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Scaled model test on cyclic response of footing on geotechnical seismic isolation layer

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ABSTRACT: Sand-rubber mixture (SRM) is widely considered as an energy-dissipating layer for vibration mitigation in soils. The present study is focused on using the SRM as an energy dissipation layer below building foundation referred to as the Geotechnical Seismic Isolation layer (GSI) which acts as a buffer to incoming vibrations. Geosynthetic reinforcement is included in the above GSI system to accentuate the damping mechanism and prevent seismic settlements during shaking. The present study aims to experimentally evaluate the dynamic response of the geogrid reinforced SRM-GSI system through scaled model tests. Model footing resting on the geogrid reinforced SRM-GSI system was subjected to continuous cyclic loads and the results are evaluated in terms of load-settlement response for different cycles of loading. It was observed that the geogrid reinforced SRM-GSI system is crucial in reducing the seismic settlement at various loading cycles and the soil-foundation system's overall dynamic response.

1 INTRODUCTION

Geotechnical seismic isolation is a recent trend in earthquake geotechnical engineering that aims to protect buildings and structures from the detrimental effects of earthquakes using a low-stiffness isolation layer beneath the building. The basic principle behind this method is to isolate the structure from the ground, so that the vibrations of an earthquake do not transfer to the building. In conventional base isolation systems, energy dissipation is achieved through the use of isolation bearings (made of natural rubber and lead) are placed between the building structure and foundation. On the other hand, geomaterials such as rubber, geosynthetics, sand, and gravel are often used in GSI method as they provide a flexible and durable barrier between the building foundation and the ground, and they offer a cost-effective and sustainable alternative to traditional isolation systems (Tsang 2008; Pitilakis et al. 2015; Dhanya et al. 2020; Forcellini 2020). One common practice is the use of sand mixed with rubber particles from crushed recycled tires, referred to as Sand-Rubber Mixture (SRM), for seismic isolation. The SRM provides a combination of low stiffness, high flexibility, and damping that helps to dissipate the energy of seismic waves below the foundation level (Tsang 2021).

The use of rubber particles from scrap tires is becoming increasingly popular in civil engineering applications due to its environmental advantages and the large amount of scrap tires produced worldwide. Research have showed that using shredded scrap tires mixed with soil is an effective solution as a lightweight back-fill material for retaining walls, highway embankments, and as vibration absorption layers for underground structures and foundations (Kirzhner et al. 2006; Hazarika et al. 2010). The damping ratio of SRM at small strains is higher than that of pure granular soils and it increases with higher rubber fractions and larger shearing strain amplitudes making it an ideal choice for vibration mitigation studies (Senetakis et al. 2012). Studies

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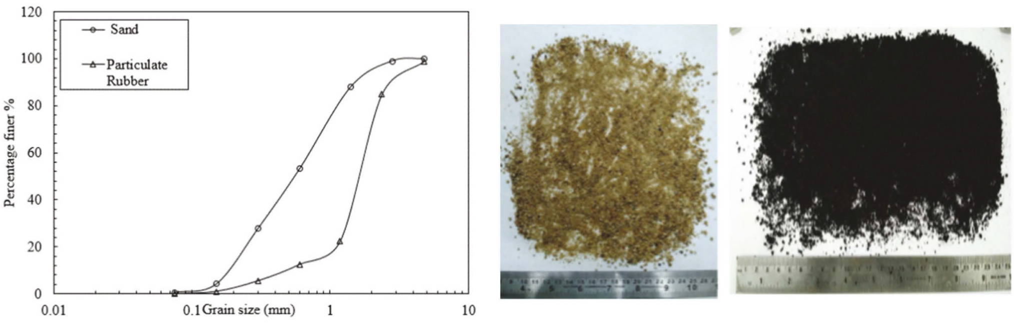
have also shown that increasing the rubber fraction in a granular sand-rubber mixture beyond 30% leads to a decrease in the mobilization peak and large-strain angle of friction of the mixture, making the mechanical response more rubber-like (Zornberg et al.2004).

In general, SRM exhibits a higher degree of compressibility compared to pure sand due to the presence of elastic and deformable rubber particles. This results in immediate settle-ment similar to that of sand during static loading. However, the settlement response under repeated loading needs to be thoroughly examined when SRM is utilized as GSI layer be-low foundations when considering building safety under seismic and other ground borne vibrations. Several researchers have conducted extensive laboratory studies to investigate the cyclic behavior of SRM and the influence of rubber content and particle size on the shear strength and deformation of the mixture (Ehsani et al. 2015; Senetakis et al. 2012). However, model studies on the response of footings resting on GSI layers under repeated loading are limited. Therefore, the current study aims to experimentally investigate the be-havior of a scale model footing on a sand-rubber mixture GSI bed under cyclic loading conditions in terms of load-settlement response.

