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Experimental investigation of load-deformation behavior of railway embankment mixed with tire derived aggregates (TDA)

Abstract

The available technical literature shows that the load-deformation behavior of railway embankment mixed with tire derived aggregates (TDA) has not been well investigated. For this reason, firstly the GW-GC soil was selected as base material and tire derived aggregates (TDA) were utilized for laboratory tests. In the first stage, the plate loading tests were performed on the mix of soil with 5, 10 and 15 percent of TDA and consequently Ev_2 values were obtained. In the second stage, three embankments with 7m height with 1:15 scale were constructed in a loading chamber. These embankments included embankment without TDA, embankment with 10 percent TDA and embankment containing TDA core (with 3m height). The test results indicated that the embankment soil failure load and crest settlement were decreased 24.78 and 17.21 percent by adding 10 percent TDA in comparison to embankment without TDA. On the other hand, this comparison showed 40.8 and 28 percent in case of using TDA as an embankment core.

Keywords: railway embankment, tire derived aggregates, plate loading tests, load deformation behavior

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Introduction

Recently, rail transportation system has significant advantages respect to other transportation systems. One of the essential parts in railway tracks is embankment that has high executive operations and construction time. The embankment should supply a stable support for moving different trains. In embankments that are constructed using natural materials, limitations arising from the weakness of the material used in execution should be considered. The embankment failures are classified as four groups that are failure caused by local and general cracks or gaps in body of the embankment, failure caused by local or general slide, failure caused by shear failure and failure caused by deformation of soft sub grade.[1] In order to avoid the mentioned failures forms of embankment, allowed values of the density, bearing capacity of California (CBR) and elasticity modulus of plate loading for embankment materials should be considered based on regulations related to railway earthworks.[2–5] Soil materials utilized in the embankment should provide the regulation requirements until the suitable bearing capacity and allowed settlement supply. One of the important issues in recent years in different countries is waste tires. Shred tires in different sizes can be used in embankment construction, road substructure, and bridges embankment. In this regard, various studies related to the embankment behavior mixed with shred tires have been done. For example, Humphrey & Holtz[6] studied conditions of different embankments mixed with shred tires and they approved their performance. Yoon et al.[7] studied mix of soil and shred tires as filler material for embankments. Aderinlewo et al.[8] studied the response of embankment including waste shred tires by using the analytical software. The previous studies show that the soil mixed with shred tires as rail sub grade or embankment has not been well investigated. So in this paper by focusing on the modulus of elasticity and settlement of soil mixed with shred tires, firstly a series of laboratory tests including bearing capacity of California (CBR) and compaction were performed on GW-GC soil with 5, 10 and 15 percent of shred tires. Then, the current soil without and mixed with shred tires were compacted in chamber box in school of railway engineering according to ASTM D698 standard[9] and cyclic plate loading tests by 30 tons loading jack in three cycles were carried out. The results indicated that the maximum acceptable shred tires mixed with embankment materials should be 10percent. In continuation, the behavior of the load-deformation of embankment containing shred tires was studied. Three embankments were constructed in a loading chamber. The first embankment was constructed without shred tires, the second embankment was constructed with 10percent shred tires and finally third embankment included shred tires as core of embankment. All three embankments with a high of 7meters and scale of 1:15 were loaded in the loading chamber.

Characteristics of materials

Soil materials utilized in this study were broken stones. They were named GW-GC according to Unified Soil Classification. Also, shred tires utilized in this study consist of old vehicle rubbers tires that were shredded mechanically in various steps. They were supplied by Company of Ghadir rubber.[10–12]

Plate loading tests (PLT) on the soil mixed with shred tires

For plate loading tests (PLT), a loading chamber including dimensions 1.2×1.2×1m was used Figures 1-3. For loading in chamber, a hydraulic jack 30tons and square plate with dimensions 30×2.5cm were considered. A gauge was utilized for measuring displacement.

