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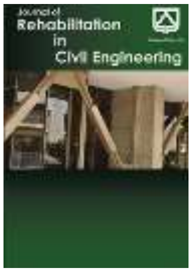

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Stabilization of Earth Slope by Waste Tire Using Experimental Tests and PIV

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ABSTRACT

The issue of environmental protection has led researchers to pay serious attention to waste tires. Civil engineers have found that waste tires can increase bearing capacity, earth slope stability, and other useful applications in civil engineering. In this paper, a series of experimental modeling have been performed to investigate the effect of waste tires on increasing the stability of sand slopes. The position and height of the waste tire are investigated to find the most suitable location to use the waste tire. Digital images were taken during the loading on the slope. Particle image velocity (PIV) is used to measure the deformation of the slope during loading. The results show that the reinforced waste tires reduce displacement by 78% and increase the bearing capacity up to 260%. The optimal position of tire pile with reinforcement heights of B, 2B, 3B inside the slope is upslope in terms of bearing capacity and displacements.

1. Introduction

Nowadays, burying the waste tire has become a major environmental issue in many countries. In many countries, large amounts of waste tires are left in the environment.The rate of this waste materials increase every year. Many waste tires are either dumped in landfills or stored in large quantities [1-3].

The use of waste tires in various geotechnical issues help to reduce the environmental pollution in nature. However, a full understanding of environmental pollutants and their use in engineering is essential. Waste tires not only cause environmental problems but are also a location for mosquitoes and pests. They also are location for the fire hazard [4].

Reinforcing the slopes has been investigated by various researchers [5-8]. Application of waste tires for construction purposes has started several years ago in the developed countries [9]. Also, waste tires have used as reinforcement in slopes by many researchers

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[10-13]. Retaining Walls [14-18], embankments [19-20], foundations [21-23] and improvement of soil properties [14, 24-27] are geotechnical issues can be reinforced by waste tires. Some researchers presented small-scale experimental tests and numerical analyses to reinforce the sand slope using geogrid layers. They resulted that if the reinforcement layers were implemented correctly, the bearing capacity of circular and ring footings over slopes would significantly increase. Noorzad and Ravishi [29] pointed out that one of the most important reasons for using retail tires is that they are economically and environmentally friendly. On the other hand, rubber particles improve the sand strength. Therefore, it is better to shred the waste tire for use in many applications. They show that shred tire act as reinforcement and increase shear strength. Increasing the shred tire further reduces shear strength. Results of Bahaori and Farzalizade [30] indicated that the use of tire powders and tire shreds decreases pore-water pressure due to liquefaction. As the tire powder increases, the shear modulus of the reinforced soil increases. Furthermore, the mean damping ratio increases with the increase in tire powder content.

Shariatmadari et al. [31] conducted a series of stress controlled undrained cyclic torsional test. The results showed that the required energy for liquefaction occurrence decreases with the increase in the rubber content. As the result, the inclusion of crumb rubber decreases the liquefaction resistance of sand. Jamshishi Chenari et al. [32] performed a series of large scale oedometer experiments were conducted to investigate the compressibility properties of the mixtures. It was concluded that deformability of tire-sand mixture increases with soft inclusion. The combination of rubber and dry sand increases the bearing capacity and flexibility of shear strain. Increasing the amount of rubber causes the linear behavior and reduce the angle of internal friction [33]. Hajiazizi et al. [34] performed an experimental study on sand slopes reinforced using layers of waste tires and indicated that these waste materials are quite effective in increasing bearing capacity of slopes. Results showed that scrap type reinforcement highly improved the strength of the sandy slopes model. Furthermore, much higher stresses mobilized inside the sandy slope, which bearing capacity about 3.5 times higher and settlement about 3 times lower in comparison with the unreinforced sandy slope.

There is a dearth of literature about load - displacement behavior of reinforced sandy slopes using waste tire layers (in the shape of piles) with variable height and location beneath footing. The purpose of this study is to better and further understanding of the behavior of waste tire elements as vertical columns with different location and elevation, as reinforcing technique in sand slopes. This study used large-scale physical modeling tests to gain more information about the performance of these reinforcing elements in sandy slopes.

The use of these waste materials in different applications can provide an alternative way to consume the huge stockpile of waste tires from all over the world and consequently reduce some environmental problems due to scrape tires and give these wastes an ecological and economical value.

The studies conducted so far in slopes and embankments were just mixtures of crushed tire-soil or tire horizontal elements. So far, studies of tires as vertical elements (tire pile) have not been investigated on a slope. In this paper, tires as vertical elements of different heights in different positions on the inside and crown slope investigated. The novelty of this study is presenting new technique called tire pile as a reinforcing element in case of slope stabilization, especially sandy soils which studied here.

2. Specimens and Equipment

2.1. Model Box and Footing

The experimental test attempted to study the effects of stabilization of the sand slope on the settlement and bearing capacity of a strip footing adjacent to the slope crest. The main elements of the laboratory apparatus are a box, a horizontal steel beam over the box, and a sand-raining box. Using the pluviation system, a homogeneous slope with a given unit weight can be created. The test box, having inside dimensions of 2.0*1.0 m in plan and 1.0 m in depth, made from steel with the front wall made of 12 mm thickness glass as shown in Fig. 1. The glass side allows the sample to be seen during model preparation, loading and sand particle deformations during testing. These sides also allow the observation of final deformation and slip surface mechanism after the failure. The tank box made sufficiently rigid to maintain plane strain conditions by minimizing the out-of-plane displacement. The inside walls of the box are polished smoothly to decrease friction with the sand as much as possible. The loading system includes hand operated jack and loading ring. The loading system is made of a steel column and it is connected to a rigid beam. A load cell with an accuracy of 0.01% is placed under the loading system. There was also a loading plate 999 mm length, 150 mm width, and 30 mm thick. The length of footing was assumed to be equivalent to the width of the tank box. A steel strip footing model is used to apply the load. Tire reinforced slope models with a slip ratio of 1:1.6 and a final height of 0.50 m were prepared and tested. The bearing capacity is measured by a load cell located on the footing. Twenty-two series of experiments have been performed to investigate the effect of the tire pile height and its optimal location. The geometry of the slope is shown in Figure 2.

