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Experimental Study on Waste Tire Chips-Reinforced Sand using Cyclic Plate Load Test

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Abstract. The scarcity in availability of suitable land and the associated huge costs for construction of deep and large foundations supporting tall superstructures subjected to heavy loads has compelled engineers across the globe to resort to numerous ground improvement techniques to improve the subsoil properties. With the emphasis on sustainable construction practices and waste management techniques gaining attention worldwide, research towards the same to alleviate engineering problems has witnessed a surge. Therefore, use of industrial, common and construction wastes for enhancement of structural properties in fresh construction is being studied widely. Similarly, utilizing shredded waste tire chips as reinforcement in soil has shown promising results recently. In the present study, cyclic model footing load tests are performed on square footing supported by a sand bed reinforced with randomly distributed waste tire chips in a square tank. Various intensities of cyclic loads (loading, unloading, and reloading) are applied on the model footing and subsequently, the elastic rebound of the footing corresponding to each intensity of loading and the pattern of variation of the coefficient of elastic uniform compression (C_u) of reinforced sand is assessed. The influence of different percentage of tire chips (5% - 40%) is analyzed by randomly mixing them in the soil medium at 70% equivalent relative density for a depth of up to width of the footing. The results indicate that tire chips addition can significantly improve the bearing capacity as well as the coefficient of elastic uniform compression (C_u) and this improvement can further be enhanced on increase in the percentage of reinforcement (improvement of up to 50% is observed).

Keywords: Cyclic Plate Load Test; Tire Chips; Ground Improvement Techniques; Coefficient of Elastic Uniform Compression; Model Footing Test; Sustainability

1 Introduction

Waste tire management has put forward a major challenge to the environmentalists all around the world. Waste tires are disposed and converted to the form of tire derived fuel to be consumed further in cement kilns, power and paper plants. However, the rise in air pollution due to this practice has become a serious environmental concern

[1]. A major percentage of waste tires (40%) produced in the United states of America was used in the generation of tire derived fuels, while other applications included manufacturing of ground rubber products (26%), landfills (13%), roads (6%), retread (7%) etc. However, as per the U.S. Scrap Tire Management Summary - 2017 (2018), the use of waste tires in civil engineering applications has witnessed a significant rise as it increased by almost 97% from 2013 to 2017 (327.78 thousand tons in 2013 to 646.78 thousand tons in 2017), while their use as tire derived fuel reduced by 13% from 2013 to 2017 [2]. Use of tire wastes in geotechnical engineering is very promising as it can help in sustainable consumption of large quantities of wastes [3]. The use of various forms of waste tires has also been found to be very effective in case of shallow foundations due to the observed substantial improvement in bearing capacity (up to 11 times) at different settlement ratio under static conditions [4-5]. However, the existing laboratory studies (using cyclic triaxial tests, resonant column tests) on granulated rubber or powdered rubber reinforced sand have suggested a negative effect on the stiffness of the reinforced soil mass due to the rubber inclusion under dynamic loading. The main limitation of these tests was the size of the representative reinforced soil sample (approximately 70 mm diameter) and therefore the mean size of the tire reinforcement was restricted to less than 4.75 mm in most of the cases to avoid the boundary effects [6-8]. This reduction in stiffness may be overcome if larger interaction between soil and reinforcement can be established. Therefore, the use of the larger size of tire reinforcement (tire chips/tire shreds) needs further investigation under cyclic/dynamic loading. Also, the application of waste tire chips as reinforcement in case of machine foundation needs to be established where dynamic load applies repetitively over a very large period, though its magnitude is small. In designing a machine foundation, the coefficient of elastic uniform compression of soil (C_u) is the most important parameter. Nevertheless, this has not been comprehensively investigated.

Moghaddas Tafreshi et al. (2018) studied the cyclic response of tire chip (mean size 14 mm) reinforced sand spread in different number of layers below the foundation and evaluated the optimum thickness and number of reinforced layers [9]. It was observed that C_u decreases with the inclusion of rubber sand mixture, while the damping ratio was found to increase. However, in their study, the rubber sand mixture was spread in layers of varying thickness starting from 0.2D (D = diameter of footing) distance below the ground level. The present study, on the other hand, studies the effect of sand tire chip mixture if spread continuously below the square foundation under cyclic loading conditions as the increase in bearing capacity and settlement reduction are found substantial under both static concentric and eccentric inclined loading conditions for this type of arrangement [4-5,10].