2 SCALED MODEL STUDY

2.1 *Materials*

In this study, river sand sourced from Chennai, India that was classified as poorly graded sand (SP) per IS: 1498 (BIS 1970) was used. The scrap rubber tyre with steel reinforcements removed and fragmented into angular-shaped granulated tire particles with a size less than 4.75mm and were also classified as an equivalent of poorly graded sand (SP). Research has shown that a rubber content of 20% to 35% (gravimetric) mixed with soil is optimal for achieving maximum shear strength (Edil and Bosscher 1994; Rao and Dutta 2006). Additionally, SRM with a 30% rubber content has been found to exhibit a high damping ratio and adequate stiffness compared to higher rubber contents (Senetakis et al. 2012; Dhanya et al. 2019, 2022). Therefore, in this study, SRM with a rubber content of 30% was used. Undrained triaxial test results on the sand the SRM samples showed peak internal friction angle of 37.5° and 28.5 ° respectively.



(a) (b) (c)

Figure 1. (a) Grain size distribution for sand and rubber (b) sand (c) rubber granules.

2.2 *Test setup and procedure*

Figure 2 presents a general overview of the laboratory test, including the testing tank and test bed. Load tests were performed on a model footing that was placed on a GBI layer made of SRM, in a laboratory setup that simulates a sand-bed tank. The test tank was made of steel and had dimensions of 1m x 1m x 1m. The model square footing was constructed using a square steel plate with a dimension of 100mm and a thickness of 10mm based on model scaling laws of similitude by Wood (2004). The steel plate was connected to pneumatic actuators that were attached to a reaction frame composed of steel beams and columns. The loading was applied on the load plate in a displacement-control mode using a computer-controlled pneumatic actuator. The load was measured using an electronic load cell with a capacity of 20 kN and the displacement was measured by a displacement transducer (LVDT). For more detailed information on the arrangements of the testing apparatus and procedure, please refer to the work of Dhanya et al. (2019).

Initially, the load tests were conducted on a footing resting on a sand bed compacted at a relative density of 85%. The sand bed was prepared in layers of 0.1m each, using the sand pluviation/rainfall technique (Cresswell et al. 1999) where the sand was poured from a fixed height to achieve the desired density. The next series of tests were conducted on a footing placed on a GSI layer, which was prepared by excavating the required depth and size of the GSI layer in the sand bed and backfilling it with SRM. An aluminium sheet box of the plan size of the GSI bed was placed inside the sand bed to prevent caving in and control compaction during the preparation of the GSI layer. The excavated space was filled with SRM mixture and compacted in layers of 25mm to achieve a relative density of 85%. The depth of the GSI layer was varied as 0.1 B and 0.2 B, where B is the width of the footing while the width of the GSI layer was kept constant as 3B.

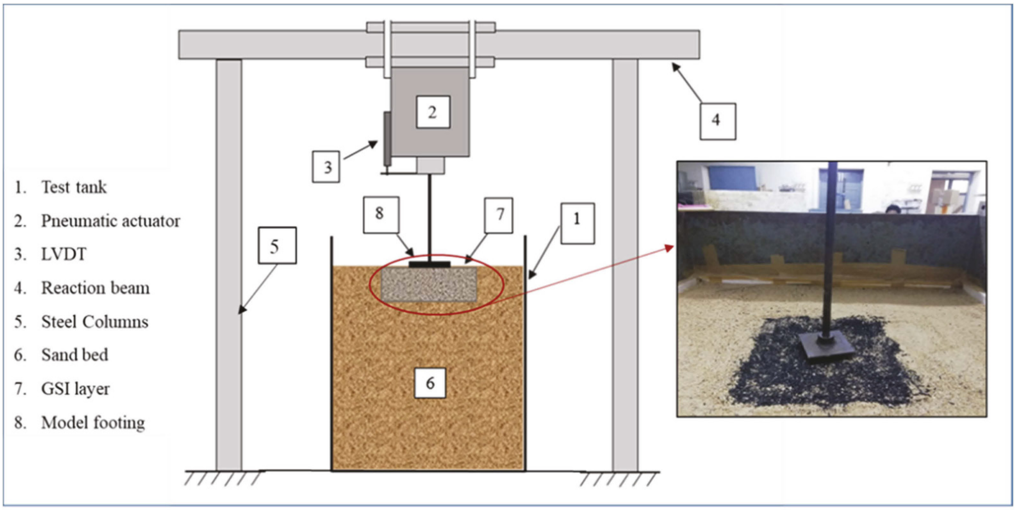


Figure 2. Experimental setup of model footing placed on GSI bed in the test tank.

