Geomechanics and Engineering, *Vol. 22, No. 3 (2020) 197-206*
DOI: https://doi.org/10.12989/gae.2020.22.3.197

Stabilization of backfill using TDA material under a footing close to retaining wall

Ali Arefnia*[1,2], Ali Dehghanbanadaki[3,4], Khairul Anuar Kassim[2] and Kamarudin Ahmad[2]

[1]Department of Civil Engineering, Roudehen Branch, Islamic Azad University, Roudehen, Iran
[2]Department of Geotechnics & Transportation, Faculty of Civil Engineering, Universiti Teknologi Malaysia, Skudai, Johor, Malaysia
[3]Department of Civil Engineering, Damavand Branch, Islamic Azad University, Damavand, Iran
[4]Research Center of Concrete and Asphalt, Damavand Brach, Islamic Azad University, Damavand, Iran

(Received June 13, 2019, Revised May 27, 2020, Accepted June 28, 2020)

Abstract. Reutilization of solid waste such as Tire Derived Aggregate (TDA) and mixing it with soft soil for backfill material not only reduces the required volume of backfill soil (i.e., sand-mining procedures; reinforcement), but also preserves the environment from pollution by recycling. TDA is a widely-used material that has a good track record for improving sustainable construction. This paper attempted to investigate the performance of Kaolin-TDA mixtures as a backfill material underneath a strip footing and close to a retaining wall. For this purpose, different types of TDA i.e., powdery, shredded, small-size granular (1-4 mm) and large-size granular (5-8 mm), were mixed with Kaolin at 0, 20, 40, and 60% by weight. Static surcharge load with the rate of 10 kPa per min was applied on the strip footing until the failure of footing happened. The behaviour of samples K80-G (1-4 mm) 20 and K80-G (5-8 mm) 20 were identical to that of pure Kaolin, except that the maximum footing stress had grown by roughly three times (300-310 kPa). Therefore, it can be concluded that the total flexibility of the backfill and shear strength of the strip footing have been increased by adding the TDA. The results indicate that, a significant increase in the failure vertical stress of the footing is observed at the optimum mixture content. In addition, the TDA increases the elasticity behaviour of the backfill.

Keywords: kaolin; tire derived aggregate (TDA); strip foundation; optimum mixture; backfill settlement; wall displacement

1. Introduction

Soil stabilization methods can improve the geotechnical properties of soft clays such as settlement and ultimate bearing capacity (Alrubaye *et al.* 2018, Dehghanbanadaki *et al.* 2019). Different additives such as cement and lime were used for stabilization of problematic soils (Hamidi *et al.* 2018 and Dehghanbanadaki *et al.* 2020). In recent years, the increasing amount of waste tires has resulted in a critical risk to the environmental health (Niyaz *et al.* 2015). The European Union generated approximately a total of 3,418 million tons of scrap tires in 2012 (ETRMA 2013). Based on these records, 39% of the total production was used as recycling materials for general applications in civil engineering; 37% was used for energy recovery; almost 5% was disposed in landfills; and the remaining quota was sold or traded abroad. Some successful applications of shredded tires are used in various construction projects i.e., embankments, backfill for walls, road insulation and rubber-modified asphalt (ETRMA 2013).

Tire waste by-products can successfully be used as a tire-derived geo-material either for stand-alone applications or in composite mixture applications (Yasuhara 2007 and Ganjian *et al.* 2009). For example, tire chips can be mixed with untreated soil for being used as backfill material (Ganjian *et al.* 2009). Based on the result of triaxial testing, Hyodo *et al.* (2007) proved that when tire chips are mixed with sand, a significant decrease in potency of liquefaction of loose sand in backfill is reached (providing appropriate mixing and optimum dosage of additives is also incorporated) (Hazarika *et al.* 2007). Hazarika *et al.* (2007) also reported the same observations through the shaking table physical tests. On the basis of model testing when mixing 50% -by volume- of tire chips blended with sand, even for the backfill, the potency of liquefaction decreased. In addition, the same improvement effect was observed with relative density reaching as low as 50%. Many research works (e.g., Ghazavi 2004) and Youwai and Bergado (2004) and Hazarika *et al.* (2010), Tiwari *et al.* (2017), Yadav and Tiwari (2017), Gill and Mittal (2018), Gill and Mittal 2019) investigated several physical properties of the tire chips-sand mixtures i.e., compressibility, permeability and consolidation. For example, Hazarika *et al.* (2010) assessed the stiffness of the tire chips when used in cement-treated clay mixture and the resistance against the development of cracks during strain. In the other study, Gill and Mittal (2019) evaluated the use of waste tire-chips in shallow footings in sandy soils under the eccentric loading conditions. They revealed that, the ultimate bearing capacity of sand significantly increased on addition of waste tires. In their study, maximum tire chip

*Corresponding author, Ph.D.
E-mail: a.arefnia@yahoo.com

ISSN: 2005-307X (Print), 2092-6219 (Online)

content of 30% was proposed.

Tire Derived Aggregate (TDA) are used and tested in various research projects (Rao and Dutta, (2006), Dutta and Rao (2009), Yoon *et al.* (2008), Naval *et al.* (2013), Mohammadinia *et al.* (2018), Shariatmadari *et al.* 2018 Abbaspour *et al.* 2019 and Bekhiti *et al.* (2019)). Dutta and Rao (2009) proved that when the aspect ratio, the chip content and confining pressure were increased, TDA mixed with sand could better absorb static energy and increase the shear strength of the composite material. In the other study (Abbaspour *et al.* 2019), the effects of adding waste tire textile fibers on the geotechnical properties of the clay and sandy soils were evaluated. Several tests such as direct shear, Unconfined California Bearing Ratio (CBR), and Compressive Strength (UCS) were conducted on the stabilized samples. Their results showed that, all geotechnical properties of the sandy soil samples increased, while in the clay samples the CBR and UCS of the samples decreased. Bekhiti *et al.* (2019) also evaluated the effects of waste tire rubber fibers (TRF) on the various geotechnical properties of stabilized bentonite clay. The main results showed that adding the TRF within cemented soil raised the UCS.

Other researchers have also investigated the performance of mixtures composed of sand and TDA. For instance, plate-load tests on sand reinforced with TDA were conducted while the used sand samples had relative densities of 40%, 50%, and 70% (Yoon *et al.* 2008). The result proved that the bearing capacity ratio of loose sand was improved when TDA was added to sand. In another study, Naval *et al.* (2013) demonstrated that when scrap-tire chips were added to sand, the shear strength of the composite material was increased. In addition, according to Tafreshi and Norouzi's investigations (2012), the results of plate-load tests on a square footing sample of sand blended TDA specimens were also significantly improved (i.e., at least 2.68 times compared with untreated samples). Edeskär (2004) discussed that when tire shreds and/or tire chips are utilized as backfill material, the active lateral pressure on the wall is reduced. A study conducted by Ahn and Cheng (2014) demonstrated that the amount of wall deformation increased using TDA mixed with Kaolin as backfill material; whilst the induced dynamic pressure resulting from TDA backfill on the wall substantially decreased. Arefnia *et al.* (2015) compared numerical and physical modelling of Kaolin's behavior as a backfill material for polymer concrete retaining walls. The investigations looked into load-settlement and load-horizontal displacement via laboratory tests. The results were compared with numerical analysis aimed to simulate the failure mechanisms of the walls. Based on the results, when compared with use of untreated Kaolin, a reduction of 9% to 45% in maximum dry density was observed when TDA was mixed with Kaolin (Arefnia *et al.* 2014), this is attributed to the considerably low unit weight of TDA. The lower unit weight implies that induced active pressure acting on the surrounding soil is reduced. Subsequently, this reduces the horizontal displacement and increases the stability of the retaining wall. Therefore, as literature suggests TDA is proven to be a positive stabilizer for fine soil and can be used as a backfill material.

