile and shear strength of sand.

Yoon et al. [17] carried out plate load test on sand reinforced with tire chips at different relative densities such as 40, 50, 70%. At depth reinforcement 0.2 times of width of plate, bearing capacity ratio was observed 2.5. However, the ratio of bearing capacity reinforced sand to pure sand became lower as relative density increased.

Masad et al. [12] investigated the effect of granulated tire chips on shear behavior of sand. Granulated tire chips having maximum size of 4.75 mm were used. Tests were carried out on mixtures containing 50% tire chips by volume at relative density of 90%. Results done at confining pressure in the ranges of 150 to 350 kpa were studied. Contrary to previous studies on sand – tire chips mixtures, no shear strength was observed. Similar to Masad et al. [12], Youwai and Bergado [18] faced to reduction in shear strength o sand reinforced by granulated tire chips having average size of 5 mm.

Fooseet al. [8] conducted large-scale directs hear tests on mixtures of rysand and shredded was tetires. For the majority of their tests, a peak shear stress was not observed. Instead, the shearstresscontinuedto increase throughout the test. They reported the shear stress at a horizontal displacement of 2.5 cm as the shear strength for specimens with nopeakshear stress.

Ahmed [1] carried out compaction tests on sand-tire chips mixtures. He investigated the effects of specimen preparation, the method of compaction and sizes of tire chips on compressibility of sand-tire chips mixtures. He found that the content of tire chips considerably affects the compressibility of mixtures. However, the effect of compaction method on compressibility of mixtures is insignificant. Edil and Bosscher [7], Bosscher et al. [5] and Humphrey et al. [10] reported high initial plastic strain of sand-tire chips mixtures under loading due to considerable voids of mixtures.

In geotechnical projects, it's important to consider impression of waste tires to environment. Humphrey et al. [11] studied the effect of tire-chips fills placed above the groundwater table. The results of research showed that inorganic substances can potentially leach from tires were at low levels in groundwater.

2 Materials

In this research, Babolsar fine – grained sand was passed through 1 inch grain-size sieve. The particle size distribution for Babolsar sand is indicated in Fig.1 and also effective size (D_{10}), mean size (D_{50}) and other engineering properties of the sand are listed in Table 1 and Table 2. By considering of sand characteristics, it can be concluded that it is SP.

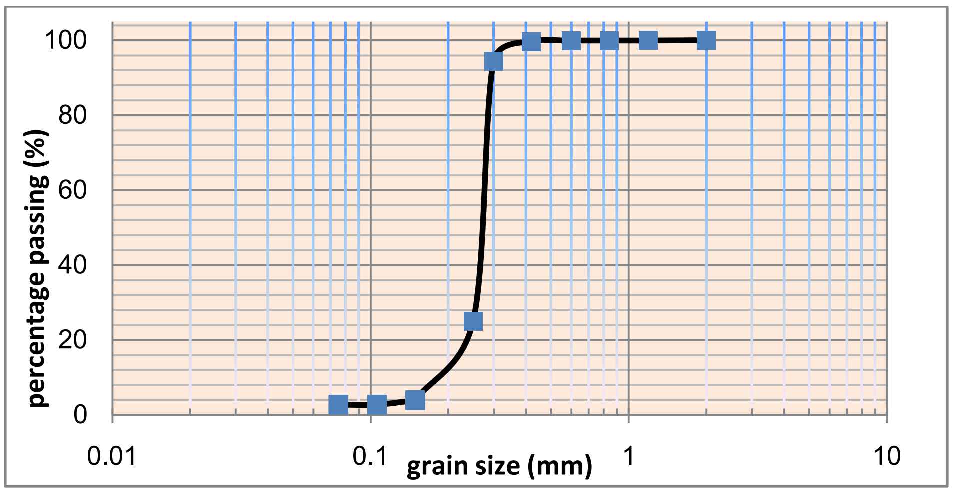

Fig.1.Grain size distribution curve for Babolsar sand

Table1.Engineering properties of sand used in the study

D_{10} (mm)	D_{30} (mm)	D_{50} (mm)	D_{60} (mm)	C_c	C_u
0.2	0.25	0.27	0.23	1.07	1.45

Table2.Maximum and minimum unit weight values of sand

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Maximum unit weight (gr/cm^3)	Minimum unit weight (gr/cm^3)
1.74	1.48

Tire chips with sizes in the ranges of 4-9 mm were used in this study.These tire chips are prepared by grinding the waste tires in a few stages with specialized machinery. These tire-chips removed from metal wires are classified as granulated rubber-chips. By consider of ASTM D854, The unit weight and specific gravity values for these tire chips are attained 12.1kN/m^3 and 1.34 respectively.

