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The Experimental Investigation of the Repeated-Loading Behaviour of the Sand-Rubber-Mixture (SRM)

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Abstract. Nowadays the waste rubber problems are concerned due to the environmental issues, storage, and recycling difficulty. However, the rubber base equipment has been widely used to protect structures for vibrations - that has been generated by the structure or induced from the vicinity area or the bedrock into the structure - due to the notable capability of absorbing energy. In this study, the repeated-loading behaviour of the Sand Rubber Mixture (SRM) has been investigated and the remarkable energy absorption properties of the mixture have been illustrated. The test soil material that has been used in this study was a well-graded sand (SW) with a mean grain size of 2 mm. The test martial rubber that has been used was grain particles with a uniform size of 4.76 mm. The sand rubber mixture (SRM) was prepared by using 7.5% rubber inclusion because it was found as the optimum rubber content. A series of force control repeated-loading CBR tests have been arranged. The effect of mixing rubber particles with the well-graded sand (SW test material) has been investigated. This shows the remarkable energy absorption capability of Sand Rubber Mixture (SRM) to protect the bed of a machine's footing that is generating repeated loads. The SRM usage could be extended to be employed as a part of an energy absorption unit and dampers facilities beneath a machine footing or structures that are sensitive to the vibration to prevent destructive deformation and resonance phenomenon.

1. Introduction

The abandoned waste worn-out tire is dangerous for the environment. It could provide a suitable place for rats and insects and cause outbreaks especially in the vicinity of human residents. Stashing worn tires requires lots of space and always has a danger of ignition. Moreover, burning out the tires could release dangerous gases that can cause cancer and dangerous disease in humans. The fascinating mechanical and dynamical properties of rubber (i.e., low density, intense strength, electrical conductivity properties, durability and high damping and friction properties), makes this material -even the waste type- interesting to be used in geotechnical engineering. Many studies[1-16] have been investigated the mechanical and dynamical properties of rubber in company with soil (mixture, reinforced or even as part of the supper structure). Rubbers in many shapes (grained, shred, powder, sheet and even intact tire) have been used in many field projects, including the lightweight backfilling for retaining walls and highway engineering applications [17]. Mixing rubber with soil is effective to protect the rubber from erosion and ignition and may improve the mechanical and dynamical properties of the mixture (deformation, compressibility, damping, shear modulus etc.)



The previous study shows the employment of the grained waste rubber (or tire) as the light-weight backfill for retaining walls [18-20]. The rubber soil mixture can reduce the geostatic pressure over the retaining wall and increased the shear resistance of the backfill [21]. Uchimura, Chi [22] also show the usage of the rubber grains to protect buried pipes by reducing pore water pressure and decreasing liquefaction risk. Furthermore, Vinod, Sheikh [23] reported the increase of the shear strength of the rubber sand mixture in comparison to the intact sand by conducting a large scale direct shear test. Nakhaei, Marandi [6] have conducted a series of consolidated undrained large-scale dynamic three axial tests to investigate the sand rubber mixture (SRM) dynamic properties variation with various confining pressure and rubber content. They found that the dynamic shear modulus reduces by increasing the rubber content and vice versa by increasing the confining pressure. They also found that the, as the rubber content increases the effect of confining pressure on the dynamic shear modulus decreases. They also found that, as the rubber contents increases in the case of low confining pressure, the damping ratio decreases and in the case of high confining pressure, the damping ratio increases. Zakeri, Moghaddas Tafreshi [9] by conducting a series of semi-large-scale steady-state vibration tests by using a machine foundation model (FMRT apparatus [24, 25]) show the benefits of using a thin rubber sheet beneath a machine foundation to improve the dynamic response of the vibrating system. They found that employing a rubber sheet beneath a machine foundation could significantly decrease the resonant frequency and the equivalent dynamic shear modulus of the vibration systems bed in any case and may increase the equivalent total damping ratio and decrease the resonant amplitude in the case of small dynamic angular forces and large static weights (representing the small dynamic shear strain and large confining pressure over the bed of rubber sheet and soil). Madhusudhan, Boominathan [17] et al. have been investigated the effect of the SRM on the shear strength and dynamic properties of the soil (including shear modulus and damping ratio) by using the strain-controlled consolidated undrained triaxial tests and strain-controlled dynamic triaxial tests (R. Madhusudhan et al., 2017). They found that mixing 10% of rubber with soil could reasonably improve the dynamic properties to seismically isolate low-rising buildings. Zakeri and Moghaddas Tafreshi [8] assess the static bearing capacity of the SRM with various rubber grains content and sizes by using standard CBR test apparatus. They found that the 7.5% by weight of rubber grains is the most suitable content of rubber to increase the bearing capacity of the SRM mixture.

