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Research Article

DESIGNING THE STRIP ANCHOR AND INVESTIGATING ITS EFFECTS ON INCREASING THE STRENGTH OF GRANULAR SOILS

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ABSTRACT

For the construction of structures on granular soils that have a sloping surface, it is necessary to stabilize due to low soil adhesion. There are many methods to reinforce soil and increase the stability and improvement of soil resistance parameters. One of these methods is the use of a steel strip. In this method, the steel strips are placed into the soil as strips. So the strength of the soil and strips increases versus shear forces. In other words, the strip performance inside the soil is used to enhance the tensile strength of the concrete like the performance of armature in concrete. While simple strips have advantages in increasing shear strength parameters in terms of pullout strength, they also have disadvantages. For this purpose, in this paper, the design of strip anchor is investigated and the effects of this tool on increasing the tensile strength along with the strength of granular soils are investigated which increases the strength and stability of the soil slope by increasing the shear strength parameters using the methods of soil improvement and reinforcement with strip anchor. In other words, due to the reinforcement of the soil with strip anchor in non-cohesive soils, soil strength properties, internal friction angle, adhesion, hardness, and elasticity model are significantly increased.

Keywords: Strip Anchor, Pullout, soil reinforcement, direct shear test, shear strength

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INTRODUCTION

Vertical anchor plates are structural elements often used to withstand tensile forces acting on structures such as sheet pile retaining walls. They derive their load bearing capacity from the passive resistance of soil and may consist of vertical sheet piles or concrete anchor walls. Anchorage may be continuous or a series of separate anchor plates, or slabs tied to the main wall. The pullout response of anchor plates depends on many factors such as the soil type, relative density, the embedment depth, the anchorage geometry, and any vertical surcharge pressure on the soil. The behavior of anchors with different sizes and embedded at different depths in different soils has been the point of interest of many researchers [1–13].

With the inclusion of reinforcing elements (in the form of natural or synthetic fibers, metal strips, soil nails and anchors, and micropiles) into the soil mass, its various engineering properties are improved. The basic principle behind ground improvement using geosynthetics is that the reinforcing elements absorb the tensile loads or shear stress within the structure and thus preventing its failure due to shear or excessive deformation [14].

The use of soil reinforcement has also attracted considerable interest in recent years in different areas such as retaining wall design, embankment construction, and subgrade improvement underneath shallow foundations. The improvement of the subgrade behavior by utilizing horizontal layers of reinforcement has been studied by several investigators [15–19]. Using vertical elements as soil reinforcement to resist the lateral soil deformations has also been studied [20–23]. Bassett and Last [20] and Verma and Char [21] reported the possibility of using vertical reinforcement for increasing the bearing capacity of the subgrade soil. Mahmoud and Abdrabbo [22] studied the behavior of strip footings supported on sand reinforced by utilizing vertical reinforcing elements made of aluminium strips. It was reported that this type of reinforcement increases the bearing capacity of the subgrade and modifies the load-displacement behavior of the footing. Mandal and Manjunath [23] used geogrid and bamboo sticks as vertical reinforcement elements and studied their effect on the bearing capacity of strip footings. It was reported that vertical reinforcement results in a significant improvement in the bearing capacity of the footing.

Soil slope instability is one of the most important risks of running a structure or maintaining a trench. Slope slips are unstable because of their low shear and tensile strength. The decrease in shear strength of soils is due to the pore pressure of precipitation and underground, that it causes the slope slip or soil bed of a structure to fall and causing irreparable damages. In general, solutions to facing with geotechnical conditions and inappropriate materials include: 1) Avoid construction at that location, 2) Design the desired structure according to the conditions, 3) Improving the geotechnical properties and materials of the area. In the meantime, improving the properties of materials and geotechnical conditions is becoming increasingly necessary for many projects. In fact, the issue of land consolidation and reinforcement is a very important issue in geotechnical operations. The overall objectives of the reform and improvement of the soil generally in accordance with the following factors can be considered: 1) Increasing strength, haulage, and shear strength parameters using remediation methods, 2) Reduce erosion, 3) Reduce the subsidence, 4) Permeability control, reduction of pore pressure, 5) Preventing harmful physical, chemical reactions caused by environmental conditions, etc. One method of soil reinforcement is to use reinforcing materials to stabilize the slopes slip.

