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M S. Mashiri
University of Wollongong, msm617@uowmail.edu.au

M Neaz Sheikh
University of Wollongong, msheikh@uow.edu.au

J S. Vinod
University of Wollongong, vinod@uow.edu.au

Hing Ho Tsang
The University of Hong Kong, tsanghh@hkucc.hku.hk

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SCRAP-TYRE SOIL MIXTURE FOR SEISMIC PROTECTION

M. S. Mashiri[1], M. Neaz Sheikh[1], J. S. Vinod[1], Hing Ho Tsang[2]
[1] University of Wollongong [2] University of Hong Kong

ABSTRACT

Scrap tyre stockpile has been a significant disposal problem around the world. Significant research attention has been devoted in recent years to find new beneficial ways to recycle and reuse the huge stockpile. This paper proposes a new method of utilizing scrap tyres for infrastructure protection. The method involves mixing scrap tyres with soil materials and placing the mixtures around foundations for vibration absorption. This method provides two major benefits: (i) the low-cost would make it accessible to developing countries and rural areas of developed countries where resources and technology are not adequate for earthquake mitigation with well-developed, expensive, techniques and (ii) potential to consume the huge stockpiles of scrap tyres all over the world. However, the success of the proposed method depends on the static and dynamic properties of scrap tyre-soil mixtures. This paper presents results of recent experimental investigations on tyre (tyre crumbs)-soil mixtures carried out at University of Wollongong.

1 INTRODUCTION

Recent earthquakes in China (2008), Haiti (2010) and Chile (2010) once again reminded us of the destructive power of earthquakes, particularly in developing countries and rural areas of developed countries where structures are not designed for adequate earthquake protection. It is believed to be one of the most significant challenges that the earthquake engineering community is facing nowadays. For the protection of structures against seismic ground motion, seismic isolation using bearings was first proposed in New Zealand in the 1960s. During that time the concept was considered very impractical by structural engineers. In the past three decades seismic design philosophy has been changed significantly and seismic isolation is considered one of the effective methods for seismic protection of infrastructure. Sophisticated seismic isolation devices have been developed. Different seismic isolation mechanisms have also been introduced. However, all of the developed seismic isolation mechanisms are expensive and need expertise for the design and installation of seismic isolators. The high cost and expertise needed for the installation of seismic isolators preclude their use in developing countries and rural areas of developed countries where 80% of the fatalities occur. Hence, a low cost seismic protection method is necessary for these areas.

Our planet, on the other hand, is facing another environmental disaster due to large stockpile of scrap tyre. It is estimated that more than 680 million EPU (equivalent passenger unit) tyres will reach Australian landfill in the next 20 years (Australia Government 2010). This figure is in line with the estimates in other developed countries. Europe and some states in the USA have already put a ban on the disposal of tyres as landfill. It has become a challenge for civil engineering to find out ways to use scrap tyre in civil construction industry. Although different uses of scrap tyres have been proposed, the amount of tyres estimated to be used in those proposals is still limited. More innovative applications are needed to reduce the huge stockpile in an environmentally friendly way.

This paper proposes an innovative use of scrap tyre for seismic protection of infrastructure. The method involves mixing scrap tyres with soil materials and placing the mixtures around the foundation for vibration absorption. This method provides two major benefits: (i) the low-cost would make it accessible to developing countries and rural areas of developed countries where resources and technology are not adequate for earthquake mitigation with well-developed, expensive techniques and (ii) potential to consume the huge stockpiles of scrap tyres all over the world. The focus of this paper is to present results of recent experimental investigations on tyre (tyre crumbs)-soil mixtures carried out at University of Wollongong.

2 INFRASTRUCTURE PROTECTED BY TYRE-SOIL MIXTURE

A seismic isolation system is defined as a flexible or sliding interface positioned between a structure and its foundation for the purpose of decoupling the horizontal motions of the ground from the horizontal motions of the structure, thereby reducing earthquake damage to the structure and its contents. The mechanism proposed in this study consists of replacing the soil surrounding the infrastructure by scrap tyre- soil mixture. The scrap tyre-soil mixture has the ability to absorb seismic energy; therefore, energy dissipation will be reflected in the reduction of shaking level of the structure.

Tsang *et al* (2009) have numerically modelled the use of scrap tyre-soil as a seismic isolator, which protects the structure through a cushion effect against earthquake ground motion. The result presented in the paper has shown the great potential of scrap tyre-soil mixture in seismic protection of infrastructure in low to moderate seismicity regions or rural areas of developed countries where structures are not generally designed for adequate seismic protection.

