Pullout Tests on Strips with Anchorage Elements under Low Stresses

M. R. Selamat[1], M. H. Roslan[2], and M. A. M. Ismail[3]
[1,2,3]*School of Civil Engineering, Universiti Sains Malaysia, 14300 NibongTebal, Penang, Malaysia*
E-mail: cemrs@usm.my

ABSTRACT: The lack of pullout capacity in reinforcement strips has often compromised the finishing quality of the mechanically stabilized earth (MSE) structures. In this research, three strips were each attached with 6 anchorage elements of 1cm, 2cm, and 3cm deep respectively in order to enhance the pullout capacities, while another strip was plain. Each strip was subjected to pullout tests under low normal stresses ranging from 1.61kPa to 13.20kPa to simulate shallow emplacement in the field. Under the low normal stress of 1.61kPa, the pullout capacities of strips with anchorage elements were enhanced up to 366% of the plain strip capacity while under the higher normal stress of 13.2kPa, the pullout capacity enhancements were only up to 163% of the plain strip capacity. The results indicate the merit of attaching anchorage elements to strips under shallow overburden in a MSE structure and the significant increase in pullout capacity achievable by such strips.

KEYWORDS: Reinforcement strip, Anchorage element, Pullout capacity, Shallow overburden

1. INTRODUCTION

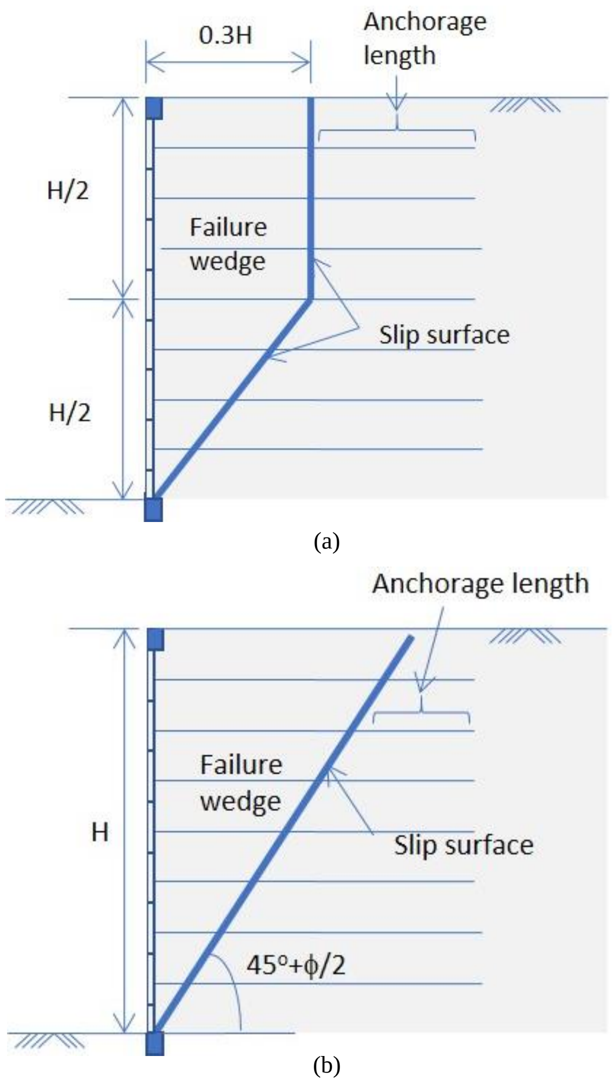
The mechanically stabilized earth (MSE), also known as the reinforced retaining wall, the reinforced embankment, or the reinforced soil, depending on the method of application, has been widely used in geotechnical projects where it provides a low-strain, strong, and durable solution for backfill stabilization of the embankment structure. In a MSE structure, reinforcement strips which are either metallic or synthetic, and plain or ribbed, are placed horizontally in the midst of layers of sand which is normally the type of soil used for the backfill. When properly assembled, the components of a MSE form a composite structure capable of sustaining a significant tensile load.