General explanation

The anchors consist of a cubic member and a rod member that is welded to the two sides of the strip. This mechanism causes not only the surface of the strip to interact with the soil but also the soil around the strip to participate in the process through anchors. Shear strength and pull out strength have increased dramatically in experimental results and numerical investigations have increased dramatically.

These strips are used for strengthening and stabilizing the slope slip, and increasing the shear strength parameters. In this pattern, Changes to the type of straps made this model superior to other similar cases:

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1- Increasing strips pull-out resistance
2- Increasing soil and strip interaction
3- Having high resistance to static and dynamic forces
4- Non-corrosion against moisture
5- Increased elastic modulus due to soil reinforcement prevents non-uniform subsidence, stroke, and quake
6- Increasing resistant to earthquake

One of the disadvantages of steel strips is their relatively smooth surface, which reduces soil and strip interaction and As a result, resistance decreases substantially than pullout, which engineers compensate for by increasing the length of time that increases the volume of construction operations and consequently increases project costs. In the past, researchers have attempted to compensate for this defect by placing small bumps on the surface of the strips that could increase the pullout strength of the strips. The strips are made of galvanized iron to prevent corrosion. The members as anchors are attached to the two sides of the strip to enhance the interaction between the soil and the strip and to prevent pullout. This will increase the pullout strength of reinforce and also improve one of the mechanisms of reinforced soil deterioration. The following figure shows the mechanism of passive pressure caused by the soil drift behind the anchors when being pulled out. Strength due to reinforced strip anchor increases pullout strength with soil shear strength.

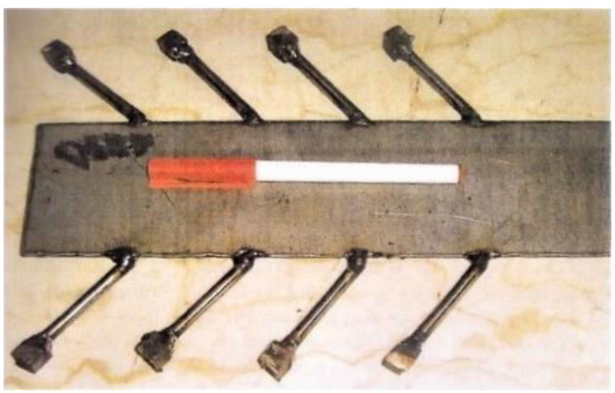

Figure 1 Designed Strip Anchor

Innovations and goals

In this study, it is suggested that in order to increase the interaction between the soil and the strip and to prevent the pullout, some elements should be attached as anchors to the two sides of the strip. This increases the reinforced pullout strength and improves one of the mechanisms of reinforced soil deterioration. Figure 2 shows the passive pressure mechanism caused by the soil drift behind the anchors when being pulled out. Resistant force created by the frictional force of the soil and reinforced soil, increases the strength against pullout.

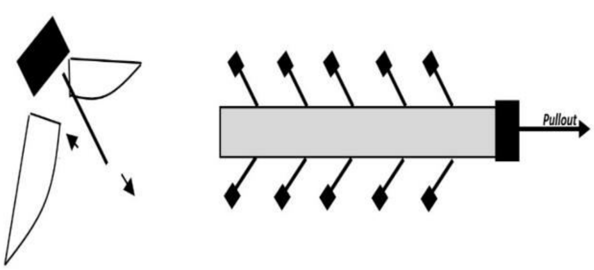

Figure 1 The passive pressure mechanism behind the anchors when pulling out

The main purpose of this study is to numerically analyze the pullout test on these types of strips and traditional strips and finally compare their results with each other. In this research, by designing and making the laboratory pullout, more precise tests are carried out, the procedures are faster, and multiple and precise tests are done.