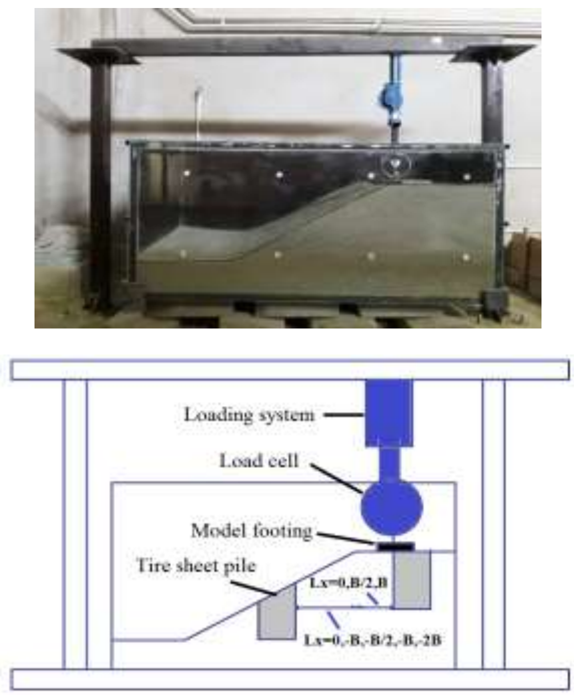


Fig. 1. Schematic view of the experimental apparatus and loading plate width=B.

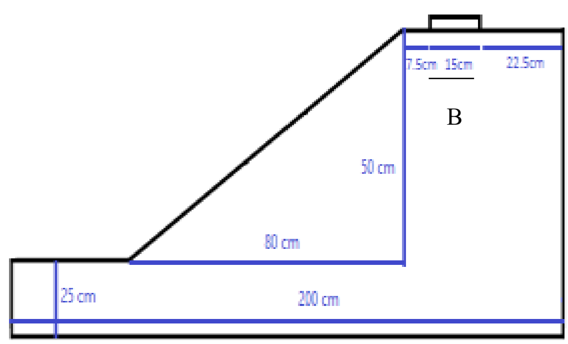


Fig 2. Geometric parameters of sand slope model.

2.2. Test Materials

The sand used in this research was washed sand. The maximum and minimum dry densities of the sand were 19.49 and 16.36 $\frac{kN}{m^3}$, respectively. The average particle size (D50) was 0.93 mm, and the average unit weight of the soil in testing found to be 17.30 $\frac{kN}{m^3}$. The estimated internal friction angle and cohesion determined by a small direct shear test, the results of which were 38° and .00 kPa.

Particle size distribution was determined using the dry sieve method and the results are shown in Fig. 3.

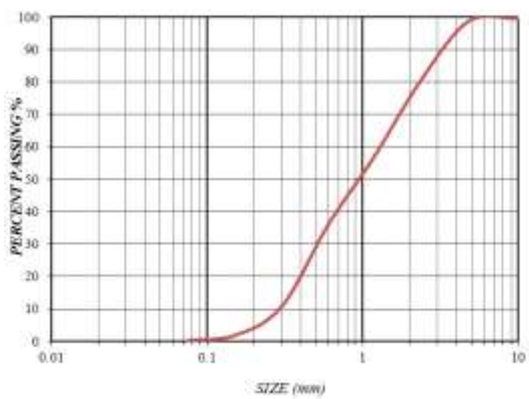


Fig 3. Grain size distribution of the used sand.

All the model slopes were reinforced with small waste tires from wheelchair wheels having a diameter of 18 cm and a height of 5 cm. A total of 25 experimental tests were carried out. Slopes were investigated with a number of different layers (3, 4, 6, 8, and 9) of different lengths (20, 40 and 60 cm) on which the tires were tied together using a metal wire. It should be mentioned that in all experiments there were five tire piles (tire pile) through the width of the slope with a distance of 5 cm from the sidewalls. Tires used in the experiment are shown in Figure 4.

The digital images taken from the soil conducted during the experiment from the front side of testing tank. The photos were processed using the GeoPIV 8 software, expanded at Cambridge University [35]. PIV analysis was run using patches of 16*16 pixels, spaced at 16-pixel center to center, and a search area of 32*32 pixels.

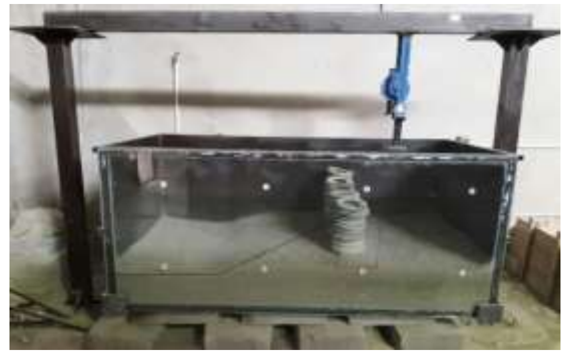


Fig. 4. Tires used in tests.

2.3. Setup Program

In order to investigate the effects of tire reinforcement in sand slopes, a total number of 22 tests were performed to study the soil deformation pattern in unreinforced and reinforced slopes. Slope models were constructed at a height of 500 mm and a length of 800 mm. Tires were placed by hand vertically in the intended location. Afterwards, the footing was placed in position, and the load was applied gradually to the point of failure (the footing collapses and the load decreases). Table 1 illustrates the summary of all the test programs.

Table 1. Experimental Testing Program.

Test name	Position of reinforcement	Distance from the edge of the slope	Height of reinforcement
A1	Unreinforced slope		
A2	Middle of the slope	0	B
A3		B/2	
A4		B	
A5		2B	
A6	Crown of the slope	0	
A7		B/2	
A8		B	
A9	Middle of the slope	0	2B
A10		B/2	
A11		B	
A12		2B	
A13	Crown of the slope	0	
A14		B/2	
A15		B	
A16	Middle of the slope	0	3B
A17		B/2	
A18		B	
A19		2B	
A20	Crown of the slope	0	
A21		B/2	
A22		B	

3. Experimental Modeling

3.1. Unreinforced Slope

A1, as the first test, conducted on unreinforced slope. In this test, the bearing capacity equal to 27.03 kPa (the maximum force applied on the footing). General displacements under the footing equal to 5.73 cm. Soil displacement vectors and critical slip surface for unreinforced slope (A1) shown in Fig 5.

3.2. Slope stabilized Using Tire Piles with Length of B

In this part of the experiment, tire piles as reinforcement with a height equal to the width of footing in different situations (7 tests) are considered. Finally, the results of these cases compared with those of the unreinforced slope.

3.2.1. Inside the Slope

In this section, four tests carried out. The comparison of ultimate bearing capacity and ultimate displacement of tire-reinforced slopes with a height equal to the width of footing inside the slope with unreinforced slope shown in Table 2.

Table 2. Behavioral results of tire reinforced slope with a height equal to the width of footing in different situation inside the slope.