Fig.2: View of tire chips with sizes in the range of 4 to 9 mm

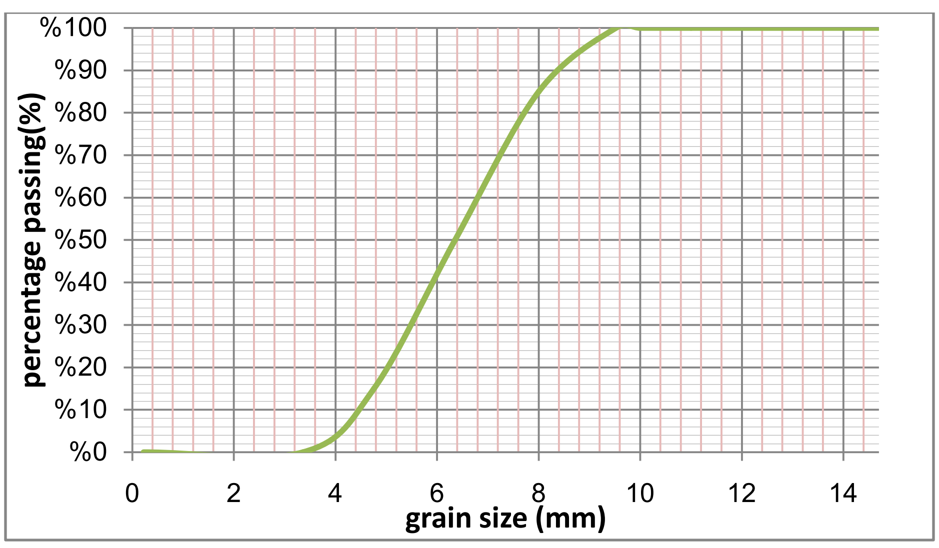

Fig.3.Grain size distribution curve for tire chips

3 Testing program

Most of previous investigations on sand and tire-chipsmixtures were done by direct and triaxial shear tests. According to these researches, adding tire-chips to sand increases shear strength parameters and compressibility, in this study,to consider both shear strength parameters and compressibility effects on bearing capacity, model of footing is used.

In this study, load applied to the square footing to attain the bearing capacity of sand reinforced with different tire chips contents and determine best case which has highest value of bearing capacity. Then, the effects of tire chips on the settlement of footing resting on sand-tire chips mixture were investigated. These tests were done in relative density of 55% which pure sand and mixtures had the same relative density. The reinforced depth and width are 1B and 6B (B is the footing width), respectively. Moreover, in the best case, several tests were conducted to achieve optimum reinforced depth.

3.1 Density method

In this study, for creating the same density in all mixtures, relative density method is used. Maximum specific weight of mixtures is attained from vibratory table test (ASTM D4253 [3]) that frequency of 50 Htz in 10 minutes was used. ASTM D4254 [4] is utilized to achieve minimum specific weight of mixtures. It is important to notice that in both maximum and minimum specific weight methods, sand – tire chips mixtures should be placed by funnel having 13 mm distance to the already deposited mixturein the cylindrical metal mold. Funnel must move in rotary motionsfrom the outside to the center of mold.

Table5. Minimum and maximum unit weight values of the sand-tire chips mixtures (size of tire chips: 4 to 9 mm)

Tire chips content(% by weight)	Maximum unit weight (gr/cm^3)	Minimum unit weight (gr/cm^3)
5	1.62	1.35
9	1.57	1.33
10	1.56	1.31
11	1.51	1.30
12	1.52	1.29
15	1.47	1.27
20	1.43	1.24

