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Laboratory investigation on the effect of waste plastic bottles filled with soil as transverse members on pullout resistance of steel strip for reinforcement fine sand

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Abstract: The aim of this study is to investigate the feasibility of utilizing the waste plastic bottles filled with soil as the transverse element attached to the steel stripe in the Mechanically Stabilized Earth Walls (MSEWs). Transverse members of reinforcement have a major effect on increasing the pullout resistance. This system is comprised of a steel stripe as a longitudinal member and waste plastic bottles filled with soil as transverse members attached to it. To understand this, pullout tests were conducted on one steel strip and seven steel stripes with one to seven bottles. More than 18 laboratory large-scale pullout tests (i.e. length1.20 m, width 0.6 m, and height 1 m) under different normal stresses were conducted to evaluate the performance of the newly suggested reinforcement element. The results showed that creating a third dimension on a flat steel strip has a great effect on increasing the pullout resistance, the most efficient adding four transverse members to the steel strip with the ratio of distance to diameter (S/D) equal to 3, that the pullout resistance was to average about 5 times greater than the steel strip alone. The ultimate pullout resistance for steel strips with transverse members and without transverse members increased by increased vertical stress.

Keywords: pullout resistance: transverse members: waste plastic bottles: reinforcement soil: pullout test

1 Introduction

Increasing use of mechanical stabilized earth and reinforced soil in the world are developing. The modern method for reinforcing soil was invented by French engineer Henri Vidal in the 1 960 s. The application of modern methods for reinforcing soil for the construction of earth retaining walls, embankments, and slopes has raised the need to evaluate the reinforcement interaction parameters. The soil reinforcement method is one of the branches of Geotechnical Science that use appropriate materials and materials in soil reinforcement with scientific principles and use new technologies.

Bergado et al.[1] results of the study, steel grid for soil reinforcement show that the major contribution to the pullout resistance of grid reinforcements consists of the passive resistance mobilized in front of the transverse members. The results of the study by Horpibulsuk et al[2] on pullout resistance of bearing reinforcement embedded in sand show that the length of the transverse member does not play any significant role in the interference factor.

The results of the study, loads in steel strip soil reinforced by Miyata et al[3] show that many walls have been built steel strip reinforced soil successfully in Japan with cohesive-frictional soils with higher fine contents, and friction angles are less than 35°. The results of the study by Suksiripattanapong et al.[4] on pullout resistance of bearing reinforcement embedded in coarse-grained soils have show that the pullout friction resistance of the bearing reinforcement is mainly controlled by only the angle of internal friction of soil. That is regardless of distribution grain size soil.

Lajevardi et al.[5] have shown that with increased vertical stress on welded steel mesh in the pullout tests, the value of the apparent friction coefficient decreases. Alam et al.[6] studied the pullout behavior of soil reinforcement with steel grid, has shown that soil in the influence zone in front of the bearing members was subject to high strain and in the strain-softening phase of its behavior. The results of the study by Han et al.[7] on the pullout resistance of smooth steel strip reinforcement with transverse members show that the bearing resistance of the improved reinforcement was about 33%–66% of the total pullout resistance. Also, the bearing bond coefficient, considering the interference effect, gradually converged when normal stress was higher than a certain value. The results of the study by

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Ćwirko et al[8] on the behaviour of the steel welded grid during a simplified pullout test in fine sand showed that the low deformability (hence greater stiffness) of the tensile welded meshes embedded in the soil allows them to be used for soil reinforcement in all types of reinforced soil structures. The study of pullout resistance of metal reinforcements has been studied by various researchers[9−17]. The results of study by Qing et al.[18] show that with the earth pressure on reinforced retaining wall back gradually changes from linear distribution to nonlinear distribution. The results of study by Sukmak et al.[19] on pullout resistance in cohesive–frictional soils show that the use of locally available soils as backfill is particularly cost-effective for construction sites where there is a lack of available quality materials. The results study Horpibulsuk et al.[20] show that the friction pullout resistance of red clay is lower than that of the claystone. Xiao et al.[21] showed that the retaining wall compressions increase gradually with the increased time, especially in the first 50 days, then the increase rates gradually decrease.

According to Reuters (2018), in a single year, 481.6 billion bottles were used worldwide. This will increase to 583.3 billion bottles, according to the most up-to-date estimates 2021, from Euro monitor International's Global Packaging Trends report. In the recent few years, due to the prevalence of COVID-19, the production and use of PET (polyethylene terephthalate) bottles for hygienic materials and disinfectants have increased considerably.

The use of PET bottle plastics to improve soil mechanical properties has been studied by many researchers. Nadaf et al.[22] studied the use of fly ash as backfill material in slopes using waste PET bottles as reinforcement and proposed to use fly ash-filled waste plastic PET bottles for slope reinforcement. Farah et al[23] used plastic wastes for soil improvement and showed that such technique led to enhance the shear strength and California Bearing Ratio (CBR) of reinforced sand. Moghaddas et al.[24] performed tests on disposable waste bottles filled with soil for improving footing bearing capacity. The results show that the use of such soil-filled bottles as a reinforced bed is highly rigid, delivering very high bearing capacities at small soil displacements. Most research studies in the past focused on using crushed disposable bottle chips mixed with soil to strengthen the ground. Therefore, the use of bottles filled with soil is a relatively new idea to strengthen steel strips and reinforce soil for increasing pullout resistance. The current study has been performed to evaluate the pullout performance of the bottles filled with soil attach to steel strip as transverse members[25–31].

In most of the research literature, the granular soil used for backfill in soil structures are usually not at the project site and they must be transported from another location to the project site, which is costly and uneconomical. Therefore, it is necessary to evaluate the solutions that cause the existing soils in the project site to be used for the implementation of reinforced soil structures.