Test name	Q_u (Ultimate bearing capacity) [kPa]	D_{max} (general displacement under the footing) [mm]	D_{max} (Ultimate displacement at the slope top edge) [mm]
A1	27.03	5.73	3.04
A2	37.81	3.53	2.63
A3	28.08	4.49	2.66
A4	27.12	4.76	2.94
A5	29.41	4.33	2.97

Slip surface for tire-reinforced slope with height equal to the width of footing shown in Fig.6 for various positions inside the slope. “B” showed in Fig. 2. General displacement “U” (i.e. absolute displacement) below the footing and against depth “D” for tire reinforced slope with a height equal to the width of footing in different situations inside the slope are presented in Fig 7.

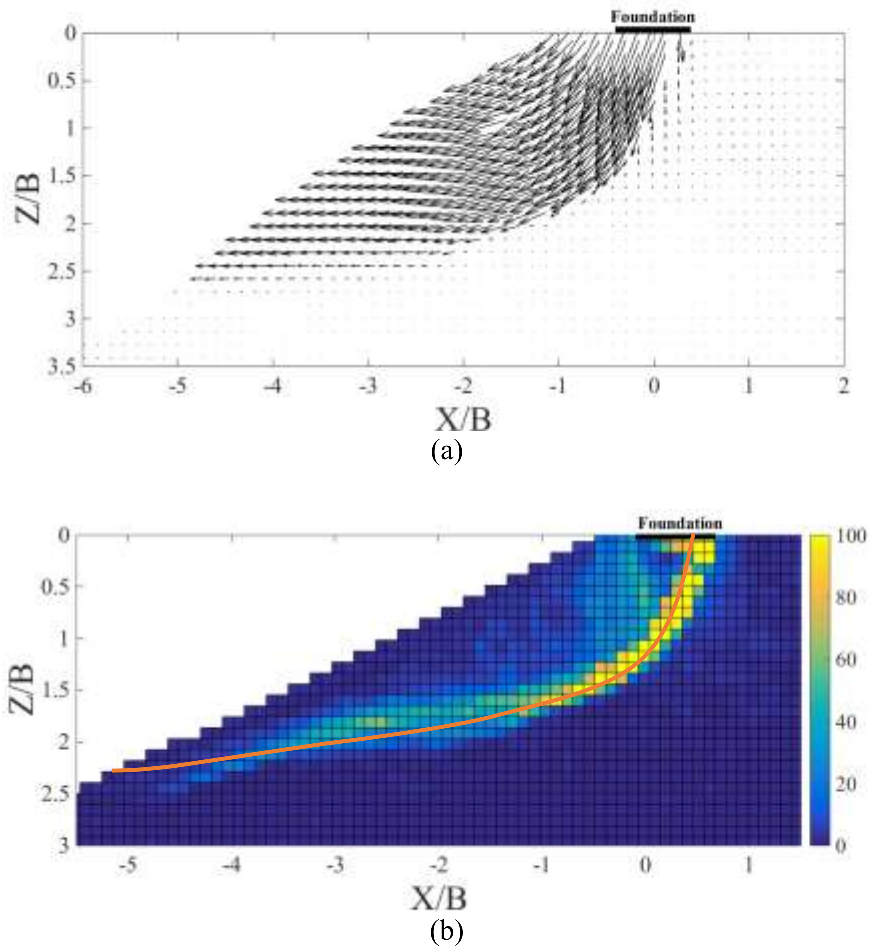


Fig. 5. (a): Soil displacement vectors in unreinforced slope. (b): Critical slip surface for unreinforced slope.

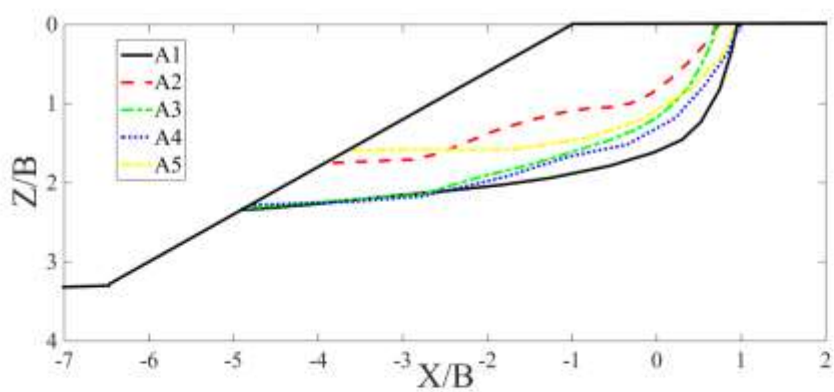


Fig. 6. Slip surface comparison between tire-reinforced slope with height equal to the width of footing in different situations inside the slope and unreinforced slope.

As shown in Fig. 6 in the presence of reinforcement with length of B in different positions inside the slope, smaller mass of soil displaced comparing to unreinforced model.

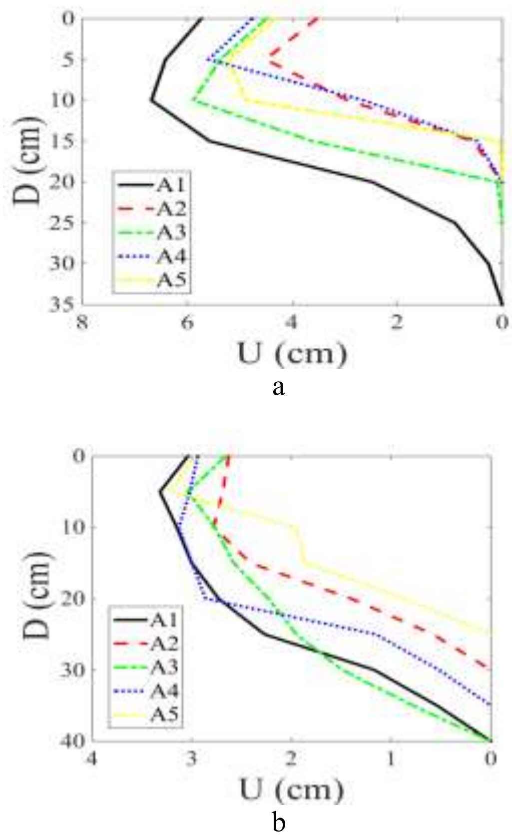


Fig. 7. Displacement curves of tire reinforced slope with a height equal to the width of footing in different situations inside the slope. (a): beneath the footing (b): on the edge of slope.

3.2.2. Crown of the Slope

In this section, three tests performed with the reinforcement height of B in different locations of the slope crown and their behavior compared to unreinforced slope. The comparison of ultimate bearing capacity and ultimate displacement of tire-reinforced slopes within various situations and unreinforced slope shown in Table 3.

Table 3. Behavioral results of tire reinforced slope with a height equal to the width of footing in different situations of the slope crown.