In this study, the SRM repeated loading behaviour has been investigated by using an ordinary, cost-effective and easy to use CBR test apparatus. While, the CBR value is not the main purpose of this study, but the force-penetration trend of the loading shaft has been studied.

2. Test Materials and Methods

The soil has been used in this study was a Well-Graded Sand (SW) according to the Unified Soil Classification System, ASTM-D2487-17 [26]. The specific gravity (G_s) of the soil is estimated about 2.68. The sand mean grain size is about $D_{50}=2\text{mm}$. According to the Modified Proctor Compaction Test, ASTM D 1557 [27], the maximum dry density is estimated about 1.92 g/cm^3 , and the optimum moisture content is established about 11.5%. Also, the minimum dry density is estimated about 1.57 g/cm^3 . The rubber has been used in the study was granulated particles with a specific gravity ($G_{s,r}$) of 1.2. The granulated rubber has an almost uniform particle distribution and the mean size of the rubber grains (D_{50} rubber) was about 4.76 mm. The SRM that has been used in this study was provided by 7.55% by weight as it was found to be the optimum content of rubber according to Zakeri and Moghaddas Tafreshi [8].

In this study, the CBR test apparatus has been used. The inner diameter of the CBR mould is about 15.2 cm and the mould height is about 11.6 cm. The measurement system includes displacement transducers as well as a load cell which all were connected to a digital datalogger that logs all the live data and demonstrates them on the connected monitor. The datalogger comprises electronic circuits and control systems including signal transmission elements which all were developed by the authors. All sand layers were prepared by the specific density of 93%. But to prepare the SRM layer due to the compressibility of the rubber it was not possible to reach the compaction so the constant energy similar to that was used to compact the soil layer

has been employed to compact the SRM layers (8 Layers for of SRM in the CBR mould compacted by a 5.3 kg hammer that is falling from the height of 10 cm, 12 times for each layer). The test program is shown in Table 1. The rubber content of SRM was 7.5% and the surcharge was 2 kg. A series of pressure control repeated-loading tests have been conducted by using three maximum force of the penetrating shaft of 175, 365 and 545 kg.

3. Results and Discussion

In this study, the standard CBR test procedure was not the purpose, but the shaft penetration through the prepared specimens was investigated. Therefore, the results are presented as a Force-Displacement diagram of the CBR loading shaft. In this study, the total penetration, elastic penetration and plastic penetration of the sand and SRM specimens have been compared.

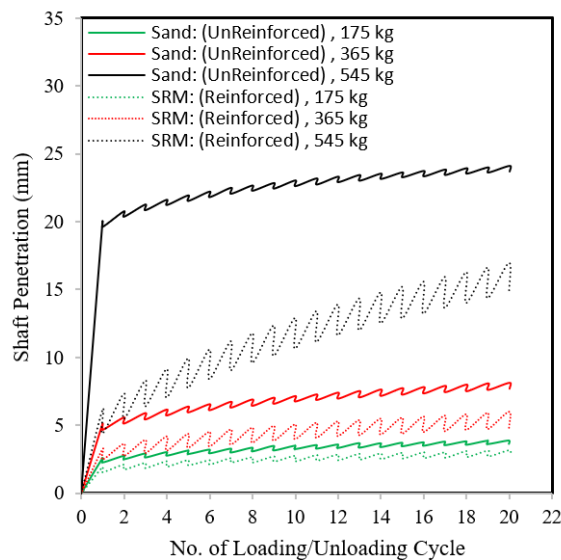


Figure 1. Variation of the loading shaft penetration versus the number of repeated loading cycles for the sand and SRM specimens

Figure 1 shows the variation of the loading shaft penetration versus the number of repeated loading cycles for the Sand and SRM specimens. All tests are loaded and unloaded 20 times. The total shaft force was limited to 175, 365 and 545kg. According to Figure 1, in the case of sand or SRM specimens, the total displacement of the loading shaft is increased as the number of loading/unloading cycle increases. However, for the similar total shaft force, the shaft penetration of the SRM specimens are significantly reduces compared to the similar sand specimens.

