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Experimental evaluation of mechanically stabilized earth walls with recycled crumb rubbers

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ABSTRACT

Traditional techniques for treatment of waste rubber, such as burning, generate some highly non-degradable synthetic materials that cause unrepairable environmental damages by releasing heavy metals, such as arsenic, chromium, lead, manganese and nickel. For this, scrap tires are used as lightweight alternative materials in many engineering applications, such as retaining wall backfilling. In the present study, 90 laboratory models were prepared to evaluate the stability of mechanically stabilized earth (MSE) walls with plate anchors. Then, the bearing capacity and horizontal displacements of the retaining walls were monitored by exerting a static loading to investigate the effects of adding different contents (5 wt%, 10 wt%, 15 wt% and 20 wt%) of recycled crumb rubber (RCR) to the fill of a mechanically stabilized retaining wall with plate anchors. To visualize the critical slip surface of the wall, the particle image velocimetry (PIV) technique was employed. Results showed that the circular anchor plates almost continually provided a higher bearing capacity and wall stability than the square plates. Moreover, the backfill with 15 wt% RCR provided the maximum bearing capacity of the wall. Increasing the weight percentage of RCR to 20 wt% resulted in a significant reduction in horizontal displacement of the wall, which occurred due to the decrease in lateral earth pressure against the whole walls. An increase in RCR content resulted in the decrease in the formation of failure wedge and the expansion of the wall slip surface, and the failure wedge did not form in the sand mixtures with 15 wt% and 20 wt% RCRs.

1. Introduction

Waste tires are used for various applications because they can provide homogenous materials with different physical characteristics, such as geometry, size, and removable fibers and wires. Generally, waste tires are recycled by converting them to tire shred, tire chips, tire crumb, and tire buffing for use as lightweight filling materials (Edinçliler et al., 2010). Combining recycled tires with soil (mainly sand) leads to a considerable decrease in fill compressibility and flammability compared with the one-piece crumb rubber mode (Ahmed and Lovell, 1993; Humphrey et al., 1993). Among the advantages of recycled tires are their low weight, satisfactory thermal insulation (eight times better than soil), high permeability, and shock absorbance. Recycled tires can be applied as an alternative for backfills of mechanically stabilized earth (MSE) walls and bridge abutments, aggregate in leach beds for septic systems, additive to asphalt, substitute for leachate collection stone in landfills, sound barrier, admixture in bituminous concrete, scrap tire pad as a low-cost seismic base isolation pad, infrastructure for train roads for damping vibration, and insulation to reduce the freezing effect (Humphrey, 2003; Salgado et al., 2003; Edinçliler, 2007; Balunaini et al., 2009; Mashiri et al., 2016).

Different experiments have already been conducted on scrap tire–soil mixes, for example, direct shear test, static and dynamic triaxial tests, consolidation test, specific gravity test, density test, and permeability test, among others (Ahmed, 1993; Edil and Bosscher, 1994; Foose et al., 1996; Zornberg et al., 2004; Ghazavi and Sakhi, 2005; Attom, 2006; Srivastava et al., 2014; Bali Reddy et al., 2015; Xiao et al., 2018). Ahmed (1993) and Foose et al. (1996) performed several shear tests on a tire-derived material–sand mixture in different sizes and reported an increase in internal friction angle (φ) of up to 65°. Edil and Bosscher (1994) suggested tire particle sizes smaller than 50 mm to deal with unauthorized compaction. Zornberg et al. (2004) suggested 35 wt% as the optimal content by evaluating sand–crumb rubber mixture and proved that an increase in overall shear strength resulted in an

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increase in the aspect ratio (proportion of length to width) of crumb rubber in a given weight percentage. Ghazavi and Sakhi (2005) and Attom (2006) performed a direct shear test on a sand–crumb rubber mixture and reported increases in the internal friction angle φ and the aspect ratio by increasing the crumb rubber content and mix compaction. Srivastava et al. (2014) proved a reduced swelling potential by adding crumb rubber to expansive black cotton soil and demonstrated the better performance of coarse crumb rubber (2–4.75 mm) than that of small crumb rubber (0.075–2 mm). Bali Reddy et al. (2015) showed a 43% decrease in void ratio by adding 40 wt% tire chips to sand and found that φ values increased with the tire chip content up to 30 wt%. Their study indicated that the optimum percentage of tire chips of the selected size was 30–40 wt% (equivalent to 50%–60% by volume). Xiao et al. (2018) investigated the effectiveness of polyurethane foam adhesive (PFA) in improving the strength and ductility of a well-graded gravel soil. Using drained triaxial compression tests on the unimproved and PFA-improved soils as the basis for comparison, the peak and residual strengths of the PFA-improved soil increased significantly (from 1.5 to 7 times and from 1.4 to 5.4 times of that of unimproved soil, respectively) with increasing PFA content (from 2% to 8%) at a confining pressure of 100 kPa. Given its ductile response and stress-strain-strength characteristics, PFA-improved gravel soils could offer a promising alternative for high rockfill dams or railway embankments.