Test name	Q_u (Ultimate bearing capacity) [kPa]	D_{max} (Ultimate displacement under the footing) [mm]	D_{max} (Ultimate displacement at the slope top edge) [mm]
A1	27.03	5.73	3.04
A6	37.80	3.71	2.95
A7	57.24	2.00	1.18
A8	40.53	2.26	2.63

Slip surface with tire-reinforced slope with height equal to the width of footing different positions in slope crown shown in Figure 8.

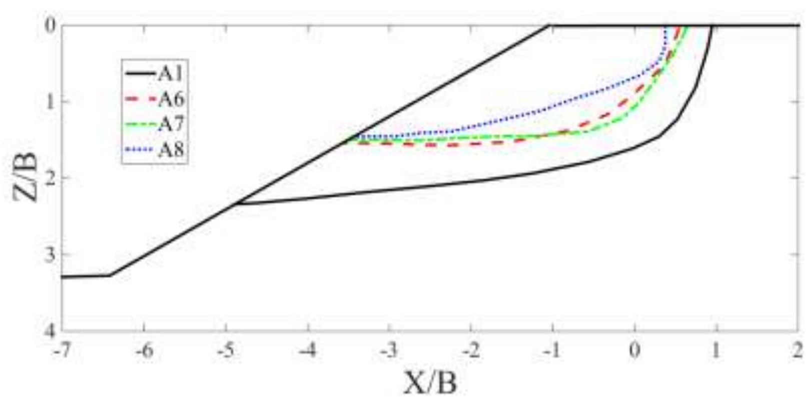


Fig. 8. Slip surface comparison between tire-reinforced slopes with a height equal to the width of footing in different situations in the crown of slope and unreinforced slope.

General displacement (U) below the footing and against depth (D) for tire reinforced slopes with a height equal to the width of footing in a variety of situations in the crown of slopes are presented in Fig 9.

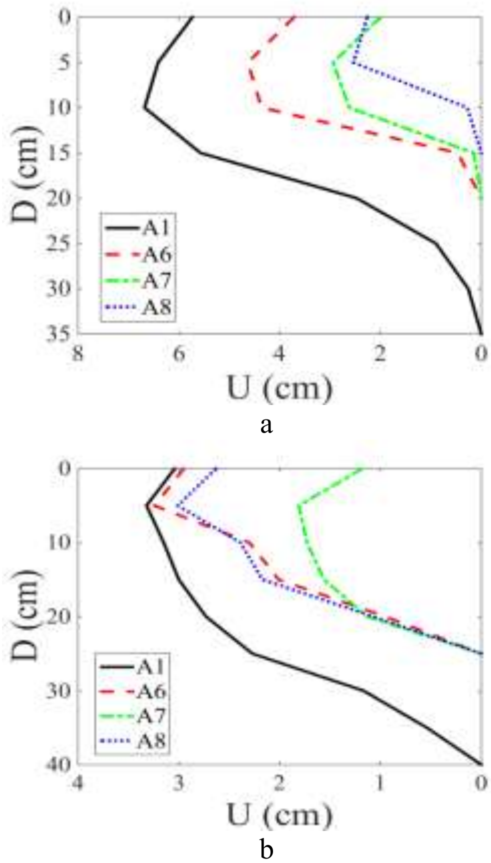


Fig. 9. Displacement curves of tire-reinforced slope with a height equal to the width of footing in different situations in the crown of slope. (a): beneath the footing (b): on the edge of slope.

3.3. Slope Stabilized Using Tire Piles with Length of 2B

3.3.1. Inside the Slope

In this section, four series of tests with height of 2B in different locations inside the slope performed, and its behavior has been compared to unreinforced slope.

Results of tire-reinforced slopes which height is twice the width of footing in various situations are illustrated in Table 4.

As shown in Fig. 10, in the A9 test, when reinforcement with 2B height placed in the upstream slope, smaller amount of soil displaced compared to other tests. In order to understand the effects of pile with 2B inside the slope, slope displacements indicated in figure 11. This figure shows that the presence of reinforcement with a 2B length inside the slopes transmitted the displacements toward surface in comparison with unreinforced slope.

Table 4. Results of tire reinforced slope which height is twice the width of slope in different situations.

Test name	Q_u (Ultimate bearing capacity) [kPa]	D_{max} (Ultimate displacement under the footing) [mm]	D_{max} (Ultimate displacement at the slope top edge) [mm]
A1	27.03	5.73	3.04
A9	40.50	4.27	2.31
A10	36.18	4.17	2.48
A11	30.78	4.22	2.86
A12	29.73	4.29	2.93

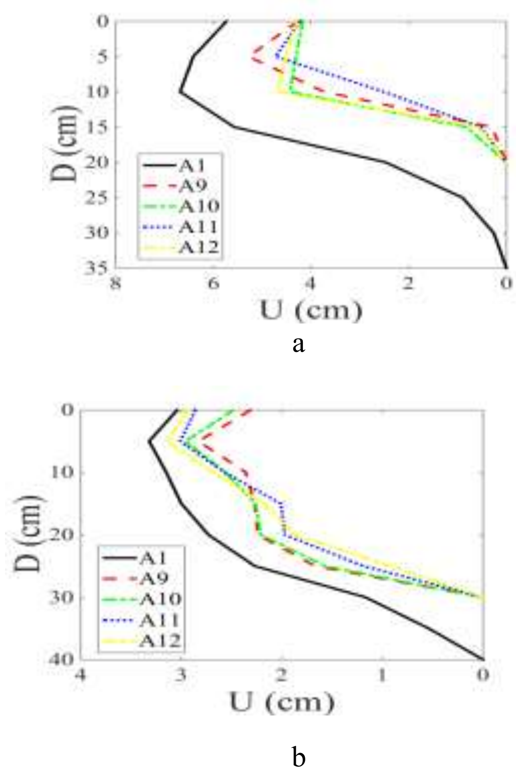


Fig. 11: Displacement curves of tire-reinforced slope with a height equal to 2B in various situations inside the slope. (a): beneath the footings (b): on the edge slope.

3.3.2. Crown of the Slope

In this section, three tests with reinforcement height of 2B in different locations in crown of slope carried out and their behavior compared to unreinforced slope.

Results of tire-reinforced slope with height of equal to 2B in different situations of the slope crown are illustrated in Table 5.

Table 5. Behavioral results of tire-reinforced slope with a height equal to 2B in different situations in the slope crown.