The design and analysis of a MSE consider internal and external stabilities, i.e. the integrity of the failure wedge as well as wedge equilibrium against slides or toppling. The pullout capacity and the consequent interface friction between soil and strip is the most important design parameter. The tension in the reinforcement improves the shear strength in the soil mass and hence reduces the horizontal deformation (Abdelouhab et al., 2011; Sieira et al., 2009; Chen et al., 2007; Schlosser and Elias, 1978). The confining stress within the ground beyond the failure wedge provides the necessary anchorage in holding the soil mass against translation.

Studies involving the MSE and reinforced embankments have been carried out by many researches (Bergado and Teerawattanasuk, 2008; Bathurst et al., 2005; Skinner and Rowe, 2005 a, b; Haeri et al. 2000; Ochiai et al., 1996).Various types of instabilities involving rupture of facing panels, failure of connections, and toppling or sliding of failure wedge have been reported in the literature (Mosallanezhad and Nasiri, 2015; Balunaini and Prezzi, 2010; Khedkar and Mandal, 2009). These instabilities might have been caused, among others, by pullouts due to the insufficient pullout capacity of the reinforcement strips particularly under low normal stresses. Reinforcement strips with anchorage elements similar to the one described here have been researched in the laboratory involving smaller compartment but higher confining stresses (Esfandiari and Selamat, 2012).

The research presented in the current paper particularly addresses the fact that the upper or shallower strips are held by a lesser normal stress thus inherently lacking the pullout capacity. This condition is believed to have led to incidents involving the dislocation of facing panels of the MSE, particularly in the upper rows. The photo of Figure 1, taken in Nibong Tebal, Malaysia, shows a compromised feature that would lead to loss of backfill material and the eventual rupture. MSE failures nevertheless have been widely reported in literature and media ranging from minor shifts affecting only the quality to the more serious damages and collapses causing tremendous loss of property. The use of strips with anchorage elements for selected positions within a MSE could be a solution to the problem. Note that the pullout capacity of a strip can only develop for the tail portion embedded within the anchorage ground of a MSE, i.e. behind the slip surface or beyond the failure wedge in Figure 2. Therefore the actual length of a strip that could effectively contribute to the pullout capacity would be quite limited despite its normally extensive total length. In the case of a partially extensible metal strip of Figure 2(a), the slip surface in the backfill starts from the foot, then steering backwards, gradually distancing away from the facing panel, as it rises towards the ground surface, thus shrinking the available anchorage ground, although it does so only up to the halfway mark. Such problematic situation of the lack of ground for strip emplacement could even get worse in the case of working in an already tight space. Furthermore, the lateral earth pressure would increase with each compaction effort carried out on the layers of sand, thus straining the panels that eventually could culminate into an increased pullout force of the strips. For a strip emplaced deeper under the overburden of a MSE structure however, the wider anchorage ground and the higher confining stress would both contribute to a higher pullout capacity, thus there is less problem of the lack of it there. Therefore, the anchorage elements discussed in this paper are probably more applicable to the shallower strips of a MSE than to the deeper ones.

Figure 1 Photo of a dislocated facing panel in Nibong Tebal, Penang



(a)

(b)

Figure 2 Conceptual slip surfaces of the MSE (a) Case of inextensible strip (b) Case of extensible strip (Salgado, 2008)

2. MATERIALS AND METHOD

2.1 Sand

The fill material used in this research was well graded sand, classified as SW according to the Unified Soil Classification System (USCS). The physical characteristics and shear strength parameters were determined according to appropriate ASTM standards (ASTM, 2004; 2007a, b). The main properties of the sand used are summarized in Table 1 while the particle distribution curve is given in Figure 3. The SW was selected as it is the choice fill material for MSE structures in real projects, could easily fill the spaces among the strips and tight corners behind the facing panels, and does not change much in moisture content throughout the preparation process of filling the reinforcement compartment such as carried out in this research. The internal friction angles for the sand at the given relative densities were determined by laboratory direct shear tests involving normal stresses of 10 kPa, 20kPa and 40 kPa. Just a note, the normal stresses used in the pullout tests ranged between 1.61 and 13.2 kPa.