The numerical study carried out on the feasibility of using soil-scrap tyres as a seismic isolator in Tsang *et al.* (2009) was based on the available experimental results in the literature. Edil and Bosscher (1994), Ghazavi (2004), Humphrey *et al.* (1993) and Feng and Sutter (2000) have previously reported properties of different soil-scrap tyre mixtures. However, studies reported in the literature are not complete for seismic analyses in terms of expected strain level in the tyre soil mixture under seismic ground motion. Hence, comprehensive experimental studies on the properties of tyre-soil mixture are paramount for the success of the proposed method. This aim of the ongoing research of the authors is to carry out detailed investigations on the static and dynamic properties of scrap tyre-soil mixtures. Experimental studies on the static properties of tyre-soil mixture are presented herein. Also, ongoing investigation on dynamic properties of tyre-soil mixture has been briefly reported.

3 EXPERIMENTAL STUDIES ON TYRE-SOIL MIXTURE

3.1 STATIC TESTS

3.1.1. Description of Materials

This section presents the result of the static tests on tyre crumbs-sand mixture. The mixture has two components: sand and tyre crumbs. The sand used in the study is classified as poorly graded soil, with e_{min} (minimum void ratio) = 0.55 and e_{max}(maximum void ratio) = 0.76. *Tyre Crumbs Australia Pty Ltd* provided two types of tyre crumbs with different gradations. The experimental investigations reported herein were performed using TC_1 (tyre crumb type 1), which is finer than TC_2 (tyre crumbs type 2). The properties of both materials, sand and tyre crumbs (type 1 and 2) are presented in Table 1. These tests were conducted according to Australian standards (AS 1289.5 & AS1289.2).

Table 1: Properties of sand and tyre crumbs

Parameter	Sand	TC_1	TC_2
D_{10} (mm)	0.23	0.49	0.13
D_{30} (mm)	0.29	1.01	1.65
D_{60}(mm)	0.38	1.52	2.45
D_{50}(mm)	0.34	1.39	2.2
C_u	1.64	3.10	1.91
C_c	0.94	1.37	0.87
G_s	2.64	1.17	1.17
w (%)	0.15	0.5	0.5

The bulk density of the tyre crumbs and the moisture content for the tyre crumbs were adopted from Table 2 provided by the manufacturer. The tyre crumbs obtained are in the form of granules without steel belt. This kind of scrap tyre was chosen especially to allow experimental investigations using triaxial testing apparatus.

3.1.2. Methodology

To the knowledge of the authors, no experimental result is available in the literature on the properties of tyre crumbs soil mixture. This paper is the first of its kind on such investigations. The investigation on the static behaviour of tyre crumbs soil mixture is considered important in understanding the engineering behaviour of such mixture.

Five mixtures in dry condition, composed of different proportions of rubber crumbs and soil, have been tested at undrained unconfined (UU) condition in a static triaxial apparatus for different cell pressures. Specimens composed of 100% sand were also tested. One specimen composed of 100% tyre crumbs at cell pressure 207 kPa was tested to have the base line for tyre crumbs behaviour. The experiments were performed by applying axial deformation at a constant rate of 0.5 mm/min (strain-controlled test). The peak value was defined as the highest deviator stress before the occurrence of any stress drop.

Table 2: Chemical Analysis and Technical Information of Tyre Crumbs
(Provided by Tyre Crumbs Australia Pty. Ltd.)

Chemical Analysis	**G1030-25** **(TC_1)**	**G1040-25** **(TC_2)**	**Technical Information**	**G1030-25** **(TC_1)**	**G1040-25** **(TC_2)**
Ash at 550°C	5%	5%	Bulk Density (kg/m^3)	440	440
Carbon Black Content	32%	32%	Moisture Content	0.50%	0.50%
Rubber Hydrocarbon (Polymers)	50%	50%	Steel Content	<.1%	<.1%
Extractables	13%	13%	Fibre Content	<.1%	<.1%

The percent of rubber added to sand was based on volume. Although intuitively the mixture by mass would be easier; however, the sample preparation by mass may face difficulty due to large difference in specific gravities of the two materials. This also makes it difficult to have constant dry unit weight for different mix ratios. The investigation carried out in the paper was based on constant void ratio of the mixture. The selected void ratio is the mean void ratio of sand, $(e_{max}+e_{min})/2$. It is assumed that tyre crumbs and sand will have the same initial void ratio at the time of mixing. Based on this assumption parameters of the mix were selected. S-TCx% stands for Sand-Tyre Crumb where x is the percent of tyre crumbs by volume. Table 3 provides the detailed information of the specimen tested.