During the testing phase, the following loading pattern is applied to the soil bed: first, a static load is applied at a gradual rate until it reaches 100 kPa. The static load is then maintained until no further settlement occurs or the rate of settlement is negligible. Next, a cyclic load, which is sinusoidal with a frequency of 1 Hz and is applied until the rate of settlement becomes negligible. The static load of 100 kPa was chosen as it simulates the weight of a low-rise structure, which is often the minimum factor of safety adopted in the field. The ratio of dynamic load amplitude to the static load amplitude is maintained as 0..3 as it is commonly found in seismic and machine vibration problems, as reported in Tafreshia & Dawson (2012).

3 RESULTS AND DISCUSSION

The focus of this study is to examine the settlement of a foundation specifically caused by cyclic loading. An initial monotonic loading is applied to simulate the weight of the structure and foundation, but elastic settlement from static loading is not considered. Figure 3 presents the variation of peak cyclic settlement of footing (S_c) normalized with the footing width (B) with the number of load cycles under cyclic loading for the footing with and without GSI cases. The general characteristics of loading can be categorized into three zones: a rapid settlement in the initial cycles, a secondary slow settlement until a critical point, and a minimal rate of settlement (Zone C). It is observed that there is a significant increase in settlement in the first few cycles of loading, particularly in the GSI layers, and it is noted that the cyclic settlements are higher for GSI layers of greater depth. However, the rate of settlement decreases and becomes minimal around 1000-1500 cycles of loading. In general, it can be inferred that the stiffness of the GSI layer increases as the number of loading cycles increases, mainly due to particle reorientation and densification of the sand-SRM matrix. This is caused by the deformation of rubber particles in the SRM matrix which fill in the voids in the sand skeleton.

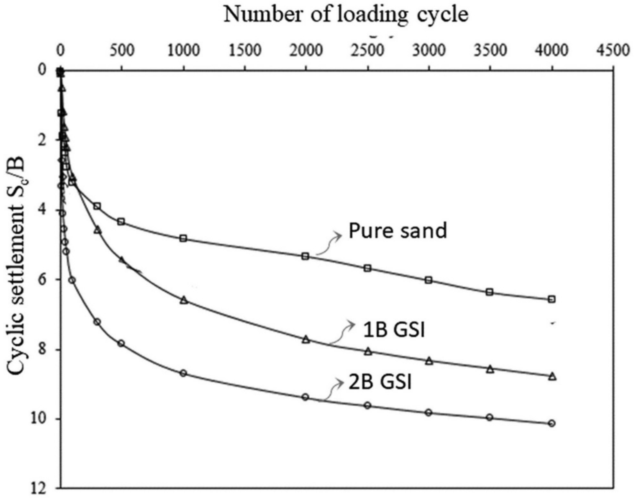


Figure 3. Variation of footing settlement (Sc/B) with number of load cycle for Sand and GSI.

Figure 4 presents the variation of load with the cyclic settlement under cyclic loading for the footing with and without GSI cases. The figure illustrates that the footing response on the sand bed demonstrated a narrow hysteresis loop, indicating hardening of the sand bed with minimal energy dissipation and no plastic deformation. On the other hand, the GSI system exhibited a broader hysteresis loop compared to the sand bed, which suggests higher energy dissipation by the GSI layer during the cyclic loading phase. Furthermore, the hysteresis loop of the GSI bed shows that the loop becomes consistent after a certain number of cycles, indicating densification of the GSI bed and a decrease in plastic deformation.

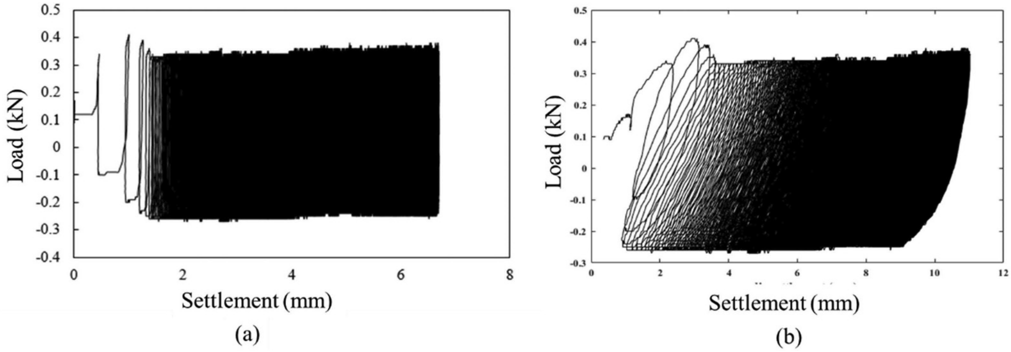


Figure 4. Load vs settlement hysteresis loop: a) Sand bed (b) GSI bed of 2B depth.

