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Design and analysis of retaining wall backfilled with shredded tire and subjected to earthquake shaking

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ABSTRACT

The applicability of shredded tire as an economical alternative for conventional granular soil backfill for retaining walls was investigated by conducting geotechnical and structural designs as well as finite element simulations. A literature survey was conducted to compile and document the engineering properties of shredded tire. It was found that the key geotechnical engineering properties vary significantly with shred size and shredding method. Then, a gravity-cantilever retaining wall was designed for dynamic loading conditions considering seismic design parameters corresponding to the Charleston, SC area. Geotechnical design revealed a longer toe compared to heel for shredded tire backfill to maintain stability; however, a shorter footing was needed to maintain overall stability compared to that of granular backfill. Conventional designs and finite element simulations showed significant reductions in computed horizontal deflection at the tip of the wall, structural demand in terms of maximum shear force and bending moment, and construction cost in terms of excavation and material when shredded tire was used as the backfill. Upper and lower bound curves of maximum shear force and maximum bending moment in the stem were also produced based on the results of parametric studies conducted by varying the friction angle and cohesion of shredded tire, and the amplitude and mean period of the input motion.

1. Introduction

About 266 million waste tires are generated annually in the United States [21] and the number keeps growing annually. Most of these tires are stockpiled, disposed of in landfills or dumped unlawfully which creates serious fire, health, and environmental hazards while providing breeding grounds for mosquitoes and rodents. Disposing of these waste tires by burning can cause serious environmental and safety problems as they add harmful gases to the air and are very difficult to extinguish and clean. Disposing of waste tires in landfills is also counterproductive because it can cause exothermic reactions due to oxidation of exposed metal, and it's expensive to monitor and take necessary action if needed. Studies have shown that waste tires disposed in landfills damage landfill covers due to uneven settlement [25].

Using waste tires in the form of shreds in Civil Engineering projects is a promising method of recycling this waste material [27]. In 2011, 7.8% of scrap tires were utilized in various Civil Engineering projects [21]. These Civil Engineering applications include fill for highway embankments, backfill material for retaining walls, drainage material for septic fields, and vibration absorbent rail lines [3]. It is also used for surfacing playgrounds, making automotive parts, mixing with asphalt pavements, and in agriculture and horticulture application/soil amendments [25].

Use of shredded tire as a lightweight backfill material for retaining walls is gaining widespread attention in recent years [19,20,4]. Cecich et al. [4] reported, based on conventional design outcomes considering static loading condition, about 40% reduction in volume of backfill and about 67% reduction in total cost for a 30-ft high retaining wall when backfilled with shredded tire instead of conventional granular soil. Based on their preliminary numerical studies, Ravichandran and Huggins [19] reported that a significant reduction in maximum shear force and bending moment induced in the wall is possible when the shredded tire is used as a backfill. Reddy and Krishna [20] reported from their experimental investigation that the horizontal displacements and lateral earth pressures are reduced to about 50–60% of that of granular soil backfill by using sand-tire chip mixtures which

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functioned as lightweight backfill materials.

In this paper, the results of a comprehensive study conducted to investigate the economic benefits of using shredded tire over the conventional granular soil backfill are presented for earthquake loading conditions. Then, based on the results of parametric studies conducted by varying the properties of the backfill materials, properties of the structural wall and peak ground acceleration of the ground motion, upper and the lower bounds for the maximum shear force and bending moment in the stem were computed. The details of the procedure are presented in the subsequent sections.

2. Properties of shredded tire

The engineering properties of the shredded tires required for this investigation were established on the basis of a literature survey. The key parameters of the backfill material required for the design and the finite element modeling are the unit weight, shear strength parameters, elastic material parameters, and hydraulic conductivity, the data of which is summarized in Table 1. An examination of the data in Table 1 reveals that the properties of shredded tire vary with shred size, gradation, composition of tire, method of shredding, and the type of geotechnical test performed.

