Dynamic Properties of Sand-Tyre Chips Mixtures

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ABSTRACT

The stockpiling of scrap tyres is a significant environmental hazard and has attracted ample research attention to explore viable solutions to recycling and reuse of scrap tyres. The authors have recently proposed a novel seismic isolation method using sand-tyre chips (STCh) mixture for protecting buildings and infrastructure. Although the static properties of STCh mixture have been extensively studied, the investigation on the dynamic properties of the mixture has been limited. The dynamic properties of STCh mixture are important to its application for seismic protection of infrastructure. This paper presents the dynamic properties (shear modulus and damping ratio) of STCh mixture for medium to large range of shear strain levels (0.15% to 0.5%). The effects of the level of cyclic shear strain, number of cycles and effective initial confining pressure have been investigated. The dynamic properties of STCh mixture presented in this paper will also be essential for the application of the mixtures in other civil engineering projects.

Keywords: Scrap tyres, sand-tyre chips mixture, seismic isolation, shear modulus, damping ratio.

1 Introduction

Structures in most developing countries are not designed with adequate seismic resistance and are at the mercy of the destructive power of earthquakes. Seismic isolation mechanisms for protecting structures against seismic ground motion were first introduced in New Zealand in the 1960s. Since then, sophisticated seismic isolation methods have been developed. However, all developed methods to protect infrastructures are expensive and need significant expertise especially for the design and installation of seismic isolation devices. The high cost and expertise needed for the developed seismic isolation methods preclude their use in developing countries where more than 80% of the earthquake-induced fatalities occur (Tsang et al., 2012). Hence, a low cost seismic isolation method for protecting infrastructures especially in developing countries is important.

On the other hand, the increase in the number of vehicles worldwide has negatively impacted the global environment with the increase in the stockpiles of scrap tyres. Stockpiling of scrap tyres is highly undesirable as it not only causes environmental pollution but also creates fire hazards and health risks. The use of scrap tyres in environmentally friendly ways is the present challenge for the engineering community. Currently, the use of scrap tyres includes generation of tyre derived fuel (TDF), ground rubber applications (e.g., new rubber products, playground and other sports surfacing and rubber-modified asphalt, etc.), and few civil engineering applications (e.g., soil reinforcement in road construction, ground erosion control, slope stabilization and light-weight materials for backfilling of retaining structures). The environmental pollution created to generate TDF makes recycle and reuse of scrap tyres as preferred options (Genan, 2010). There is a growing demand on civil engineering community to reuse scrap tyres in civil engineering projects. However, the amount of scrap tyres currently used in civil engineering projects is rather very limited.

The authors and research collaborators have recently proposed the use of sand-scrap tyre mixture (STCh) for seismic isolation of low-to-medium-rise building, especially suited for developing countries. The innovative use of scrap tyres for seismic protection of infrastructure (Tsang, 2008; Tsang et al., 2009) is an attractive method due to its low cost and the potential of consuming huge stockpiles of scrap tyres. Tsang et al. (2009; 2012) numerically modelled the soil-tyre (scrap tyre) mixture as a seismic isolator for low-to-medium-rise buildings. The STCh mixture underneath the foundation of the low-to-medium-rise buildings protects the structure through cushioning effect against earthquake ground motions. The numerical model used the dynamic properties of STCh mixtures based on available experimental results in the literature (Edil and Bosscher, 1994; Ghazavi, 2004; Humphrey et al., 1993; and Feng and Sutter, 2000). However, the reported dynamic properties of scrap tyre-sand mixtures were derived from experimental investigations on sand mixed with tyre crumbs (small granules). Also, the papers reported the dynamic properties only at small strain levels. Tsang et al. (2009; 2012) extrapolated the values of the dynamic properties for the strain range of interest (0.15% - 5%) for the numerical modelling.

The authors of this paper previously investigated the static properties of sand-tyre crumbs and sand-tyre chips (STCh) mixtures. The shear strength of sand was reported to be reduced by the inclusion of tyre crumbs to sand (Sheikh et al., 2013). On the other hand, the behaviour of sand mixed with tyre chips improved the shear strength of sand (Zornberg et al 2004). From the monotonic tests carried out previously by the authors, three behavioural zones of the STCh mixtures were clearly identified in terms of the percentage of tyre chips in the mixture

(Mashiri et al. 2013). This allowed the determination of an optimum STCh mixture, where the maximum amount of tyre chips inclusion is achieved together with improvement of sand static properties (strength and dilatancy).