2 Test Materials

2.1 Tire-chips

Waste tire chips of size 12-14 mm and specific gravity = 1.08 are used in the present study. The tire pieces mixture was free from any metal or steel. Fig. 1 shows the picture of the tire chips used.

Fig. 1. Tire chips used in the experimental study

2.2 Soil

Sandy soil used in the experimental program was procured from a local site. The soil is classified as poorly graded sand as per the Unified soil classification system. The grain size distribution curve is shown in Fig. 2. The average grain size of the sand particles is 0.2 mm, coefficient of uniformity = 1.86 and specific gravity of the sand is 2.65 assessed as per ASTM D2487 (2017) [11] and ASTM D854 (2014) [12] respectively. Maximum and minimum dry density of the sand calculated as per ASTM D4254 (2016) [13] is 1510 kg/m3 and 1360 kg/m3 respectively. Poison's ratio of the sand is assessed to be 0.30.

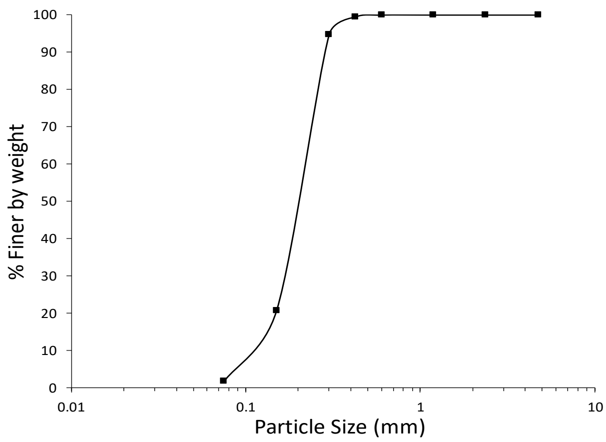


Fig. 2. Grain Size Distribution Curve of Local Sand

3 Experimental Program

3.1 Test equipment

Model cyclic plate load tests were performed on square footings resting on reinforced or unreinforced sand bed having relative (or equivalent relative) density of 30% or 70% depending upon the testing requirements. Model footing was machined to the precise size of 75 mm x 75 mm and was made of mild steel plate of thickness 12.5 mm. Bottom of the footing was made irregular to simulate the field conditions. The size of the tank was decided as per the zone of the influence for the size of the footing [14]. Tank of cross section 500 mm x 500 mm and height 500 mm was used. The deflection of the sides of the tanks were measured during some preliminary tests which came out to be negligible and hence ensured the rigidity of the tank.

3.2 Preparation of sand bed below footing

Firstly, the unreinforced sand was placed in the tank to the desired height in the layers of 75 mm thickness. Each layer of unreinforced sand was loosely filled to achieve the relative density of 30%. Thereafter, the sand reinforced with the desired percentage of waste tire chips was placed manually in layers and compacted to achieve 70% equivalent relative density. The dry density of sand (ρ_d) corresponding to 30% and 70% equivalent relative density values were determined as 1.39 g/cm^3 and 1.44 g/cm^3 respectively [4-5, 10]. These dry density (ρ_d) values were adhered to while placing the sand layers of required weight in the desired depth. 70% equivalent relative density for the reinforced sand was mainly kept to assess the effect of both compaction and inclusion of tire chips on a loosely packed sand. The main purpose behind studying the effect of both compaction and reinforcement is that if loosely packed poorly graded sand is to be improved in the field, it can be mixed with the recommended amount of reinforcement and then correspondingly compacted as well to get into a denser state. The mixing of sand and tire chip was done manually. Quantity of the tire chips by weight (depending upon the desired equivalent relative density, 70% in the present case) was added in different proportions in the top reinforced zone in equal layers. Mass of the mixture corresponding to a depth was placed and compacted with a wooden rammer.