3.2 Model Description

Testing equipmentconsists of foundation, column and main beam (IPB24) that was designed to bear maximum force of 30 tones is indicated in fig. 4. According to figure 4, box used in this studyhas dimensions of 130 cm by 130 cm and 100 cm in height.Box walls are made of plexiglass. So, inside of the box is visible during the test. The model footing is made out of a steel plate, 2.5 cm in thickness, 10 cm in width and10 cm in length. The model footing plate is placed on the surface of the compacted sand-tire chips mixture. Square Hollow Structural Sections (HSS) are used in this study as reference beams. Three dial gauges are mounted on reference beams to measure the settlement of footing. According to ASTM D1194 [2], the minimum capacity of the loading jack should be 50 tons or 440 kN. Therefore, in this research, a 50-ton hydraulic jack is used. Load is applied with a constant rate of strain of 1.0 mm/min. The load and displacements are recorded at small displacement increments until plate settlement reaches to 25% of plate diameter. The average displacement from dial gauge readings and the average load are recorded at increments of 0, 0.5, 1, 2, 4, 8 and 15 minutes in each stage of loading. It is important to note that the depth of the mentioned box and the distance between footing and the wall of box are greater than four times of the footing width. So, the boundary effects on the test results are considered insignificant (according to Boussinesq's stress distribution theory).

Fig.4: Testing equipment

3.3 preparations of mixtures

At first, maximum and minimum specific weights of each mixture are attained, and then by considering of the relative density of 55%, natural state dry unit weight is achieved. So, by having the reinforced volume, weight of mixture is determined for each test. Then,according to percentage of tire chipsin each mixture,contents of sand and tire chips are calculated. By consider of sand optimum water content (14%), water is added to the container which contains Sand and tire chips. Then sand and tire chips are mixed randomly to obtain uniform mixture.

3.4 Bearing capacity of sand-tire chips mixtures

In this study which comprises model footing tests, load-settlement curves of sand reinforced with tire chips were compared with pure sand's. Tests were conducted atreinforced depth and width of 10 cm (1B) and 60 cm (6B), respectively. Fig.5 shows bearing capacity ratio (BCR) of sand reinforced with tire chips. It is worth mentioning that BCR is defined as the ultimate bearing capacity of a square footing resting on reinforced sand to the ultimate bearing capacity of the same footing resting on pure sand.The percentages of

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tire chips with sizes in the range of 4 to 9 mm to sand were 5, 9, 10, 11, 12 and 15%by weight.When sand is reinforced with 10-cm layer of sand- tire chips mixture, bearing capacity of sand increases significantly and also, settlement decreases appreciably. As shown in Fig.5, the optimum 4 to 9 mm-tire chips content is 10% which increases the bearing capacity up to 55%. However, adding more tire chips leads to a decrease in the bearing capacity of sand. According to the results of tests, it is obvious that the maximum amount of increase in shear strength parameters occurs by addingoptimum tire chips content. But after optimum value, shear strength parameters decrease gradually.

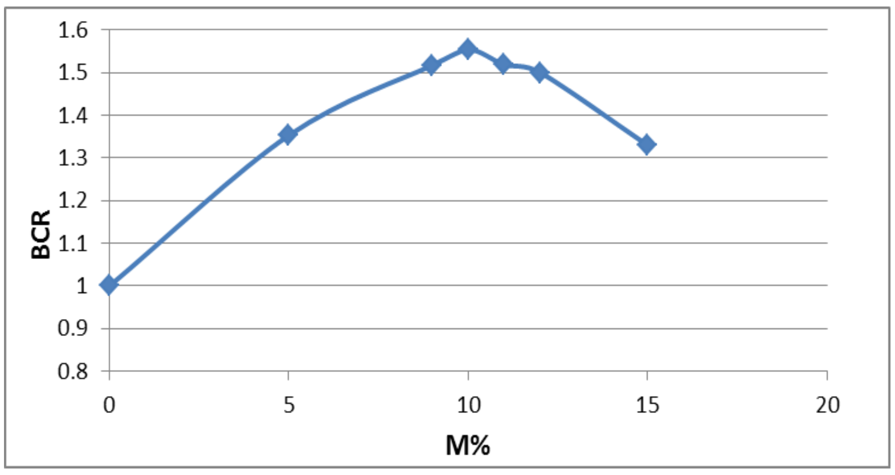

Fig. 5: Effect of tire chips with sizes in the range of 4 to 9 mm on BCR

3.5 Settlement of sand reinforced with tire chips

To show how settlement of footing is varied by stress-settlement diagram, parameter of E_{eq} is used. According to $S=\frac{qB(1-\mu^2)}{E}I$ which presents settlement of a footing resting on the surface of elastic half-space, E_{eq} can be attained in term of $\frac{q}{s}=\frac{E}{B(1-\mu^2)}\times\frac{1}{I}=E_{eq}$.