Implementation Method

To reinforce the earth structure, the strips are placed into the soil in grids or stripes and then covered with facade components. The facade parts form the vertical surfaces of the structure and limit the apparent role of mass deformation.

Methods of examining the plan and experiments

In situ tests at the project site

Pull-out test

The tensile strength of soil interaction is surveyed with a strip by the Pull-out test. The test was conducted according to ASTM C900 and ASTM D7853 standards.

In situ direct shear test

Examination of soil shear strength before and after reinforcement can be measured by direct shear testing. In this experiment, shear strength can be measured with or without surcharge. Especially in a saturated state where critical conditions are considered. According to the simulation carried out in the laboratory model, the laboratory method was used in this study.

Laboratory tests

Automatic pull-out laboratory testing

This device and this method are designed and built based on the need for extensive and accurate testing and are similar to the pull-out used locally, however, a gearbox motor is used as a propulsion motor and a load cell to measure tensile force. Increasing the speed of operation, accuracy in loading rates, and the ability to perform numerous tests and high precision are the advantages of using this device which requires electricity due to the engine.

Large scale direct shear

Investigating the shear strength condition of the soil is very convenient and reliable, but its limitations make it difficult to test it multiple times. For this purpose, the model is first examined by laboratory tests and then carried out at the site for further investigations. The basis of this test is the standard test named ASTM D3080.

Parametric analysis

Effect of strip anchor with the pull-out experiment

In this study, due to the limitations of using the existing pull-out device which was not sufficiently accurate in addition to being time-consuming, the laboratory pull-out device was designed and manufactured.

Figure 2 Direct-shear test device

Apparatus Specifications:
Numerous pull-out experiments were performed under different conditions with different angles and various number of strip anchors on different test specimens. Due to the capabilities of the device, the results of the experiment were obtained with great accuracy.
For example, the result of one test without a strip anchor and another using a strip anchor can be seen below (Figures 4, 5 and Tables 1, 2).

Table 1 Type A test data - without using the strip anchor

Sample Type:		A-0						
Normal Stress: (Kg/cm2)		0.5	Normal Stress: (Kg/cm2)		1	Normal Stress: (Kg/cm2)		1.5
F(Kg)	T(Kg/cm^2)	L-H (0.01mm)	F (Kg)	T(Kg/cm^2)	L-H (0.01 mm)	F (Kg)	T(Kg/cm^2)	L-H (0.01 mm)
0	0.000	0.0	0	0.000	0.0	0	0.000	0.0
22.1	0.025	0.5	31.5	0.035	0.5	62.9	0.070	0.5
44.1	0.049	1.0	63	0.070	1.0	116.1	0.129	1.0
66.2	0.074	1.5	94.5	0.105	1.5	223.2	0.248	1.5
104.8	0.116	2.0	126	0.140	2.0	266.9	0.297	2.0
121.3	0.135	2.5	170.1	0.189	2.5	363.9	0.404	2.5
176.4	0.196	3.0	220.5	0.245	3.0	436.3	0.485	3.0
231.5	0.257	3.5	315	0.350	3.5	572.1	0.636	3.5
270.2	0.300	4.0	396.9	0.441	4.0	630.2	0.700	4.0
292.2	0.325	4.5	439.1	0.488	4.5	703.3	0.781	4.5
325.3	0.361	5	510.3	0.567	5	770.9	0.857	5
347.3	0.386	6	551.3	0.613	6	829	0.921	6
358.4	0.398	7	602.3	0.669	7	897.1	0.997	7
369.4	0.410	8	653.3	0.726	8	955.2	1.061	8
380.4	0.423	9	678.5	0.754	9	994.1	1.105	9
396.9	0.441	10	704.3	0.783	10	1018.1	1.131	10
402.5	0.447	11	719.5	0.799	11	1042.5	1.158	11
402.5	0.447	12	734.6	0.816	12	1061.8	1.180	12
402.5	0.447	13	745.3	0.828	13	1080.9	1.201	13
396.9	0.441	14	755.4	0.839	14	1085.7	1.206	14
396.9	0.441	16	760.4	0.845	16	1095.9	1.218	16
396.9	0.441	18	760.4	0.845	18	1100.6	1.223	18
385.9	0.429	20	765.5	0.851	20	1105.4	1.228	20
385.9	0.429	22	765.5	0.851	22	1110.3	1.234	22
380.4	0.423	24	760.4	0.845	24	1110.3	1.234	24
374.9	0.417	26	755.4	0.839	26	1105.4	1.228	26
369.4	0.410	28	750.3	0.834	28	1100.6	1.223	28
363.8	0.404	30	745.3	0.828	30	1095.9	1.218	30