Table 3: Test specimens.

Specimen	% V_{TC}	% M_{TC}	$\gamma_{dS\text{-}TC}$ (kN/m^3)	γ_{dS} (kN/m^3)	γ_{dTC} (kN/m^3)	e
S-TC0%	0%	0%	15.62	15.62	n/a	**0.655**
S-TC10%	10%	4.69%	14.75	15.62	6.92	**0.655**
S-TC20%	20%	9.97%	13.88	15.62	6.92	**0.655**
S-TC25%	25%	12.86%	13.44	15.62	6.92	**0.655**
S-TC30%	30%	15.95%	13.01	15.62	6.92	**0.655**
S-TC40%	40%	22.80%	12.14	15.62	6.92	**0.655**
S-TC100%	100%	100.00%	6.92	15.62	6.92	**0.655**

It is evident from Table 3 that the dry unit weight of the mixture ($\gamma_{dS\text{-}TCx\%}$) decreases when percentage of tyre crumbs by volume (x% V_{TC}) increases for a constant void ratio of the mixture.

3.1.3. Preparation of specimens

The mixing of sand and crumbs was carried out manually by stirring both materials with a spoon, producing a homogeneous sand-tyre crumbs mixture. The method used to prepare the specimens was using the "Dry deposition Method" described by Ishihara (1996).

Specimens were prepared in a cylindrical forming jacket with internal dimension of 38 mm (height) by 76 mm (diameter). A thin rubber membrane was used to hold the specimen together. The membrane is held to the bottom platen by an o-ring. Once the o-ring is in place, the platen is put at the bottom end of the forming jacket and the membrane covers the wall of the forming jacket. The height of the specimen is checked, making sure that the bottom platen is at the right location and horizontal. The rubber membrane was checked for detecting any puncture. Then vacuum is applied between the jacket's wall and the membrane. This vacuum ensures that the membrane totally embraces the wall of the forming jacket. Therefore, the specimen has the right diameter and friction between membrane and tyre crumb-sand is minimal.

The mass of each component in the mixture determines the dry unit weight, since the volume of the sample is constant. Some compaction was needed to achieve the dry unit weight for the required void ratio. This compaction was done mainly by tapping the walls of the forming jacket. Vibration was avoided as for lighter weight of the tyre crumbs may cause segregating the sample. Care was taken to produce homogeneous samples.

3.1.4. Experimental results

Four different cell pressures were chosen to test the mixtures in the static triaxial apparatus. These cell pressures are the same as that reported in Feng *et al* (2000): 69 kPa, 207 kPa, 345 kPa and 483 kPa.

Figure 1 presents axial strain versus the deviator stress of S-TC0%, S-TC10%, S-TC30% and S-TC100% at a confining pressure of 207 kPa. It is evident from Figure 1 that the deviator stress decreases and failure strain increases with the increase in the percentage of tyre crumbs. However, it is noted that brittle behaviour, exhibited by the sand specimen, is inhibited with the addition of tyre crumbs. Hence, ductility capacity of tyre crumbs and mixture is higher than pure sand. The increased ductility capacity of the material is important for their use in seismic condition, although dynamic properties of the mix would be more useful for their application as geotechnical seismic isolator.

Figure 2 presents deviator stress versus the axial strain for S-TC25% at the four different cell pressures. It is important to notice that there is an increase in the axial strain as the cell pressure increases. The improvement of the axial strain at higher confining pressure reflects the ductile behaviour of the mixture. Similar behaviour was also observed for other soil-tyre crumb mixtures tested in this study.

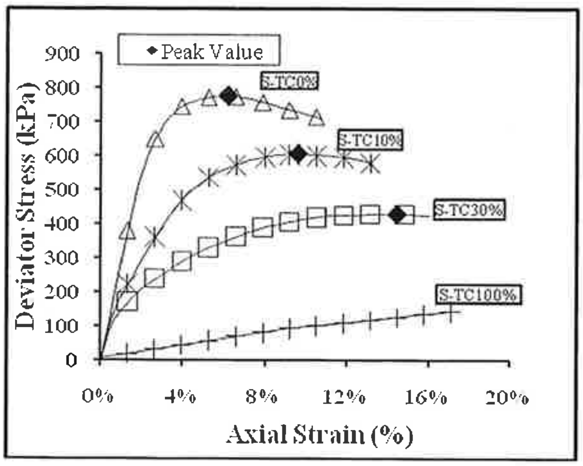

Figure 1: Deviator Stress versus Axial Strain (cell pressure = 207 kPa)