Evaluation of foundation bearing capacity was performed on reinforced and un-reinforced soil–recycled tire mixes under static and cyclic loadings by Tavakoli Mehrjardi et al. (2012), Moghaddas Tafreshi and Norouzi (2012), and Moghaddas Tafreshi et al. (2013, 2016). Tavakoli Mehrjardi et al. (2012) applied a cyclic loading on buried flexible pipes in reinforced soil with geocell–tire chips and reinforced soil with geocell–tire crumbs. They demonstrated that the maximum subsidence, which is the transmission of the highest pressure to the pipe, and the maximum strain of the pipe body occurred on soil–tire chips. In addition, a decrease in subsidence level, a reduced plastic radial strain of the pipe, and less fatigue occurred in a mix of soil with 5 wt% crumb rubber. Moghaddas Tafreshi and Norouzi (2012) proved a 2.68-fold increase in bearing capacity of a square model footing for soil–crumb rubber mixes with 5% optimum content. Moghaddas Tafreshi et al. (2013, 2016) investigated the effect of reinforcement on multilayer geocell in both original soil and mixes containing 8 wt% crumb rubber in a pilot scale and reported the following results:

(1) A higher bearing capacity and a lower loading plate settlement were achieved by replacing the soil of geocell layers with soil–crumb rubber mixes.
(2) The bearing capacity did not increase and the loading plate settlement did not decrease over a three-layer mix.

Only a few studies have been conducted on the effect of recycled rubber on the pullout capacity of mechanical reinforcements, such as geogrid and metal strip (Balunaini et al., 2014; Umashankar et al., 2014). Balunaini et al. (2014) and Umashankar et al. (2014) performed uniaxial pullout tests on geogrid and metal strip, and showed a significant increase in geogrid pullout strength of soil–crumb rubber mixes in comparison with that of crumb rubber. They reported a reduction in metal strip pullout strength by increasing the crumb rubber content, the apparent size of crumb rubber, and the confining pressure.

Many studies have been conducted to evaluate the effect of using recycled rubber on retaining wall backfill, trenches, embankments, roadbeds, and even pavements (asphalt) under static and dynamic loads (Humphrey and Eaton, 1995; Cecich et al., 1996; Bosscher et al., 1997; Tweedie et al., 1998; Marandi, 2011; Ahn and Cheng, 2014; Edinçliler and Yildiz, 2015; Reddy and Krishna, 2015; Li et al., 2016; Ding et al., 2017; Khabiri et al., 2017; Ma et al., 2017). Humphrey and Eaton (1995) described a field trial that uses tire chips as an insulating layer to limit frost penetration beneath a gravel-surfaced road. Based on the analysis of the first two winters in service, a 152 mm-thick tire chip layer overlain by 305 mm-thick gravel reduced the depth of frost penetration by 22%–28% compared with that in the adjacent control section. Cecich et al. (1996) used retaining wall modeling with sand–crumb rubber mixes in their experiments and reported cost saving and an increased safety factor in the prepared wall compared with the one prepared using sand–fill. Bosscher et al. (1997) evaluated the use of tire chips as a highway embankment material and supported the use of tire chips as an environmentally acceptable lightweight fill in highway applications if properly confined. They provided recommendations for design procedures and construction specifications for the use of tire chips in highway fills. Tweedie et al. (1998) evaluated the stability of a 4.88 m-high retaining wall by adding tire shreds from three suppliers to the backfill. They showed that the horizontal stress for the tire shred backfill was about 35% less than the active stress for conventional granular backfill. The inclination of the sliding plane with respect to the horizon was estimated at 61°–70° for the three types of the tire shreds. Marandi (2011) conducted dynamic triaxial tests and retaining wall dynamic analyses, and reported a reduction in shear modulus, dynamic pressure, and residual displacement with increasing crumb rubber content. Ahn and Cheng (2014) found an increasing rate of wall slide and a reduced applied dynamic pressure from tire-derived aggregate backfill by conducting a large-scale shaking table test. Edinçliler and Yildiz (2015) performed a dynamic test on a soil–crumb rubber mix at both cold (0 °C) and room temperatures (20 °C) and reported an increasing reduction of seismic hazards in the mix at 0 °C. Moreover, Reddy and Krishna (2015) showed a 50%–60% reduction in horizontal displacement and lateral pressure of retaining walls made of sand–rubber chips mix compared with sand–fill. Li et al. (2016) evaluated sand–crumb rubber mixes and presented a significant effect of mix ratio and particle size on the dynamic shear modulus and liquefaction susceptibility. They found that an increase in rubber fraction leads to an increase in liquefaction strength. Khabiri et al. (2017) proved that an increase in the penetration depth of rubber powder in backfill caused an increase in safety factor against road slip. In similar researches conducted on asphalt, Ding et al. (2017) and Ma et al. (2017) demonstrated that normal crumb rubber and desulfurized crumb rubber have obvious positive effects on the properties of neat asphalt and asphalt–rubber mixtures. Compared with the normal crumb rubber asphalt, the desulfurized crumb rubber asphalt showed lower viscosity and better storage stability. They indicated that the plant-produced crumb rubber asphalt exhibited good storage stability and satisfied road properties compared with other binders, and the asphalt mixture prepared with plant-produced crumb rubber asphalt showed satisfactory road performance.

Plate anchors are mechanical reinforcements that have one or multiple load-bearing plates along with a bar or cable. These reinforcements have widespread applications in onshore and offshore activities, such as constructing mechanical retaining walls, dealing with foundation uplift, fixing reservoirs and offshore floating platforms against sea waves, and protecting buried and submerged pipelines. Examples of mechanical anchors include simple horizontal, inclined, and vertical plate anchors; deadman anchors; multi-plate anchors; cross-plate anchors; expanding pole key anchors; helical anchors; drag embedment anchors; vertically

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