In this paper the effect of TDA in clay (kaolin) is considered while a retaining wall was considered as a part of model in order to measure wall displacement. The primary objective of the present study is to investigate the influence of Kaolin-TDA mixture as a backfill material in retaining structures towards decreasing the potential of settlement and wall displacement. For this purpose, a series of physical modelling tests using different mixtures (i.e., in both unreinforced and reinforced backfill materials) were conducted.

2. Materials and methods

2.1 Kaolin clay

Industrial Kaolin clay was selected as the base material in this study. To be mentioned that the Kaolin clay was purchased from Kaolin (Malaysia) Sdn. Bhd. It is chemically known as hydrated aluminium silicate (Al2SiO5). Table 1 summarizes the physical and chemical properties of the Kaolin used in this study.

2.2 Tire derived aggregates

Tire Derived Aggregates (TDA), derived from used tires, have low unit weight with high permeability and are also relatively cheap in comparison to other materials with similar properties for practical civil engineering applications. In order to investigate the performance of Kaolin-TDA mixture as a backfill material, various types of TDA were obtained from a local supplier. As shown in Fig. 1, the types of TDA used in this study are: (a) large-size

Table 1 Physical and chemical properties of Kaolin used in this study

Physical Properties	Index Properties
Moisture Content (%)	4.5
24 Mesh per cm Residue (%)	16
Chemical Composition	
XRF Test Method	
Al_2O_3 (%)	15.0-25.0
SiO_2 (%)	60.0-75.0
Fe_2O_3 (%)	4.5
K_2O (%)	1.6
Mg O (%)	0.7
Loss on Ignition 1025 °C (%)	5.0-10.0
Geotechnical Properties	
Classification	MH
Specific Gravity (G_s)	2.67
Maximum Dry Density $(\rho_d)_{max}$ (kg/m^3)	1750
Optimum Moisture Content $(\omega)_{opt}$ (%)	16
LL (%)	57.39
PL (%)	35.06
PI (%)	22.33

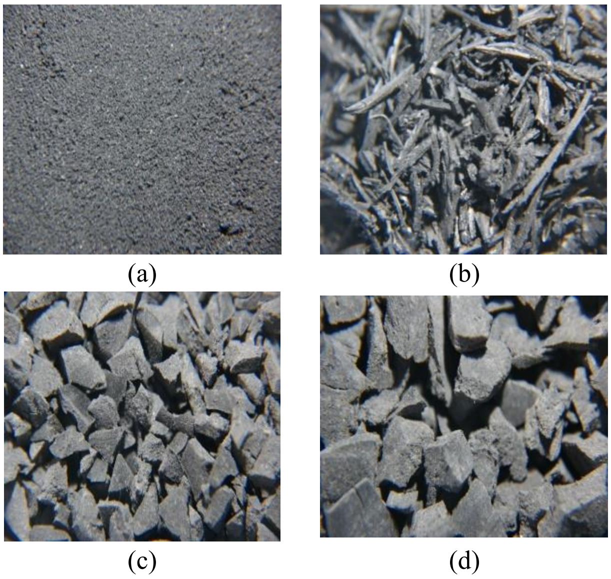


Fig. 1 TDA used in this study: (a) Powdery TDA (80 mesh), (b) Shredded TDA (6-19 mesh), (c) Small size Granular TDA (1-4mm) and (d) Large size Granular TDA (5-8 mm)

granular (5-8 mm), (b) small-size granular (1-4 mm), (c) shredded (0.9 mm-3.36 mm) or (6-19 mesh), and (d) powdery (0.18 mm) or (80 mesh). To be mentioned that TDA was purchased from Yong Fong Rubber Industries Sdn. Bhd.

2.3 Preparation of the backfill material

In order to prepare the Kaolin-TDA mixtures for physical modelling, the materials were mixed by machine first then the material were thoroughly and sufficiently mixed manually in order to prevent material flocculation at optimum moisture content. The mixing procedure was conducted in accordance with BS 1377 (1990). Moreover, the mixtures were cured for 24 hours inside the sealed plastic to achieve uniform distribution of moisture content before using in physical modelling. The mixing proportions of the composite material are summarised in Table 2.

2.4 Program of prototype modelling

In the present study, the use of different types and content of Kaolin-TDA was investigated to establish the potential of their application as a backfill material. In particular, backfill settlement and wall displacement were investigated against loading till failure (see section 2.5). As described in Arefnia *et al.* (2015), in previous research, pure industrial Kaolin clay has been researched as a potential backfill material. The findings suggest that numerical modelling results for Kaolin clay, based on computer programming, confirm the experimental results of physical modelling.

2.4.1 Retaining wall model

The retaining-wall size was based on the available database provided from Huang's research (1998). One such

Table 2 Kaolin-TDA mixture percentage by weight

Material	Type and amount of Material				
	K (%)	P (%)	SH (%)	G(1-4) (%)	G(5-8) (%)
K100	100	-	-	-	-
K80-P20	80	20	-	-	-
K60-P40	60	40	-	-	-
K40-P60	40	60	-	-	-
K80-SH20	80	-	20	-	-
K60-SH40	60	-	40	-	-
K40-SH60	40	-	60	-	-
K80-G(1-4)20	80	-	-	20	-
K60-G(1-4)40	60	-	-	40	-
K40-G(1-4)60	40	-	-	60	-
K80-G(5-8)20	80	-	-	-	20
K60-G(5-8)40	60	-	-	-	40
K40-G(5-8)60	40	-	-	-	60

* K=Kaolin
P=Powdery TDA
SH=Shredded TDA
G(1-4)=Granular(1-4mm) TDA
G(5-8)=Granular(5-8mm) TDA
**Kα-TDAβ;
α=Percentage of Kaolin, β=Percentage of TDA