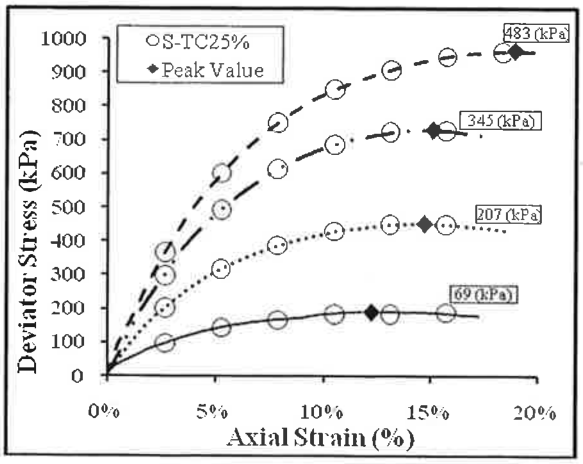

Figure 2: Deviator Stress versus Axial Strain (S-TC25% for different cell pressures

Table 4 presents the data obtained for S-TC0% and S-TC25% in the static triaxial test for four different cell pressures. From this table it is evident that axial strain in tyre crumb-soil mixture increases with increasing cell pressure. Similar behaviour has also been observed for shear strength and normal stress. However, the peak friction angle decreases with the increase of cell pressure. Therefore, the tyre crumb-soil mixture is behaving in a similar way as sand. This is an important fact since the soil mixture has being tested assuming it as a soil material. The important difference in the behaviour of two materials will be discussed in the later part of this paper. The results of the static behaviour show a great gain in axial strain on sand by the addition of tyre crumbs.

The shear strength of the mixtures was calculated according the Mohr-Coulomb failure criteria. Mohr's circles for each sand-tyre crumb mixture at the different cell pressures were drawn. The peak friction angles are included on the same graph. Peak friction angle is the angle defined by the tangent to the Mohr circle passing through the origin for each cell pressure. The Mohr failure envelope was drawn using a common tangent to the Mohr's circles at the cell pressures for each mixture.

Table 4: Static Triaxial Test Results for S-TC0% and S-TC25%

$\gamma_{S\text{-}TCx\%}$	Axial Strain % (ε)	Cell Pressure kPa	Peak Deviator Stress σ_d kPa	Peak Friction Angle ϕ° (Deg)	Shear Strength τ' kPa	Normal Stress σ' kPa
S-TC0% 15.62 kN/m^3	5.66%	69.00	313.06	43.95	112.69	116.89
	6.18%	206.90	775.00	40.69	293.84	341.78
	7.24%	344.83	1265.15	40.33	482.22	568.00
	7.76%	482.76	1460.42	37.01	583.07	773.38
S-TC25% 13.44 kN/m^3	12.24%	69.00	187.73	35.19	76.71	108.77
	14.74%	206.90	451.36	31.45	192.53	314.84
	15.13%	344.83	723.03	30.78	310.58	521.32
	18.95%	482.76	964.56	29.98	417.74	724.02

Figure 3 and 4 presents the Mohr's circles for S-TC0% and S-TC25%. The shear strength envelope of S-TC25% is clearly nonlinear. This effect can also be appreciated on the peak friction angle's curve. This is the difference between the mixtures and sand alone as mentioned before. The shear failure envelope of the mixtures has a nonlinear behaviour.

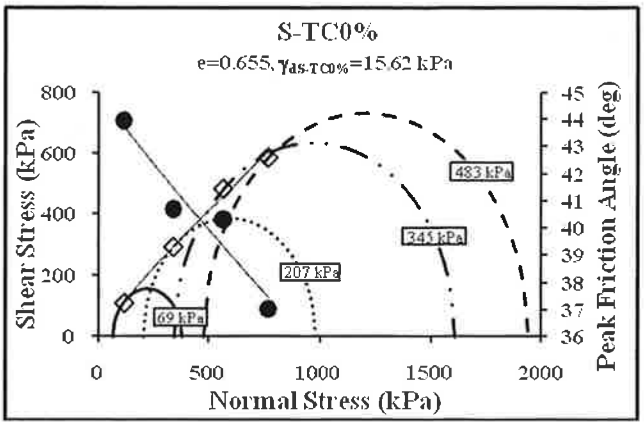

Figure 3: Mohr's Circle for Peak Friction angle and Shear Strength failure envelope S-TC0%.