The maximum and the minimum values of the unit weight of shredded tire obtained from the literature review are 7.31 kN/m^3 and 5.13 kN/m^3, respectively, with a maximum value less than half of the unit weight of the conventional granular soil backfill. Similarly, significant variations are observed in shear strength parameters (cohesion varies from 0 to 81 kPa, and friction angle varies from 6° to 32°). The modulus of elasticity ranges from 770 kPa to 3394 kPa, and Poisson's ratio ranges from 0.2 to 0.33. The drainage parameter, hydraulic conductivity, varies between 0.0335 cm/s and 8.25 cm/s. The mean and standard deviation of the key parameters, computed based on the collected data, are also shown in Table 1. The high standard deviations of the modulus of elasticity, cohesion, and friction angle indicate a significant variation of these properties with the size of tire shred, test equipment, and procedure used.

The numeric values of the hydraulic conductivity and the strength parameters indicate that shredded tire can be used as a retaining wall backfill under certain conditions. In this study, the benefits of using shredded tire as a retaining wall backfill over granular soil were investigated through traditional designs and finite element simulations considering earthquake loading condition. The results are presented in the subsequent sections.

3. Geotechnical and structural design of retaining wall

3.1. Problem definition

The example application considered in this study consists of a gravity-cantilever retaining wall with a design height of 6.5 m and

Table 1
Engineering properties of shredded tire (100% pure tire).

Source	Size (mm)	Unit weight (kN/m^3)	Friction Ang. (deg)	Cohesion (kPa)	E (kPa)	Hyd. Cond. (cm/s)	Poisson's ratio
[4]	12.5	5.68	27	7.038	—	0.0335	
[4]	—	6.97	22	5.746	—	—	—
[28]	16	7.05	30	—	—	—	0.33
[13]	50	6.3	21	17.5	3394.4	—	—
[15]	50	6.25	15	0.3943	—	0.2	—
[15]	50–100	7.25	32	0.3735	—	0.55	—
[15]	100–200	6.5	27	0.3735	—	0.75	—
[22]	75	6.38	22	9.5	1100	0.1	0.3
[26]	75	7.31	—	—	—	7.035	—
[11]	38	6.064	25	8.6	770	1.5	0.32
[11]	51	6.299	21	7.7	1130	2.1	0.28
[11]	76	6.074	19	11.5	1120	4.8	0.2
[27] DST	10	5.73	32	0	1129	—	0.28
[27] – 10%[a]	10	5.73	11	21.6	1129	—	0.28
[27] TT – 20%[b]	10	5.73	18.8	37.7	1129	—	0.28
[8]	50	6.3	21	7.6	—	—	—
[1] – 10%[a]	13	6.19	11.6	22.7	—	—	—
[1] – 20%[b]	13	6.19	20.5	35.8	—	—	—
[1] – 10%[a]	25	6.32	12.6	25.4	—	—	—
[1] – 20%[b]	25	6.32	22.7	37.3	—	—	—
[1] – 10%[a]	25	6.42	14.6	22.1	—	—	—
[1] – 20%[b]	25	6.42	25.3	33.2	—	—	—
[1] – 10%[a]	25	6.75	14.3	24.6	—	—	—
[1] – 20%[b]	25	6.75	24.7	39.2	—	—	—
[7] DST	50–100–150	5.65	30	3	—	—	—
[14] – 10%[a]	4.6	6.18	6	70	—	—	—
[14] – 15%[c]	4.6	6.18	11	71	—	—	—
[14] – 20%[b]	4.6	6.18	15	81	—	—	—
[24]	—	5.9	30	0	—	—	—
[10]	—	5.8	23	0	—	—	—
[6] (average)	12–76–305	5.13	22	9.55	1010	8.25	—
Mean		**6.26**	**20.90**	**21.05**	**1362.68**	**2.53**	**0.28**
Standard deviation		**0.49**	**6.86**	**22.37**	**830.23**	**3.06**	**0.04**
Mean for 50–150 mm		**6.31**	**23.00**	**6.75**	**1550.88**	**2.97**	**0.26**
Standard deviation for 50–150 mm		**0.65**	**5.43**	**6.02**	**1031.65**	**3.28**	**0.05**

Note.

[a] Triaxial test at 10% strain.

[c] Triaxial test at 15% strain.

[b] Triaxial test at 20% strain.