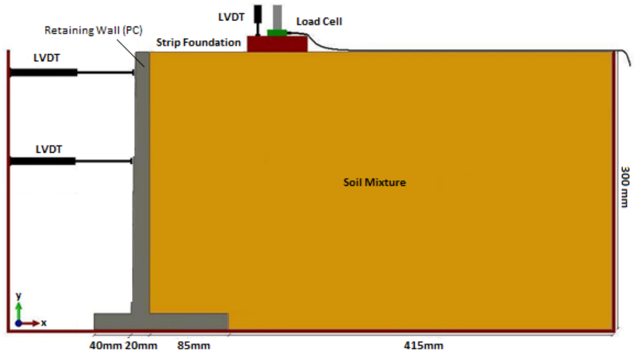


Fig. 2 Physical modeling schematic scaled down at 1:20

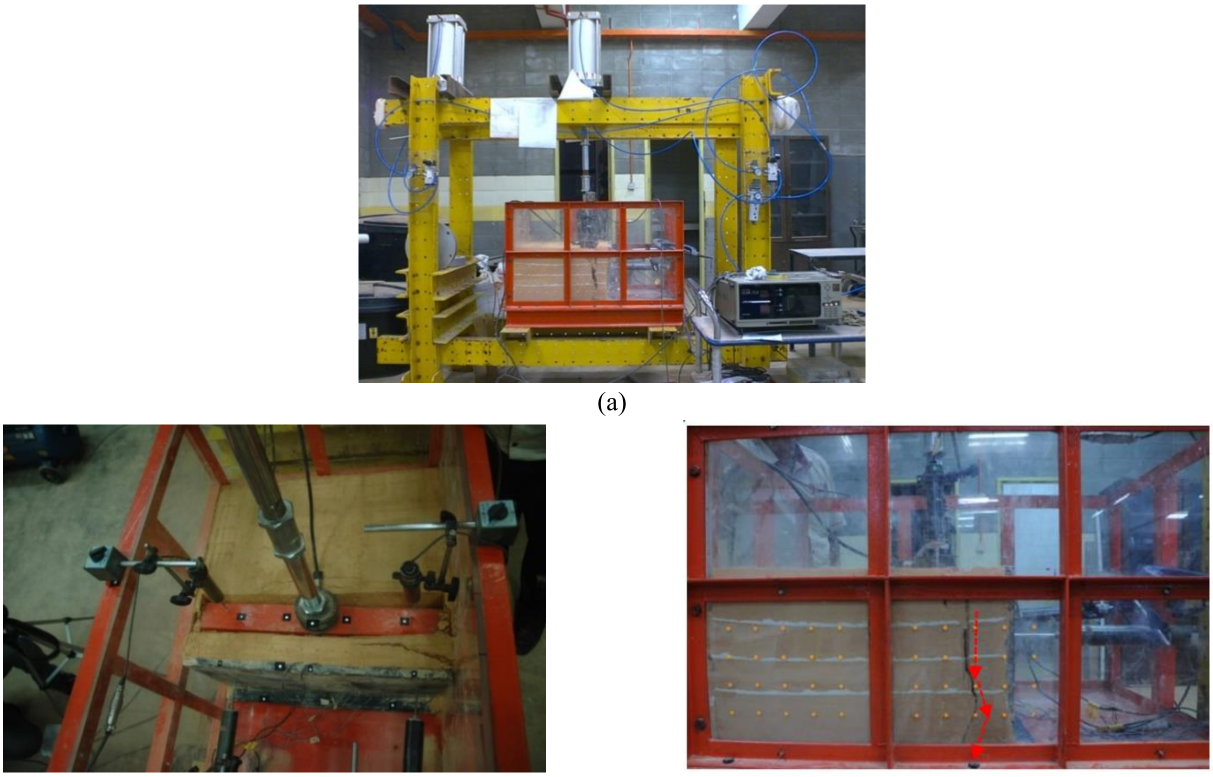
design was scaled down to 1:20 to provide convenience for pre-simulation of the model's boundary condition. The model was appropriately scaled to accomplish similitude with the prototype wall. In addition, for size of the modelled retaining wall, the height of prototype wall was calculated in accordance to the procedure for limit equilibrium conditions (Huang 1998). Also, the length of the wall was specified based on the limitations of the test facilities available, such as size of loading frame and air-jack capacity.

2.4.2 Retaining-wall dimension

The height of a wall as a vital parameter influences scale effects and the response of the model when compared with a prototype. It is generally accepted while the height of a model is greater, the obtained results will be considerably

Table 3 Polymer concrete wall properties

Properties	Unit	Value
Polymer Concrete Wall		
Elasticity Modulus (*E*)	(kN/m^2)	27.28 E 6
Weight (*W*)	(kg)	11.71
Volume (*V*)	(m^3)	4.339125E-3
Unit Weight (γ)	(kN/m^3)	26.996



(a)

(b) (c)

Fig. 3 Test instruments: (a) The arrangements of strip footing with different instruments, (b) Failure condition of the footing and (c) Failure wedge of soil

more accurate. For example, previous research from Koseki *et al.* (1998) and Watanabe *et al.* (2003) created prototype walls with a significant height of 0.5 m.

In the present study, a polymer-concrete retaining wall with 0.3 m in height and an average of 17.5 mm thickness was put in the test box foundation. The dimension aspect ratio of the physical model was scaled down by 1:20. In the physical modelling, the top of the wall was 15 mm and 20 mm at the bottom. The base of the wall was 145 mm wide and 17.5 mm thick. The width of the backfill was 500 mm and the height was 300 mm. In addition, all the tests were performed with a wall height of 300 mm.

2.4.3 Retaining-wall material

To calculate the stress-strain relationship along the wall, it is important to assess the details of strength and durability of the retaining wall. Polymer concrete (PC) is a relatively innovative material with well-established durability and high mechanical strength; which reduces maintenance time, cost and frequency of required repairs. Fast curing time isanother advantage of PC, as it can be remoulded only a few another advantage of PC, as it can be remoulded only a few hours after concrete placement. The characteristics of polymer concrete are inherited from the substitution of a polymeric material with the cement binder (Gorninski *et al.* 2004). Table 3 shows the properties of the polymer concrete wall used in this study.

2.5 Physical modelling equipment

A series of scaled model experiments were carried out in a model box with inner dimensions of 0.6 m × 0.9 m in plan and 0.6 m in height. It should be mentioned that, the boundary conditions of physical modeling tests were evaluated and verified using computer programming by ABAQUS in previous publication of Arefnia et al (2015). Besides, the selection of model materials was conducted taking account of scaling laws (Gibson 1997). Plates of transparent Plexiglas (also known as acrylic glass) were used for all sides of the test box so soil deformation during the test can be easily observed and photographed. By lubricating the sidewalls of the box using transparent tapes, friction was minimized. The box was made sufficiently rigid in order to help the reinforced wall model simulate the plane-strain conditions. In addition, a load cell was positioned on the strip foundation to control the loading. A total of four Linear Variable Displacement Transducers (LVDTs) were used in this research. While two LVDTs were used to monitor vertical displacement of backfill to measure the induced backfill settlement. Two LVDTs were used on the wall to measure wall displacement.

2.5.1 Backfill material compaction

For backfilling and compacting in physical modelling, British Standard Methods (BS 1377-4: 1990) were used. Therefore, the backfill compaction was conducted in 5 layers and 27 blows based on the optimum moisture content for different Kaolin-TDA mixtures and percentages.