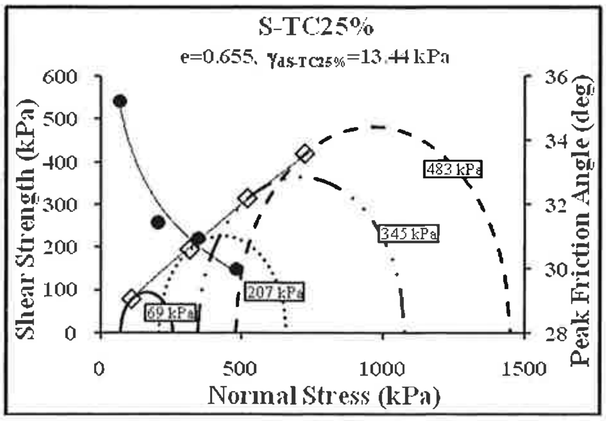

Figure 4: Mohr's Circle for Peak Friction angle and Shear Strength failure envelope S-TC25%

It is clear that the shear strength and friction angles have not been improved by the addition of tyre crumbs to sand at the level of normal stress tested, contrary to previous publications where the shear strength of sand-scrap tyre were tested and an improvement in shear strength and friction angle compared to sand alone was found. Foose *et al.* (1996), Ahmed *et al.* (1993), Edil and Bosscher (1994), Tatlisoz *et al.* (1998) have reported that sand can be reinforced by adding tyre chips to sand, increasing the shear strength and friction angles. It is important to note that the reported result was based on studies carried out under normal stress of 100 kPa where scrap tyre sizes are significantly larger than the tyre crumbs in this study.

Figure 5 presents the shear failure envelopes for all the tyre crumb-sand mixtures. All the tyre crumb-sand mixtures have the same nonlinear behaviour as S-TC25%. As the percent of tyre crumbs increases the failure envelope becomes more curved. It is clear that the relationship between normal stress and shear stress is nonlinear in the range of cell pressure tested. An exponential relationship to represent the shear envelopes' nonlinear behaviour is noticed for range of normal stresses between 100 and 800 (kPa). The study of the behaviour of the mixtures for normal stresses under 100 kPa is not yet complete and is a part of ongoing research.

The size of the tyre crumbs may have an important effect on the shear strength of the mix. The effect of the size of the tyre crumbs granule was checked by using the bigger granule crumbs, TC_2. Two different mixtures were prepared, the first one with 10% of TC_2 and the second one using 5% of TC_1 and 5 % of TC_2. The results of these tests are plotted in Figure 6 where all mixtures were tested for the same dry unit weight along with 100% sand.

Note that the three sand-tyre crumbs mixtures and sand have the same dry unit weight; therefore the void ratios are different. Also, S-TC100% has a different dry unit weight and void ratio than the mixtures.