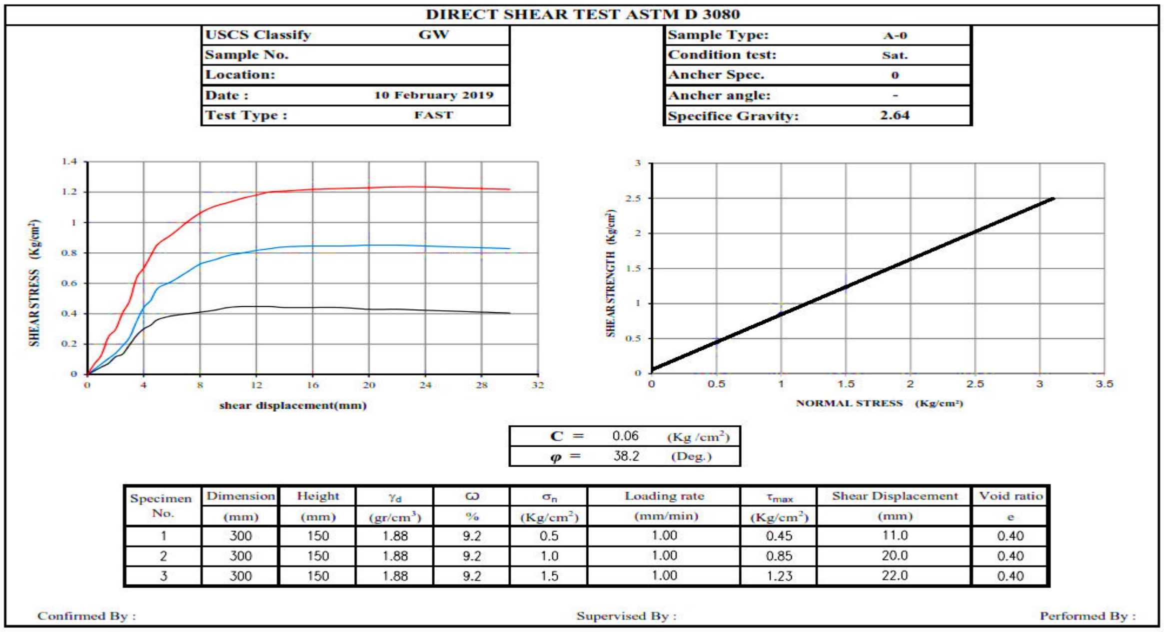

Figure 3 Diagrams and main parameters of type A test - without using the strip anchor