3.3 Loading system

The top of reinforced or unreinforced sand was properly leveled, and the square footing was placed in position for testing. The load application system was hand operated jack system with 50 kN capacity, supported against relatively strong reaction beam. The load was increased to a certain desired value and then was brought down to zero. This sequential loading and unloading made it possible to separate the elastic (recoverable component) and plastic (non-recoverable component) settlement. Two dial gauges were mounted on the footing, and the average of the two readings was taken as the settlement of the footing. Settlement at every increment of loading and unloading was recorded when readings of dial gauges became reasonably constant and then it was utilized for obtaining pressure-settlement curves. The schematic diagram of the test setup is shown in Fig. 3.

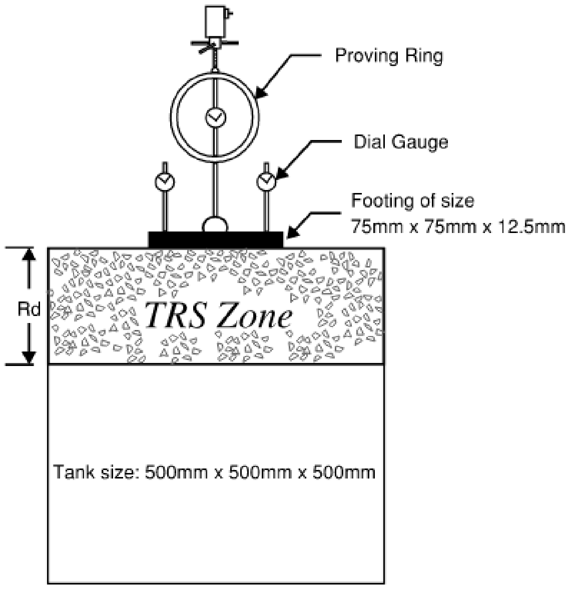


Fig. 3. Schematic diagram of the test setup

3.4 Testing details

Total 6 tests on model square footing were conducted under cyclic loading conditions to study the effect of tire chip content. Each test was repeated up to 3 times to ensure the reproducibility of the obtained test data. The testing details are mentioned in Table 1. Mittal and Gill (2018) recommended the depth of reinforced zone as 1B (B = width of the footing) to obtain the optimum performance under static loading conditions from both strength and economy perspective [4]. Therefore, in the present study, the depth of reinforced zone is maintained as 1B.

The unreinforced sample test series name is taken as UR30 which implies 'Unreinforced sand at 30% relative density', while the reinforced sample test series name is considered in the form TRS70A1B10 implying 'Tire-chip Reinforced Sand sample at 70% equivalent relative density which is reinforced by the addition of tire chips in top 1B layer equal to 10% by weight of sand in that layer'. It is to be noted that relative density of all the unreinforced layers below the reinforced layers was maintained at 30%.

Table 1. Details of the performed cyclic plate load tests

Test Series	Type of zone below foundation	Relative density (D_r)	Percentage of tire chip reinforcement	Depth of reinforced zone (R_d)	Number of tests performed
UR30	Unreinforced	30%	--	--	1
TRS70A1B05	Reinforced	Equivalent Relative Density = 70%	5	1B	5
TRS70A1B10			10	1B	
TRS70A1B20			20	1B	
TRS70A1B30			30	1B	
TRS70A1B40			40	1B	

4 Results and Observations

The present section describes the effect of cyclic loading on the pressure-settlement response of unreinforced sand and tire chip reinforced sand. A brief discussion on the optimum amount of reinforcement and the pattern of variation of C_u is also presented. The settlement values are presented in non-dimensional form (settlement/Width, s/B%) to utilize them in field applications avoiding possible scale effect.

4.1 Unreinforced sand

Fig. 4 depicts the pressure-s/B (%) curve of the unreinforced sand at 30% relative density.

