Experimental Study of Sand Slopes Reinforced by Waste Tires

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ABSTRACT

In recent years, scraped tires have become an environmental burden and economic problem. Reusing waste tires for reinforcing slopes can be a suitable solution for the disposal and reduction of the number of waste tires. In this paper, a series of experimental model tests have been carried out to investigate the behavior of Horizontal Elements of Waste Tire (HEWT) in stabilizing sandy slopes. Digital images taken of the side of the model during incremental loading and Particle Image Velocimetry (PIV) were used to investigate the slope under surcharge loading. Some important parameters such as the length, number, and location of the reinforcing tire layers were studied in this paper. There is an obvious plastic zone on the unreinforced and reinforced sandy slope shown using PIV. It shows that scrap-type reinforcement highly improved the strength of the sandy slopes and the model resulted in bearing capacity about 3.5 times larger and settlement about three times less in comparison with an unreinforced sandy slope.

Keywords : *Bearing Capacity, Sand Slope, Settlement, Waste Tires*

1. Introduction

Thousands of landslides occur every year in the world, and in some cases, they cause huge financial damages and even fatalities. Landslides, especially in slopes, have always been an interesting topic for discussion. Different types of slope stabilization methods have been studied, and they include modifications in the geometry of the slope, drainage, retaining walls, stone columns, soil nailing, electro-osmosis, biological methods, diaphragm walls, sheet pile or piles, steel-fiber-reinforced shotcrete, etc. One of the new methods in slope stabilization is the utilization of scrap tires, which are not only environmentally suitable but also they are economical.

With the rapid growth of the number of cars around the world, about 2-3 billion tires are discarded annually [1-2]. In recent years, waste tires have been an urgent and serious environmental and economic issue [3-4]. The utilization of scrap-tire-derived recycled materials in civil engineering applications has been increasing largely because of their economic potential and environmental benefits [5-6]. However, scrap tires can cause several environmental problems and become serious health threats in all parts of the world. Although scrap tire piles do not spontaneously combust, if they are set alight, they are difficult to extinguish and can potentially burn for long periods [7]. According to Maine's Joint Standing Committee on Natural Resources (Maine DEP, 2000) [8], open tire fire emissions include pollutants such as soot, carbon monoxide, sulfur oxides, nitrogen oxides, poly-nuclear aromatic hydrocarbons, dioxins, furans, hydrogen chloride, benzene, polychlorinated biphenyls, arsenic, and mercury.

Numerous ways of recycling scrap tires have been introduced. Tires can be used as reinforcement in geotechnical engineering, and as an alternative intended to strengthen the slopes, retaining walls, embankments, foundations, road sub-layer and also to improve soil properties [9-14]. Effects of shredded tire chips on geotechnical properties of soils investigated by many researchers, (Saberian et al., 2017; Kaushik et al., 2015; Kalkan, 2013; Hazarika et al., 2010; Bhalla et

al., 2010; Tanchaisawat et al., 2010; Reddy et al., 2008; Akbulut et al., 2007; Youwai and Bergado, 2004) [15-23]. Their studies indicated that the use of these elements to enhance strength properties, stability, unconfined compression strength, and bearing capacity of soils is significant. They also showed that tire mixtures could demonstrate capabilities in collecting leachate and sealing the waste disposal sites.

Discarded tires used as reinforcing materials have been distinctive merits, such as high tensile strength, good anti-friction, fine flexibility, and durability. Waste tires were used as completely mechanical elements or as altered shapes (pieces or crushed rubber) in these studies and projects. A mixture of tire shreds and sand is an effective substance to make backfill material [24]. Tire shreds plus soil mixtures of backfill were used in Mechanically Stabilized Earth (MSE) walls, and their advantages over ordinary backfills were proved. These advantages consist of better drainage mechanism, higher shear strength, and lower compacted unit weight [25].

The early use of tire-reinforced soil can be traced back to 1984, where a 5-meter high and 10 meters long retaining wall was strengthened in France. In 1990, another wall in Brazil, 4 meters high and 60 meters long, was strengthened utilizing spent tires [26].

Reddy and Krishna (2015) [27] studied the use of recycled tire shreds in Sand–Tire Chips (STC) mixture for retaining wall applications. Their experimental results indicated that the horizontal displacements and lateral earth pressures through STC mixtures reduced to about 50–60 % of those of control case since they functioned as lightweight backfill materials.

Li et al. (2016) [28] studied a small-scale tire-reinforced embankment. The results showed that tire reinforcement highly improved the strength of the model embankments since much higher levels of stress were mobilized inside the soil mass (about two times higher compared to the unreinforced embankment). Mandal et al. (2005) [29] showed that an increase in the safety factor could be achieved by an increase in the percentage of the tire chips (2.5 % to 10 %). Dammala et al. (2015) [30] experimented with a small-scale cantilever wall backfilled with sand-tire chip mixtures. They compared the results with the control case

(only sand). Tire chips were mixed with sand in three different percentages 5%, 10%, and 15% by weight. The model wall was built in a Perspex container and tested under both static and seismic loading conditions. CRW backfilled with 15% STC mixture demonstrated better performance compared to the conventional cohesion-less sand backfill. The application of STC mixtures for retaining wall backfill could lead to a reduction in wall displacements and accelerations in the backfill. Therefore, the utilization of tire scraps in sands proved as an effective method [31-32], which could readily reinforce sandy soils. The researchers observed noticeable results such as; the lower the density of sand, the higher reduction of settlement [33]. Use of sand-mixture can increase liquefaction resistance and reduce deformations caused by liquefaction [34-35].

In the past, most of the small-scale experimental studies have been done on the behavior of tires as reinforcement for retaining walls and embankments. In this study, the aim was to investigate the bearing capacity and settlement of a footing that had been constructed adjacent to a tire-reinforced sandy slope, by considering various locations and lengths for a horizontal reinforced layer. Finally, the optimized arrangement of the tire-reinforced layer on the surface of the slope was found. In addition, different types of surface failure in tire-reinforced slope and unreinforced slopes were compared to each other.