In order to determine the soil conditions without shred tires and mixed with different percents of shred tires, a series of plate loading tests were performed. Table 1 shows the elasticity modulus in the first and second loading cycles for soil mixed with various shred tires.[11,12] As can be seen from Table 1, the elasticity modulus in the second loading cycle is greater than it in the first loading cycle because of soil compaction in the first cycle. Generally, the ratio of Ev_2 to Ev_1 approximately can be equal to 1.05. On the other hand, both of elasticity modulus in first and second cycles decreased by increasing the shred tires. So, UIC R719 regulation has been determined the minimum elasticity modulus values equal to 45MPa in the second loading cycle for grain materials. Therefore, the maximum shred tires mixed with soil is equal to 10 percent.

Figure 1 Chamber box for PLT

Figure 2 Soil sample GW-GC

Figure 3 In-situ density test

Table 1 Elasticity modulus for mix of soil-shred tires

Elasticity modulus in the first cycle	Elasticity modulus in the second cycle	Soil mixed with various shred tires (percent)
EV1 (MPa)	EV2 (MPa)	
73.6	77.5	0
53.6	56.2	5
47.9	49.7	10
33.8	35.4	15

Embankments loading tests

As stated in the previous section, the percentage of shred tires mixed with soil must be limited to 10 percent. In this regard, firstly the load deformation behavior of soil mixed with 10 percent shred tires was investigated. In the next part, shred tires were placed in core of embankment and were subjected to load. The obtained results were compared with soil without shred tires. In continuation, the results of loading tests are described.

Loading test on embankment without shred tires

After preparation of sample according to results of compaction tests, the embankment was compacted in 5 layers of 10cm with optimum humidity of 6.82 percent per thirty times rolling passes. For experiments, firstly the degree of displacement gauge was set to zero and the load was incrementally applied by using the hydraulic cylinder. The loading processes continue until the embankment failed completely. It should be noted that the settlement of embankment crest and sub grade is recorded for each 500kg. Figure 4 shows the load-displacement diagram for embankment without shred tires.

Based on Figure 4, the nonlinear parabolic equation can be approximated by the following form:

$$p = -0.0018d^2 + 0.39d - 0.805 \qquad R^2 = 0.989 \quad (1)$$

In this equation, p is load in terms of ton and d is vertical displacement of embankment.

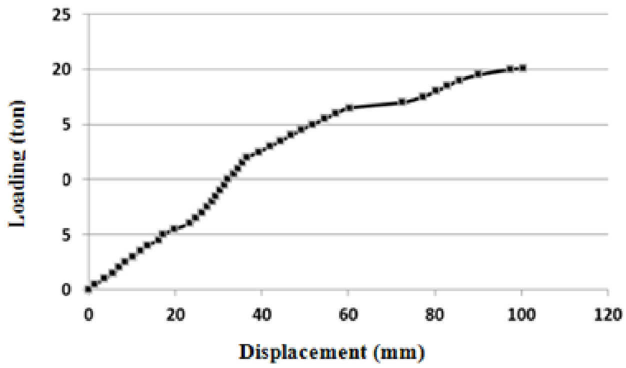

Figure 4 Load-displacement for soil without shred tires.

As can be observed, settlement in embankment increased by increasing the load value until value of force and corresponding settlement reached to 20.1 tons and 10.5cm respectively and then embankment failed. Figure 5 shows the form of embankment without shred tires before and after failure.

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A. Before failure B. After failure

Figure 5 Embankment without shred tires.

Loading test on embankment mixed with shred tires

According to the results of plate loading tests on embankment with classified shred tires, 10 percent efficiency was obtained from initial laboratory experiments. In this regard, embankment with 10 percent shred tires with maximum compaction and optimum humidity of 8.95 percent with 30 times roller passes was implemented on the sub grade. Figure 6 shows the diagram of load-deformation in this case.

The equation related to the load- displacement can be derived as follows:

$$p = -0.0009d^2 + 0.28d - 1.536 \qquad R^2 = 0.976 \tag{2}$$

In this equation, p is value of load in terms of ton and d is vertical displacement of embankment. Figure 7 shows the form of embankment mixed with 10 percent shred tires before and after failure.