The aim of reinforced soil is the improvement of the tensile properties of soil with frictional effects of reinforcement for soil strengthener. In this study, the frictional effects of steel strips inside of soil and the passive resistance of soil to the displacement of transverse members attached to steel strips are investigated for improving the tensile properties of soil. The steel strip is inextensible material for reinforced soil. The steel strip for reinforcement soil is conveniently transported, and rapidly installed on the wall facing, however the function is frictional and needs to be strengthening by transverse members. Thus, understanding the pullout resistance mechanism of waste plastic bottles filled with soil as transverse members attached to steel stripe reinforcement under various conditions of vertical stress in fine sand backfills is fundamental for the design and construction of soil reinforce structures at a reasonable cost. This study aims to evaluate the pullout resistance mechanism of bearing reinforcement in fine sand soils by pullout test. This study also seeks to offer pullout resistance equations in laboratory conditions.

2 Materials

2.1 Soil

The soil used in this research is fine-grained silica sand with an average particle size of 0.22 mm. This was fine sand soil with fine particles less than 2%. The soil granulation curve used is shown in Fig.1. The soil properties used presented in Table 1.

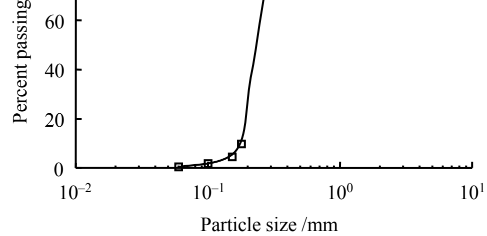

Fig. 1 Grain size distribution of fine sand soil

Table 1 Soil characteristics

D_{10} /mm	D_{30} /mm	D_{60} /mm	Uniformity coefficient C_u	Curvature coefficient C_c	Specific gravity G_s	Relative density D_r /%	Friction angle (φ) at D_r=80% /(°)	Sand-geogrid interface angle (δ) for sand at D_r=80%/(°)	Max. dry unit weight γ_{dmax} /(kg • m^{-3})	Min. dry unit weight γ_{dmin} /(kg • m^{-3})	Dry unit weight γ_d /(kg • m^{-3})
0.17	0.18	0.24	1.4	0.8	2.67	80	35	22	1 616	1 400	1 570

Note: D_{10}, D_{30}, D_{60} are the size at 10%, 50% and 60% finer by weight respectively.

2.2 Reinforcement

In this research, one type of steel strip and seven steel strips with transverse members were used as reinforcement. Dimensions of steel strip: length 125 cm, width 5 cm, and thickness 0.5 cm. Steel strips (ST 37) are made of construction steels that have good ability welding due to their low carbon content. Also, at least yield strength is about 235 MPa and its tensile strength is about 360 MPa.

2.3 Disposable waste bottles (PET)

Recycled plastic bottles with a length of 200 mm and a diameter of 54 mm were used, which were usually used as small bottles. The bottles were made of polyethylene terephthalate (PET). PET is a clear, strong, and lightweight plastic that is widely used for packaging foods and beverages, especially convenience-sized soft drinks, juices and water. The bottle filled with soil under compressive force in the pressure device and two bottles filled with soil shown in Fig. 2. The mass of the empty bottle was 20 grams and the mass of the bottle filled with soil is 570 grams.

Fig. 2 The bottle filled with soil under compressive force in the pressure device and two bottles filled with soil

The results of compression tests on bottles showed that a bottle, filled with soil deformed by 15 mm could withstand 100 kN vertical load (Fig.3). The soil-filled closed-lid bottle has slight deformation under the vertical loading, and even if it was damaged during testing, it would be deformed slightly under the vertical pressure. During the pullout test, the bottles attached to the steel strip are subjected to vertical stress. Therefore, in this study, soil-filled recycled bottles were used as transverse members for strengthening the steel strip.

2.4 The new system for reinforcement soil

This study introduces a new system for reinforced soil called steel strip-bottle. This system comprised a steel stripe as a longitudinal member and waste plastic bottles filled with soil as transverse members attached. to it. Creating the third dimension by adding transverse

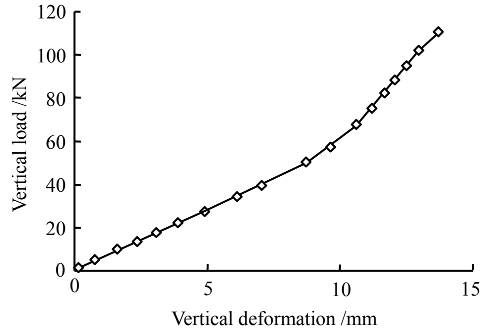

Fig. 3 Variation of load-deformation of a soil-filled closed-lid bottle

members to the steel strip, were an effective way to improve the interaction between steel strips and soil. The length of the embedded steel strip reinforcement was set as 100 cm. In this study, the studs have a diameter of 20 mm and a height of 60 mm. The stud connectors are components used to ensure proper shear transfer between steel girders and composite slab, and made of stainless steel. The studs welding to steel strip for support base holds up of waste plastic bottles filled with soil (transverse members) on surface of steel strip. The components of the system are shown in Fig.4. These studs can be welded to steel strip at high speed and have the high strength. The yield strength is about 350 MPa and its tensile strength is about 450 MPa. This new reinforcement has two advantages, steel strip and transverse member for reinforcement soil, which enables simple and rapid installation with a high pullout resistance. The steel strip reinforcement is conveniently transported and rapidly installed on the wall facing, however, it is the pullout force of only includes frictional effects between soil and steel strip surfaces. The steel strip with waste plastic bottles filled with soil as transverse members have both frictional resistance and bearing resistance. In fact, it has a very high pullout bearing resistance because of the reinforced steel strip with transverse members. The steel strip-bottle reinforcement system introduced in this

Fig. 4 The bottle filled with soil, two steel strips, and a stud

research can be a cost-effective soil reinforcement. This new reinforcement system can be widely used for reinforcement soil projects.