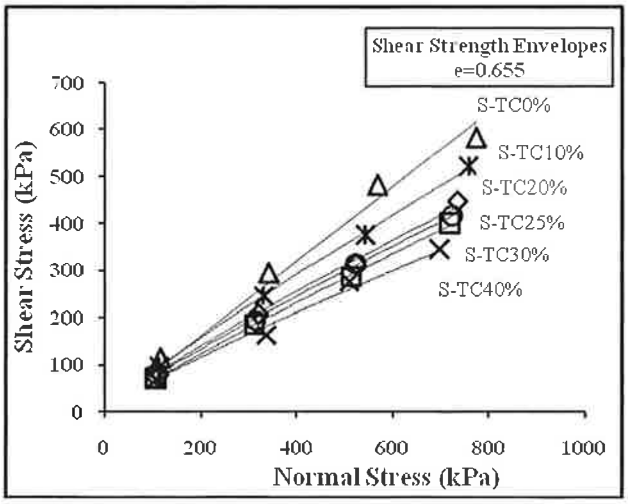

Figure 5: Shear strength Envelope for all mixtures

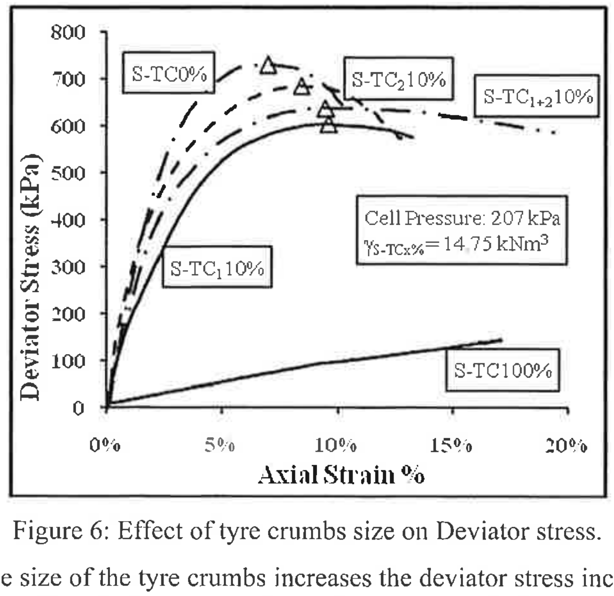

Figure 6: Effect of tyre crumbs size on Deviator stress.

Figure 6 shows clearly as the size of the tyre crumbs increases the deviator stress increases and the axial strain is still greater than sand alone, although its increase is smaller compared to the specimen with smaller granules. The mixture with both tyre crumbs (TC_1 and TC_2) shows better strength behaviour than the mixture with smaller granules keeping the same level of axial strain. Therefore, an in-depth study is needed to investigate the optimum gradation of sand-tyre crumbs and would be a topic for further investigation.

Ductility is a property of material used by seismic structural engineering to reduce the impact of earthquakes on structures. Therefore, improving the soil ductility has promising future in seismic and geotechnical engineering. Ductility of a material can be proved by the Brittleness Index. The ratio of the irreversible plastic energy consumed during failure (plastic energy capacity) and the recovered deformation energy obtained just before failure (elastic energy capacity) defines the Brittleness Index of a material (BI). Smaller brittleness indicates higher ductility capacity of the material (Topçu, 1997).

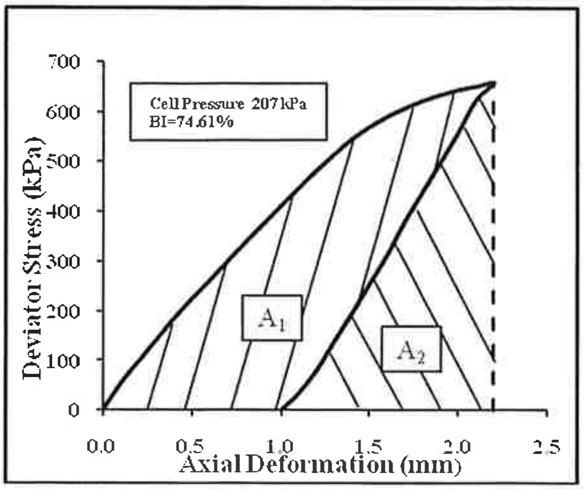

Figure 7: Brittleness Index for S-TC0%

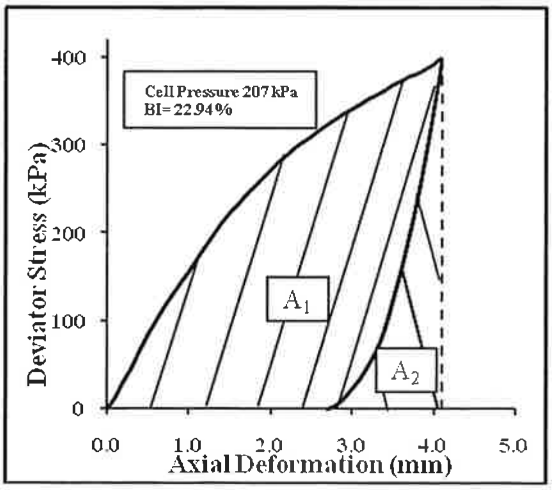

Figure 8: Brittleness Index for S-TC25%

The brittleness of the mixture was tested by loading a specimen in the static triaxial apparatus to 85% of the peak value of the deviator stress obtained from the static analysis. Then the specimen was unloaded at the same rate, until the deviator stress was equal to zero. As described before, the brittleness index is the ratio of A_2 over A_1. The results of these tests proved the ductility of the mixture compared to sand alone, since all the mixtures at the cell pressure tested (207 and 483 kPa) have a BI lower than sand alone. Figures 7 and 8 are plots of the results for S-TC0% and S-TC25% at a cell pressure of 207 (kPa)

Ductility of the material can be related to damping ratio. The greater the ductility the larger is the damping ratio (Parulekar *et al.* 2004). This is clearly promising for the use of tyre crumb sand mixture for seismic protection of infrastructure. However, dynamic triaxial tests will enable to accurately quantify the damping ratio with shear strain.