2.5.2 Loading procedure

In this study, strip footing was modelled by a steel plate of thickness of 25 mm, 580 mm in length and 75 mm in width. The width of the box was made almost equal to the length of footing (20 mm less than the width of the experimental box) to maintain optimal plane strain conditions. In addition, in order to reduce the friction, the ends of the footing plate were polished. After the box was filled with the backfill material, the top surface of the backfill was levelled and the physical model was moved to a pre-determined location. In this respect, the centre of the plate was 100 mm away from the retaining wall which takes into account the ratio between the distance of the retaining wall from the footing and the particle size of the TDA used (Das and Sobhan 2013). The load from the air jack was concentrically applied to the footing. Measurements of the applied loads on the footing and the induced displacements were recorded in 30 seconds intervals. The displacements were measured using two digital LVDTs on each side of the footing. The loading procedures were conducted under stress-controlled conditions with increments of 10 kPa per minute (Das and Sobhan, 2013). Physical modeling in schematical form is presented in Fig. 2. Fig. 3(a) shows the arrangements of strip footing with different instruments, Fig. 3(b) and Fig. 3(c) demonstrate the failure conditions of the footing and the underlying soil. As can be observed from the developed failure patterns in the backfill, the progressive cracks were produced during loading stages (note the arrows in Fig. 3(c)).

3. Results and discussion

3.1 Maximum vertical stress of the strip footing

Figs. 4 to 7 show the stress-strain response of the strip footing rested on pure Kaolin and Kaolin stabilized by different sizes, shapes and percentages of TDA. The vertical settlements of the footing were normalized by the height of the backfill for considering the strain. Fig. 4 depicts the stress-strain curve of Kaolin-Powdery TDA. As can be seen, the mixture Kaolin with 20% of TDA showed the highest vertical stress on the footing. In this case, the footing tolerated 142 kPa vertical stress and then failed. This vertical stress was approximately 105 kPa in the case of pure Kaolin. Therefore, based on Fig. 4, It can be concluded that when the percentage of powdery TDA increased above 20%, this led to a vulnerable mixture and the displacements between the Kaolin-Powdery TDA mixtures and pure Kaolin became higher. Considering the effective stress conditions, and knowing that there is an increase in the rubber content in the mixture matrix, this is due to the lack of cohesion between the particles in mixtures including 40% and 60% Powdery TDA. On this account, as shown in Fig. 4, increasing Powdery TDA more than 20% in the mixture is undesirable for shear resistance, vertical loading and bearing capacity. The changes of shear strength in mixed soil of this study by 20% TDA was consistent with the results of Rao and Dutta (2006). In their study, the sandy soil were mixed with tire chip and the stress-strain behaviour of the mixed soil showed that adding tire chips leads to a slight increase in shear strength of the mixture. Fig. 5 shows this behaviour in mix of Kaolin with Shredded TDA. As can be seen, in this case 40% TDA showed the highest vertical stress for the footing. This fact proves that the size of TDA can influence on the strength behaviour of the mixture.

Fig 6 shows this trend in the case of Kaolin-Granular (1-4 mm) TDA. Compared to pure Kaolin, inclusion of 20% Granular (1-4 mm) increased the maximum stress of the footing up to 300 kPa. As illustrated in Fig 6, the settlement increases with increased stress in both Kaolin-TDA mixtures and pure Kaolin. However, the gradient of the curves increases with increased replacement of Kaolin by TDA in the mixture. According to Figs. 6 and 7, the behaviour of samples K80-G (1-4 mm) 20 and K80-G (5-8 mm) 20 were identical to that of pure Kaolin, except that the maximum footing stress had grown by roughly three times (300-310 kPa). Therefore, it can be concluded that, by adding the TDA, the total flexibility of the backfill and shear strength of the strip footing have been increased.

Fig. 8 presents the variation between maximum stress at the footing and Kaolin-TDA mixtures for four types of TDA. As can be depicted from Fig. 8, in general, a 20% partial replacement of Kaolin with Powdery TDA improved maximum footing stress of the mixture by approximately 35% (on average). Adversely, a 60% replacement with Powdery TDA decreased the cohesion among the particles of the mixture and decreased maximum footing stress by 45%. Using 20% Shredded TDA, the strength of the mixture improved by 128% compared to using pure Kaolin. A 40% replacement of Shredded TDA with Kaolin