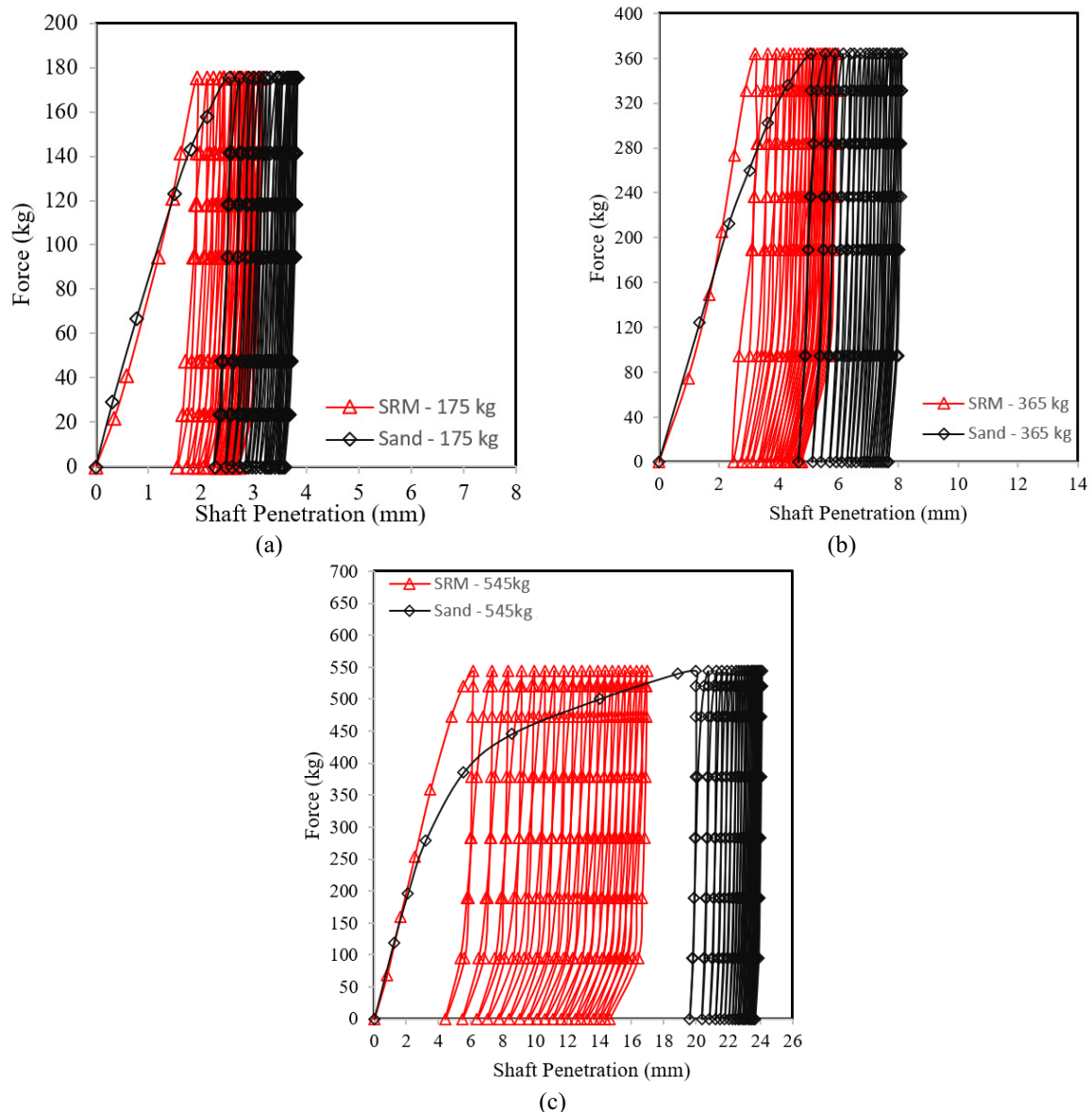


Figure 2. The shaft force versus shaft penetration diagram of sand and SRM specimens for (a) 175, (b) 365 and (c) 545kg total shaft force