3.2 DYNAMIC TESTS

The dynamic response of a layer of soil can be described in the concept of wave propagation. The amplification function depends on the geometry and properties of the soil-mixture layer. The geometry is the thickness of the layer and the properties involved in the amplification function are the shear wave velocity and damping ratio (Tsang 2008).

The magnitude of shear strain in a soil is related to a mechanical characteristic. Strain level of 10^{-6} to 10^{-4} is considered as elastic, 10^{-4} to 10^{-2} as elasto-plastic and greater than 10^{-2} as failure (Ishihara, 1996). The dynamic properties of soils depend on the soil shear strains. The nonlinear characteristics of soil can be represented by two strain-compatible materials parameters, secant shear modulus G and damping ratio ξ. G_{max}, the maximum shear modulus of soil, is obtained on conditions of very low shear strains (10^{-5}-10^{-3}). The ratio G/G_{max} represents the strain-dependent degradation of shear modulus. Soil damping is composed of two effects: the first is the viscous component that is independent of the shear strain of the soil layer. It is represented by ξ_i (initial damping ratio). The second effect is the hysteric component that is associated to the degradation of the shear modulus and it is a strain-dependent component.

Feng *et al.* (2000) used a torsional resonant column device on their tests, obtaining the small strain dynamic properties for soil-tyre scrap mixtures. Tsang (2008) used the result of Feng *et al.* (2000) for the analytical study. However, extrapolation was needed for the full range of shear strain amplitude. Figure 9, adopted from Tsang (2008), shows the extrapolation by dashed lines. It is noted that shear strain amplitude large than 0.1% is needed for seismic analysis of the mixture. The ongoing research on dynamic properties of the material will check the validity of such curve fitting of the data obtained from low shear strain amplitude.

Dynamic tests to determine shear modulus and damping ratio for the different mixtures at larger shear strain are in progress. Bender element tests and dynamic triaxial tests are planned to achieve this objective. The bender element tests will provide the value of G_{max} for all the sand-tyre crumbs mixtures and the dynamic (cyclic) triaxial tests will provide values of the shear modulus and damping ratio for larger shear strain.

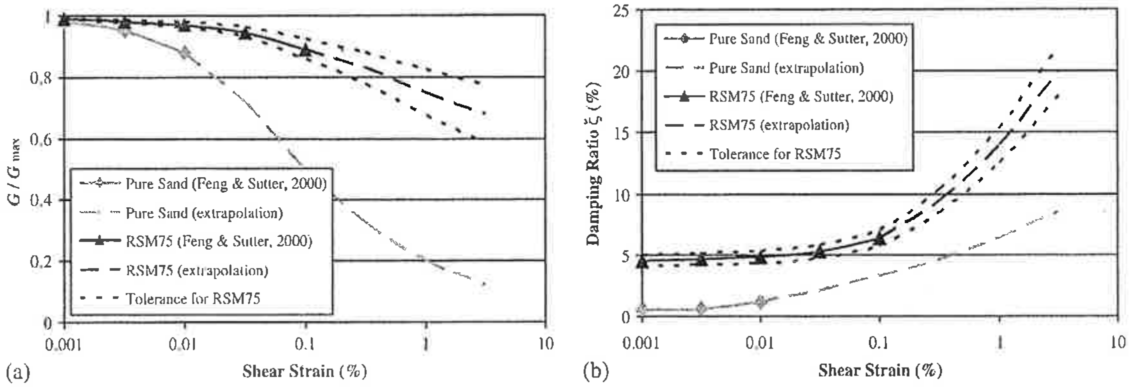

Figure 9: (a) Shear Modulus degradation curves and (b) damping curves adopted by Tsang (2008).

4 DISCUSSION

Static triaxial tests were carried out for sand and sand-tyre crumbs mixtures to determine shear strength and friction angles. Due to the large difference in specific gravities of the two materials it was not possible to keep same dry unit of the mix for different proportion of the mix. All the samples prepared in this investigation have the same void ratio. Hence, the samples with higher percentage of tyre crumbs have lower dry unit weight.

Static triaxial test apparatus is used to study the behaviour of tyre crumb sand mixture. (S-TCx%). The cell pressures used were 69, 207, 345 and 483 (kPa) and the value of x in the mixtures are 0, 10, 20, 25, 30 and 40%. It is clear that although there is no improvement of the deviator stress of the soil-mixture compared to sand alone, there is a great gain in axial strain in the mixtures (Figure 1).