2.2 Strips

Each strip was 6.0m in length, 5.0cm in width, and 5.0mm in thickness, as commonly used in real projects. The first was plain while the next three were each attached with 1.0cm, 2.0cm and 3.0cm deep anchorage elements respectively. The elements were cut from the same source as the strip thus also having the same width and thickness. Each strip had six elements of equal depth attached and they were spaced evenly at 1.0m distance from one to another. The 1.0cm diameter hole for pin connection to the pullout rod was positioned 5.0cm from the pulling end of the strip. The specifications of a strip with anchorage elements are given in Figure 4. Photos of the strips are given in Figure 5. Some information on the properties of the metal is given in Table 2. In order to protect the members from corrosion, an oil based metal primer was applied, although zinc coating was used in real applications. In a typical test, the strip was positioned with elements pointing downward and fully penetrated into the sand in the test compartment.

Table 1 Properties of Sand

Soil Property	**Value**
D_{10}[a]	0.19mm
D_{30}[a]	0.55mm
D_{50}[a]	0.91mm
D_{60}[a]	1.17mm
Coefficient of Uniformity, Cu[a]	6.15
Coefficient of Curvature, Cc[a]	1.36
Maximum Dry Unit Weight, (kN/m^3)[b]	19.00
Optimum Moisture Content, %	14.5
Specific Gravity, G_s	2.651
Maximum void ratio, e_{max}	0.74
Minimum void ratio, e_{min}	0.54
Angle of friction at field D_r= 60%[c]	36°
Angle of friction at field D_r = 90%[c]	42°
USCS classification	SW

[a]In accordance with ASTM D2487 (ASTM, 2007a, b)
[b]In accordance with ASTM D698 (ASTM, 2007a, b)
[c]In accordance with ASTM D3080 (ASTM, 2004)

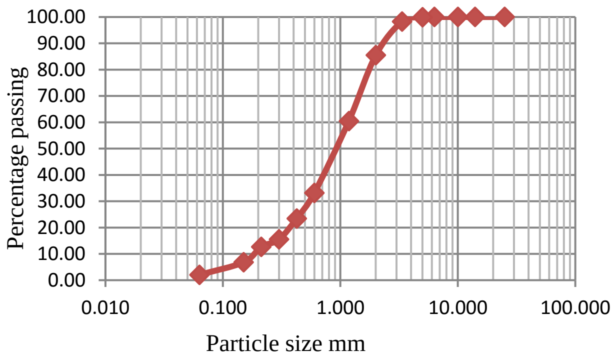
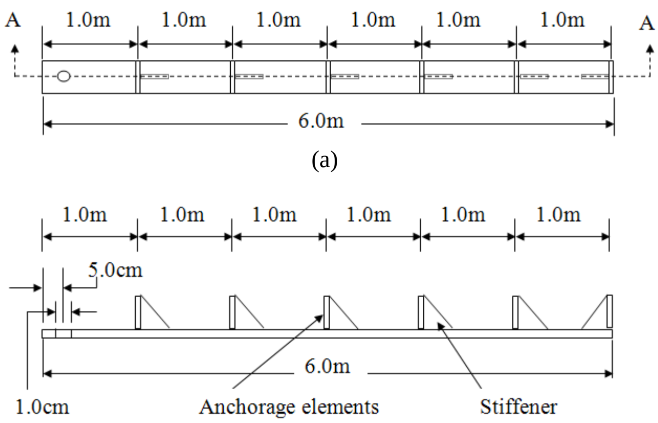


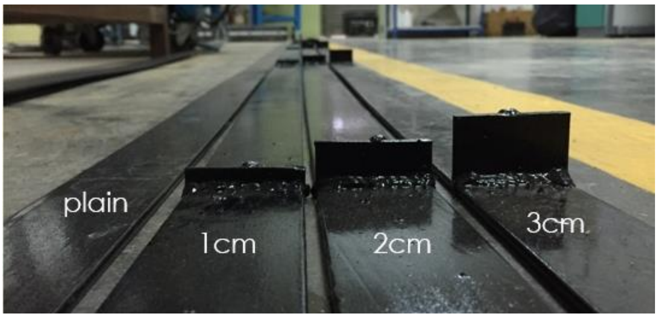
Figure 3 Grain size distribution of sand