For this work, a large-scale soil box (L*W*H=2.0m*1.0m*1.0m) was built to investigate the mechanical performance of a scrap tire-reinforced sandy slope. The effect of the location of the scrap tire was also considered.

2. Experimental Tests

2.1. Test Equipment

Testing of the main sections is briefly described as follows:

All slope models were prepared within an appropriate designed steel box of 2.0m*1.0m*1.0m, with one 12 mm armor-plated side glass panel. Soil medium using a dry pluviation system was prepared to achieve a uniform and homogeneous relative density. The glass sides were built sufficiently rigid to maintain plane strain condition and prevent lateral displacements, glass walls allowed the sample to be seen during model preparation, precipitation, and loading. These sides also allowed for the observation of final deformation and slip surface mechanism after the failure. The inner walls of the box were lubricated using oil in order to reduce the friction with sand as much as possible. The loading system for this box included manually-operated hydraulic jack and loading ring. The loading system consisted of heavy steel columns and a horizontal beam that supported the loading system. A load cell with an accuracy of ±0.01 percent was also used and placed between the loading system and strip footing with a capacity of 18 kN in order to be able to precisely measure the applied loading on the slope crest. The experiment equipment is shown in Figure 1. The length of footing was assumed equivalent to the width of the box. Also, the strip footing model was made of steel. Tire-reinforced slope models with a slip ratio of 1:1.6 and a final height of 0.50 m were prepared and tested. In the tests, bearing capacity of the footing was measured with a load cell and footing settlements were measured.

2.2. Test Material

Figure 2 shows the particle size distribution of the sand used in this experiment. The maximum and minimum dry densities of the sand were about 19 kN/m³ and 16 kN/m³, respectively. The average particle size (D50) was 0.93 mm, and the average unit weight was 17.30 kN/m³. The internal friction angle and cohesion, determined by a direct shear test, were 38 degrees and 0, respectively.

The slopes were reinforced using waste tires (Figure 3). Diameter and thickness of waste tires were 20cm and 5cm respectively. The slopes were reinforced by using several different layers (3, 4, 6, 8, and 9) and lengths (20, 40, and 60 cm) in which the tires were tied together using a metal wire. It should be mentioned that in all reinforced experiments there were four tires through the width of the slope with a distance of
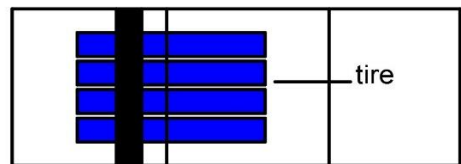
10 cm from the sidewalls.
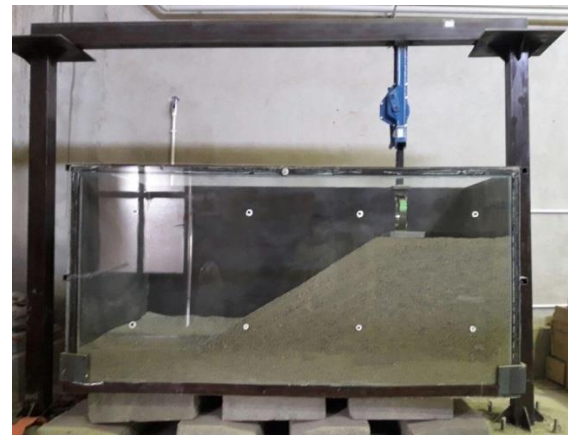
(a)
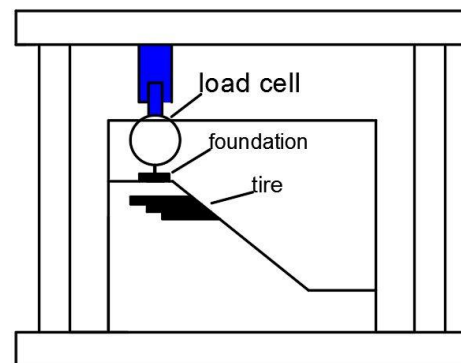
(b)

(c)

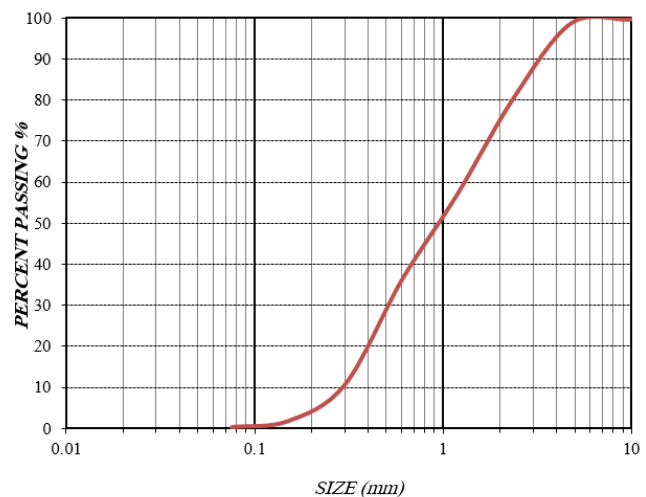Figure 1. The experimental apparatus (a) Test box, (b) Side view, and (c) Up view

Figure 2. The grain size distribution of the sand

Figure 3: Tires were used in tests

2.3. Image Analysis by PIV Method

The digital images were taken from the soil during the experiment from the front side of the testing tank. The photos were processed using Geo-PIV 8 software, which is developed at the University of Cambridge [36]. PIV analysis was run using patches of 16*16 pixels, spaced at the 16-pixel center to center, and a search area of 32*32 pixels. Adequate textural detail provided a better track for the patches.

2.4. Test Program

In order to investigate the effects of tire reinforcement in sand slopes, 25 tests were performed to determine the pattern of soil deformation in reinforced and unreinforced slopes. Sand slope models were constructed at the height of 500 mm and a length of 800 mm. Tires were manually placed in the intended location horizontally. Next, the footing was placed in the position, and the load was applied gradually up to the point of failure (when the footing collapsed, and the load decreased). All models had been place in a distance of 125 mm from the footing center to the edge slope; it is to neutralize the effects of sidewalls on test results. Table 1 illustrates a summary of all the tests programs.