Table 2 Type A test data - with using the strip anchor

Sample Type:		A-4						
Normal Stress: (Kg/cm2)		0.5	Normal Stress: (Kg/cm2)		1	Normal Stress: (Kg/cm2)		1.5
F(Kg)	T(Kg/cm^2)	L-H (0.01mm)	F (Kg)	T(Kg/cm^2)	L-H (0.01mm)	F (Kg)	T(Kg/cm^2)	L-H (0.01mm)
0	0.000	0.0	0	0.000	0.0	0	0.000	0.0
33.6	0.037	0.5	62	0.069	0.5	119.1	0.132	0.5
61.2	0.068	1.0	154.2	0.171	1.0	248.1	0.276	1.0
92.4	0.103	1.5	243.4	0.270	1.5	416.7	0.463	1.5
132	0.147	2.0	338.7	0.376	2.0	575.5	0.639	2.0
163.2	0.181	2.5	415.8	0.462	2.5	730.3	0.811	2.5
211.7	0.235	3.0	524.7	0.583	3.0	855.3	0.950	3.0
277.8	0.309	3.5	600.3	0.667	3.5	952.6	1.058	3.5
324.2	0.360	4.0	672.8	0.748	4.0	1053.8	1.171	4.0
350.6	0.390	4.5	709.2	0.788	4.5	1099.5	1.222	4.5
390.4	0.434	5	742.4	0.825	5	1151	1.279	5
416.8	0.463	6	787.7	0.875	6	1216.5	1.352	6
430.1	0.478	7	810.4	0.900	7	1246.2	1.385	7
443.3	0.493	8	831.6	0.924	8	1272.1	1.413	8
456.5	0.507	9	839.2	0.932	9	1289.9	1.433	9
476.3	0.529	10	845.3	0.939	10	1311.8	1.458	10
483	0.537	11	851.2	0.946	11	1321.6	1.468	11
483	0.537	12	855.8	0.951	12	1327.6	1.475	12
483	0.537	13	861.8	0.958	13	1329.6	1.477	13
476.3	0.529	14	864.9	0.961	14	1339.6	1.488	14
476.3	0.529	16	861.8	0.958	16	1339.6	1.488	16
476.3	0.529	18	855.8	0.951	18	1329.6	1.477	18

463.1	0.515	20	846.7	0.941	20	1317.8	1.464	20
463.1	0.515	22	833.1	0.926	22	1291.9	1.435	22
456.5	0.507	24	824	0.916	24	1272.1	1.413	24
449.9	0.500	26	816.5	0.907	26	1240.4	1.378	26
443.3	0.493	28	808.9	0.899	28	1210.5	1.345	28
436.6	0.485	30	801.4	0.890	30	1190.7	1.323	30