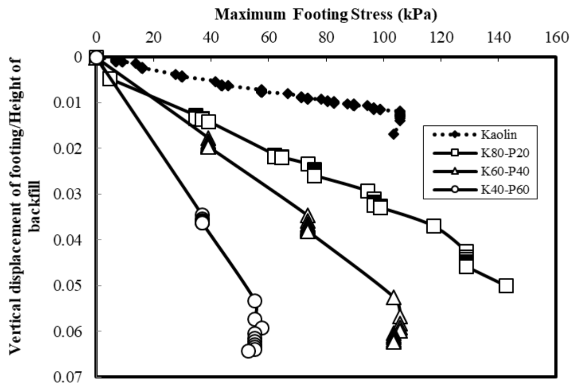


Fig. 4 The stress-strain curve of Kaolin-Powdery TDA

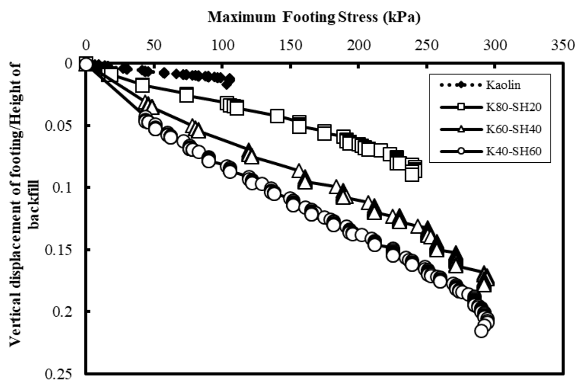


Fig. 5 The stress-strain curve of Kaolin-Shredded TDA

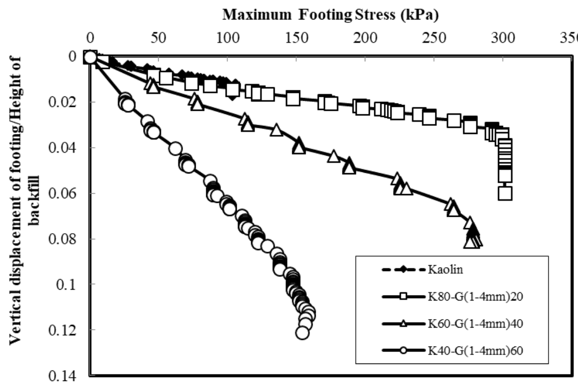


Fig. 6 The stress-strain curve of Kaolin-Granular (1-4 mm) TDA

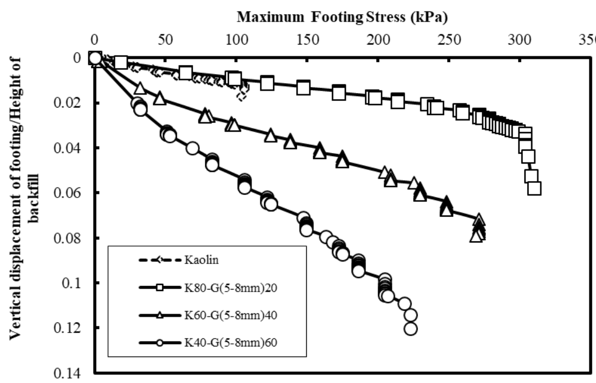


Fig. 7 The stress-strain curve of Kaolin-Granular (5-8 mm) TDA

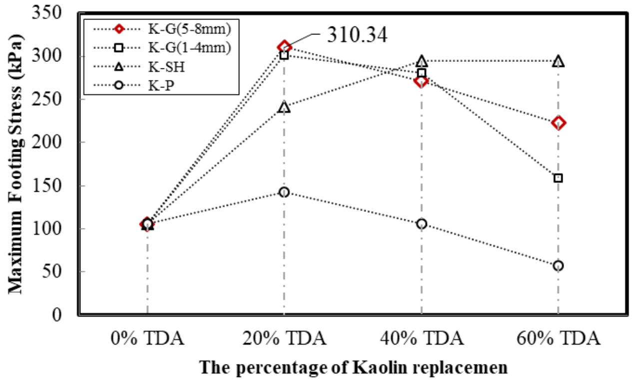


Fig. 8 The variation between maximum footing stress and Kaolin-TDA mixture

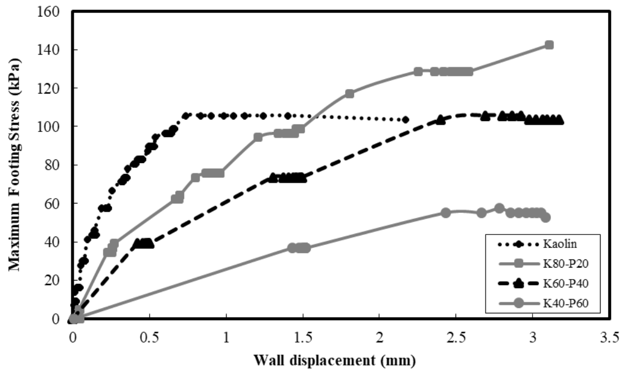


Fig. 9 The footing stress-wall displacement of Kaolin-Powdery TDA

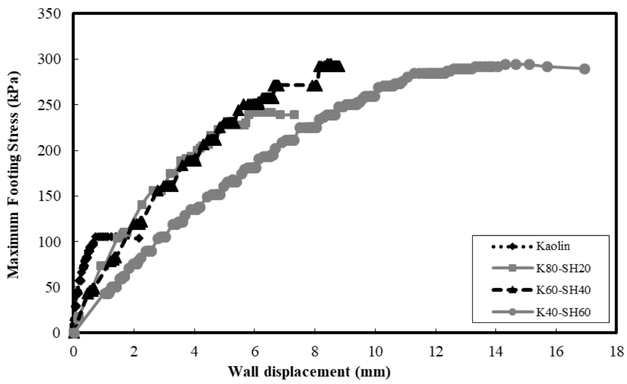


Fig. 10 The footing stress-wall displacement of Kaolin-Shredded TDA

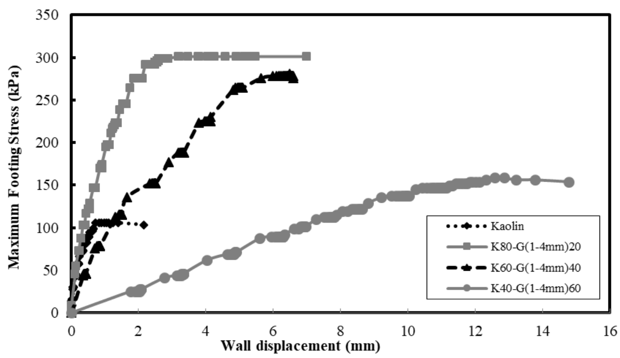


Fig. 11 The footing stress-wall displacement of Kaolin-Granular (1-4 mm) TDA

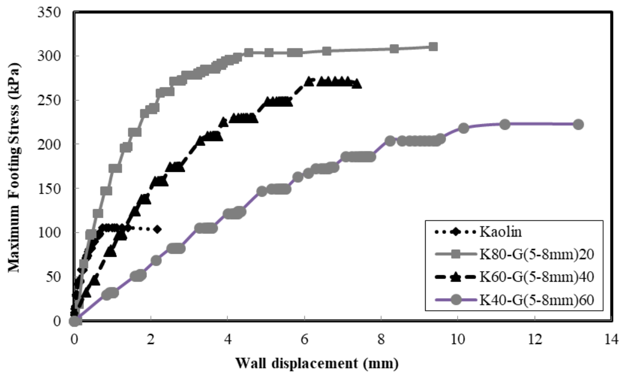


Fig. 12 The footing stress-wall displacement of Kaolin-Granular (5-8 mm) TDA

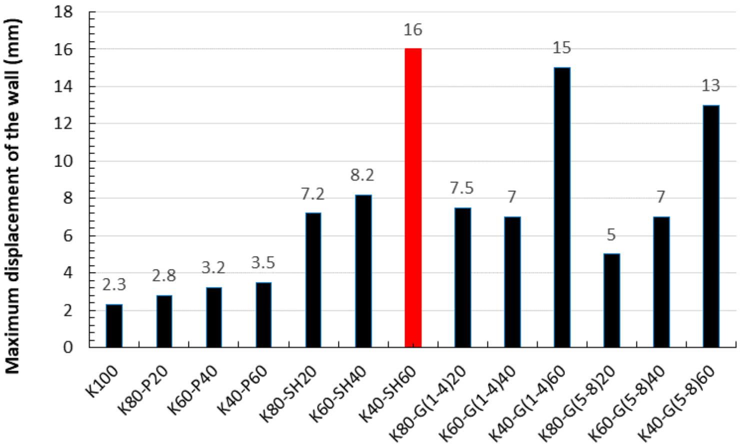


Fig. 13 Maximum lateral displacement of the wall at failure moment

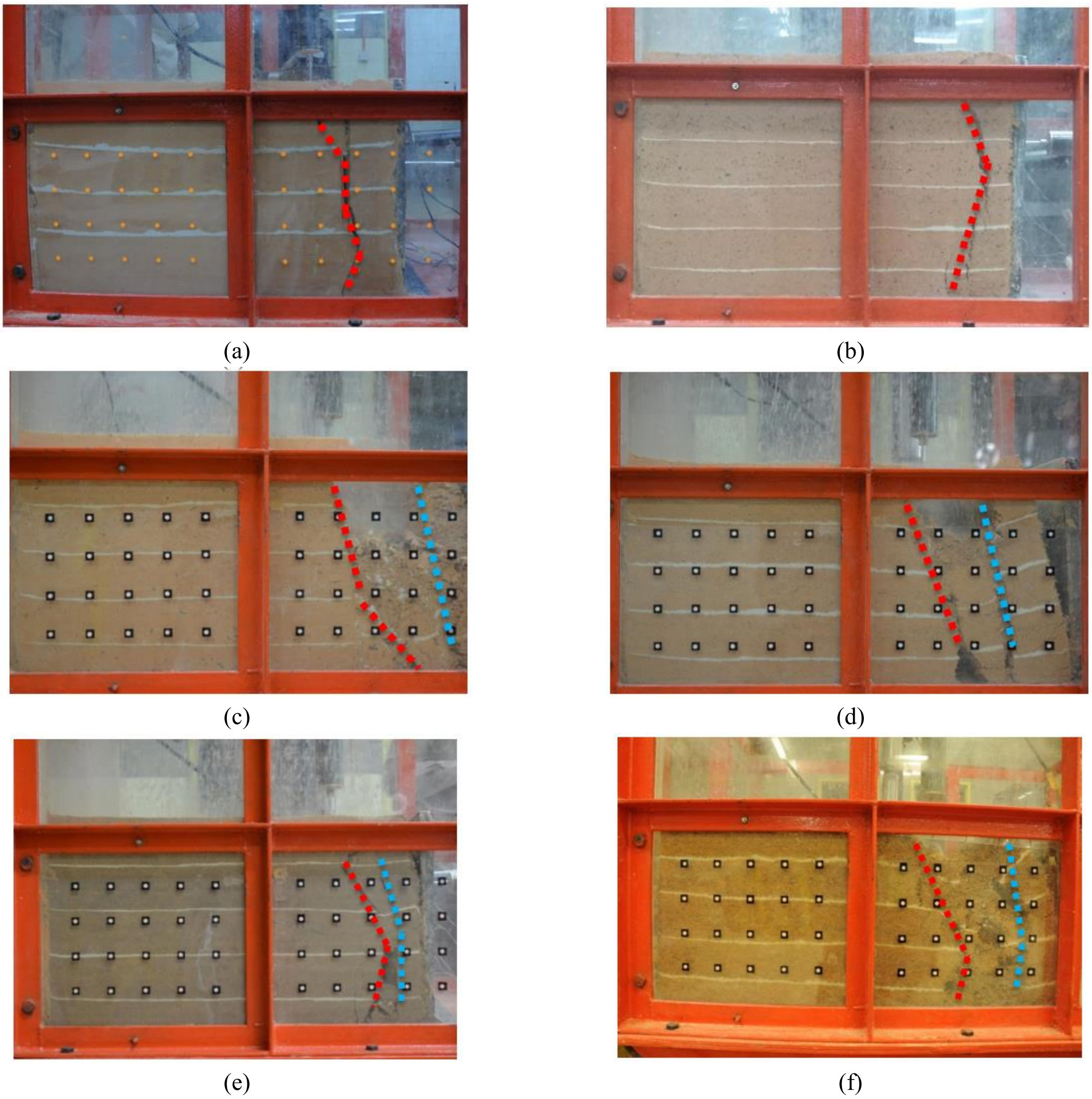


Fig. 14 Failure pattern of the retaining wall for the various type of backfill (a) Kaolin soil only, (b) Kaolin 80% - Small Size Granular (1-4 mm)20%, (c) Kaolin 80% - Large Size Granular (5-8 mm) 20%, (d) Kaolin 80% - Shredded 20% and (e) Kaolin 80% - Powdery 20% and (f) Kaolin 60% - Shredded 40%

improved maximum footing stress further to 178%, as well as a 60% replacement. This implies that both a 40% and a 60% replacement of Kaolin with Shredded TDA provide the same footing stress. Using 20% of 1-4 mm or 5-8 mm Granular TDA, the strength of the mixture increased, improving the footing stress by 184% and 193%, respectively; the 5-8 mm type improved the footing stress slightly more. Replacement of 40% Granular that of pure Kaolin by 50% and 110%, respectively, as shown in Fig. 8.

3.2 Maximum wall displacement at failure point

As discussed in methodology part, the wall movements were measured on the wall by using two LVDTs as measured on two-third of the wall height from the base. According to sliding movement related to the wall, both points had approximately similar displacement. Consequently, the selected movement of wall was considered as average of two LVDTs. Figs. 9 to 12 illustrate and compare the difference of stress and lateral wall displacement related to Kaolin-TDA mixtures in physical modelling. For example, Fig. 9 shows and compares stress-wall displacement of Kaolin-Powdery TDA mixture. As can be seen, adding TDA increased the ductility behaviour of the backfill in the loading stages. This increase in ductility of the mix was also proved by some researchers (Singh and Vinot 2011, Bekhiti *et al.