(a)

(b)

Figure 4 Views of a strip with anchorage elements and stiffeners (a) Plan view (b) Side view through Section A-A



(a)

(b)

Figure 5 Photos of plain strip and strips with anchorage elements of 1cm, 2cm, and 3cm respectively (a) Front view (b) Oblique view

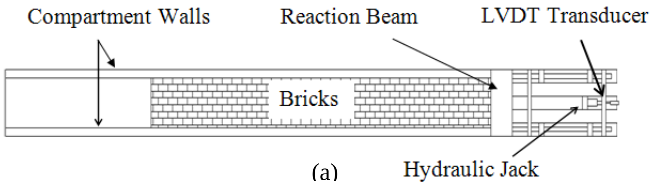
Table 2 Properties of steel for strips and anchorage elements

Property	Value
Density, ρ (kg/m^3)	7850
Elastic modulus, E (kN/m^2)	2x10^8
Poisson's ratio, ν	0.3

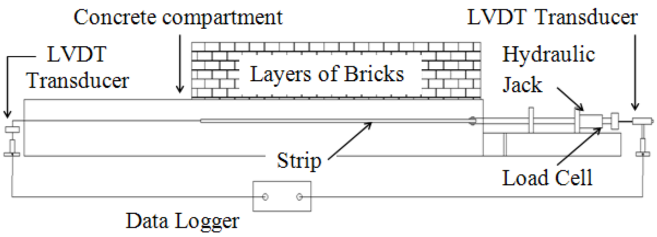
2.3 Test Setup

The components of the test facility were compartment, bricks, load cell, data logger, laptop computer, pulling rod, pullout frame, hydraulic jack, LVD transducers, pedestal, reaction beam, and concrete base, among others. The compartment consisted of a pair of parallel reinforced concrete walls, 10.0m long and separated from each other at 0.75m. The height of the walls above the ground was 1.0m. The sand was placed inside the compartment, layer upon layer, each uniformly compacted to about 0.2m thick until full. The compaction was carried out using the mechanical hand held compactor. Compaction uniformity over the entire volume was an aim of the procedure. When about full, more sand was added, compacted, and leveled off against the top of the compartment walls. Field density tests were carried out and the results were closer to the relative density value of 60% of Table 1, than to the higher value of 90%. A shallow groove was made into the sand along the centre of the compartment to make way for laying the strip with the anchorage elements facing down and fully penetrating into the fill. A thin layer of sand was laid above it, further compacted, and leveled off. Bricks were placed on top of the sand, covering the whole width of the compartment between the two walls, and the whole length of the strip. The area covered by the stack of bricks was 4.32m^2 which was 0.75m wide and 6.0m long. The weight of bricks for each layer was determined by surveying the individual masses of a representative number of bricks for each layer and multiplying the average mass by the total number for the layer. The total mass of stack of bricks was therefore the sum of the masses coming from each layer. The normal stress applied onto the strip was therefore the total weight of bricks divided by the area covered. The thin layer of sand covering the strip was considered negligible.

The pullout resistance of a strip was measured using a calibrated load cell. The pullout displacements were measured using LVDT transducers positioned at both ends of the strip. The front end of the strip was attached to the pulling rod that connects to the pullout frame. The pullout force was provided by a hydraulic jack and monitored by the load cell. The pullout assembly was positioned adjacent to the sand compartment. To prevent any moment transfer from the strip to the pull rod, a pin connection was used for the joint, as in a real project. The maximum pullout force which could be measured by the load cell was 44.48kN, which was much larger than the maximum pullout force of 21.59kN measured in the tests. The readings of the load cell and of the front and the rear displacement transducers were transmitted to the data logger that was interfaced with a laptop computer. The software used was WINHOST, capable of viewing and analyzing the collected data while on site. Figure 6 shows the schematic drawings of the pullout test, in plan and side views. Figure 7 shows the apparatuses involved in a test. The tests were carried out outdoor in the field.