Table 1. Experimental Testing Program

Test name	The number of reinforcement layers	Position of reinforcement	Length of reinforcement in the horizontal direction (cm)
A1		Unreinforced slope	
A2	4	In the upper half of the slope	60
A3	4		40
A4	4		20
A5	4	In the lower half of the slope	60
A6	4		40
A7	4		20
A8	8	Across the slope	60
A9	8		40
A10	8		20
A11	3	In the upper one-third of the slope	60
A12	3		40
A13	3		20
A14	3	In the middle one-third of the slope	60
A15	3		40
A16	3		20
A17	3	In the lower one-third of the slope	60
A18	3		40
A19	3		20
A20	6	In the upper two-thirds of the slope	60
A21	6		40
A22	6		20
A23	9	Across the slope	60
A24	9		40
A25	9		20

3. Test Results

3.1. Unreinforced Slope

A1 model (the first test) was conducted on the unreinforced slope. In this test, the bearing capacity equaled to 24.32 kPa (the maximum force applied to the footing) and settlement equaled to 6.31cm. Soil displacement vectors and critical slip surface for unreinforced slope (A1) are shown in Figure 4 which are determined using PIV.
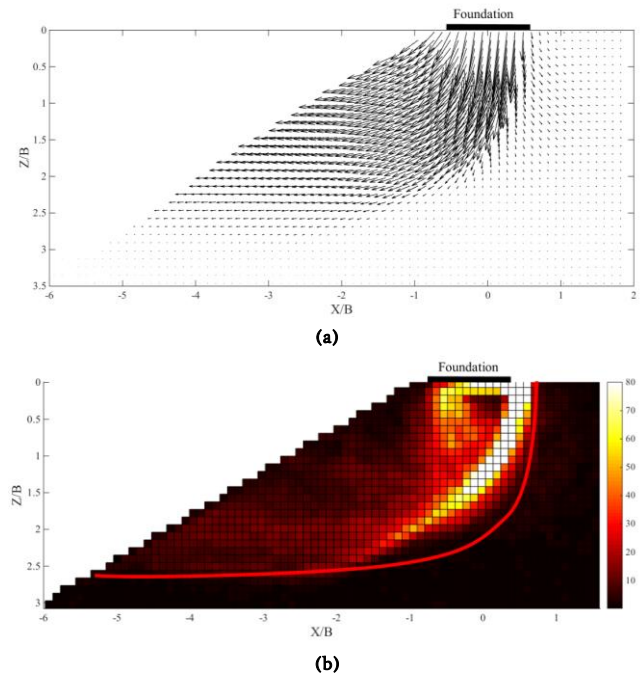

(a)

(b)

Figure 4: (a) Displacement vectors in unreinforced slope, (b) Displacement and critical slip surface for unreinforced slope

3.2. Reinforcements of Four- and Eight-Layered Tires in Slope

In this part of the experiment, four and eight layers of tire-reinforcement with different horizontal lengths (20, 40, and 60 cm) were considered. Reinforcements of four-layer tires were located at two different positions (in the lower half and upper half part of the slope) and reinforcements of eight-layer tires were located across the slope. Finally, the results of these cases were compared with those of an unreinforced slope.

Soil displacement vectors and critical slip surface of reinforced slope with four 20-cm tire-reinforced layers, located in upper half part of the slope and lower half part of the slope are illustrated in Figures 5 and 6, respectively.
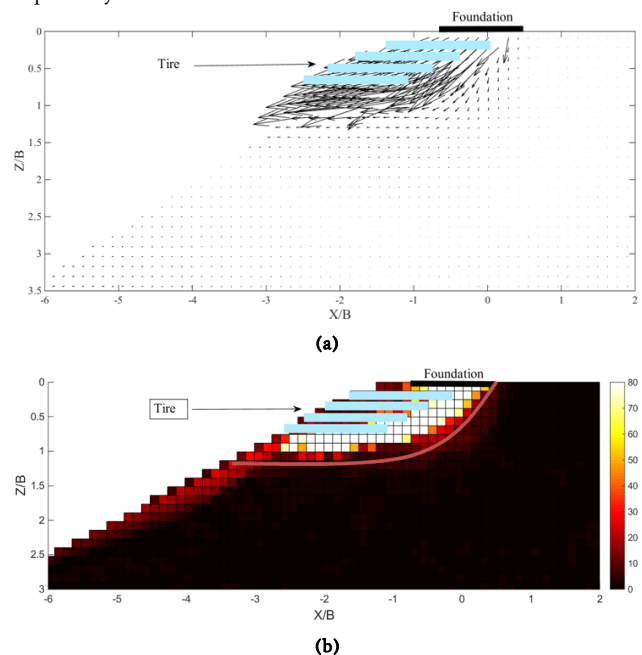

(a)

(b)

Figure 5: Reinforced slope with four-layered tires in the upper half, with a length of 20 cm (a) Displacement vectors (b) Displacement and critical slip surface
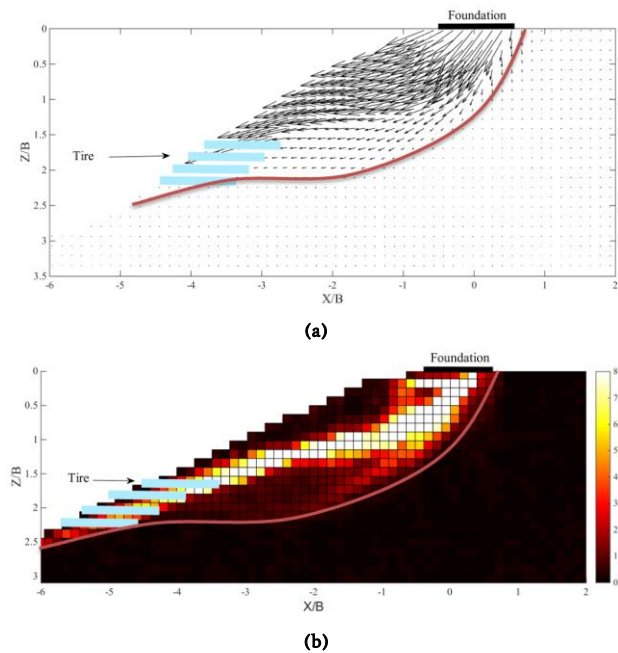
(a)

(b)

Figure 6: Reinforced slope with four-layered tires in the lower half of the slope, with a length of 20 cm (a) Displacement vectors (b) Displacement and critical slip surface

The comparison of ultimate bearing capacity and ultimate vertical settlement of tire-reinforced slopes (with four and eight layers) with an unreinforced slope is summarized in Table 2.