Test name	Q_u (Ultimate bearing capacity) [kPa]	D_{max} (Ultimate displacement under the footing) [mm]	D_{max} (Ultimate displacement at the slope top edge) [mm]
A1	27.03	5.73	3.04
A13	56.72	2.82	1.73
A14	67.54	2.17	0.53
A15	43.28	3.79	1.69

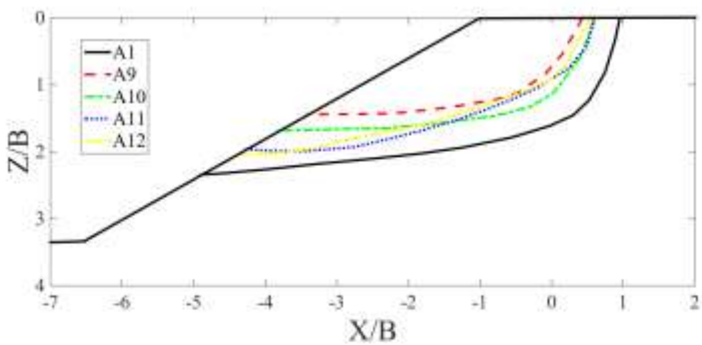


Fig. 10. Slip surface comparison between tire-reinforced slopes with height of 2B in different situations inside the slope with unreinforced slope.

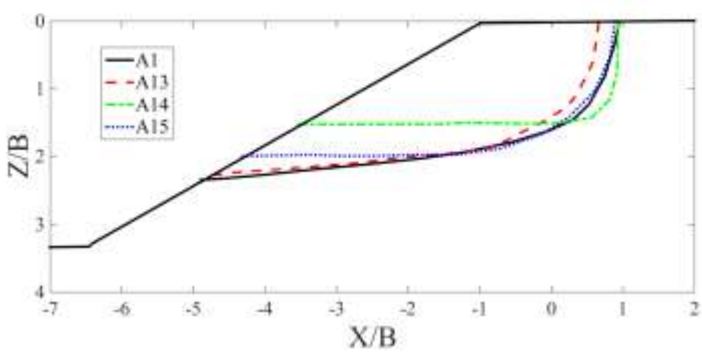


Fig. 12. Slip surface comparison between tire-reinforced slopes with a height equal to twice the width of footing in various situations in the slope crown and unreinforced slope.

As shown in Fig. 12, in the A14 test, when reinforcement with 2B height placed in beneath footing, less soil mass displaced compared to other tests.. Figure 13 shows the reinforcement effects in reducing displacements in depth.

3.4. Slope Stabilized Using Tire Piles with Length of 3B

3.4.1. Inside the Slope

In this section, four model of reinforcement with 3B height in different locations inside the slope tested and their behavior compared with unreinforced slope.

The comparison of ultimate bearing capacity and ultimate displacements of tire-reinforced slope with 3B height in different positions are shown in Table 6.

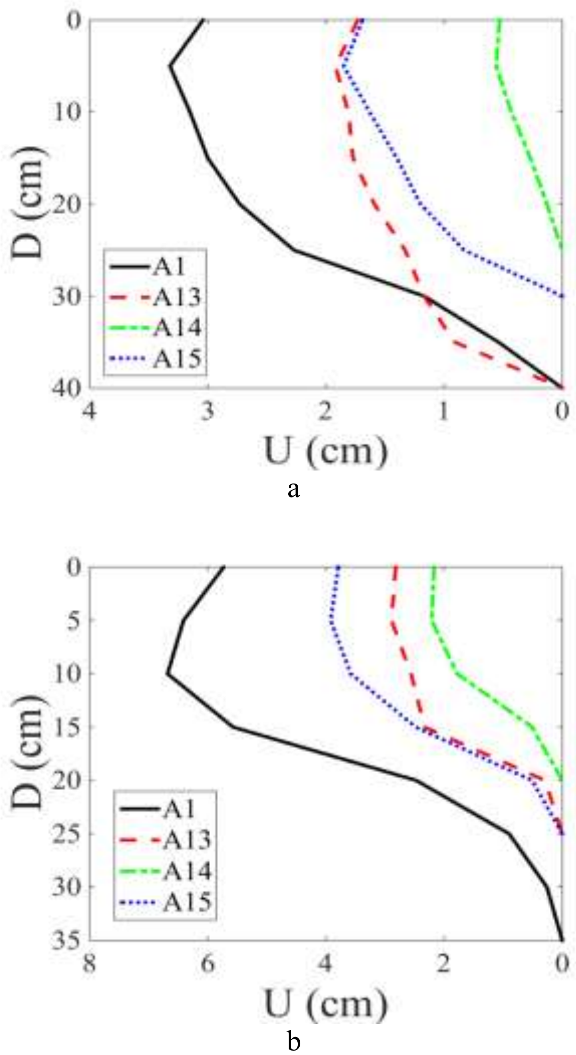


Fig. 13. Displacement curves of tire-reinforced slopes with a height equal to 2B in various situations in the slope crown. (a): beneath the footings (b): on the edge of slope.

Soil displacement vectors and critical slip surface of stabilized slope using tire pile with 3B length at the top of the slope, illustrated in figure 14.

Table 6. Behavioral results of tire-reinforced slopes with 3B height in various situations inside the slope.

Test name	Q_u (Ultimate bearing capacity) [kPa]	D_{max} (Ultimate displacement under the footing) [mm]	D_{max} (Ultimate displacement at the slope top edge) [mm]
A1	27.03	5.73	3.04
A16	43.22	3.60	2.23
A17	35.18	3.55	2.45
A18	32.40	3.79	2.51
A19	29.78	4.62	2.73

Slip surfaces for tire pile reinforced slopes with a height equal to 3B in different locations, shown in figure 15.

As shown in Fig. 15, in the A16 test, when reinforcement with 3B length placed in the upstream of slope, a smaller amount of soil displaced compared to other tests (i.e. A17, A18, and A19). Displacement curves of tire-reinforced slope with 3B length in different situations illustrated in Fig. 16.

Figure 16 shows the reinforcement effects in reducing displacements in the depth.

3.4.2. Crown of the Slope

In this section, three model of reinforcement with 3B height in different locations of slope crown placed and their behavior compared to unreinforced slope.

Soil displacement vectors and critical slip surfaces of stabilized slope using tire pile with a height equal to 3B at the beneath of the footings is illustrated in figure 17.

The comparison of ultimate bearing capacity and ultimate displacements of tire pile reinforced slopes with 3B length in crown of slopes are shown in Table 7.