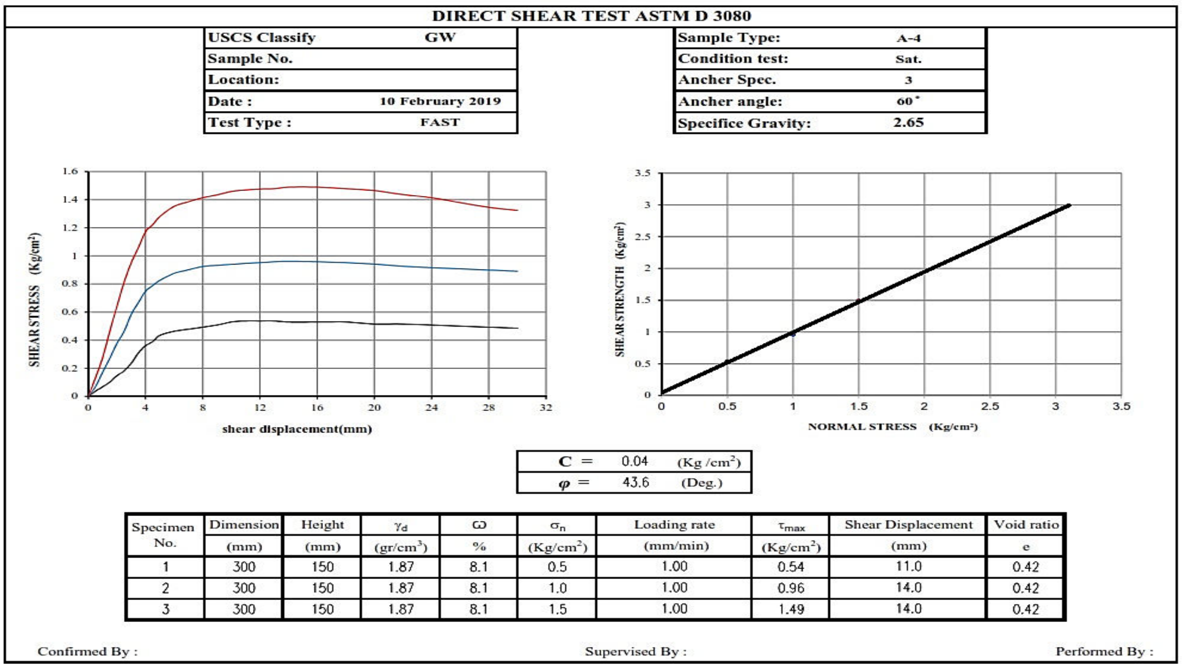

Figure 4 Diagrams and main parameters of type A test - with using the strip anchor

Using the results of experiments, the effects of angle, length and distance of the anchors were investigated. The table below compares the results of the experiments (Table 3).

Table 3 Summarize and compare the results of all tests

Sample Nme	USCS Classification	Anchor Specs	Anchor Angle	Friction Angle (φ)	Cohesion (C)	Description
A-0	GW	0	-	38.2	0.06	Soil without anchor
A-1	GW	2	45	39.5	0.12	
A-2	GW	2	60	40.3	0.1	
A-3	GW	3	45	41.8	0.05	
A-4	GW	3	60	43.6	0.04	
B-0	GC	0	-	33.6	0.19	Soil without anchor
B-1	GC	2	45	36.5	0.19	
B-2	GC	2	60	39.9	0.16	
B-3	GC	3	45	39.5	0.17	
B-4	GC	3	60	43.4	0.18	
C-0	SC	0	-	28.5	0.29	Soil without anchor
C-1	SC	2	45	31.3	0.14	
C-2	SC	2	60	32.7	0.22	
C-3	SC	3	45	32.5	0.31	

C-4	SC	3	60	35.5	0.15	

Comparison of the power of the two reinforcement systems in the pull-out tests
After reaching the optimum dimensions of the effective parameters, the displacement of the optimum strip anchor is compared with the traditional strip under different surcharge pressure and pullout forces and the results are shown in Figure 6. The results show a significant decrease in displacement and consequently an increase in pullout strength of the strip anchor in comparison with the traditional strip.

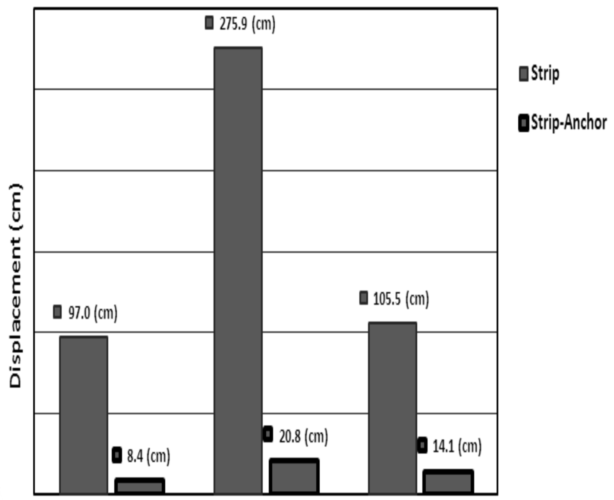

Figure 5 Displacement of strips and strip anchors under different surcharges and pullout force

Influence of strip anchor on soil shear strength parameters
Three types of soils were selected to investigate the effect of strip anchors on soil stability with respect to the mechanism of effect and how they affect different soil types.
Type 1: Well-graded Gravel with Sand (GW)
Type 2: Clayey Gravel with Sand (GC)
Type 3: Clayey Sand with Gravel (SC)

GW, Well-graded Gravel with Sand
GC, Clayey Gravel with Sand
SC, Clayey Sand with Gravel