Table 2: Ultimate Bearing Capacity and Ultimate Vertical Settlement of Tire-Reinforced Slope with Four and Eight Layers compared with an Unreinforced Slope

Test name	Ultimate bearing capacity (q_u) kPa	Improvement compared with unreinforced slope for (q_u) (%)	Ultimate vertical settlement (S_{max}) mm	Improvement compared with unreinforced slope for (S_{max}) (%)
A1	24.32	0	6.31	0
A2	78.37	222.2451	3.33	47.2266
A3	35.01	43.95559	4.16	34.0729
A4	24.72	1.644737	4.51	28.5261
A5	40.53	66.65296	4.98	21.0777
A6	25.92	6.578947	5.28	16.3233
A7	24.34	0.082237	4.86	22.9794
A8	86.40	255.2632	2.08	67.0365
A9	36.18	48.76645	3.88	38.5103
A10	30.78	26.5625	4.06	35.6577

The Bearing Capacity Improvement (BCI) of the footing due to slope stabilization was presented using a non-dimensional factor, called BCI Factor. This factor is defined as the ratio of the ultimate bearing capacity of the footing in a reinforced slope to ultimate bearing capacity of the footing in an unreinforced slope (q_u). Lx is the length of the horizontal tire-reinforced layers, which were placed in the slope. The ultimate bearing capacities of the footing-soil systems were obtained from the load-settlement curves as the pronounced peaks, after which the footing would collapse, and the load was reduced.

As the unreinforced case (A1) is compared with the case of four 20-cm tire-reinforced layers in upper half part of the slope (A4), it can be inferred that the bearing capacity did not change significantly, but the settlement decreased approximately 40 percent in the reinforced case. While there were four 40-cm tire-reinforced layers in upper half part of the slope (A3), bearing capacity increased to 1.4 times higher and settlement decreased about 51 percent. As the table demonstrates, while there were four 60-cm tire-reinforced layers in upper half part of the slope (A2), the bearing capacity, increased by more than 3 times and

settlement decreased about 89 percent when compared to the unreinforced slope. In the case of four tire-reinforced layers with a horizontal length of 60 cm in the lower half of the slope (A5), the bearing capacity increased by more than 1.6 times and settlement decreased for 27 percent compared with those of the unreinforced slope. Moreover, the bearing capacity reduced and settlement significantly increased in all cases by reducing the length of the horizontal reinforcement layer. While the length of the horizontal layer was 60 cm, reinforcement tires passed from the failure wedge and it significantly increased bearing capacity and reduced the settlement of the footing.

Then eight tire-reinforced layers were placed across the slope with the length of 20 cm (A10) and were compared with unreinforced slope. It was found that the bearing capacity increased 1.26 times higher and settlement reduced by 55 percent. In this situation when reinforcement length was 40 cm (A9), bearing capacity increased approximately 1.5 times higher, and the settlement reduced more than 60 percent compared to the unreinforced slope. When the horizontal length of eight-layered tires was 60 cm (A8), bearing capacity increased more than by 3.5 times and settlement decreased by more than 3 times compared to the unreinforced slope. BCI diagrams in terms of length for four- and eight-layered reinforcement tires are shown in Figure 7.
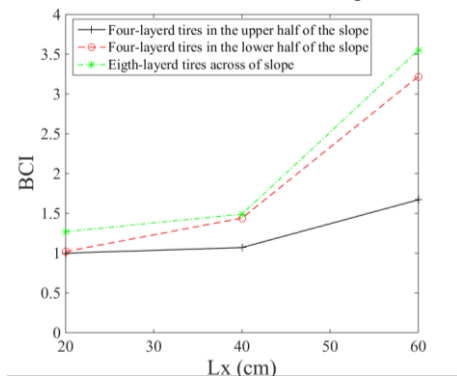

Figure 7: Variations of BCI for different L_x (20, 40, and 60 cm) of four and eight layers of tire in reinforced slope and unreinforced slope

During the experiment procedure, footing settlements were measured instantly, and they were drawn against the applied vertical pressure in Figure 8.
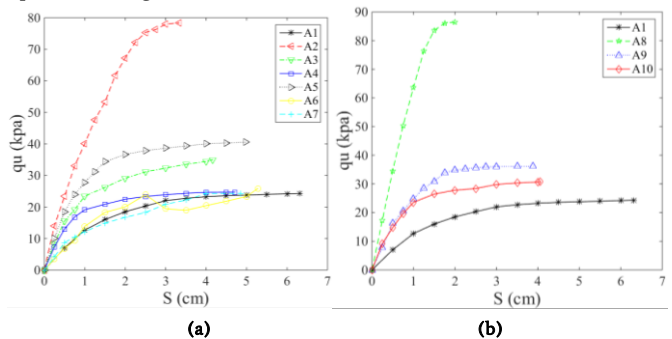

(a)   (b)

Figure 8. Variations of applied surcharge pressure (q) with settlement (S) for footing model (a) Four-layered tire reinforcement slope and unreinforced slope (b) Eight-layered tire reinforcement and unreinforced slope

The results showed that four and eight tire-reinforced layers played an important task in reducing the amount of vertical settlement in all tests. As it is shown in Figure 8, the best position for using the four tire-reinforced layers in terms of bearing capacity and settlement was at the upper half of the slope. In other words, when four-layered reinforcement tires (A2,A3,A4) were placed in the upper half of the slope, bearing capacity and settlement of the constructed footing adjacent to the slope were improved significantly compared to when the four tire-reinforced layers were located in the lower half of slope (A5,A6,A7).