3 Testing equipment

3.1 Test device

The box of the pullout device having dimensions, length 120 cm, width 60 cm, and height 100 cm was designed and manufactured, and used for tests. The device had a capacity of digital command and PC for data acquisition. The device was manufactured for performing pullout tests that conform to the standard recommendations ASTM D6706-01[32] and EN 00189016[33]. Large-scale pullout device components include the following components: 1. pullout box, 2. 8 reaction arms, 3. keeper, jack, and load cell, 4. LVDT, 5. clamp, 6. load cell, 7. the hydraulic jack, that shown in Fig.5.

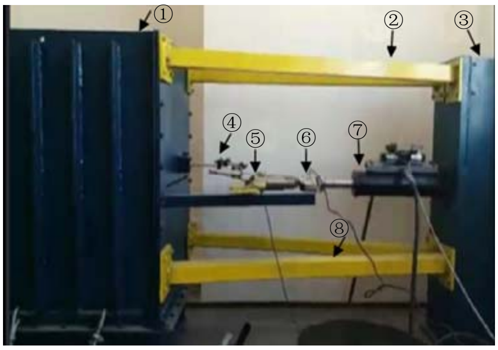

Fig. 5 Large-scale pullout test device

A hydraulic jack was used for applying the horizontal pullout force on steel strip buried in the soil box. This force was transferred to the reinforcement head by the clamp and encapsulated steel strip was being pulled out under tension. A load cell and a LVDT were used to measure the pullout force and horizontal displacement of steel strip during the tests, respectively.

Figure 6 shows the sleeve with dimensions of 60 cm×20 cm×1 cm inside the box, the gap sleeve is 1.6 cm. a clamping system is outside the box. A gap is created with dimensions of 60.0 cm×1.6 cm along the front side of the box to connect the steel strip to the clamp after passing the gap. To prevent the outflow of soil particles from the gap during the pullout test, all voids between the steel strip and gap are covered with cotton. The vertical force is applied using an airbag. The airbag pressure is supplied by the air compressor. S is the distance between the bottles, T is the direction of the pullout force.

ASTM D6706 recommends that the minimum distance between the reinforcement and the wall is at least 150 mm. The effects of wall friction can be avoided. In this paper, considering that the proposed reinforcement is of the strip system type and the minimum mentioned distances are satisfied.

In order to minimize the friction effects of the front wall, the sleeve according to the ASTM D6706 standard has been used.

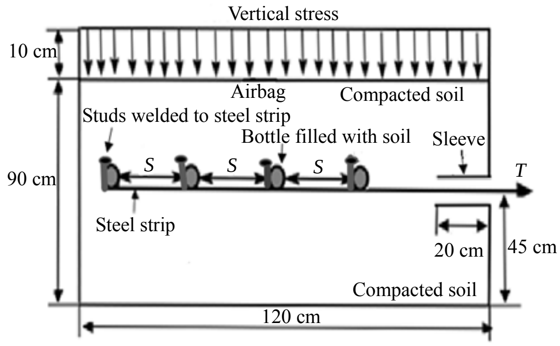

Fig. 6 Schematic view of pullout test box, steel strip, and bottles filled with soil (Not in scale)

3.2 Test procedure

The relative density of soil samples in all laboratory tests was 80%. The thickness of each soil layer was 15 cm layer. Each layer of soil was compacted by four blows of a 0.07 kN steel hand hammer that dropped from a height of 30 cm and was used in the method of a center to center for compaction soil. After pouring the three layers of soil and compacting, the steel strip or steel strip with waste plastic bottles filled with soil was positioned on the soil and connected to the clamp. Then, the next layers of soil were poured over the reinforcement, compacting with a steel hand hammer, and the box was filled with soil to the height of 90 cm. To ensure uniform compaction in different layers, cans of specified weight had been used. After complete sampling, the cans were carefully pulled out and weighed. This had been repeated several times to make sure. After that, a rigid steel plate was positioned on the soil under the airbag. Then an airbag was placed and the door of the box was closed. The air pressure inside the airbag was supplied by the air compressor. This compressor was equipped with a pressure regulator to contain the constant vertical stress during the tests. The horizontal force was applied with a constant displacement rate of 1 mm/min, as recommended by ASTM D5321[34]. In this study, the number of transverse members, N, was 1 to 7. The pullout friction resistance of the steel strip as the longitudinal member was investigated from the pullout test on a single steel strip. The length of the embedded reinforcement was settled down of 100 cm with a width of 5 cm inside the soil compacted in the pullout box.

3.3 Calibration of the device for pullout test

To ensure the test results repeatability, three similar pullout tests on steel strip were performed at the same conditions and the results were in good agreement, demonstrating reasonable repeatability.

4 Results and discussion

4.1 Theory of interaction soil–steel strip with and without transverse members

The pullout response of a steel strip is skin friction. Pullout force is defined as the sum of force friction on both sides of the steel strip. The maximum pullout force can be presented by the following equation:

$$P_{\mathrm{f}} = 2\sigma_{\mathrm{n}} WL \tan\delta \tag{1}$$

where P_{f} is the pullout force (kN), in Eq. (1) is the number 2 for calculating friction two surfaces of steel strip; σ_{n} is the normal stress (kPa); L is the reinforcement length inside of the soil; W is the width of steel strip and δ is the skin friction angle between the reinforcement and the soil in degrees.