Testing of soil aggregation and classification with hydrometer analysis test and determination of Atherberg based on the standards (ASTM D6913, D422, D2487, and D4318) were done on all three samples and the results are as follows.
For this purpose, direct shear test was performed on all three soils before reinforcement. Then, considering the optimum distance and the limitation of the mold dimensions, the experiments were performed on the mentioned soils with two and three strip anchors, with both 45 and 60 degrees angles, in saturation and fast states. The reason for selecting the experiment with the fast and saturated states was to consider the effect of pore pressure on instability and to create a critical state.
The results of all three types of soils generally showed the greatest effect of the strips on the clayey soils and with increasing the slope and the number of strip anchors, the amount of friction angle increased. The test results are attached.
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Modeling and numerical analysis
In this study, PLAXIS 3D TUNNEL software was used for numerical analysis. PLAXIS allows the user to make extensive use of geotechnical issues such as deep excavation, tunnels, and ground structures. The program is capable of applying static and dynamic force and stage construction conditions. The elements used in this software are 15-node 3D elements. The pullout test mechanism is modeled in PLAXIS program and the surcharge is applied to the system. Then the strip anchor system and the traditional strip have been tensed and the displacement has been measured. In this research ،displacement is considered as a criterion for measuring pullout strength. Figure 7 illustrates an example of model geometry, layout, and reinforcement system displacement.

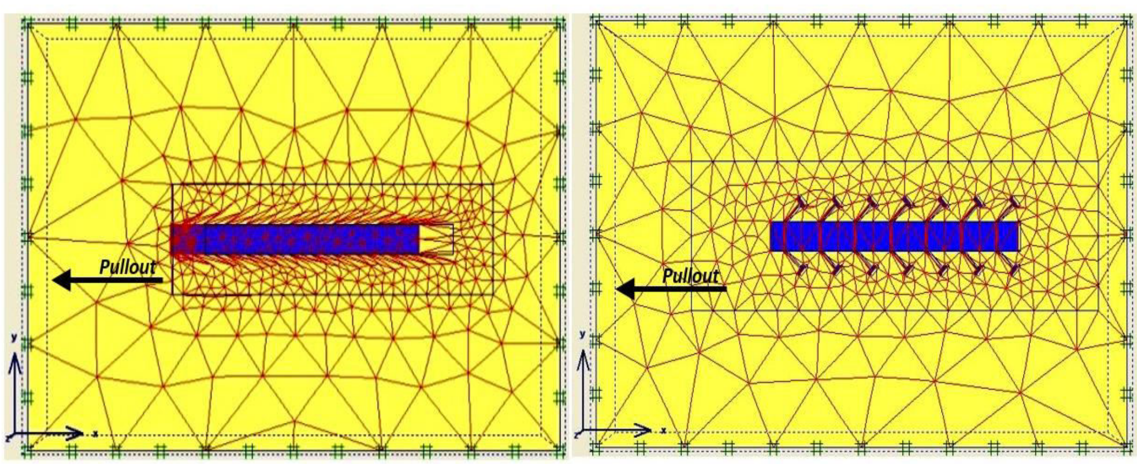

Figure 6 The method of modeling and deforming of the elements of the strip and strip anchor model

The soil used for modeling the sand and strip anchor is made of steel and their mechanical properties are given in Table 1. A 5 mm steel strip, with the width of 7 cm and the length of 70 cm steel was selected.

To begin the analysis, the prototype strip anchor was modeled by attaching 5cm anchors with a 1cm cubic element, with the distance of

10cm and the angle of 45 ° to the traditional strips and then, these parameters are optimally compared.

CONCLUSION

After parametric analysis, it was found that the optimum angle of the anchors is 45 ° with respect to the minimum displacement at this angle and its applicability in the workshops. The optimum anchor length was 7 cm and the optimum anchors distance was 10 cm.
The optimum strip anchor and traditional strip reinforcement systems were then compared under the same conditions in terms of surcharge pressure and pullout force. The results show that the displacement of the strip anchor is 7.5 times lower in the lowest case and in the highest case 13.3 times lower than that of the traditional strip, indicating the resistance of this system to the pullout force and successful performance of this innovative reinforcement system.

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