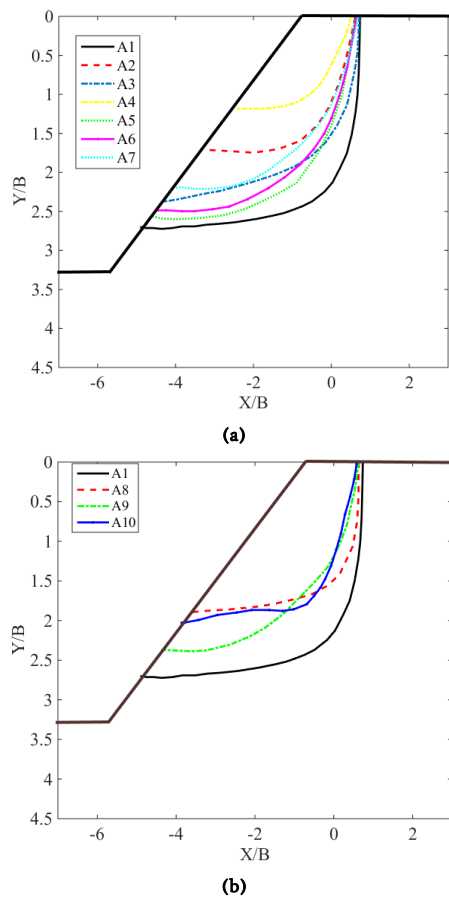The comparison of slip surface shapes with four- and eight-tire-reinforced layers is shown in Figure 9.

(a)

(b)

Figure 9: Slip surface comparison with different positions of tire layers (a) four-layered tire reinforcement (b) eight-layered tire reinforcement

As it is shown in Figure 9, the failure modes of the reinforced and unreinforced slopes are rather different. The unreinforced slopes generally demonstrate a shear failure, whereas the failure region decreases in size with tire layer as well as the reinforcing arrangement. When the reinforcement was placed in the upper half of the slope, (A2, A3, and A4) the failure mode became smaller and moved upward in comparison with the cases of A5, A6, and A7. In other words, the best position of reinforcement for stability was in the upper half of the slope. Vertical settlements below the footing and against depth for four and eight tire-reinforced layers slopes are presented in Figure 10.
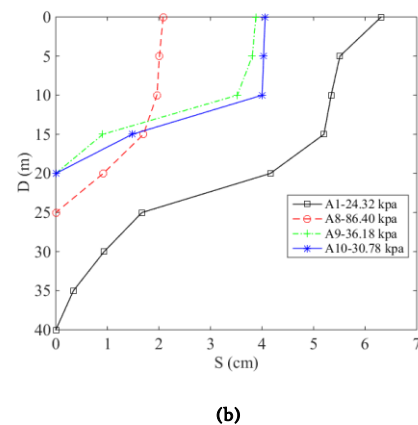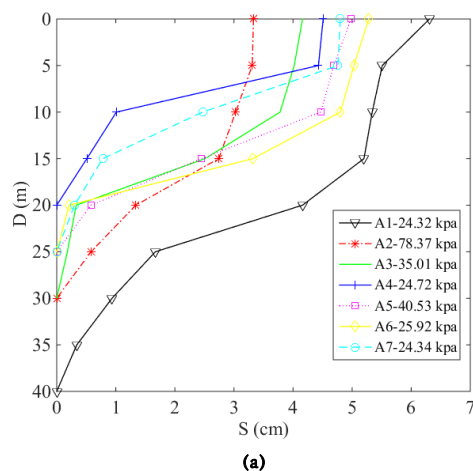

(a)

(b)

Figure 10: Settlement beneath the footings at various depths of the slope (a) Four-layered tire reinforcement (b) Eight-layered tire reinforcement

Figure 10 shows the differences between the vertical settlement curves in various depths of the footing in the case of both reinforced and unreinforced slopes. When reinforced cases were compared to unreinforced one, vertical settlement beneath the footing transmitted to a shallower depth.

According to Figure 10, when there were the best arrangement and length in four- and eight-tire-reinforced layers (A4, A9, and A10), vertical settlement beneath the footings transmitted to the depth of 20 cm. While in unreinforced slope, the vertical settlement beneath the footings transmitted to the depth of 40 cm. In other words, in the case of reinforced slope the settlement beneath the footing transmitted to a much shallower depth (half size) than that of the unreinforced slope.

3.3. Three, Six, and Nine-Layered Tire Reinforcement in Slope

In this section, three, six, and nine tire-reinforced layers on different horizontal lengths (20, 40, and 60 cm) were investigated. Soil displacement vectors and critical slip surface for reinforced slope with three 60 cm tire-reinforced layers were located at upper, middle, and lower parts of the slope as presented in Figures 11, 12, and 13, respectively.
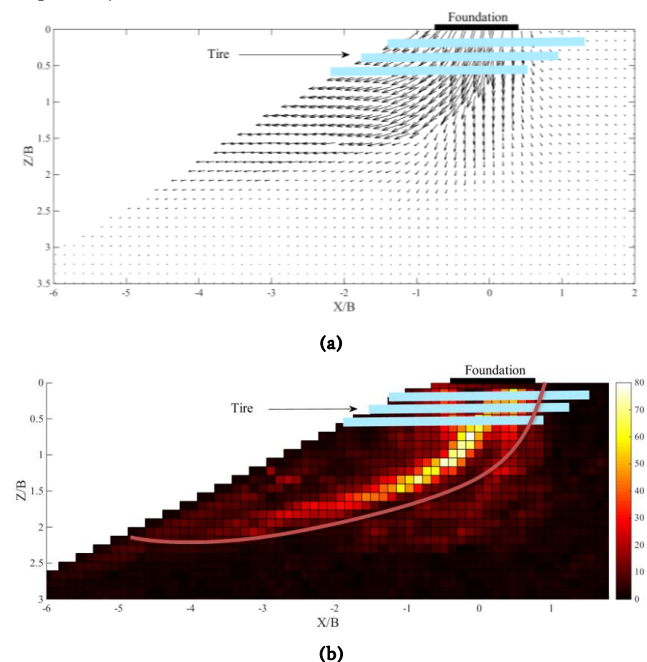