According to Figures 2 that is illustrating the shaft force versus shaft penetration diagram of sand and SRM specimens for 175,365 and 545kg total shaft force, the total and irreversible penetration (that represents the plastic penetration) of the loading shaft of the SRM specimens are considerably reduces compared to the similar intact sand specimens. The total and permanent loading shaft penetration variation versus the number of loading/unloading cycles for 175, 365 and 545kg total shaft force for sand and SRM specimens are shown in Figure 3. It indicates that the total and permanent loading shaft penetration of the SRM specimens reduces compared to the sand specimens. Furthermore, It was observed that mixing rubber grains with sand could be more efficient in case of inducing large deformation in the mixture; As the shaft is driven further in the SRM specimen, the affected area beneath the shaft compacted and consequently, the sand–rubber grains surface contact area, the normal stress between grains and the total internal friction angle of the mixture enhanced. In the case of excessive loading shaft force, as the total number of loading/unloading increases, the rubber and sand grains will take apart from each other, thus irreversible

deformation will increase. According to the results, in the case of excessive loading shaft penetration, the rate of shaft penetration reduces as the total number of loading/unloading cycle increases. This shows the importance of the first loading/unloading cycle. Therefore, the penetration reduction in the first loading/unloading cycle is one of the advantages of using SRM, especially for road construction.

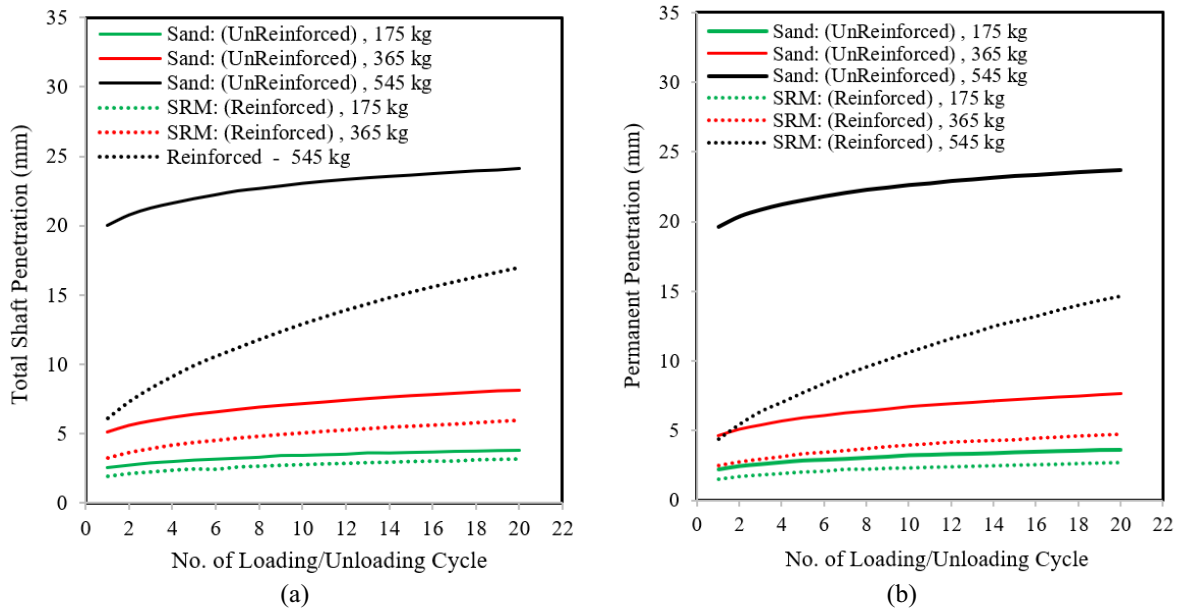


Figure 3. The (a) total and (b) permanent loading shaft penetration variation versus the number of loading/unloading cycles for 175, 365 and 545kg total shaft force for Sand and SRM specimens

The reversible penetration that could represent the Elastic Penetration of the loading shaft and the rate of Elastic Penetration versus the number of loading/unloading cycles in the cases of 175, 365 and 545kg total shaft loading are presented in Figure 4. The rate of elastic penetration was calculated by dividing the elastic penetration of the shaft for any cycle by the total penetration of that cycle. It shows that the rate of the elastic penetration of the SRM specimens increases compared to the sand specimens.