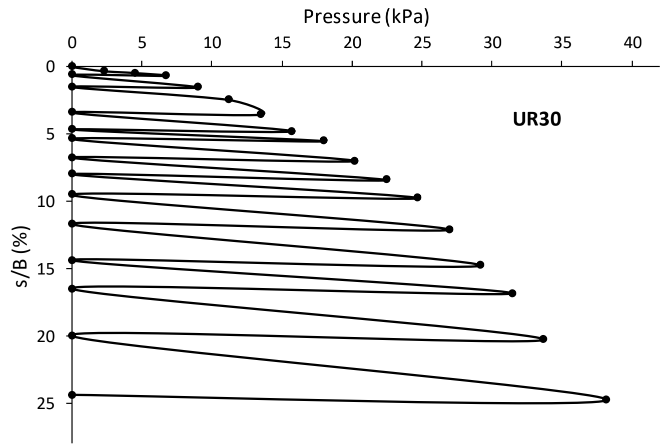
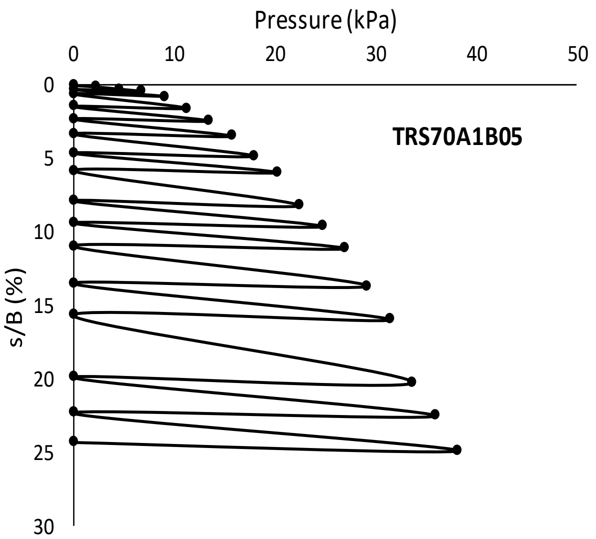
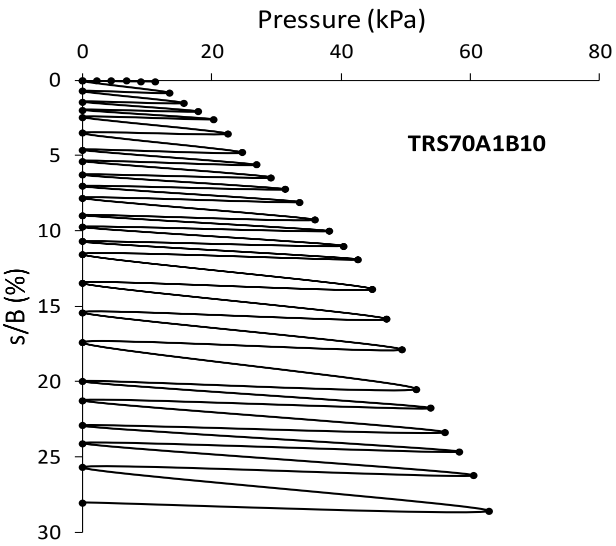


Fig. 4. Pressure settlement curve of unreinforced sand (D_r = 30%)

4.2 Reinforced sand

Pressure -s/B (%) curves of reinforced sand are shown in Fig. 5 for different tire chip content. It can be roughly observed from the Fig. 5 that the pressure settlement behavior of the reinforced sand improves on increase in the tire content even after the addition of very small quantity i.e. 5% by weight. Moreover, the pressure was found to be significantly increased at 30% tire chip content ratio at all strain level.