(a)



(b)

Figure 6 Schematic diagram of field pull out test apparatus (a) Plan view (b) Side view

(a)

(b)

Figure 7 Photos of pullout test apparatuses (a) Pullout assembly consisting of pulling rod, pullout frame, hydraulic jack, load cell, LVD transducer, pedestal, reaction beam, and concrete base (b) Overall assembly consisting of compartment walls, layers of bricks, data logger, laptop computer, and the pullout assembly

A total of twenty pullout tests were carried out involving the plain strip and the three strips with anchorage elements of 1cm, 2cm and 3cm respectively, each under the normal stresses of 1.61kPa, 2.93kPa, 4.40kPa, 8.80kPa and 13.20kPa. Each normal stress was provided by 1 layer, 2 layers, 3 layers, 6 layers and 9 layers of bricks respectively.

3. RESULTS AND DISCUSSION

3.1 Results of pullout tests

The aim of the tests was mainly to observe the pullout capacities of the strips, plain and with anchorage elements, under the given range of relatively low normal stresses. The test results are summarized in Table 3, while the force-displacement curves for plain strip are given in Figure 8. The force-displacement curves for strips with anchorage elements of 1, 2, and 3cm deep are given in Figures 9, 10, and 11 respectively.

The interaction coefficient, f_b, as given by Jewell (1990) is defined by the following Eq. 1:

$$P_R = 2 f_b L_R \sigma_n \tan \emptyset \qquad \text{Eq. 1}$$

Where
P_R= Pull-out capacity for 1m wide strip (kN/m)
f_b= Pull-out soil-reinforcement interaction coefficient
L_R= Effective length of strip reinforcement (m)
σ_n= Normal stress (kN/m^2)
$\emptyset$ = Angle of internal friction of sand (°)

The equation indicates a pull out capacity that is a function of the soil-strip contact area, normal stress, angle of friction of sand, and the interaction coefficient. As much as the pull out capacity could be gained from the values of the first three parameters, it could also be gained from the interaction coefficient amount. Thus a high interaction coefficient should be viewed as favorable in terms of the pull out capacity it is associated with.

Table 3 Results of pullout tests

rip	Normal stress (kPa)	Pullout capacity (kN)	Displacement at front (mm)	Displacement at rear (mm)	P_R (kN/m)	Interaction Coefficient, f_b
Plain	1.61	1.81	7.56	4.30	36.20	2.579
	2.93	3.30	8.37	5.96	66.00	2.584
	4.40	4.78	9.67	6.72	95.60	2.492
	8.80	9.64	13.31	10.44	192.8	2.513
	13.2	13.24	15.69	12.77	264.8	2.301
Strip with 1 cm deep anchorage element	1.61	3.81	27.7	20.88	76.20	5.429
	2.93	5.56	58.1	50.77	111.2	4.353
	4.40	7.49	77.05	65.34	149.8	3.905
	8.80	12.63	98.04	77.32	252.6	3.292
	13.2	16.73	100.5	85.41	334.6	2.907
Strip with 2 cm deep anchorage element	1.61	5.41	69.00	44.19	108.2	7.708
	2.93	7.00	72.50	58.31	140.0	5.480
	4.40	9.24	30.71	21.64	184.8	4.817
	8.80	15.01	80.81	67.98	300.2	3.913
	13.2	18.92	83.21	69.95	378.4	3.288
Strip with 3 cm deep anchorage element	1.61	6.62	49.70	31.87	132.4	9.432
	2.93	8.73	52.50	45.76	174.6	6.835
	4.40	10.36	59.80	49.13	207.2	5.401
	8.80	16.71	100.5	87.43	334.2	4.356
	13.2	21.59	102.9	89.65	431.8	3.752