The focus of this paper is on the investigation of the Shear Modulus (G) and Damping Ratio (ζ) of optimum sand-tyre chips mixture, STCh(35%), at medium to large shear strain levels (0.15 % to 0.5%), which is particularly important for the investigation on the use of STCh mixture for seismic isolation of infrastructure. The influences of the effective initial confining pressure of the STCh mixtures and number of cycles have been investigated.

2 Methodology

Cyclic Triaxial tests have been conducted on STCh mixtures. The tyre chips used in this study have an aspect ratio of 4. Tyre chips have been cut into rectangular shapes for uniform widths (smaller dimension) of 5 mm. The thickness of the tyre chips has been found to vary from 3 to 7 mm with specific gravity ($G_{s,TCh}$) of 1.12. The particle size distribution of sand (beach sand) used in this study has been shown in Figure 1. The inset in Figure 1 shows the properties of the sand. The sand is classified as poorly graded (SP). Void ratios for sand, tyre chips (TCh), and STCh mixtures have been obtained according to the testing procedures in ASTM D 4253 and ASTM D 4254. The proportion of tyre chips by mass (χ%) in STCh mixture considered in this study is 35%, corresponding to a proportion of tyre chips by volume of 50%. STCh(35%) was identified as the optimum STCh mixture for use in civil engineering projects to exploit fully the beneficial properties of sand and tyres (Mashiri et al., 2013). The minimum and maximum void ratios of TCh have been found as 0.83 and 1.30, respectively. The minimum and maximum void ratios of STCh(35%) are 0.25 and 0.46, respectively. The specific gravity of the STCh(35%) is 1.78.

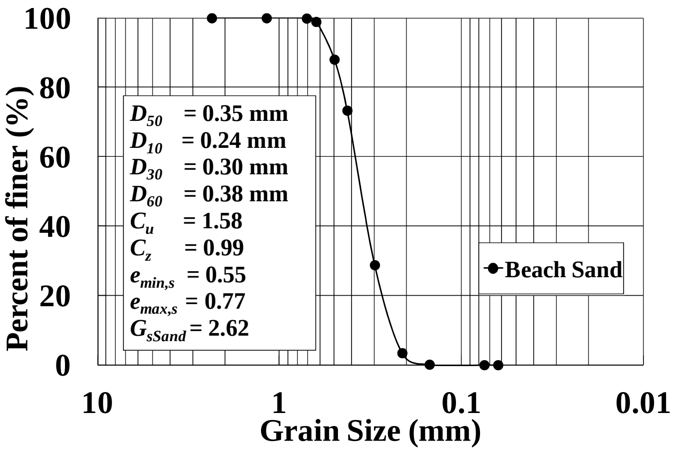

Figure 1: Sieve analysis of beach sand

Specimens with a diameter of 100 mm and height of 200 mm for the consolidated undrained (CU) cyclic triaxial tests have been prepared to an initial relative density (D_r) of 50%. The STCh mixture samples have been prepared in three layers. Every layer has been compacted by tamping the walls of the mould. Afterwards, the samples have been saturated to a *b*-value

>0.95, using back pressure saturation technique (ASTM D 7181-11). The specimens have been consolidated to the desired effective initial confining pressure (σ_{3c}'). The cyclic tests have been carried out using stroke controlled test where a constant cyclic deformation is applied to the specimen. The single cyclic amplitude has been determined in mm, corresponding to the desired axial strain (ε_1). The specimen's initial properties are recorded after the isotropic consolidation to the desire effective initial confining pressure (i.e., height, volume and relative density). Then, the datum at this condition has been set to 0 mm.

The tests have been performed at three different effective initial confining pressures, σ_{3c}'= 23, 69 and 138 kPa. The tests have been carried out at frequency *f* = 1 Hz.. The shear strains considered in this study vary from 0.15% to 0.5%. The cyclic triaxial tests have been carried out by applying strokes imposing compression as well as tension stresses to the specimen. The load ram has been rigidly connected to the top platen by attaching an extension top cap through a vylastic sleeve. A total number of 100 cycles have been applied to each specimen with the exception of few tests where only 40 cycles have been applied. All tests have been carried out in undrained conditions.