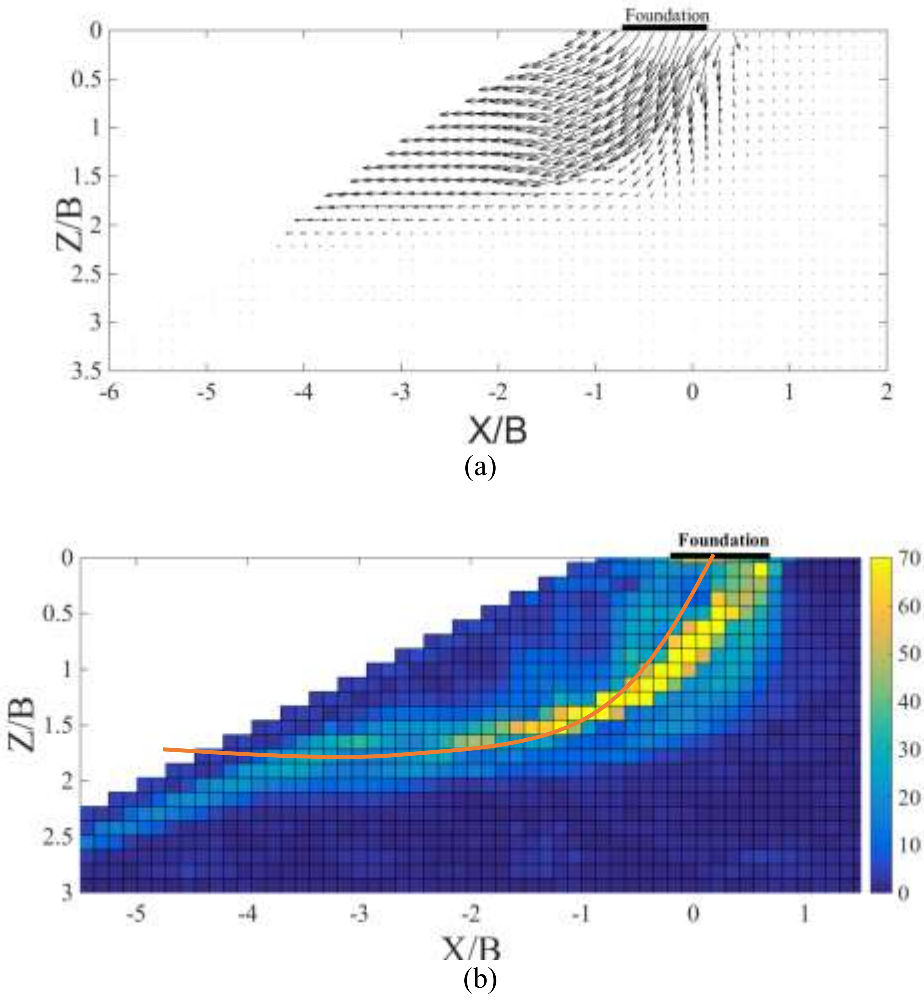


Fig. 14. Stabilized slope using tire pile with a height equal to 3B at the top of the slope. (a): Soil displacement vectors (b): Critical slip surface.

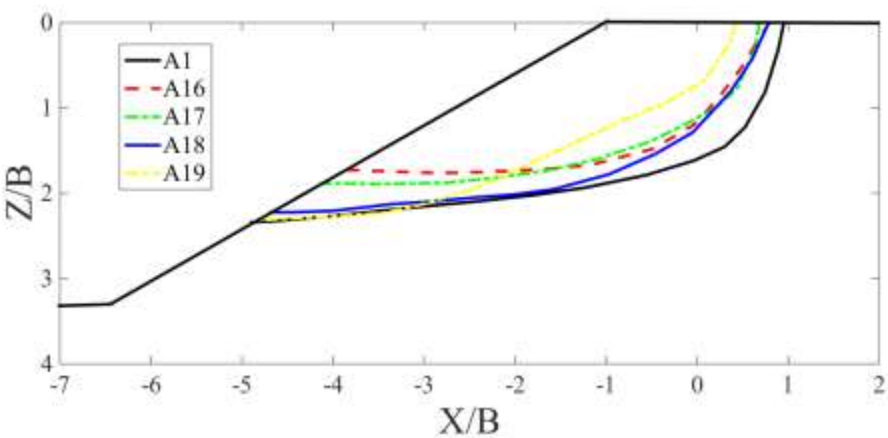
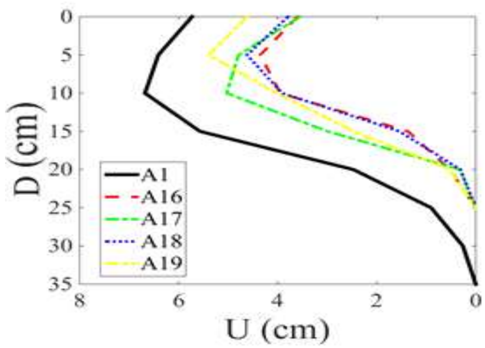


Fig. 15. Comparison of slip surfaces for tire-reinforced slopes with 3B length and unreinforced slope.



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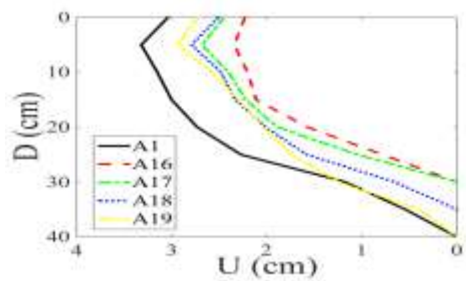


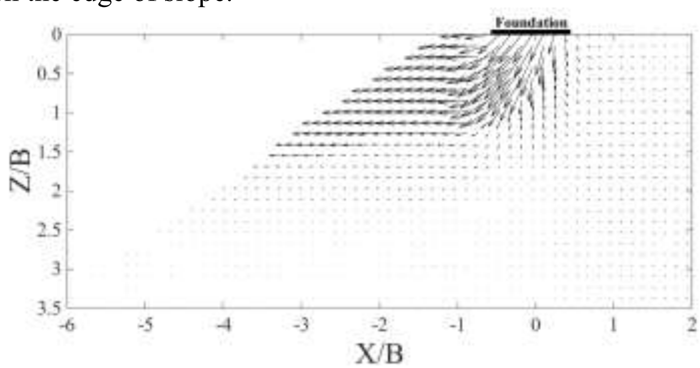
b

Fig. 16. Displacement curves of tire pile reinforced slope with 3B length. (a): beneath the footings (b): on the edge of slope.