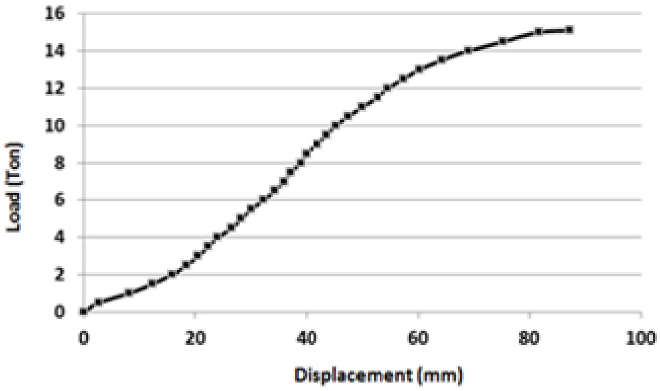

Figure 6 Load-displacement for soil with 10 percent shred tires.

A. Before failure B. After failure

Figure 7 Embankment mixed with 10 percent shred tires.

Loading test on embankment including shred tires as core

In this test, the embankment including shred tires as core with maximum compaction in 5 layers of 10cm and optimum humidity of 6.82 percent per 30 times pass a roller on the sub grade was carried out. Because of the absence of a suitable standard for determining the geometry of the shred tires as core of embankment, many numerical analyses were performed by finite element method with Plaxis 2D. Specifications of embankment model are presented in Table 2. Because of shred tires presence in core of embankment, a geotextiles layer was used for wrapping the shred tires. Table 3 shows the characteristics of geotextiles used in laboratory.

Table 2 Specifications of embankment model

Parameters	Type/Value
Model element	Plane strain
Model behavior	Mohr-Coulomb
Load	10 ton/m
Embankment width	2.5m
Embankment height	1.2m
Embankment slope	1:2
Embankment crest	70cm

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Table 3 Characteristics of geotextiles

Properties	Strength of tensional	Length increasing	Thickness	Standard
Values	16.6KN/m	50% >	3.5mm	ASTM D4595[13]

According to time consuming of loading tests on the embankment with different cores Figure 8, a series of numerical analysis were performed by using Plaxis 2D software and failure loads were calculated. After modelling in software and applying boundary conditions, the load incrementally is applied on the crest of the embankment until it failed. Figure 9 shows embankment failure for case B. The failure load and embankment settlement for four cores mentioned in Figure 8 are presented in Table 4.

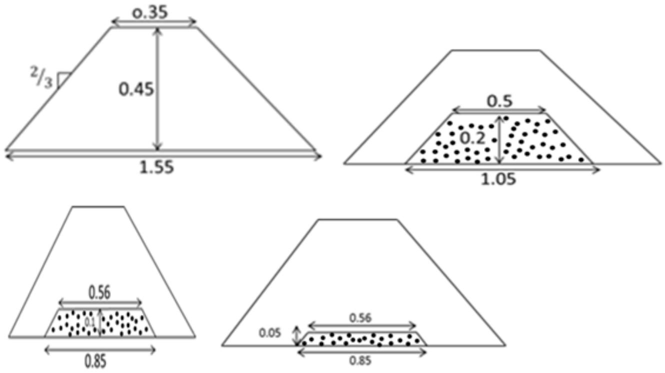

Figure 8 Different geometries for shred tires as core of embankment.

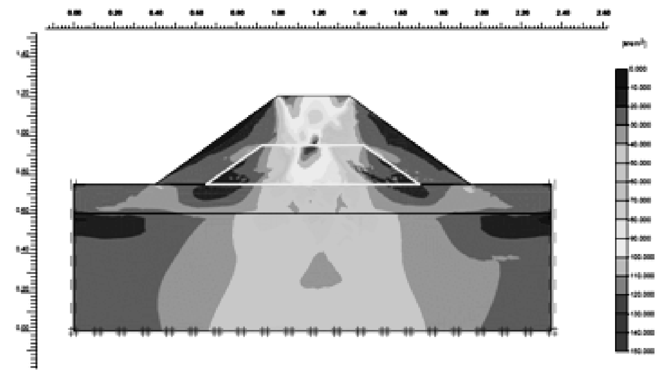

Figure 9 Stress on embankment with core of shred tires (Case B).