3 Test Results

3.1 Effect of initial confining pressure (σ_{3c}')

The effect of the effective initial confining pressure on the behaviour of the shear modulus and damping ratio has been illustrated in Figures 2 to 5. Figures 2 and 3 show the shear modulus (G) at shear strain of 0.23% and 0.50%, respectively, for 3 different confining pressures (23, 69 and 138 kPa) after the 2nd, 10th and 40th cycles. It can be observed that the shear modulus increases with the increase in the confining pressure.

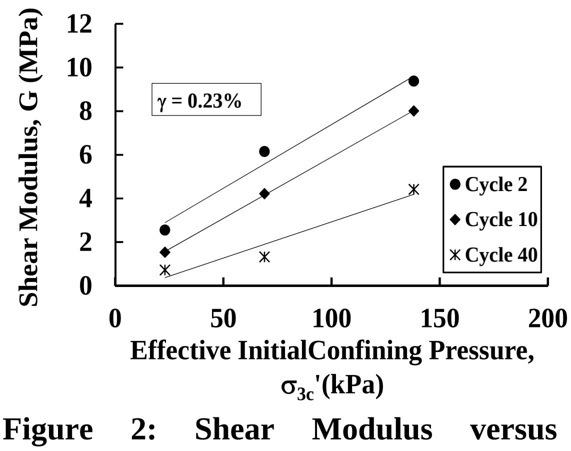

Figure 2: Shear Modulus versus Effective Initial Confining pressure for STCh(35%) at γ=0.23% and 2nd, 10th and 40th cycle.

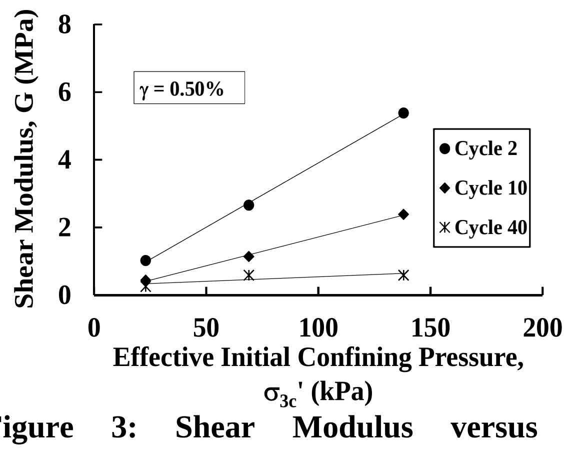

Figure 3: Shear Modulus versus Effective Initial Confining pressure for STCh(35%) at γ=0.50% and 2nd, 10th and 40th cycle.

Figures 4 and 5 show damping ratios (ζ) for shear strains (γ) of 0.23% and 0.50% at three different confining pressures (23, 69 and 138 kPa), after the 2nd, 10th and 40th cycles. For γ = 0.23%, the damping ratio has been observed to decrease with the increase in the initial effective confining pressure. However, for σ_{3c}'=69 to 138 kPa the damping ratio has been observed to be not affected by the increase in the confining pressure. For γ = 0.50%, the effective initial confining pressure does not have significant influence on the damping ratio after first few cycles. The damping ratio at larger shear strains has been observed to be slightly greater at lower initial effective confining pressures (23 and 69 kPa) compared to that at higher effective confining pressure (σ_{3c}'=138 kPa).

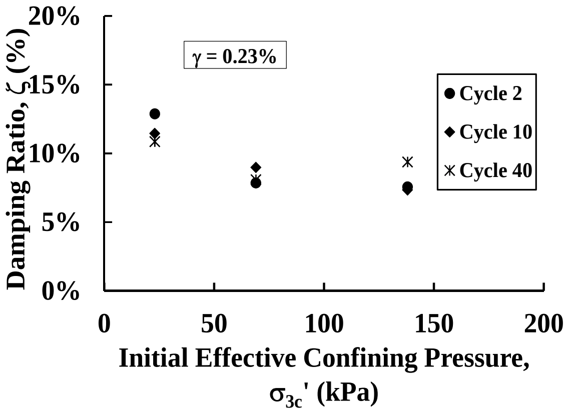

Figure 4: Damping Ratio versus Effective Initial Confining pressure for STCh(35%) at γ=0.23% and 2nd, 10th and 40th cycle.