The shear strengths and normal stresses of the mixtures are obtained by using the Mohr's Circle failure criteria. For the applied range of cell pressures, the normal stress obtained varies from 100 kPa to 800 kPa. Also, there was no improvement in the peak frictional angle of the mix with the increase of different percentage of tyre crumbs compared to the frictional angle of sand. Shear failure envelopes were drawn for all the mixtures and show that the envelopes of the mixtures have a nonlinear behaviour. As the percent of crumbs increases the shear failure envelope becomes more nonlinear (Figure 5).

The results obtained in this study differ from previous publications, where the shear strength and friction angles have been reported to be higher than those for sand alone. However, in the available publications tests were performed at normal stresses below 100 kPa. Also, larger sizes of scrap tyres were used. To check the influence of the size of the tyre crumbs, two new mixtures were tested, where a larger granule of crumbs was used to prepare the mixtures. These mixtures were tested keeping constant the dry unit weight and compared to sand alone with the same dry unit weight (not void ratio). Figure 6 shows that there is an improvement on the value of the deviator stress as the tyre crumbs size increases. The axial strain for bigger tyre crumbs decreases compared to the mixture with smaller granules, although it is still greater than the sand alone. Therefore, it is believed that the size of the tyre crumbs has an effect in the shear strength of the soil mixture. A comprehensive analysis will provide an optimum gradation sand-tyre crumb where the shear strength and axial strain are improved.

No test in this study was performed for normal stress below 100 kPa. However, from Figure 5 it can be appreciated that as the normal stress decreases, the curves for the different mixtures become closer to each other. If a linear extrapolation is done, for normal stress below to 100 kPa, the shear strength of the mixtures will have cohesion intercepts on the shear axis. Since sand is a cohesionless soil, it will pass through the origin, resulting the shear strength of the soil mixtures higher than sand. This assumption is under investigation, where additional static triaxial tests are being performed on lower cell pressures to produce lower normal stresses.

A brittleness analysis was carried out to prove that the soil mixtures have higher ductility than sand alone. A simple test was carried out where the specimens were tested in the static triaxial apparatus to 85% of the peak value and then unloaded to zero at a fix cell pressure. Figures 7 and 8 have the results of the brittleness index for S-TC0% and S-TC25% at cell pressure 207 kPa. The tyre-soil mixture has a BI (brittleness index) lower than sand, demonstrating a greater ductility. The ductility is related to damping ratio, where a greater ductility may represent a greater damping ratio, which is an important property for the mixture to act as a seismic isolator.

Due to the high compressibility of the rubber, tyre crumbs will lead to ground settlements. However, this settlement is due to a plastic compression. Once the plastic compression has happened, the compressibility decreases substantially. To eliminate this issue, preloading can help (Bosscher *et al.* 1997). Also, soil compaction increases the density of the soil mixture and reduces the void ratio which can in turn reduce the settlement. Compressibility of the sand-tyre crumbs mixtures is under study. Volumetric compressibility of tyre rubber has not been included in this study. Feng *et al.* (2000) has reported that volumetric compressibility of rubber tyre is insignificant for pressures ranging from 0 to 700 kPa. Soil solids (sand) are considered incompressible in the stress ranges utilized in this study.

5 CONCLUSIONS

Five tyre crumb-sand mixtures have been tested in a static triaxial apparatus to determine the static behaviour of the mixture. There is a significant increase in the failure axial strain for all the tyre crumb-sand mixtures tested, although a decrease in the deviator stress has been observed. It has been observed that axial strain increases with the increase of the percentage of tyre crumbs and also with the increase of cell pressure (confinement pressure).

The increase of axial strain is linked to the ductility of the tyre-soil mixtures. This study has shown a gain in ductility of sand by addition of tyre crumbs. Since greater ductility has been obtained with higher percentage of tyre crumbs, it is expected that higher damping ratio would also been obtained, which is considered important for using the mix as a seismic isolator.

The gradation of the tyre crumbs plays an important role in the strengthening of the soil mixture. This study has shown that a bigger granule of the tyre crumbs increases the deviator stress of the mixture. Therefore, the shear strength and peak friction angle of the mix increases with increasing crumb size. However, failure axial strain may decrease with the increase of the size of tyre-crumb. Therefore, an optimum gradation is to be determined for the improvement of shear strength without compromising the axial strain amplitude.

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