The increase in the length of the reinforcement is one of the methods to increase the pullout resistance. But the important point is that today reinforced soil walls are built in urban areas, which due to space limitations cannot possibly increase in reinforcement length, so the steel strip with transverse members can be a suitable solution for increasing the pullout resistance. The pullout response of a steel strip with transverse members includes two components: first bearing resistance and second skin friction.

The transverse members are waste plastic bottles filled with soil that provide high pullout bearing resistance. The passive resistance is due to the soil bearing on the transverse members of the steel strip. Effective factors for mobilizer of pullout resistance of transverse members include the number of transverse members, the distance between the transverse members, vertical stress, length and diameter of the bottles, and the ratio of space between bottles to the diameter of the bottles (S/D).

One of the most important parameters playing an essential role in the resistance to pull out the reinforcement is the passive resistance of the transversal members. Predicting the passive resistance of transverse members attached to reinforcements has been one of the topics of interest for various researchers. The bearing resistance (P_{b}) of the transverse members is a problem which is similar bearing capacity of the shallow foundation in soil and which can be evaluated based on bearing capacity equations of Terzaghi.

There are analytical formulations already available to estimate the tensile bearing strength in different types of transverse members in the pullout test. Mechanisms of failure are different which include a general shear failure, a punching shear failure, and a modified punching failure. Several researchers have presented different equations to evaluate the mechanisms of a pullout based on the failure bearing. The passive resistance in the transverse members attached to the steel strip is calculated as follows. The maximum passive force (P_{b}) can be presented by the following equation:

$$P_{\mathrm{b}} = NDL\sigma_{\mathrm{n}} N_{\mathrm{q}} \tag{2}$$

where D is the diameter or height of transverse members; L is the length of transverse members and N_{q} is the bearing capacity factor.

Sukmak at el. [35] reported the mechanism of general shear failure mode as follow

Model: 1

$$N_{\mathrm{q}} = \tan^2\left(\frac{\pi}{4} + \frac{\varphi}{2}\right)\exp[\pi\tan\varphi] \tag{3}$$

where φ is the peak friction angle of the soil.

Jewell et al. [36] found that the punching shear failure mechanism can be expressed as follow

Model: 2

$$N_{\mathrm{q}} = \tan\left(\frac{\pi}{4} + \frac{\varphi}{2}\right)\exp\left[\left(\frac{\pi}{2} + \varphi\right)\tan\varphi\right] \tag{4}$$

Values of N_{q} from equations 3 and 4 are equal to 33 and 8.8 respectively. Given that the value of N_{q} depends only on the angle of soil friction, Yu et al[37] have proposed the hybrid failure mechanism. The bearing capacity (resistance) factor N_{q} is calculated as follow.

Model: 3

$$N_{\mathrm{q}} = 43\left(\frac{N\sigma_{\mathrm{n}}}{P_{\mathrm{a}}}\right)^{-0.5} \tag{5}$$

where P_{a} is the atmospheric pressure. It equals to 101 kPa.

In Eq. 5, the value of N_{q} depends on the vertical stress and the number of transverse members, which N_{q} decreases with increasing the number of transverse members and the vertical stress. In this study, N_{q} under vertical stress of 100 kPa is as follows, the maximum N_{q} for transverse member N = 1 is 43.0 and the lowest N_{q} for transverse members N = 7 is 16.3.

To determine the pullout force of transverse members, the total pullout force of the steel strip with transverse members is minus from the pullout force of the steel strip alone. The maximum passive force for the four transverse members is attached to the steel strip, which is compared in Table 2 with the three rupture models.

According to the values of the maximum passive force of the transverse members measured in table 2 in the case of four members, it is consistent with the general shear model 2.

Table 2 Maximum pullout bearing passive force in different cases of rupture model

Type	Bearing capacity factor N_q	Maximum passive force P_b /kN
Experimental	–	36.4
Model 1	33.0	132.0
Model 2	8.8	35.2
Model 3	21.6	86.4

4.2 Pullout force of the reinforcements

In this study, pullout tests were carried out on flat steel strips with and without transverse members. Tests were performed under three vertical stresses equal to 50, 75, and 100 kPa, representing the overburden pressure at the reinforcement embedment depths of 3.2, 4.8, and 6.4 m in the mechanically stabilized earth walls (MSEWs). In all pullout tests when the displacement of reinforcement was 50 mm, the test ended. Because after reinforcement element displacement is about 50 mm, the process of changing the pullout force becomes uniform.

The results of the experiments performed on steel strips are presented in Fig.7. The steel strip has a very high tensile strength in the pullout test, for all vertical stress applied to the steel strip. in the pullout test, the frictional resistance reached its maximum value at a displacement was about 3 mm. And after the pullout resistance reached the maximum value in a small displacement, its pullout resistance gradually decreases with more pullout displacement of the steel strip inside the soil.

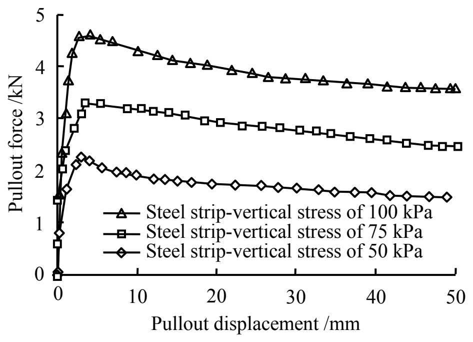

Fig. 7 Pullout force-pullout displacement curves for steel strip under different vertical stress

As such the situation above is for all three vertical stresses. The difference between peak strength and residual strength is significant. P_{Rmax} is the maximum pullout force and f^* is apparent friction. The summary of the pullout test results, on the steel strip, is prov in Table 3.