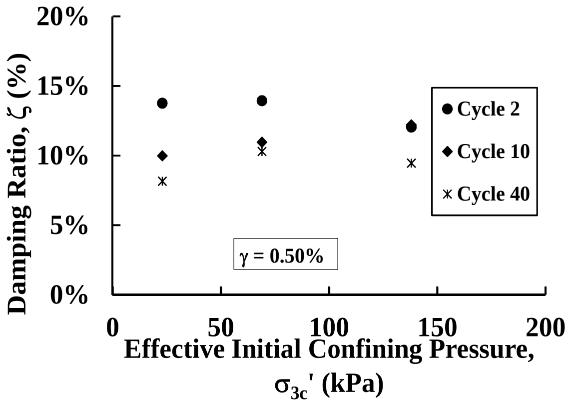

Figure 5: Damping Ratio versus Effective Initial Confining pressure for STCh(35%) at γ=0.23% and 2nd, 10th and 40th cycle.

3.2 Effect of number of cycles (N)

The effect of the number of cycles (application of strain amplitude) on the shear modulus and damping ratio can also be observed from Figures 2-5. The shear modulus decreases with the increase in the number of cycles regardless of the confining pressure and shear strain (Figures 2 and 3). On the other hand, the damping ratio decreases with the increase in the number of cycles, but the rate of decrease is not significant after first few cycles (Figures 4 and 5). More experiments need to be conducted in order to delineate a more definite trend.

3.3 Effect of cyclic shear strain (γ)

The influence of the cyclic shear strain in the shear modulus and damping ratio at σ_{3c}'= 69 and 138 kPa has been shown in Figures 6 to 9. The shear modulus has been observed to be decreased with the increase in the shear strain for both effective initial confining pressures (Figures 6 and 8). At σ_{3c}'= 69 kPa, the shear modulus has been observed to be decreased rapidly within first 20 cycles, afterwards the rate of decrease is lower (Figure 6). It can be observed that the shear modulus is not affected by the cyclic shear strain γ>0.38%. On the other hand, at σ_{3c}'= 138 kPa, for γ=0.15% and 0.23%, the shear modulus decreases with the increase in the number of cycles. However, for γ=0.30% and 0.50%γ>0.23%, the rate of decrease is significantly lower after first 20 cycles.

The damping ratio shows different behaviour at different confining pressures (σ_{3c}'= 69 and 138 kPa) (Figures 7 and 9). For the lower effective initial confining pressure (σ_{3c}'= 69 kPa), it has been found that the damping ratio at the first few cycles rapidly decreases. However, the rate of decrease has been observed to be lower with the increase in number of cycles beyond 20-40 cycles. Nevertheless, the shear strain does not seem to influence the damping ratio considerably, although the damping ratio at γ>0.50% has been observed to be higher than damping ratio at other strain levels.

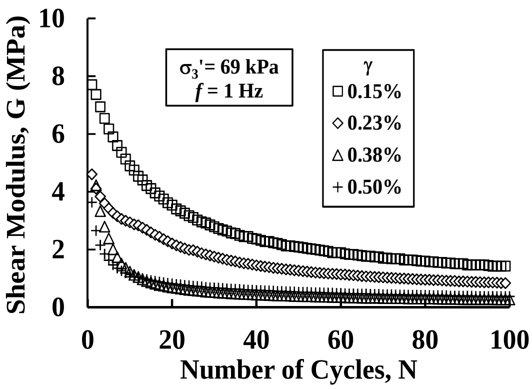

Figure 6: Shear Modulus versus Number of Cycles for STCh(35%) at different shear strains (frequency =1 Hz, and σ_{3c}' = 69 kPa)

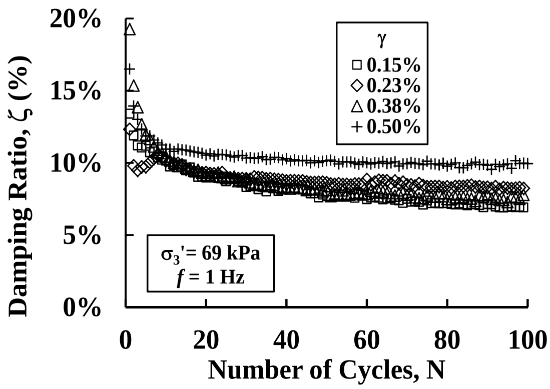

Figure 7: Damping ratio versus Number of Cycles for STCh(35%) at different shear strains (frequency =1 Hz, and σ_{3c}' = 69 kPa)