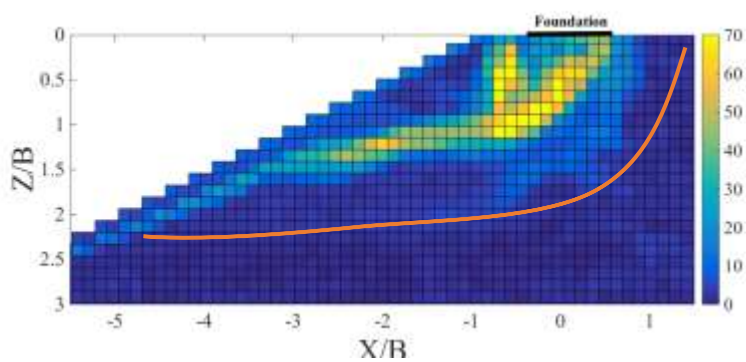
Table 7. Behavioral results of tire-reinforced slopes with 3B length in different situations in the crown of the slopes.

Test name	Q_u (Ultimate bearing capacity) [kPa]	D_{max} (Ultimate displacement under the footing) [mm]	D_{max} (Ultimate displacement at the slope top edge) [mm]
A1	27.03	5.73	3.04
A20	70.23	1.39	1.43
A21	97.21	1.25	1.23
A22	59.42	2.03	1.4

As shown in Fig. 18, in A21 test, when pile with 3B length placed beneath the footing, a smaller amount of soil displaced compared to other tests (i.e. A20 and A22). Displacement curves of tire-reinforced slopes in the crown of slope shown in figure 19. Fig. 19 shows the reinforcement effects on reducing displacements in the depth.



(a)



(b)

Fig. 17. Stabilized slope using tire pile with 3B length at the beneath of the footing. (a): soil displacement vectors (b): critical slip surface.

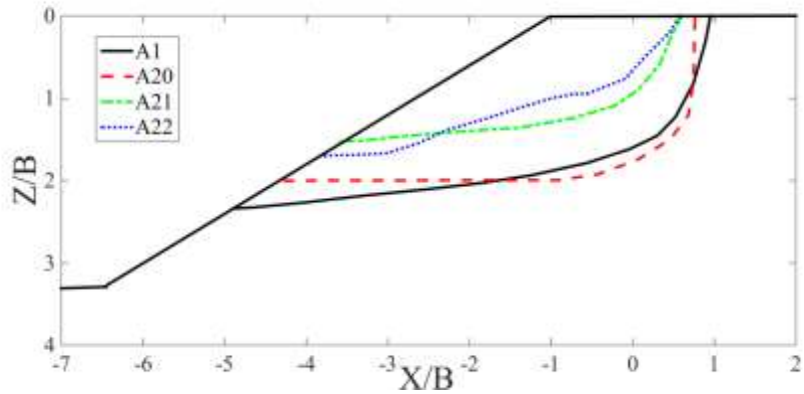
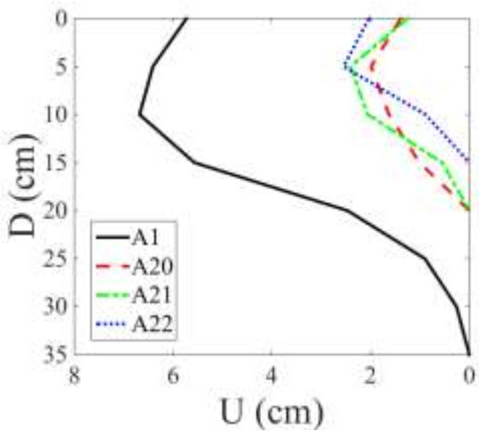


Fig. 18. Comparison between slip surfaces of tire pile reinforced slopes with 3B length in the crown of slope and unreinforced slope.



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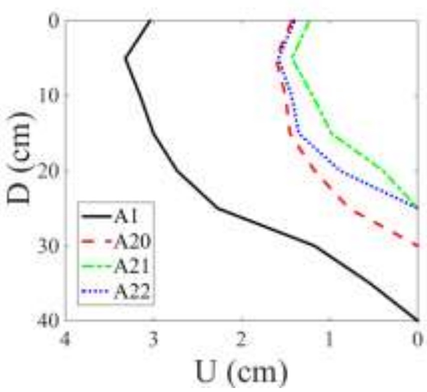


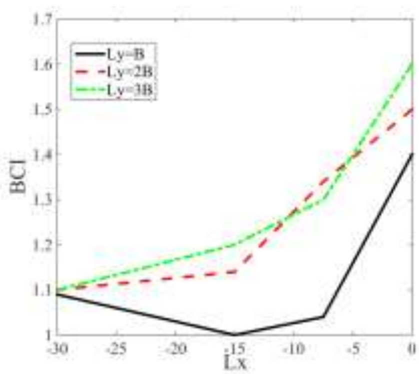
b

Fig. 19. Displacement curves of tire pile reinforced slopes with 3B length in crown of slope. (a): beneath the footings (b): on the edge of slope.

The bearing capacity improvement (BCI) of the footing due to slope stabilization is presented using a non-dimensional factor, called BCI factor. This factor defined as the ratio of the ultimate bearing capacity of the footing in the stabilized slope ($q_{reinforced}$) to ultimate bearing capacity of the footing in the unreinforced slope ($q_{unreinforced}$). Lx is the horizontal distance of reinforcements from the slope edge. The ultimate bearing capacities of the footing-soil systems are achieved from the load-displacement curves, as the pronounced peaks, after which the footing collapses and the load is reduced. BCI diagram in terms of Lx shown in Fig.20. As shown in this figure, the greatest improvement in the bearing capacity inside the slope, is upstream and in the slope crown beneath the footing.

4. Scale Effects

The scale laws and scale effects are important research topics in the field of geotechnical engineering. Finding relations between prototype and physical modeling can extend the experimental results to the real model in the field. According to the relationships proposed in both experimental models and prototypes, some features vary while others remain the same. For instance, cohesion, internal friction angel, and unit mass of soil remain constant in physical models and real models. However, parameters such as length, time, force, and mass follow specific relations, which discuss further in this section. Since 1-g models are only useful in the estimation of prototype general behaviors [36], the above-mentioned differences are due to variations in stress levels between laboratory and real models. Based on researches performed in this regard, small-scale experiments provide quicker and simpler general information in comparison to large-scale models [37].



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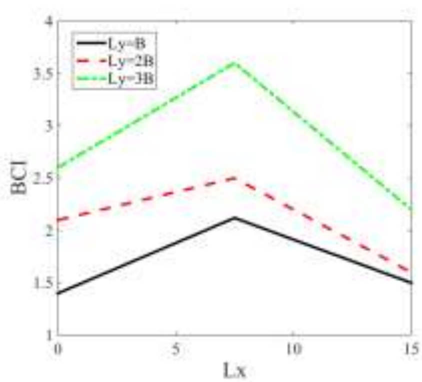

b

Fig. 20. Variations of BCI for different Lx. (a): inside slope (b): in the crown of slope.