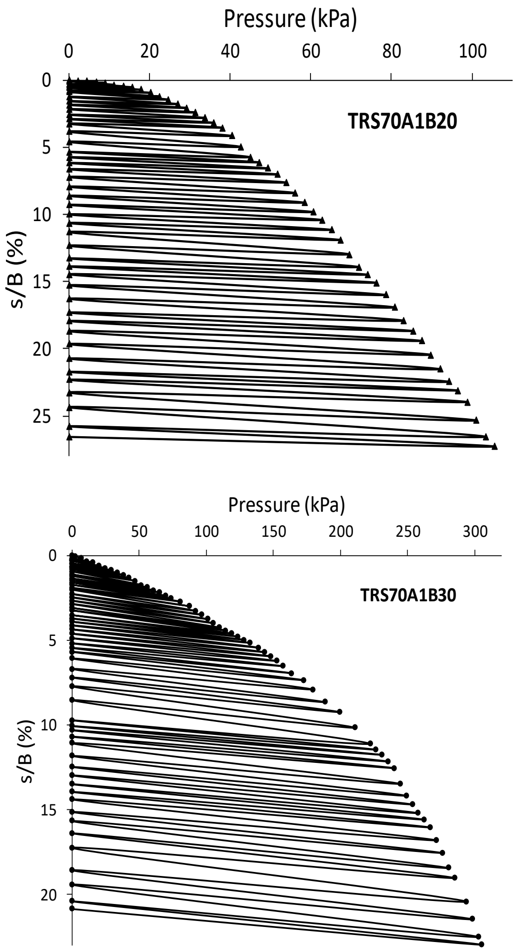


Fig. 5. Pressure settlement curve of reinforced sand

The results are shown only till the mixture with 30% tire chip content as the addition of tire chips beyond this content (i.e. 40%) led to major mixing difficulties. The compaction of the mixture to attain the desired equivalent relative density at 40% tire chip content was very challenging due to the absorption of compactive energy by the high amount of rubber content. Therefore, this content of tire chip is not recommended for field applications. Fig. 6 shows the sample at 40% tire chip content and it can be clearly visualized that the soil is merely visible from the top and the complete top area is almost occupied by the tire chips due to poor mixing.

Fig. 6. Tire Chip reinforced sand (Sample: TRS70A1B40)

5 Discussion

5.1 Bearing Capacity Ratio

Fig. 7 represents the Bearing Capacity Ratio (BCR) obtained at different tire chip content. The BCR is defined as the ratio of the bearing capacity of the reinforced sand to the bearing capacity of the unreinforced sand at a given strain level. BCR values are reported at both low strain level (2-5%) and high strain level (10-20%) in the present study. It can be clearly observed that BCR increases on increase in the tire chip content at all strain levels. The rise in BCR was not significant at very low tire chip content (i.e. at 5%), however, BCR increased to approximately 2.5 times when the tire chip content was increased to 20%. Furthermore, the most significant increase in BCR was noticed at 30% tire chip content where approximately 8.5 times improvement in BCR was observed. Also, at higher strain level, the BCR showed similar or higher improvement.

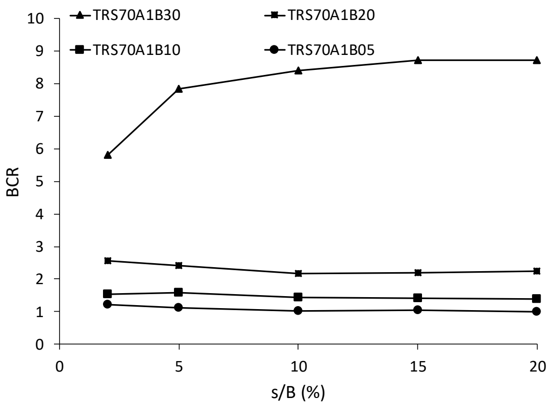


Fig. 7. Comparison of BCR at different tire chip content

5.2 Coefficient of Elastic Uniform Compression and Shear Modulus

Coefficient of elastic uniform compression can be obtained by the slope of the pressure-elastic settlement curve. For the same, the cyclic plate load test loading unloading curves (Fig. 4 & 5) were analyzed to compute the elastic settlement at each load cycle and subsequently, the pressure-elastic settlement curves were drawn. Fig. 8. shows the best fit curves of Pressure v/s Elastic settlement for all the sample types. It can be clearly observed that with increase in the tire chip content, the slope of the pressure-elastic settlement curve increases.