(a)

(b)

Figure 11: Reinforced slope with three-layered tire reinforcement with a length of 60 cm in the upper one-third part of the slope (a) Displacement vectors, (b) Displacement and critical slip surface
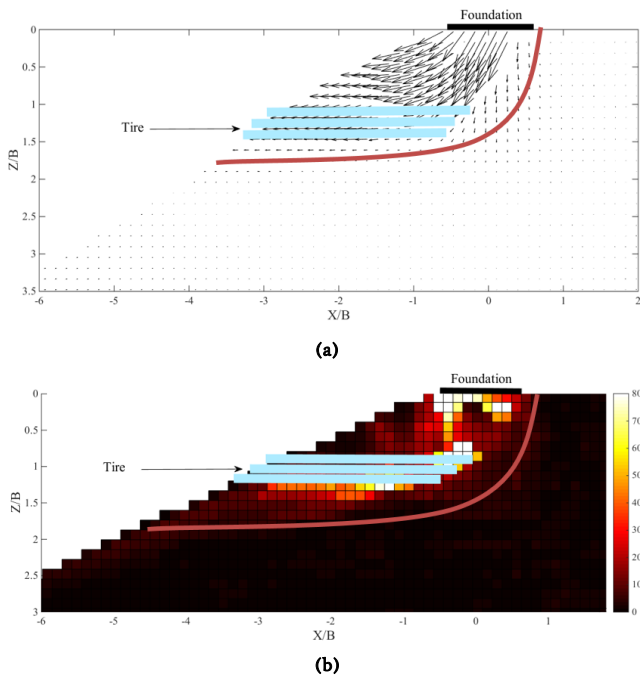
Figure 12: Reinforced slope with three-layered tires with 60 cm length in the middle one-third part of the slope (a) Displacement vectors (b) Displacement and critical slip surface
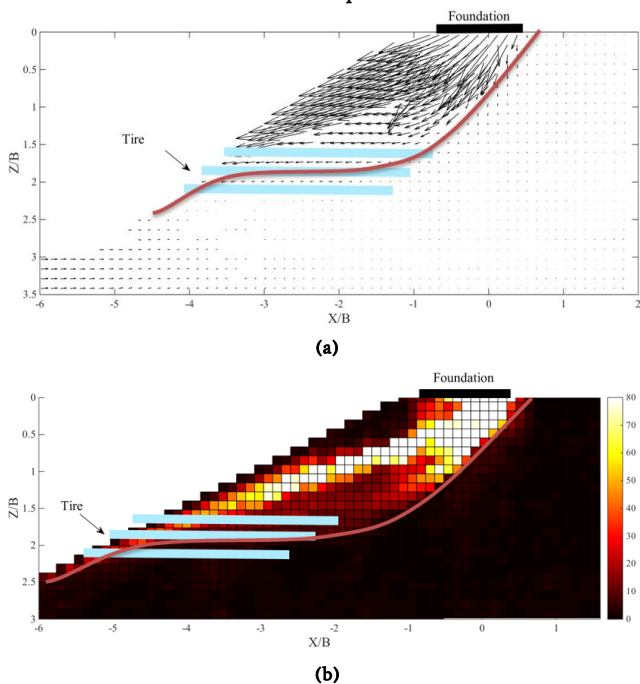

Figure 13: Reinforced slope with three-layered tire reinforcement with 60 cm length in the lower one-third part of the slope (a) Displacement vectors (b) Displacement and critical slip surface

The values of ultimate bearing capacity and ultimate vertical settlement in three-, six-, and nine-layered tire reinforced slopes, and unreinforced slope are summarized in Table 3.

Three 20-cm tire-reinforced layers were placed in the upper one-third part of the slope (A13), and it was compared to the unreinforced slope. It was observed that the bearing capacity increased by 15 percent and settlement decreased by 33 percent. Test A12 results were compared with the unreinforced slope, and it was found that the bearing capacity increased by 22 percent and settlement decreased by 49 percent.

Table 3: the values of ultimate bearing capacity and ultimate vertical settlement for three-, six-, and nine-layered tire reinforced slopes as well as unreinforced slope

Test name	Ultimate bearing capacity (q_u) kPa	Improvement compared to unreinforced slope in (q_u) (%)	Ultimate vertical settlement (S_{max}) mm	Improvement compared to unreinforced slope in (S_{max}) (%)
A1	24.32	0	6.31	0
A11	56.71	133.1826	3.62	42.6307
A12	29.72	22.20395	4.23	32.9635
A13	28.08	15.46053	4.75	24.7227
A14	35.10	44.32566	3.73	40.8875
A15	27.54	13.24013	4.52	28.3677
A16	26.46	8.799342	5.00	20.7607
A17	25.92	6.578947	4.44	29.6355
A18	25.38	4.358553	5.16	18.225
A19	25.29	3.988487	5.25	16.7987
A20	86.44	255.4276	2.28	63.8669
A21	33.48	37.66447	4.13	34.5483
A22	29.70	22.12171	4.21	33.2805
A23	88.47	263.7747	2.09	66.878
A24	36.72	50.98684	3.51	44.374
A25	31.32	28.78289	3.98	36.9255