Where S is the settlement of the footing (m), q is intensity of contact pressure(kN/m^2), B is width of the footing (m), μ is Poisson's ratio of soil, I is influence factor and E is modulus of elasticity (kN/m^2). E_{eq} andE_{eqm} are the values of the initial modulus of elasticity for pure sand and sand-tire chips mixture, respectively E_{eq} and E_{eqm} are calculated from the linear portion of load-settlement relationships of model footingtests. Fig.5shows the method of determining E_{eqm} for sand-tire chips mixture containing 4 to 9-mm tire chips with content of 5%. Figs. 6 illustrate the variation of E_{eqm}/E_{eq} ratio against tire chips content (M %).

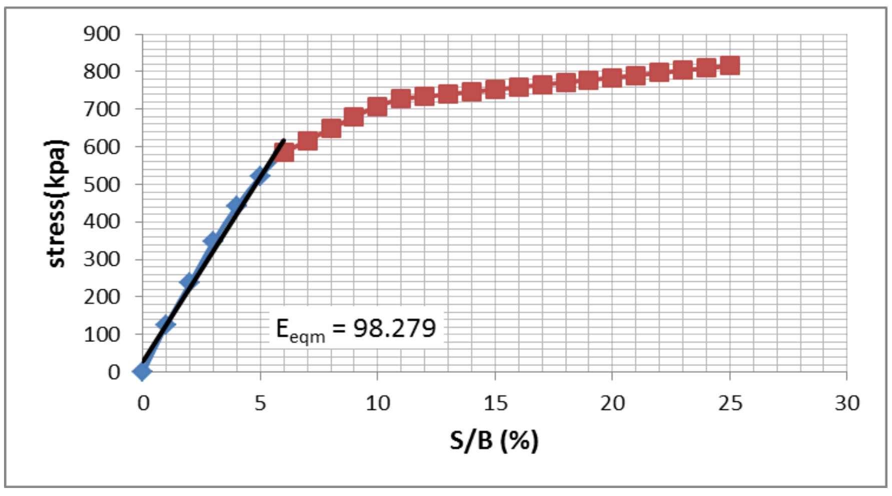

Fig. 5: method of determining E_{eqm}

As shown in Fig.6, E_{eqm}/E_{eq} increases with increasing tire chips content up to M=10%. However, E_{eqm}/E_{eq} value reduces with greater percentage of tire chips. It should be noted that in mixtures with tire chips in the ranges of 4 to 9 mm, the least settlement occurred in the optimum tire chips content. Also, the values of E_{eqm}/E_{eq} were approximately half of BCR values in the optimum percentages. Hence, tire chips are more effective onreduction of settlement at optimum content.

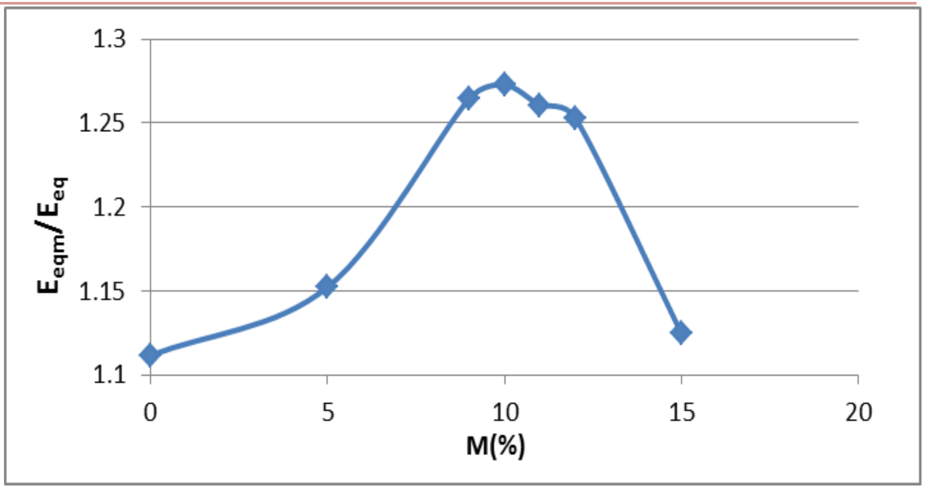

Fig. 6: E_{eqm}/E_{eq} versus tire chips content (size of tire chips: 4 to 9 mm)