* 2019, Liu *et al.* 2020). In the case of Kaolin-Shredded TDA, this slight increase in ductility was observed (Fig.10). On the other hand, in the cases of Kaolin-Granular (1-4 mm) TDA and of Kaolin-Granular (5-8 mm) TDA, this rate of increase in ductility was completely different and significantly high (Figs 11 and 12). Fig. 13 shows the maximum lateral displacement of the wall at failure moment. Experimental results for Kaolin showed that the wall experienced lateral displacement of 2.3mm at failure moment of the footing. Compared to all samples, the inclusion of shredded TDA to Kaolin (K40-SH60) showed the maximum lateral displacement of around 16 mm. Therefore, it can be concluded that the elasticity properties of the backfill material increased by adding the TDA content. One of the possible explanations for this increase could be related to the texture of TDA material. Based on Fig. 13, this rate of increase might be influenced by the size, shape and type of tire chips. This type of behaviour was mentioned in the study of Jafari and Shafiee (2004).

3.3 Mechanism of failure

After each prototype test, the deformed ground surface and failure mechanism of the soil were inspected. During the entire series of tests, due to high stiffness of the mixed soil, a sudden failure was observed as shown in Fig. 14. Previous researchers also mentioned that the failure trend of the foundations were changed from soft behaviour (punching shear) to a sudden failure such as general shear failure when the total stiffness of the soil increased (Rashid *et al.* 2015, Dehghanbanadaki *et al.* 2020, Ni *et al.* 2020). As can be observed in Fig. 14(a), in the case of untreated soil (pure Kaolin), the failure pattern was observed in the same condition as high stiffness, whilst, according to Fig. 4, the necessary strain for the failure of the Kaolin was as low as 0.01.

It can be concluded that the failure patterns changed to a steeper gradient due to the high stiffness of the Kaolin mixed with 20% Granular TDA, both small-size Granular (1-4 mm) and large-size Granular (5-8 mm). The failure patterns of Kaolin mixed with 20% Granular TDA, both small-size Granular (1-4 mm) and large-size Granular (5-8 mm) are depicted in Fig. 14(b) and Fig. 14(c), respectively. On the other hand, the failure patterns of the Kaolin-Shredded TDA and Kaolin-Powdery TDA mixtures were observed as a type of punched failure, as shown in Figs. 14(d), 14(e) and 14(f). In other words, the failure conditions happened due to the low stiffness of the mixtures compared to Granular TDAs.