As proposed by some researchers [38-40] by using precise scale laws, the obtained data from small-scale experiments could extrapolate to real models in the field. However, the authors indicated that providing the exact similar answer for both prototype and laboratory model is not simple due to difficulties in scale laws. Therefore, professional judgment is the key parameter in this issue [37]. Table 8 provides information about prototype and physical modeling.

Table 8. Scale effect for real and physical models [37].

	time	length	area	force	mass
Real	T	L	A	F	M
Experimental Model	$\sqrt{S}T$	SL	S^2A	S^2F	S^3M

5. Results and Discussion

The purpose of this study is to obtain more understanding about the failure mechanism and the mechanical behavior of a strip footing located on the failure mechanism crest of sand slope and adjacent of a tire pile stabilized the slope. Therefore, a series of experimental test performed (22 tests) and the following results obtained.

According to experimental models performed in this paper, several results obtained which described below:

According to Table 2, the effects of waste tire pile in different situations from the slope in terms of bearing capacity and displacements is different. When the reinforcement is on the upstream of slope, the bearing capacity increase and footing displacement decrease more evidently. Figures 6 and 7 show that the presence of reinforcement with the length of B inside the slope transmitted the displacements near the surface.

As shown in Table 3, the A7 test, compared to the A6 and A8 tests, showed greater improvements in the case of bearing capacity and displacement compared to unreinforced model. In other words, when the reinforcement placed in the crown of the slope, the optimal position is precisely beneath the footing. As shown in Fig. 8 in the presence of reinforcement with length of B in different positions in crown of slopes, compared to the unreinforced slope, smaller amount of soil mass displaced. It is clear from Fig. 9 that the effects of reinforcement in depth are significant in reducing the amount of displacements for the reinforced slopes comparing to the unreinforced slope. According to Table 4, by comparing this series of experiments, the optimal reinforcement position with the height of 2B is upstream of the slope (the same as reinforcement to height B). Test A9 compared to the tests A10, A11, A12 show better improvement in bearing capacity and displacement than that of unreinforced test.

As seen in Table 5, when using a row of tire pile with a height of 2B in different positions in the crown, the best position is underneath the footing based on the improvement in term of bearing capacity and displacements in this position compared to other locations. As shown in Table 6, same as the previous sections (reinforcement with B and 2B length), the best reinforcement location is the upstream of the slope.

According to Table 7, if the reinforcement elements were equal to 3B in length in different positions of the crown of slope, the optimal location in terms of bearing capacity and displacements is beneath the footing (A21). Comparison of slip surfaces for tire pile reinforced slopes and unreinforced slope illustrated in figure 18.

Using tire pile with length of B in the middle of slope, the increase in bearing capacity was 1.40 times of unreinforced state, while in the case that piles located in slope crown, the maximum enhancement calculated 2.21 time of unreinforced slope. In the condition that tire pile used with 2B length in the middle of slope, bearing capacity increased 1.50 times in comparison to unreinforced one. However, when the same pile implemented in the crown of the slope, bearing capacity enhanced 2.50 times. When tire pile with length of 3B used in the middle of slope, bearing capacity enhancement was only 1.6 times, whereas in crown of slope, this increase gained 3.6 times of unreinforced slope. In the following, more details described for each case.

In the A2 test, when the tire pile located in upstream slope bearing capacity increased by 40% in comparison to unreinforced slope (A1). Displacements of the footing and the edge of the slope reduced by 38% and 13 % respectively. Experiments in other various positions inside the slope (i.e. A3, A4, and A5) show that the optimum location is upstream of the slope.

For A7 test compared to unreinforced slope (A1), bearing capacity increased by 112% and the displacement of the footing and the edge of the slope reduced by 35% and 61% respectively. When reinforcement with B height placed in different positions of the slope crown, A7 test compared to different positions of the crown of the slope (i.e. A6 and A8) is a further improvement. As a result, the optimum location is beneath the footing.

In the A9 test, when the tire pile located in upstream of slope bearing capacity increased by 50% in comparison to unreinforced slope. Displacements of the footing and the edge of the slope reduced 25 % and 24% respectively, and other positions inside the slope (i.e. A10, A11, and A12) shows that optimal location is upstream of the slope.

A14 test compared to unreinforced slope (A1) indicates that the increase in bearing capacity will be 150%. Displacements of the footing and the edge of the slope will reduced by 62% and 83% respectively. When reinforcement with 2B height placed in different positions of the crown of the slope, experiment show that the optimum location in this case is beneath the footing.

Reinforcement with 3B height placed in upstream of the slope (A16) had better improvement in bearing capacity and reducing slope displacements compared to other positions (i.e. A17, A18, and A19). The A16 increase the bearing capacity up to 60% compared to the unreinforced slope. The displacements of footing and edge of slope decrease up to 37% and 27%, respectively. When reinforcement placed at a height of 3B beneath the footing (A21) in comparison to different situations the slope (A20 and A22 tests) is best-suited position, in terms of improving bearing capacity and displacement. For A21 the bearing capacity increased by 260% and the displacement of the footing and the edge of the slope reduced up to 78% and 60% respectively, compared to unreinforced slope.

By comparing the tests performed upstream of slopes (A2 with A16), by increasing the tire pile height, the bearing capacity increased from 40% to 60% (which is, 20% increase in bearing capacity) and there is no significant change in displacement.

By comparing the tests beneath slope (A21 with A7), by increasing the tire pile height, the bearing capacity increased from 112 to 160 percent (That is, 148% increase in bearing capacity) and there is no significant change in displacement.

By using table 8, the prototype models constructed in laboratory condition (which due to limitation of experimental tests, have some predictable and unpredictable errors) can simply considered as real models in the field.

6. Conclusion

The object of this paper is experimental study the behavior of a strip footing located on the crown of a sand slope adjacent to tire pile stabilized slopes. Based on the performed experimental results and PIV, several results are considered:

1. The optimal position of tire pile with reinforcement heights of B, 2B, 3B inside the slope is upslope, in terms of bearing capacity and displacements. When reinforcement with 3B height located on the upslope the bearing capacity increased up to 60% comparing to unreinforced slope. Displacement of the footing and the edge of the slope reduced by 37 % and 27%, respectively.
2. The best location for tire pile with all reinforcement heights of B, 2B, and 3B in slope crown is beneath footing. When reinforcement with 3B height implemented beneath the footing, bearing capacity increased by 260%, comparing to unreinforced slope. Displacement of the footing and the edge of the slope reduced by 78% and 60%, respectively.
3. In tire pile reinforced slopes compared to unreinforced slope, displacement curves and slip surfaces changed from deep-seated types to shallow ones.

4. In tire pile reinforced slopes, less soil mass transported, comparing to unreinforced slope after failure.

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