Table 3 Summary of the pullout test results for steel strip

Type of reinforcement	σ_n /kPa	Front displacement /mm	P_{Rmax} /kN	f^*
Steel strip	50	3.0	2.2	0.4
	75	3.4	3.3	0.4
	100	4.0	4.6	0.4

The results show that displacement after peak resistance is slightly affected by vertical stress. The results in Fig.8 show that the shear stress between soil particles is higher than the shear stress between soil and steel strips. Due to the fact that the surface of steel strips is smooth, it causes less friction between the soil and the steel strip is less than the internal friction angle of the soil. Soil shear strength can be calculated by

$$T_{\mathrm{f}} = \sigma_{\mathrm{n}} \tan 35 \qquad (6)$$

where T_{f} is the shear stress (kPa).

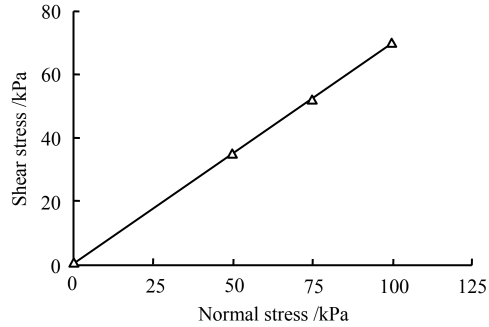

Fig. 8 Shear strength of soil under three normal stresses of 50, 75 and 100 kPa

Therefore, to improve the pullout resistance of steel strips can be transverse members attached to the steel strip. This method increases the pullout resistance of steel strips. This way strengthens the steel strip. This study introduces a new system for reinforced soil that is cost-effective. Plastic waste bottles filled with soil as transverse members were attached to the steel strip to increase its pullout resistance. In this study, the number of transverse members, *N*, was 1 to 7. Steel strip-*N*1 in this situation, the transverse member was attached to the end of the steel strip. Steel strip-*N*2 in this situation; one transverse member was attached to the end and the second at a distance of 15 cm sleeve attached to steel strip and the distance between the transverse members is 60 cm. Steel strip-*N*3 in this situation, three transverse members were attached to the steel strip and the distance between the transverse members is 25 cm. Steel strip-*N*4 in this situation, four transverse members were attached to the steel strip and the distance between the transverse members is 15 cm. The evaluation of the pullout resistance mechanism of bearing reinforcement in fine sand soil was by pullout test.

The results of the experiments performed on the transverse members that attached to steel strip, are shown in Fig. 9. These tests were accomplished under vertical stress of 50 kPa.

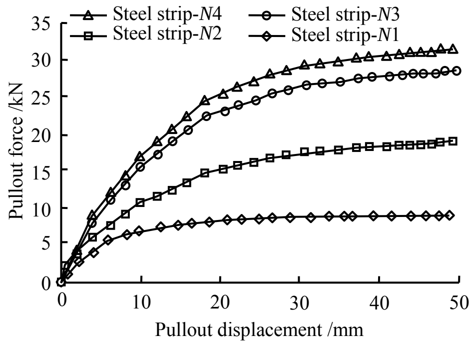

Fig. 9 Pullout force- pullout displacement curves for steel strip with transverse members (N=1 to 4) under vertical stress 50 kPa

In the evaluation of pullout resistance of steel strips with transverse members, the total pullout force is commonly calculated as a sum of the bearing resistance of the transverse members and the friction between steel strip surface and soil. The results of the experiments performed on the transverse members attach to steel strip under the vertical stress of 75 kPa are shown in Fig.10.

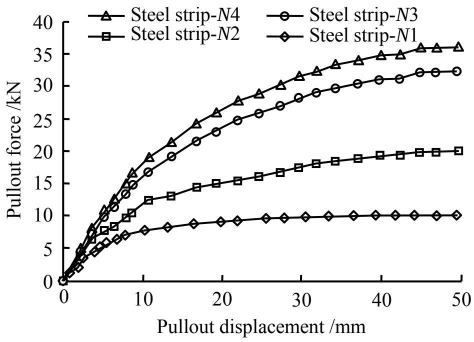

Fig. 10 Pullout force-pullout displacement curves for steel strip with transverse members (N=1 to 4) under vertical stress 75 kPa

The results show that by increasing the pullout displacement, the resistance of the transverse members is activated, and by increasing transverse members attached to the steel strip, the amount of pullout force increases. The transverse members increase bearing resistance which increases the improvement of interaction soil- steel strips with transverse members. To mobilize the maximum pullout resistance of the new system in compared to the steel strip alone more displacement is needed. This shows that the soil around the bottles filled with soil attached to the steel strip during the pullout tests is located under great stress. The results of the experiments performed on the transverse members attached to steel strip under the vertical stress of 100 kPa are shown in Fig.11.

The bearing resistance of soil in front of the displacement of transverse members major effects on increasing pullout resistance in the pullout test. The maximum bearing resistance of transverse members is mobilized with increasing displacement. The results show that with the start of the pullout test, the amount of pullout force increases sharply with displacement and then gradually increases until the displacement reaches 50 mm. When displacement is more than 50 mm, the pullout force decreases gradually and then begins to decrease gradually the pullout force with more increased displacement, which is the end of the experiment. The results in Fig. 12 show that with the increasing number of transverse members, the distance between the transverse members decreases and the interference effect of the pullout resistance is slightly reduced.