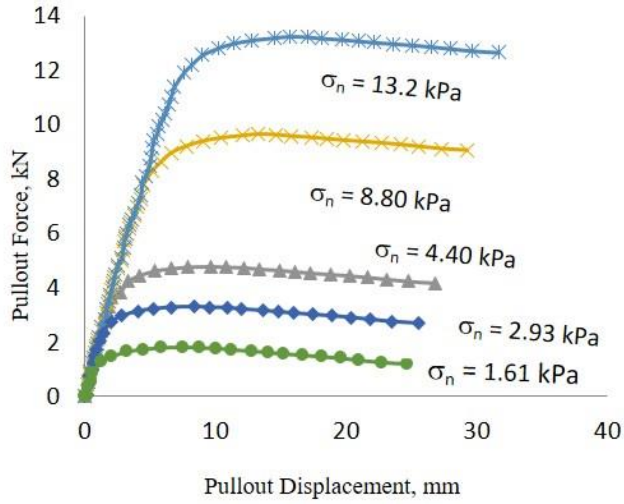


Figure 8 Pull-out forces versus displacements for plain strip under various normal stresses

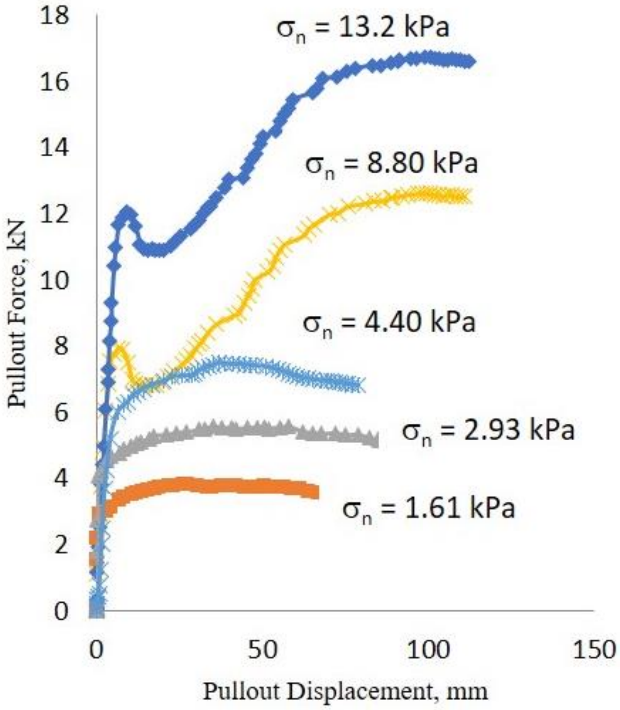


Figure 9 Pull-out forces versus displacements for strip with anchorage elements of 1cm deep under various normal stresses

In general, the pullout capacity of a strip increased with increasing normal stress and depth of anchorage elements. For any given normal stress, the coefficient of interaction increased with increasing depth of anchorage elements while for any given depth of anchorage element, the coefficient of interaction increased with decreasing normal stress. This trend suggests an increasing pull out capacity gain with increasing depth of anchorage elements and with decreasing normal stress. In other words, at a lower normal stress, especially for strip with anchorage elements, an additional length or unit of it would return a corresponding pull out capacity increase more in percentage than at a higher normal stress, indicating the merit in attaching anchorage elements to strips under shallow overburden. In practice, the convenient measure of adding strips with anchorage elements to the final rows of panels should be considered when seeking additional stability to the MSE structure.

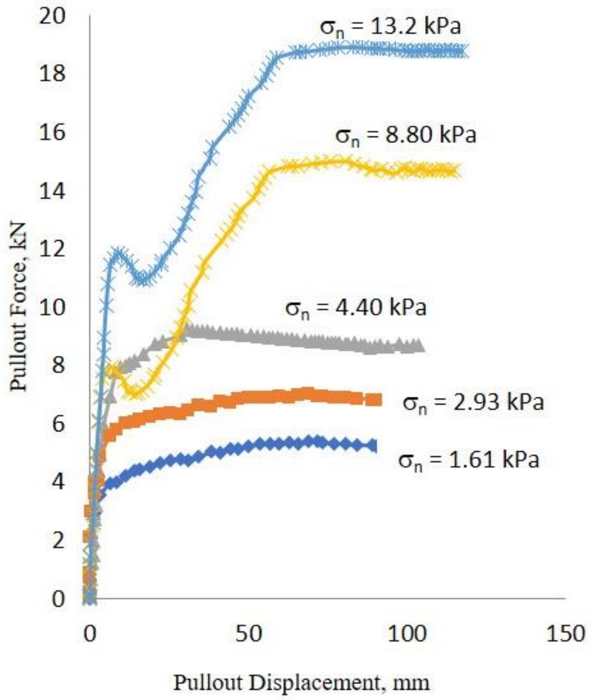


Figure 10 Pull-out forces versus displacements for strip with anchorage elements of 2cm depth under various normal stresses