According to Table 3, in the case of the three-layer tire-reinforced slope, the best position of the reinforcement was the upper one-third part of the slope. And when the length of the reinforced layer was 60 cm (A11), the maximum values of bearing capacity and maximum reduction of the settlement could be achieved (bearing capacity increased by more than 2.3 times and settlement decreased by more than 1.7 times). When the tire-reinforced layers were placed in the middle one-third part (A14, A15, A16) or the lower one-third part of the slope (A17, A18, A19) very little improvement of the bearing capacity and settlement could be achieved compared to cases when reinforced layers were located in the upper part of the slope. In the cases with six and nine tire-reinforced layers and with the best length of the reinforcement, the bearing capacity increased by 3.5 times and the settlement decreased by almost three times. This indicated that the presence of tire in the lower one-third part of the slope was not effective for improvement in bearing capacity and settlement reduction. There was no difference between six-layered and nine-layered tire reinforcements. The BCI diagram is shown in Figure 14 in terms of L_x for three-, six-, and nine-layered tire reinforced slopes.
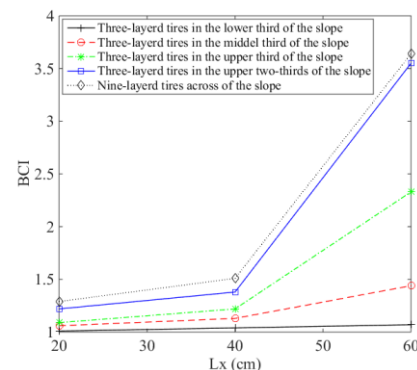

Figure 14: Variations of BCI for different L_x (20, 40, and 60 cm) with three-, six- and nine-layered tire reinforced slopes compared to the unreinforced slope

The curves for vertical settlement below footing versus depth for three-, six-, and nine-layered tire reinforced slopes are shown in Figure 15.

4. Summary and Discussion

This paper illustrates a series of large-scale physical modeling which were performed on a reinforced sand slope using waste tire. In this research, different numbers of reinforcement layers were implemented which consisted of three, four, six, eight, and nine layers. Three-layered reinforcement tires were located in the upper one-third, middle one-

third, and lower one-third of the slopes; Four-layered reinforcement was placed in the upper half and lower half of slope; Six-layered reinforcement tires were implemented in the upper two-thirds of the slopes; Eight- and nine-layered reinforcement tires were positioned across the slopes. It was found that in terms of bearing capacity and settlement, the best position for placing reinforcement layers was the upper one-third part of the slope.

decreased 74, 69, and 42 percent, respectively. When the slopes with six (A20) and nine (A23) 60-cm tire-reinforced layers were compared with the unreinforced slope, the bearing capacity increased 3.55 and 3.64 times, and the settlement decreased 2.77 and 3.02 times, respectively. Slip surface for slopes with three, six, and nine tire-reinforced layers and various positions of the reinforcement layers is shown in Figure 16.
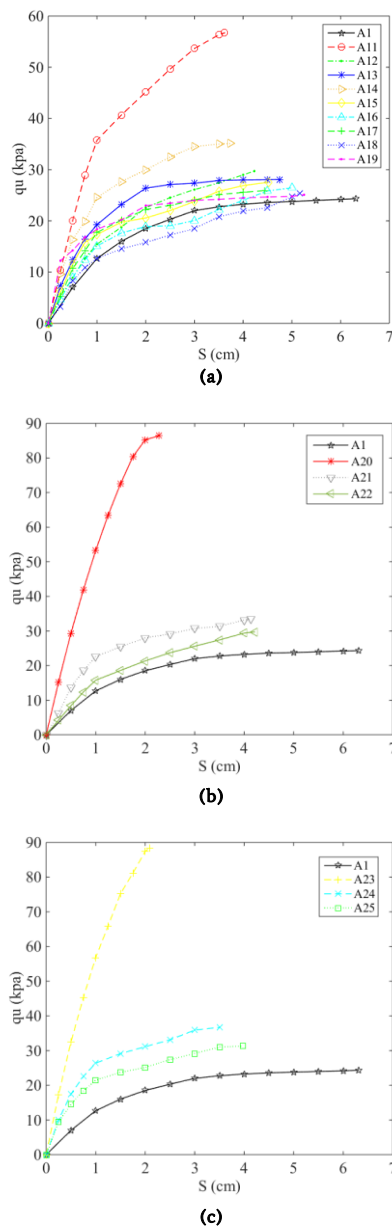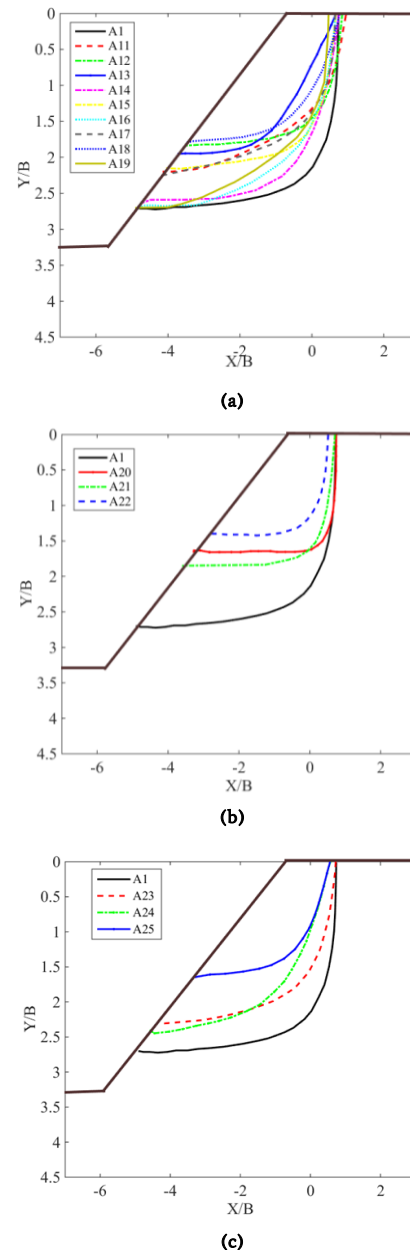

(a)

(b)

(c)

Figure 15. Variations of applied surcharge pressure (q) with settlement (S) for (a) Three-layered tire reinforced slopes (b) Six-layered tire reinforced slopes (c) Nine-layered tire reinforced slopes

(a)

(b)

(c)