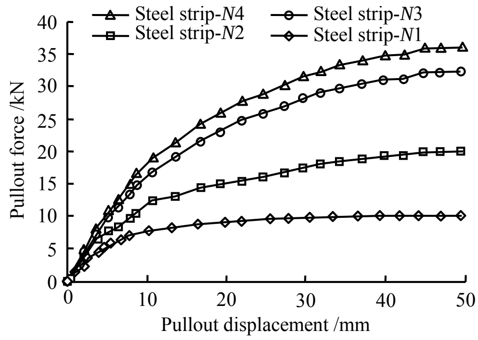

Fig. 11 Pullout force-pullout displacement curves for steel strip with transverse members (N=1 to 4) under vertical stress 100 kPa

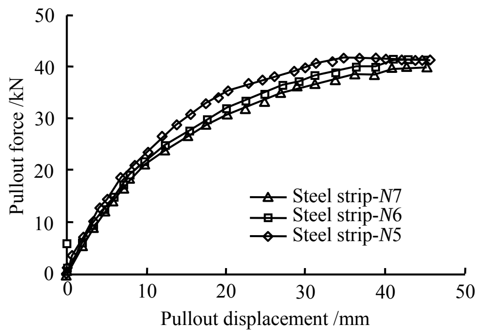

Fig. 12 Pullout force-pullout displacement curves for steel strip with transverse members (N=5, 6 and 7) under vertical stress 100 kPa

With increasing vertical stress and the number of transverse members attached to the steel strip, the interference effect on reducing the pullout strength increases. The pullout resistance of the steel strip with four transverse members is higher than that of the steel strip with the amount of 5, 6, and 7 transverse members. The results show in Fig. 9 that the pullout force of transverse members by increasing the number of transverse members higher than four transverse members due to the interference effect has no effect on increase pullout resistance or has a little increment which can be ignored. As a result, attached 4 transverse members on steel strip with a ratio of S/D=3 under three vertical stresses of 50, 75 and 100 kPa is optimal. Summary of the pullout test results on steel strip-bottles is provided in Table 4. In the design for adding transverse members to steel strips, according to the allowable amount of displacement of the reinforced soil mass, spaced between transverse members, should be more than S/D=3 that the effect of interference doesn't reduce pullout resistance.

Table 4 Summary of the pullout test results for steel strip-*N*

Type of reinforcement	Space between transverse members(S) /mm	σ_n /kPa	Front displacement /mm	P_{Rmax} /kN	f^*
Steel strip-*N*1	0	50	47	9.0	1.80
		75	50	10.0	1.30
		100	50	11.5	1.15
Steel strip-*N*2	610	50	47	18.0	3.60
		75	50	20.0	2.70
		100	50	24.0	2.40
Steel strip-*N*3	270	50	49	28.0	5.60
		75	50	33.0	4.40
		100	50	34.0	3.40
Steel strip-*N*4	150	50	49	31.0	6.20
		75	50	36.0	4.80
		100	50	41.0	4.10
Steel strip-*N*5	100	100	50	41.5	4.15
Steel strip-*N*6	66	100	50	41.2	4.12
Steel strip-*N*7	52	100	50	40.6	4.06

4.3 Interference effect in transverse members

Evaluating the interaction of soil and transverse members attached to steel strips is essential for achieving an improved and cost-effective design in soil reinforcement structures. In order to find the optimal distance between the transverse members attached to the steel strip, samples with one to seven transverse members are used. The interference between transverse members occurs when the movement of each transverse member under pullout condition, a low-stress area (softened area) is created behind it. When the next transverse member enters this area, its resistance decreases finally. In the low-stressed zone, the amount of frictional force at the steel strip-soil interface also decreases. A schematic view of the interference effect of transverse bottles attached to the steel strip is shown in Fig.13. In the new system, when one to four transverse members are displaced, a low-stressed area is created behind the transverse bottles, the distance between the bottles is greater than the length of the low-stressed area. The transverse members do not enter the low-stressed area and the effect of the interference has no effect on pullout resistance.

For transverse members $N = 5$ to 7 which attached to steel strip, despite the increase in the number of transverse members, the pullout resistance does not increase due to the phenomenon of interference. There is optimal space between the transverse members attached to the steel strip, which in this distance, is the most effective pullout resistance occurs under any vertical stress. According to the allowable amount of reinforcement displacement in the structures that reinforce soil, there is an optimal distance between the transverse members, at which distance, S/D is optimal and has the lowest interference effect. In this study S is the distance between the transverse members and D is the diameter of the bottle attached to steel strip.