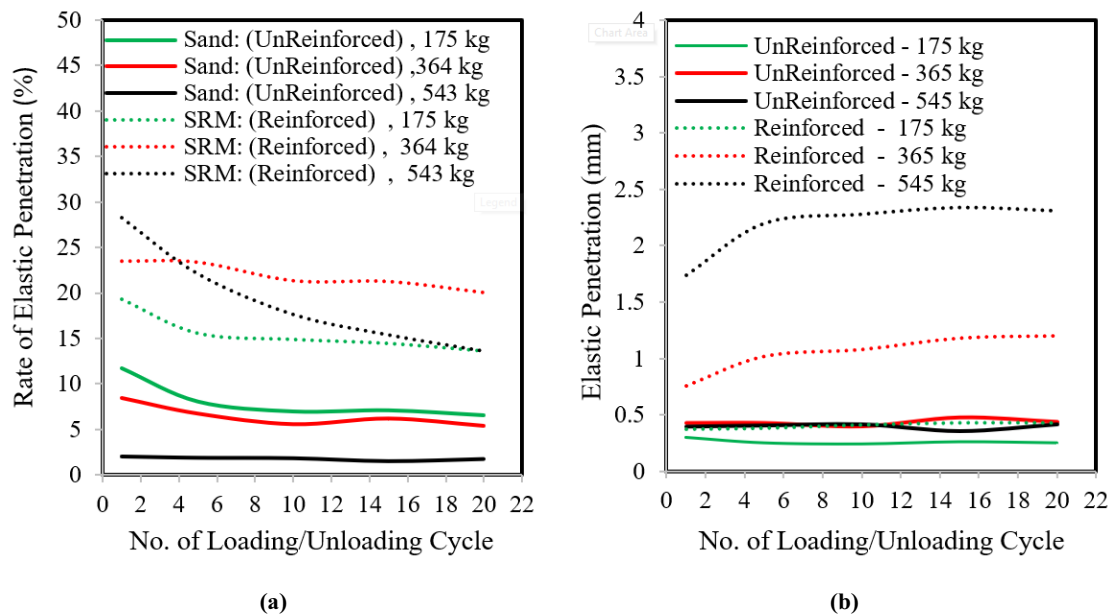


Figure 4. The reversible penetration representing the Elastic Penetration and the Rate of Elastic Penetration versus the number of loading/unloading cycles in cases of 175, 365 and 545kg total shaft loading

According to Figure 4, the rate of all specimens' elastic penetration decreases as the total number of loading/unloading cycles increases. The amount of all specimens' elastic penetration rate was considerable for the first cycle. As the total number of loading/unloading cyclic increases, the rate tends to a constant value. Also, as the cyclic force level propagated, the rate of the elastic penetration of the SRM specimens compared to the sand specimens with the same level of the shaft total force decreases. However, the significant elastic modulus of the rubber causes the elastic behaviour of SRM to preserve even for a large number of cyclic loading forces. These observations illustrate the improved energy absorption and the increased damping ratio of the SRM specimens compare to the Sand specimens. Therefore, the SRM could be employed to reduce the total and irreversible deformation and increase the reversible deformation of soil embankments.

4. Conclusions

In this study, a series of laboratory test has been conducted by using the CBR test apparatus to investigate the effect of mixing rubber grains with sand (SRM) to improve the repeated loading behaviour of embankments. The standard CBR test procedure and CBR value was not the purpose of this study. The outcomes of this study could be summarized as follow;

- 1) Mixing rubber grains with sand could minimize the initial elastic modulus of the specimen. As the loading shaft penetrates further in the specimen, the relative density of the mixture beneath the loading shaft increases and due to the enhanced rubber-soil grains interaction, the equivalent modulus of the mixture and the shaft force increases. This shows the importance of compaction in the case of using SRM.
- 2) The SRM specimens compared to the sand specimens have smaller total and permanent penetration and larger elastic penetration of the loading shaft.
- 3) This study shows the remarkable energy absorption capacity of the SRM. Therefore, the SRM could be employed as a part of the energy dissipating unit of structures or machine foundations (to act as an in-situ damper) and seismically isolate and improve the dynamic response of the foundation.

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