4. Conclusions

This study analysed the maximum pressure limit of different mixtures of Kaolin soil and Tire Derived Aggregate (TDA) under rectangular rigid footing resting. Amongst the 12 tested combinations the highest strength mixtures was found to be 20% Kaolin replacement with large-size Granular (5-8 mm) TDA. A very small reduction in strength was also noted when 20% small-size Granular (1-4 mm) TDA was replaced. The strength of this mixture is closely followed by that of mixtures with a 40% or 60% replacement with Shredded TDA. It can be concluded that as the percentage of shredded TDA increases in the samples, the shape and arrangement of the Shredded TDA increases the interlock amongst particles and maintains composition without any cohesive materials like Kaolin. The footing stress of the top three mixtures range from 310 to 294 kPa. This is compared to the footing stress of pure Kaolin, which is 105.7 kPa. In contrast, the footing stress of Kaolin-Powdery TDA mixture at a high replacement percentage of 60% is 57.5 kPa; which is significantly lower than that of the pure Kaolin due to the lack of cohesion between the powdery particles. Thus, replacement of 20% by weight of Kaolin with TDA as a backfill material increases footing stress. Using Kaolin-TDA mixtures as backfill material for retaining walls decreases horizontal pressure as well as unit weight of backfill in comparison to ordinary materials. Replacing 20% Kaolin with small-size Granular (1-4 mm) and large-size Granular (5-8 mm) TDA increases the footing stress three times and decreases the vertical displacement of footing at the same stress in comparison with pure Kaolin. Static surcharge load with the rate of 10kPa per min was applied on the strip footing until the failure of footing happened. The behaviour of samples K80-G (1-4 mm) 20 and K80-G (5-8 mm) 20 were identical to that of pure Kaolin, except that the maximum footing stress had grown by roughly three times. Therefore, it can be concluded that the total flexibility of the backfill and shear strength of the strip footing have been increased by adding the TDA. The results indicate that, a significant increase in the failure vertical stress of the footing is observed at the optimum mixture content. In addition, the TDA increases the elasticity behaviour of the backfill.

Acknowledgments

The authors would like to thank Universiti Teknologi

Malaysia (UTM) which has supported this research. This study was funded by RMC of Universiti Teknologi Malaysia (UTM). (Grant number: Q.J130000.21A2.03E21).

References

Abbaspour, M., Aflaki, E. and Nejad, F.M. (2019), "Reuse of waste tire textile fibers as soil reinforcement", *J. Clean. Prod.*, **207**, 1059-1071. https://doi.org/10.1016/j.jclepro.2018.09.253.

Ahn, I.S. and Cheng, L. (2014), "Tire derived aggregate for retaining wall backfill under earthquake loading", *Constr. Build. Mater.*, **57**, 105-116. https://doi.org/10.1016/j.conbuildmat.2014.01.091.

Alrubaye, A.J., Hasan, M. and Fattah, M.Y. (2018), "Effects of using silica fume and lime in the treatment of kaolin soft clay", *Geomech. Eng.*, **14**(3), 247-255. https://doi.org/10.12989/gae.2018.14.3.247.

Arefnia, A., Kassim, K.A, Sohaei, H., Ahmad, K. and Safuan, A. (2015), "Numerical and physical modelling of kaolin as backfill material for polymer concrete retaining wall", *Jurnal Teknologi*, **76**(2), 17-22.

Arefnia, A., Momeni, E., Jahed Armaghani, D., Kassim, K.A. and Ahmad, K. (2014), "Effect of tire derived aggregate on maximum dry density of kaolin", *Jurnal Teknologi*, **66**(1), 19-23.

Bekhiti, M., Trouzine, H. and Rabehi, M. (2019), "Influence of waste tire rubber fibers on swelling behavior, unconfined compressive strength and ductility of cement stabilized bentonite clay soil", *Constr. Build. Mater.*, **208**, 304-313. https://doi.org/10.1016/j.conbuildmat.2019.03.011.

BS 1377-1 (1990), *Methods of Test for Soils for Civil Engineering Purposes Part 1: General Requirements and Sample Preparation*, British Standard, 1.

Das, B.M. and Sobhan, K. (2013), *Principles of Geotechnical Engineering*, Cengage Learning, 704.

Dehghanbanadaki, A., Khari, M., Arefnia, A., Ahmad, K. and Motamedi, S. (2019), "A study on UCS of stabilized peat with natural filler: A computational estimation approach", *KSCE J. Civ. Eng.*, **23**(4), 1560-1572. https://doi.org/10.1007/s12205-019-0343-4.

Dehghanbanadaki, A., Motamedi, S. and Ahmad, K. (2020), "FEM-based modelling of stabilized fibrous peat by end-bearing cement deep mixing columns", *Geomech. Eng.*, **20**(1), 75. https://doi.org/10.12989/gae.2019.20.1.075.

Dutta, R.K. and Rao, G.V. (2009), "Regression models for Predicting the behavior of sand mixed with tire chips", *Int. J. Geotech. Eng.*, **3**(1), 51-63.

Edeskär, T. (2004), *Technical and Environmental Properties of Tire Shreds Focusing on Ground Engineering Applications*.

ETRMA. (2013), *European Tire & Rubber Industry Statistics Edition*, European Tyre & Rubber Manufacturers' Association; Brussels, Belgium.

Ganjian, E., Khorami, M. and Maghsoudi, A. (2009), "Scrap-tyre rubber replacement for aggregate and filler in concrete", *Constr. Build. Mater.*, **23**(5), 1828-1836. https://doi.org/10.1016/j.conbuildmat.2008.09.020.

Ghazavi, M. (2004), "Shear strength characteristics of sand mixed with granular rubber", *Geotech. Geol. Eng.*, **22**, 401-416. https://doi.org/10.1023/B:GEGE.0000025035.74092.6.

Gibson, A.D. (1997), "Physical scale modeling of geotechnical structures at one-G (p. 413)", Report no. SML 97-01, Pasadena, California Institute of Technology.

Gill, G. and Mittal, R.K. (2019), "Use of waste tire-chips in shallow footings subjected to eccentric loading-an experimental study", *Constr. Build. Mater.*, **199**, 335-348. https://doi.org/10.1016/j.conbuildmat.2018.12.024.

Gorninski, J.P., Dal Molin, D.C. and Kazmierczak, C.S. (2004), "Study of the modulus of elasticity of polymer concrete compounds and comparative assessment of polymer concrete and portland cement concrete", *Cement Concrete Res.*, **34**(11), 2091-2095. https://doi.org/10.1016/j.cemconres.2004.03.012.

Hamidi, S. and Marandi, S.M. (2018), "Effect of clay mineral types on the strength and microstructure properties of soft clay soils stabilized by epoxy resin", *Geomech. Eng.*, **15**(2), 729-738. https://doi.org/10.12989/gae.2018.15.2.729.