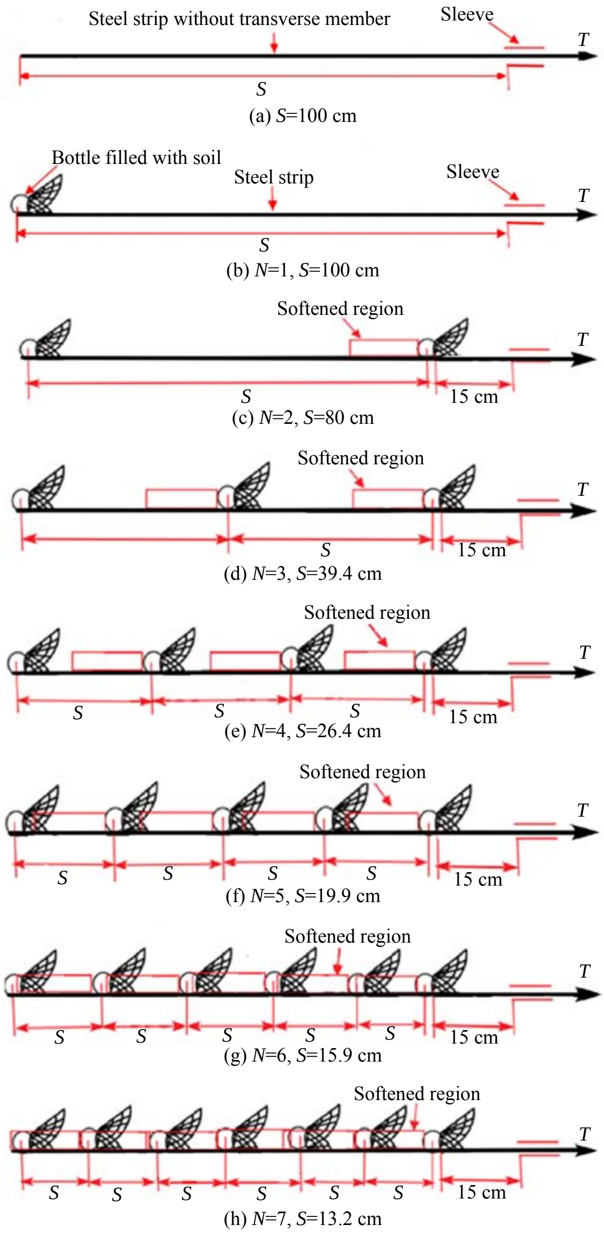

Fig. 13 Schematic view of steel strip with and without transverse members and the effect of the interference

5 Discussion

Due to the availability of fine-grained soils, the use of fine sand may be more cost-effective than coarse sand. Therefore, it is necessary to study the reinforced soil systems that are composed of fine sand and provide solutions that compensate for the weaknesses of fine-grained soils and is used for reinforced soil projects as fillers material. The purpose of this study is to evaluate the pullout resistance of steel strips with attached waste plastic bottles filled with soil as transverse members. With attached transverse members on steel strips, pullout resistance is found to increase generally. By increasing the number of plastic bottles filled with soil to the optimal number, the amount of pullout resistance increases. The influence of parameters such as the number of transverse members, vertical stress, and distance between transverse members on the pullout response of steel stripe is investigated by the large-scale pullout test. To increase pullout resistance, one method is to increase the length of the steel strip or to strengthen the steel strip by adding transverse members on it. Considering the proof of the effectiveness of the system introduced in this study, its use in practice is recommended. The system introduced in this study can be used to create reinforced soil structures in urban places which have limited space. In this study, the followings, easy and fast installation, convenient transportation, available raw materials and high resistance to pullout are considered by using the suggested system for reinforced soil which is economically viable.

6 Conclusions

(1) The test results showed that the use of waste plastic bottles filled with soil as transverse members attached to the steel strip for reinforcement of the steel strip cause a very much increased a lot amount of pullout force compared to steel strips alone. The pullout resistance was to average about 5 times greater than the steel strip alone.

(2) Adding four transverse members to the steel strip with the ratio of distance to diameter (S/D) equal to 3 has the most efficiency.

(3) The results show by the increase in the number of transverse members to 5, 6, and 7, the pullout forces are not different. By reducing the space between the transverse members, the interference effect causes the pullout resistance not to increase.

(4) The parameter that affects the apparent friction is the number of transverse members, with increasing the number of transverse members attached to the steel strip with no effect of vertical stress, the amount of coefficient of apparent friction increased.

(5) The necessary length of the reinforcement to withstand a certain tensile force in steel strips with transverse members is less than the required length for steel strips alone. Therefore, this system is more efficient and its application in practice may be economical.

(6) Increasing vertical stress under the same condition, the amount of apparent friction coefficient decreases.

(7) The ultimate pullout resistance for steel strips with transverse members increases by increased vertical stress.

References

[1] BERGADO D T, MACATOL K C, AMIN N U, et al. Interaction of lateritic soil and steel grid reinforcement[J]. Canadian Geotechnical Journal, 1993, 30(2): 376–384.

[2] HORPIBULSUK S, NIRAMITKORNBUREE A. Pullout resistance of bearing reinforcement embedded in sand[J]. Soils and Foundations, 2010, 50(2): 215–226.

[3] MIYATA Y, BATHURST R J. Measured and predicted loads in steel strip reinforced c-φ soil walls in Japan[J]. Soils and Foundations, 2012, 52(1): 1–17.

[4] SUKSIRIPATTANAPONG C, HORPIBULSUK S, CHINKULKIJNIWAT A, et al. Pullout resistance of bearing reinforcement embedded in coarse-grained soils[J]. Geotextiles and Geomembranes, 2013, 36: 44–54.

[5] LAJEVARDI S H, DIAS D, RACINAIS J. Analysis of soil-welded steel mesh reinforcement interface interaction by pull-out tests[J]. Geotextiles and Geomembranes, 2013, 40: 48–57.

[6] ALAM M J I, LO S R, KARIM M R. Pull-out behaviour of steel grid soil reinforcement embedded in silty sand[J]. Computers and Geotechnics, 2014, 56: 216-226.

[7] HAN J G, LEE K W, LEE J Y, et al. Experimental study on the pullout resistance of smooth steel strip reinforcement with transverse members[J]. Applied Sciences, 2021, 11(6): 2776.

[8] ĆWIRKO M, JASTRZĘBSKA M. Behaviour of the steel welded grid during a simplified pullout test in fine sand[J]. Applied Sciences, 2021, 11(19): 9147.

[9] BERGADO D T, LO K H, CHAI J C, et al. Pullout tests using steel grid reinforcements with low-quality backfill[J]. Journal of Geotechnical Engineering, 1992, 118(7): 1047–1062.

[10] BERGADO D T, CHAI J C, MIURA N. Prediction of pullout resistance and pullout force-displacement relationship for inextensible grid reinforcements[J]. Soils and Foundations, 1996, 36(4): 11–22.

[11] TIN N, BERGADO D T, ANDERSON L R, et al. Factors affecting kinked steel grid reinforcement in MSE

structures[J]. Geotextiles and Geomembranes, 2011, 29(2): 172–180.