At higher effective confining pressure (σ_{3c}'= 138 kPa), for γ=0.15% and 0.23%, it can be observed that the damping ratio increases with the increase in the number of cycles for up to 40-60 cycles. Afterward, the damping ratio remains constant with the increase in the number of cycles. For γ=0.30% and 0.50%, the damping ratio increases with the increase in the number of cycles for up to 10 cycles. The behaviour has been observed to be opposite as the number of cycles increases beyond 10 (effective confining pressure reduced due to the increase of pore pressure). However, after 60 cycles, the damping ratio seems to reach a value which is independent of the shear strain.

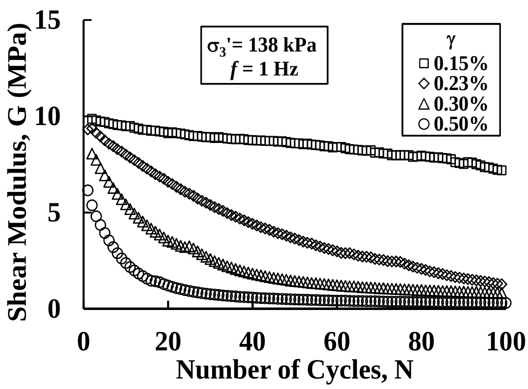

Figure 8: Shear Modulus versus Number of Cycles for STCh(35%) at different shear strains (frequency =1 Hz, and σ_{3c}' = 138 kPa)

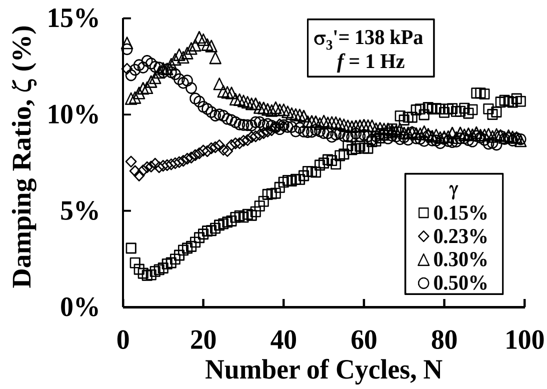

Figure 9: Damping ratio versus Number of Cycles for STCh(35%) at different shear strains (frequency =1 Hz, and σ_{3c}' = 138 kPa)

4 Conclusions

The paper investigated the effect of level of cyclic shear strain, number of cycles and effective initial confining pressure, on the shear modulus and damping ratio of sand-tyre chips mixtures (STCh(35%)).

It has been observed that shear modulus of STCh mixtures increases with the increase in the initial effective confining pressure. On the other hand, the shear modulus decreases with the increase in the number of cycles and for larger shear strain. The shear modulus of STCh mixture shows gradual decrease with the number of cycles at low shear strain and high effective confining pressure. In contrast, the shear modulus shows a rapid decrease in the first few cycles at higher shear strains for both lower and higher effective confining pressures. Afterwards, as the number of cycles increases, the shear modulus slightly decreases. Similar behaviour has been observed for lower effective confining pressure and lower shear strains. This can be explained by the increase of the pore pressure with the number of cycles reducing the effective confining pressure.

The damping ratio of STCh mixture has been significantly affected by the effective confining pressure, number of cycles and level of shear strain. It has been found that at low effective confining pressure, the damping ratio is not significantly affected by the shear strain. The damping ratio shows a slight decrease in the first few cycles, whilst it remains between 8 and 10% afterwards. However, the damping ratio at high effective confining pressure increases with the increase in the shear strain and increase in the number of cycles. In the first few cycles, the damping ratio increases at all shear strains investigated. After 40-60 cycles, the damping ratio for smaller shear strains reaches and remains at a value of 9-10%. The damping ratio at larger shear strains decreases after 10-20 cycles and reaches a value of approximately 9-10%. This behaviour can be related to the variation of the effective confining pressure as the pore pressure increases with the number of cycles and the level of shear strain.

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