Hazarika, H. and Yasuhara, K. (2008), "Tire derived recycle material as earthquake resistant geosynthetic", *Proceedings of the 1st Pan American Geosynthetics Conference*, Cancun, Mexico.

Hazarika, H., Yasuhara, K., Karmokar, A.K. and Mitarai, Y. (2007), *Shaking Table Test on Liquefaction Prevention Using Tire Chips and Sand Mixture, Scrap Tire Derived Geomaterials-Opportunities and Challenges*, Taylor and Francis, London, U.K., 215-222.

Hazarika, H., Yasuhara, K., Kikuchi, Y., Karmokar, A.K. and Mitarai, Y. (2010), "Multifaceted potentials of tire-derived three dimensional geosynthetics in geotechnical applications and their evaluation", *Geotext. Geomembr.*, **28**(3), 303-315. https://doi.org/10.1016/j.geotexmem.2009.10.011.

Huang, Y., Chen, C., Huang, C., Kuo, Y. and Chen, K. (1998), "Database for retaining wall design", *Adv. Eng. Softw.*, **29**(7-9), 619-626. https://doi.org/10.1016/S0965-9978(98)00027-1.

Hyodo, M., Yamada, S., Orense, R.P., Okamoto, M. and Hazarika, H. (2007), "Undrained cyclic shear properties of tire chip-sand mixtures", *Proceedings of the International Workshop on Scrap Tire Derived Geomaterials—Opportunities and Challenges*, Yokosuka, Japan, March.

Jafari, M.K. and Shafiee, A. (2004), "Mechanical behavior of compacted composite clays", *Can. Geotech. J.*, **41**(6), 1152-1167. https://doi.org/10.1139/t04-062.

Koseki, J., Munaf, Y., Tatsuoka, F., Tateyama, M., Kojima, K. and Sato, T. (1998). "Shaking and tilt table tests of geosynthetic-reinforced soil and conventional-type retaining walls", *Geosynth. Int.*, **5**(1-2), 73-96. https://doi.org/10.1680/gein.5.0115.

Liu, L., Cai, G., Zhang, J., Liu, X. and Liu, K. (2020), "Evaluation of engineering properties and environmental effect of recycled waste tire-sand/soil in geotechnical engineering: A compressive review", *Renew. Sust. Energy Rev.*, **126**, 109831. https://doi.org/10.1016/j.rser.2020.109831.

Melik, B., Habib, T. and Mohamed, R. (2019), "Influence of waste tire rubber fibers on swelling behavior, unconfined compressive strength and ductility of cement stabilized bentonite clay soil", *Constr. Build. Mater.*, **208**, 304-313. https://doi.org/10.1016/j.conbuildmat.2019.03.011.

Mittal, R.K. and Gill, G. (2018), "Sustainable application of waste tire chips and geogrid for improving load carrying capacity of granular soils", *J. Clean. Prod.*, **200**, 542-551.

Mohammadinia, A., Disfani, M.M., Narsilio, G.A. and Aye, L. (2018), "Mechanical behaviour and load bearing mechanism of high porosity permeable pavements utilizing recycled tire aggregates", *Constr. Build. Mater.*, **168**, 794-804. https://doi.org/10.1016/j.conbuildmat.2018.02.179.

Naval, S., Kumar, A. and Bansal, S.K. (2013), "Triaxial tests on waste tire rubber fiber mixed granular soil", *Elect. J. Geotech. Eng.*, **18**, 1623-1641.

Ni, P., Yi, Y. and Liu, S. (2020), "Bearing capacity of composite ground with soil-cement columns under earth fills: Physical and numerical modeling", *Soils Found.*, **59**(6), 2206-2219. https://doi.org/10.1016/j.sandf.2019.12.004.

Rao, G.V. and Dutta, R.K. (2006), "Compressibility and strength behaviour of sand-tyre chip mixtures", *Geotech. Geol. Eng.*, 711-724. https://doi.org/10.1007/s10706-004-4006-x.

Rashid, A.S.A., Black, J.A., Kueh, A.B.H. and Noor, N.M. (2015), "Behaviour of weak soils reinforced with soil cement columns formed by the deep mixing method: Rigid and flexible footings", *Measurement*, **68**, 262-279. https://doi.org/10.1016/j.measurement.2015.02.039.

Shariatmadari, N., Zeinali, S.M., Mirzaeifar, H. and Keramati, M. (2018), "Evaluating the effect of using shredded waste tire in the stone columns as an improvement technique", *Constr. Build. Mater.*, **176**, 700-709. https://doi.org/10.1016/j.conbuildmat.2018.05.090.

Singh, B. and Vinot, V. (2011), "Influence of waste tire chips on strength characteristics of soils", *J. Civ. Eng. Architect.*, **5**(9).

Tafreshi, S. and Norouzi, A.H. (2012), "Bearing capacity of a square model footing on sand reinforced with shredded tire–An experimental investigation", *Constr. Build. Mater.*, **35**, 547-556. https://doi.org/10.1016/j.conbuildmat.2012.04.092.

Terzi, N.U., Erenson, C. and Selcuk, M.E. (2015), "Geotechnical properties of tire-sand mixtures as backfill material for buried pipe installations", *Geomech. Eng.*, **9**(4), 447-464. http://doi.org/10.12989/gae.2015.9.4.000.

Tiwari, S.K., Sharma, J.P. and Yadav, J.S. (2017), "Geotechnical properties of dune sand-waste tires composite", *Mater. Today Proc.*, **4**(9), 9851-9855. https://doi.org/10.1016/j.matpr.2017.06.280.

Watanabe, K., Munaf, Y., Koseki, J., Tateyama, M. and Kojima, K. (2003), "Behavior of several types of model retaining walls subjected to irregular excitation", *Soils Found.*, **43**(5), 13-27. https://doi.org/10.3208/sandf.43.5_13.

Yadav, J.S. and Tiwari, S.K. (2017), "Effect of waste rubber fibres on the geotechnical properties of clay stabilized with cement", *Appl. Clay Sci.*, **149**, 97-110. https://doi.org/10.1016/j.clay.2017.07.037.

Yasuhara, K. (2007), "Recent Japanese experiences on scrapped tires for geotechnical applications", *Proceedings of the International Workshop on Scrap Tire Derived Geomaterials-Opportunities and Challenges*, Yokosuka, Japan, March.

Yoon, Y., Heo, S. and Kim, K. (2008), "Geotechnical performance of waste tires for soil reinforcement from chamber tests", *Geotext. Geomembr.*, **26**(8), 100-107. https://doi.org/10.1016/j.geotexmem.2006.10.004.

Youwai, S. and Bergado, D.T. (2004), "Numerical analysis of reinforced wall using rubber tire chips-sand mixtures as backfill material", *Comput. Geotech.*, **31**, 103-114. https://doi.org/10.1016/j.compgeo.2004.01.008.

GC