[12] BATHURST R J, HUANG B, ALLEN T M. Load and resistance factor design (LRFD) calibration for steel grid reinforced soil walls[J]. Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards, 2011, 5(3-4): 218–228.

[13] BATHURST R J, NERNHEIM A, ALLEN T M. Predicted loads in steel reinforced soil walls using the AASHTO simplified method[J]. Journal of Geotechnical and Geoenvironmental Engineering, 2009, 135(2): 177–184.

[14] ESFANDIARI J, SELAMAT M R. Laboratory investigation on the effect of transverse member on pull out capacity of metal strip reinforcement in sand[J]. Geotextiles and Geomembranes, 2012, 35: 41–49.

[15] LAMI M, AIREY D. Pullout resistance of tapered metal straps in fills with high fines contents[J]. Journal of Geotechnical and Geoenvironmental Engineering, 2018, 144(2): 06017017.

[16] LAWSON W D, JAYAWICKRAMA P W, WOOD T A, et al. Pullout resistance factors for steel reinforcements used in TxDOT MSE walls[C]//InGeo-Congress 2013: Stability and Performance of Slopes and Embankments III. [S. l.]: [s. n.], 2013.

[17] JAYAWICKRAMA P W, LAWSON W D, WOOD T A, et al. Pullout resistance factors for steel MSE reinforcements embedded in gravelly backfill[J]. Journal of Geotechnical and Geoenvironmental Engineering, 2015, 141(2): 04014090.

[18] YANG Guang-qing, NIU Xiao-di, ZHOU Shi-guang, et al. Experimental study on structural behavior of reinforced retaining wall with composite full-height rigid facing[J]. Rock and Soil Mechanics, 2021, 42(7): 1794–1802.

[19] SUKMAK K, SUKMAK P, HORPIBULSUK S, et al. Effect of fine content on the pullout resistance mechanism of bearing reinforcement embedded in cohesive–frictional soils[J]. Geotextiles and Geomembranes, 2015, 43(2): 107–117.

[20] HORPIBULSUK S, UDOMCHAI A, JOONGKLANG A, et al. Pullout resistance mechanism of bearing reinforcement embedded in residual clayey soils[J]. Geosynthetics International, 2017, 24(3): 255–263.

[21] NIU Xiao-di, YANG Guang-qing, WANG He, et al. Field tests on structural properties of reinforced retaining walls with different panels[J]. Rock and Soil Mechanics, 2021, 42(1): 245–254.

[22] NADAF B, SUSHOVAN D, MANDAL J N. Fly ash as backfill material in slopes using waste pet bottles as reinforcement[J]. Waste Management and Resource Efficiency, 2019(11): 905–913.

[23] FARAH R E, ZALIHE N. Performance of plastic waste for soil improvement[J]. SN Applied Sciences, 2019(11): 1–7.

[24] MOGHADDAS T S N, MALEKSHAH A. R, DAWSON A R. Bearing capacity improvement using soil-filled post-consumer PET bottles[J]. Geosynthetics International, 2021, 29(3): 1–29.

[25] ROUSTAEI M, TAVANA J, BAYAT M. Influence of adding waste polyethylene terephthalate plastic strips on uniaxial compressive and tensile strength of cohesive soil[J]. Geopersia, 2021, 21: 012006.

[26] YARBAŞI N, KALKAN E. The mechanical performance of clayey soils reinforced with waste PET fibers[J]. International Journal of Earth Sciences Knowledge and Applications, 2020(4): 19–26.

[27] HAJIANNEZHAD Z, KERAMATI M, NADERI R, et al. Evaluation of shear strength behaviour of Anzali port sand reinforced with polyethylene terephthalate (PET)[J]. Journal of Science and Technology, 2019(10): 1–3.

[28] PEDDAIAH S, BURMAN A, SREEDEEP S. Experimental study on effect of waste plastic bottle strips in soil improvement[J]. Geotechnical and Geological Engineering, 2018, 36: 2907–2920.

[29] CONSOLI N C, MONTARDO J P, PRIETTO P D, et al. Engineering behavior of a sand reinforced with plastic waste[J]. Journal of Geotechnical and Geoenvironmental Engineering, 2002, 128(6): 462–72.

[30] BABU G S, CHOUKSEY S K. Stress-strain response of plastic waste mixed soil[J]. Waste Management, 2011, 481–489.

[31] American Society for Testing Materials. ASTM D6706－01 Standard test method for measuring geosynthetic pullout resistance in soil[S]. [S. l.]: American Society for Testing and Materials, 2007.

[32] British Standards Institution. EN 00189016 Geotextiles and geotextile related products: determination of pullout resistance in soil[S]. [S. l.]: [s. n.], 1998.

[33] American Society for Testing Materials. ASTM D5321 Standard test method for determining the coefficient of soil and geosynthetic or geosynthetic and geosynthetic friction by the direct shear method[S]. Philadelphia: American Society for Testing and Materials, 2008.

[34] SUKMAK K, SUKMAK P, HORPIBULSUK S, et al. Effect of fine content on the pullout resistance mechanism of bearing reinforcement embedded in cohesive–frictional soils[J]. Geotextiles and Geomembranes, 2015, 43(2): 107–117.

[35] JEWELL R, MILLIGAN G, SARSBY R W, et al. Interaction between soil and geogrids [C]// Polymer Grid Reinforcement: Proceedings of a Conference Aponsored by the Science and Engineering Research Council and Netlon Ltd and Held in London. [S. l.]: [s. n.], 1985.

[36] YU Y, BATHURST R J. Analysis of soil-steel bar mat pullout models using a statistical approach[J]. Journal of Geotechnical and Geoenvironmental Engineering, 2015, 141(5): 04015006.

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