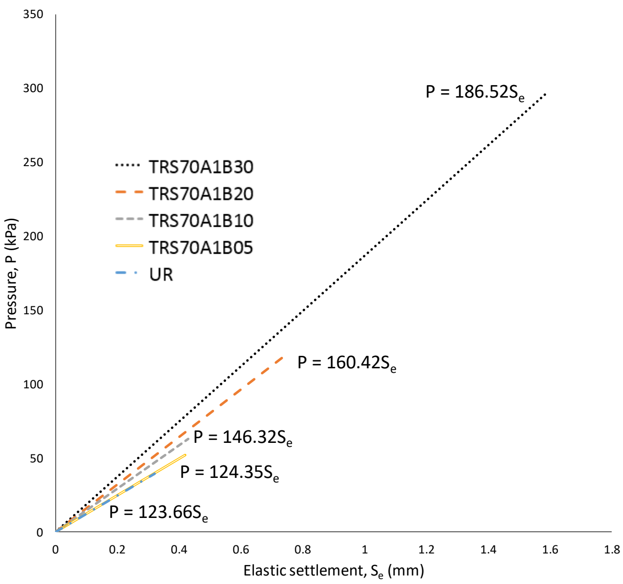


Fig. 8. Pressure v/s Elastic Settlement curve at different tire chip content

Moreover, it is evident that the C_u is directly proportional to the shear modulus of soil as given in equation 1 [15] and hence, the relative increase in the shear modulus (G) would be the same (as the other factors in equation 1, A= Area of footing, ν = Poison's ratio, have no or negligible effect of the reinforcement content or type and remain almost same). Fig. 9 is a clearer representation of the increase in the shear modulus. Shear modulus ratio can be defined as the ratio of the shear modulus of the reinforced sand to that of unreinforced sand (G in the present case for unreinforced sand is 2872.63 kPa). It can be clearly observed (Fig. 9) that tire chip addition can lead to an increase in G of up to 1.5 times. Therefore, it can be suggested that on increase in the tire chip content, the shear modulus increases. This may be due to the establishment of a greater contact area, hence greater friction between the tire chip and the soil grains which in turn leads to the increase in the stiffness of the mixture. The reduction in shear modulus found in case of granulated or powdered rubber soil mixture was possibly due to the similar size of both rubber and soil grain, which does not allow the establishment of proper inter-particle friction or bonding.

$$G = \frac{c_u\,(1-\nu^2)\sqrt{A}}{2.26 \times (1+\nu)} \tag{1}$$

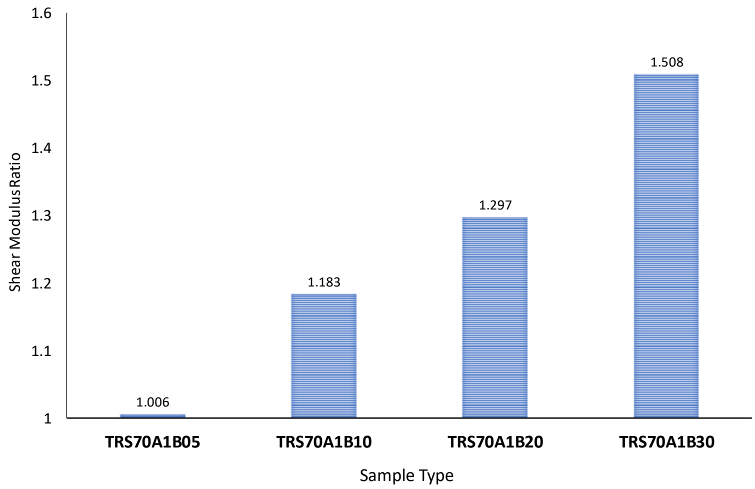


Fig. 9. Comparison of Shear modulus at different tire chip content

6 Conclusions

The present study is mainly aimed towards the analysis of the effect on shear modulus on increase in the content of tire-chip. Contrary to the existing results on granulated or powdered rubber-sand mixture, it has been observed that the addition of tire chips can lead to an increase in the coefficient of elastic uniform compression or the shear modulus. An increase of 1.01 to 1.51 times was observed on varying the tire chip content from 5 to 30%. This result can therefore be utilized in the future studies related to the sand-tire chip mixture. However, further evaluation of the accurate rise in the shear modulus is recommended using dynamic block vibration tests on field.

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