4 CONCLUSIONS

The research presented demonstrates the performance of the sand-rubber mixture (SRM) GSI system under both static and repeated loads. The results show that during the initial phase of loading, the cyclic settlement is more prevalent in the GSI system compared to the case without GSI. It is also observed that while the settlement increases with the thickness of the GSI bed, it eventually stabilizes at higher cycles of loading. The high hysteris damping mechanism of GSI that facilitates energy dissipation and vibration mitigation is evident during the cyclic loading, making it critical for vibration isolation applications. When choosing low stiffness materials for the GSI bed, such as the sand-rubber mixture layer, it is important to consider the compressibility response of the material and optimize the thickness accordingly.

The future scope of this research includes assessing the cyclic response of the SRM GSI system reinforced with geosynthetics such as geogrid and geocells which can greatly reduce cyclic settlements and enhance the applicability of SRM-GSI systems without compromising its serviceability and performance. Additional cyclic load testing on the model footing should be performed to evaluate the combined response of the geosynthetic reinforced SRM-GSI system in vibration mitigation studies in selecting appropriate parameter values for the design of footings on GSI systems.

REFERENCES

BIS (Bureau of Indian Standards). 1970. *Classification and identification of soils for general engineering purpose*. IS:1498-1970. Manak Bhawan, New Delhi: BIS.

Cresswell, A., M. E. Barton, and R. Brown. 1999. Determining the maximum density of sands by pluviation. *Geotech. Test. J*. 22 (4): 324–328.

Dhanya, J. S., A. Boominathan, and S. Banerjee. 2019. Performance of geo-base isolation system with geogrid reinforcement. *Int. J. Geo- mech*. 19 (7): 04019073.

Dhanya, J. S., A. Boominathan, and S. Banerjee. 2020. Response of low- rise building with geotechnical seismic isolation system. *Soil Dyn. Earthquake Eng*. 136: 106187.

Dhanya, J. S., A. Boominathan, and S. Banerjee. 2022. Investigation of geotechnical seismic isolation bed in horizontal vibration mitigation. *J. Geotech. Geoenviron. Eng*., 2022, 148(12): 04022108.

Edil, T., and P. J. Bosscher. 1994. Engineering properties of tire chips and soil mixtures. *Geotech. Test. J*. 17 (4): 453–464.

Ehsani, M., Shariatmadari, N. and Mirhosseini, S. M. 2015. Shear modulus and damping ratio of sand-granulated rubber mixtures. *J. Cent. South Univ*., 22, 3159–3167.

Forcellini, D. 2020. Assessment of geotechnical seismic isolation (GSI) as a mitigation technique for seismic hazard events. *Geosciences*, 10 (6): 1–14.

Hazarika H, Yasuhara K, Kikuchi Y, Karmokar AK, Mitarai Y. 2010. Multifaceted potentials of tire-derived three dimensional geosynthetics in geotechnical applications and their evaluation. *Geotext Geomembr*., 28:303–15.

Kirzhner F, Rosenhouse G, Zimmels Y. 2006. Attenuation of noise and vibration caused by underground trains, using soil replacement. *Tunn Undergr Space Technol*., 21(5):561–7.

Moghaddas Tafreshia, S.N., Dawson, A.R., 2012. A comparison of static and cyclic loading responses of foundations on geocell-reinforced sand. *Geotext. Geomembranes*, 32 (32), 55–68.

Pitilakis, K., S. Karapetrou, and K. Tsagdi. 2015. Numerical investigation of the seismic response of RC buildings on soil replaced with rubber– sand mixtures. *Soil Dyn. Earthquake Eng*. 79 (Dec): 237–252.

Rao, G. V., and R. K. Dutta. 2006. Compressibility and strength behaviour of sand-tyre chip mixtures." *Geotech. Geol. Eng*. 24 (3): 711–724.

Senetakis K, Anastasiadis A, Pitilakis K, Souli A. 2012. Dynamic behavior of sand/ rubber mixtures, Part II. *J ASTM Int*.,9(2), 1–13.

Tsang, H. 2008. Seismic isolation by rubber–soil mixtures for developing countries. *Earthquake Eng. Struct. Dyn*. 37 (2): 283–303.

Tsang, H. H., D. P. Tran, W. Y. Hung, K. Pitilakis, and E. F. Gad. 2021. Performance of geotechnical seismic isolation system using rubber-soil mixtures in centrifuge testing. *Earthquake Eng. Struct. Dyn*. 50 (5): 1271–1289.

Wood, D. M. 2004. *Geotechnical modelling*. Abingdon, UK: Spon.

Zornberg, J. G., A. R. Cabral, and C. Viratjandr. 2004. Behaviour of tire shred-sand mixtures. *Can. Geotech. J*. 41 (2): 227–241.