Figure 16: Comparison of slip surface shape with different positions (a) Three-layered tire reinforcement slopes (b) Six-layered tire reinforcement slopes (c) Nine-layered tire reinforcement slopes

With an increase in the length of the tire-reinforced layer, the bearing capacity increased significantly, and the settlement decreased in all cases. When the length of the tire-reinforced layer was 60 cm, it passed through the failure wedge and improved the performance. When three layers of tire reinforcement were positioned in the lower one-third part of the slope, increasing the length of the layer had a smaller impact on the bearing capacity and settlement. By comparing the results of the experiments when three 60-cm tire-reinforced layers were placed in the upper (A11), middle (A14), and lower (A17) one-third parts of the slopes with the unreinforced slope, it was found that the bearing capacity increased approximately 2.33, 1.44 and 1.07 times and settlement

The different failure modes of the slope were found to be distinct during the experiments. As shown in Figure 16, the unreinforced slope mobilized a much larger soil mass than that of the reinforced slopes. When the three tire-reinforced layers were located in the upper one-third of the slope (A11, A12, and A13), a lower volume of soil transmitted. Therefore, it was the best position for reinforcement positioning in terms of stability. Curves of settlement beneath the footings at various depths of the slope for three-, six-, and nine-layered tire reinforcement slopes are shown in Figure 17.
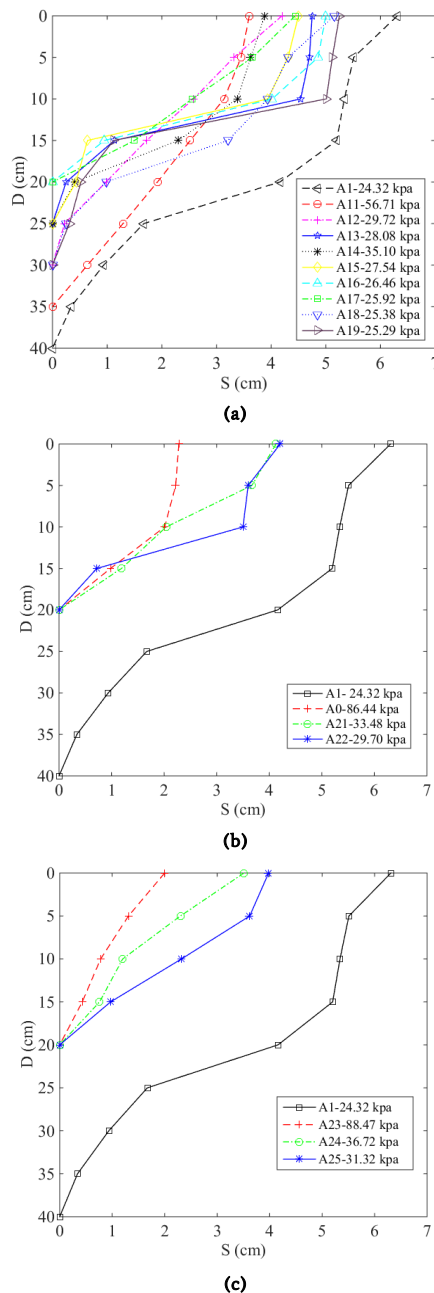
Figure 17. Curves of settlement beneath the footings at various depths of the slope (a) Three-layered tire reinforcement (b) Six-layered tire reinforcement (c) Nine-layered tire reinforcement

It can be seen in Figure 17 that the settlement of the unreinforced slope was much higher than the settlement of the reinforced slopes per each depth. It was also evident that settlements of the unreinforced slope extended to almost the toe of the slope, while in the reinforced slopes much of the deformation was concentrated on the upper part of the slope and it seems to be influenced by the arrangement and length of the tire layers.

5. Conclusion

The purpose of this paper was to study the behavior of a strip footing on a sandy slope reinforced by layers of scrap tire. Generally, it can be noted that scrape tire could solve some problems such as stability, bearing capacity and footing settlement adjacent to the slope.

Based on the results of these experimental tests (aforementioned), the

following conclusions are drawn:

1. The results of tests show that tire reinforcement layers in a suitable location can lead to a significant enhancement in the bearing capacity of footings.
2. When three tire-reinforced layers were located in an optimum position (upper one-third of the slope), the bearing capacity and settlement of the footing were improved at slope crest. In the case of three layers of tire reinforcement with the best arrangement and length (upper one-third of the slope with 60 cm length), the bearing capacity increased more than 2.3 times, and settlement decreased more than 1.7 times.
3. When four-layered tire reinforcement was placed in the upper half of slope, bearing capacity and settlement improved. The best arrangement and length of the four-layered reinforcement tires (i.e., the upper half of the slope with 60 cm length), increased the bearing capacity more than three times and reduced the settlement by a factor of two (halved it).
4. With the best length of the six-, eight-, and nine tire-reinforced layers in slope (in case of six layers reinforcement; upper two-thirds of the slope with 60 cm length, and in the case of eight and nine layers; across the slope with 60 cm length), bearing capacity increased by more than 3.5 times and settlement decreased almost 3 times. There was no marked difference between six and nine tire-reinforced layers.
5. With an increase in the length of the tire-reinforced layer, bearing capacity increased and settlement decreased, especially when the length of tire-reinforced layer passed through the failure wedge.
6. Unreinforced slope deformation was much larger than that of the reinforced slope, and it approximately spread to the slope toe. In the case of the reinforced slope, most of the deformation was chiefly concentrated on the upper part of the slope.
7. Reinforced and unreinforced slopes showed rather different failure modes. Although unreinforced slope endured a general shear failure, in reinforced slopes the failure wedge reduced in size.
8. Transitional settlement of reinforced slope (four and eight tire-reinforced layers) transmitted to a much shallower depth (almost half) than that of the unreinforced case.
9. When the four layers of tire reinforcement were placed at the upper half of the slope, the lowest volume of soil moved, and thereby the stability increased.
10. When three layers of tire reinforcement were placed at the upper one-third of the slope, the lowest volume of soil moved and thereby the stability significantly increased.

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