3.6 The effect of the reinforced depth on the bearing capacity of sand-tire chips mixtures

Results of conducted tests showed that sand-tire chips mixture containing tire chips content of 10 weight percent of sand, has the most effect on increase of the bearing capacity and settlement reduction. Hence, model footing tests were done on this mixture at different reinforced depth (D) of 0.5B, 1B, 1.25B and 1.5B to study how variation of sand bearing capacity is. Fig.7 indicates that increasing reinforced depth causes increment in bearing capacity. This increase is continued up to 1B=10 cm. However, greater reinforced depths lead to a decrease in the bearing capacity. It is noteworthy to mention that the reinforced width has been 5B=50 cm in the tests.

Local shear failure involves rupture of the soil only immediately below the footing. Local shear failure can be considered as a transitional phase between general shear and punching shear. A local shear failure occurs for soils that are in a medium dense or firm state. Therefore, based on load-settlement curves, such as Fig.5, and considering relative density of 55%, it can be concluded that local shear failure has been occurred in the tests. Internal friction angle of sand increases with increasing in amount of tire chips. So, bearing capacity increases due to this occurrence. Unlike direct shear and triaxial tests, footing model test considers effect of soil compressibility on the soil resistance. As shown in Fig.7, decrement in sand bearing capacity occurs from reinforced depth of 1B to 1.5B which can be related to the increase of soil compressibility according to the studies of Ahmed [1], Edil andBosscher [7], Bosscher et al. [5] and Humphrey et al. [10].

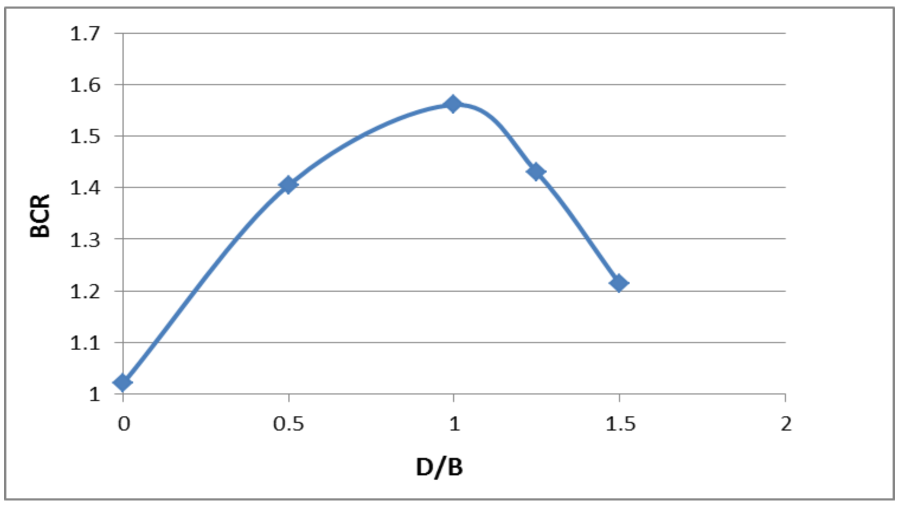

Fig. 7: Variation of BCR versus reinforced depth

4Conclusion

According to the laboratory tests, several significant results can be concluded:

1- By considering of results, obtaining from model footing tests, sand- tire chips mixtures increase bearing capacity and decrease settlement of sand. The most effective case relates to the mixture containing 10 weight percent of tire chips. This mixture increases bearing capacity up to 50%.

2- As it was mentioned, adding tire chips to sand up to 10% by weight increases bearing capacity. Then, bearing capacity decreases with greater

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content of tire chips. This certain tire chips content is called optimum percentage of tire chips.

3- Increase in depth of reinforced layer, containing mixture with 10 weight percent of tire chips, improves bearing capacity up to 1B=10 cm. After this certain depth, decrease in bearing capacity occurs. Therefore, the optimum reinforced depth is 1B= 10 cm.

4- Utilizing sand- tire chips mixtures lead sand to have less settlement against applying load. The most decrement in settlements happens in the optimum tire chips content.

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