Comparing the outputs of the case (A) with the obtained results from three last conditions indicates an increase of shred tires with respect to the first case, and so choosing a suitable geometry is important. According to obtained results for four cores, load ratio obtained for cases of (B), (C) and (D) were 0.89, 0.91 and 0.92. It was concluded that the case (B) has the most shred tires and it bears a greater load, so it was chosen for test in the laboratory. In this test, the force was applied by jack to the beam and the crest of the embankment. During the test, the applied force increased with relatively constant speed. Steps of loading were 0.25tons and they increased until the embankment failed. Finally, the embankment failed in load of 11.9tons and settlement of 7.6cm. Figure 10 shows the load– deformation for embankment with core of shred tires.

Table 4 Load-settlement for various cases

Case	The volume of the shred tires (m^3)	Load (ton)	settlement (m)
A	-	17.84	0.059
B	0. 37	16. 01	0.0573
C	0. 17	16. 2	0.0556
D	0. 072	16. 5	0.0509

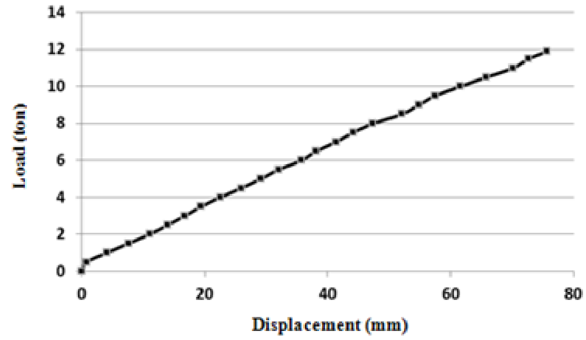

Figure 10 Load-displacement for embankment with core of shred tires.

As can be observed, the graph is almost linear; therefore it can be expressed by the following mathematical equation:

$$p = 0.1763d + 0.1623 \qquad R^2 = 0.99 \tag{3}$$

So in above equation, p is value of load in terms of ton and d is vertical displacement (settlement) in terms of mm. Figure 11 illustrates the form of embankment with core of shred tires before and after failure. Figure 11 Embankment mixed with core of shred tires

A. Before failure B. After failure

Figure 11 Embankment mixed with core of shred tires.

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Conclusion

In the current paper, a series of experiments such as compaction, CBR and plate loading tests have been done on GW-GC soil as materials of railways embankment with different percents of shred tires. For plate loading test (PLT), mixture of soil with shred tires were compacted in chamber box. In another part of this study, three embankments without shred tires, mixed with 10 percent shred tires and shred tires as a core were constructed in the chamber box by scale of 1:15 and then the behaviour of their load - displacement were investigated. The main results of the current study are summarized as follows.

I. Based on the achieved elasticity modulus in the second cycle of loading in plate loading tests, value of shred tires for use in sub grade should be 10 percent.

II. The mathematical equation between load and displacement of embankment without shred tires is nonlinear as $p=-0.0018d^2+0.39d-0.805$.

III. The mathematical equation between load and displacement of embankment with 10 percent shred tires is nonlinear as $p=-0.0009d^2+0.28d-1.536$.

IV. The mathematical equation between load and displacement of embankment with core of shred tires is almost linear as $p=0.1763d+0.1623$.

V. Adding 10 percent of shred tires to embankment cause to decrease failure load and settlement 24.78 and 17.21 percent respectively. These values for the embankment with shred tires as core were 40.8 and 28 percent respect to embankment without shred tires respectively.

Acknowledgements

None.

Conflict of interest

The author declares no conflict of interest.

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