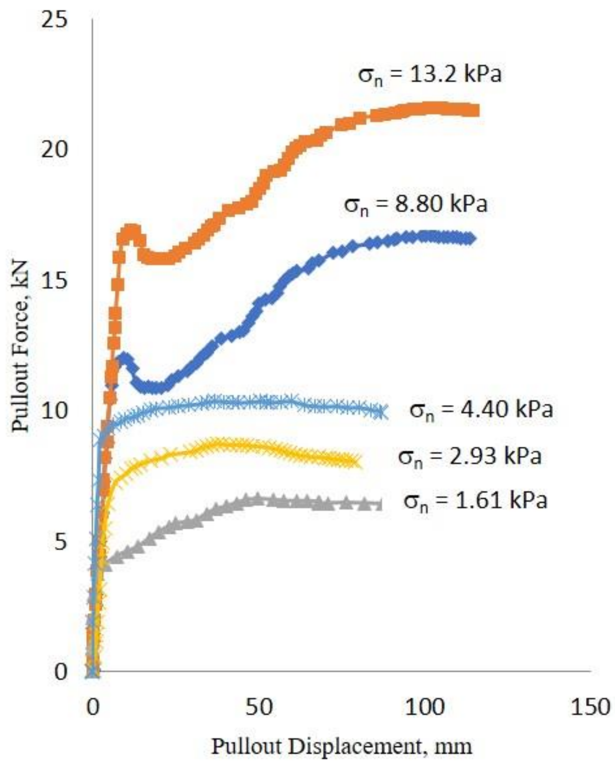


Figure 11 Pull-out forces versus displacements for strip with anchorage elements of 3cm depth under various normal stresses

Furthermore, as the highest interaction coefficient value of 9.432 was obtained under the least normal stress and with the deepest elements, the arrangement could be considered the most profitable in terms of enhancing the pullout capacity out of a given effort. On the other hand, as the lowest interaction coefficient of 2.301 was obtained with the highest normal stress and the least of the elements, this arrangement may be considered as the least beneficial for enhancing the pullout capacity within the range of parameters considered in this study. A deeply embedded strip would be held by a high normal stress anyway that even without anchorage elements it would provide a relatively strong pullout resistance. Furthermore, as given in Figure 2, the anchorage length would be longer in comparison to the shallower strips due to the availability of anchorage ground. Therefore the potential lack of pullout capacity for a deeply embedded strip would not be as critical as the lack of it in shallow ones near the top.

3.2 Pullout force-displacement relationships for plain strip

The curves of Figure 8 show curvilinear characteristics with no sharp peak for all cases. The pull out capacity increased with increasing normal stress along a straight line. The optimum displacements corresponding to the maximum pull out resistances have occurred at between 6.0mm for the least normal stress and 16.0mm for the most normal stress applied. Thus, the displacement required to mobilize the capacity of a strip can vary significantly depending on the normal stress. The pull out capacity was achieved at a lesser displacement for strip under a lesser normal stress than for strip under a higher normal stress. The results suggest that for strips lightly embedded in the field, the potential pullout capacity lost would be imminent once shifted by only a few mm.

3.3 Pullout force-displacement relationship for strip with anchorage elements of 1 cm deep

The results of pull out tests for strip with anchorage elements of 1.0 cm deep of Figure 9 indicate curvilinear characteristics with no sharp peaks for curves corresponding to the lower normal stresses. As for the curves corresponding to the higher normal stresses, they exhibit the sharp peaks probably due to slips of the shear surfaces created by the anchorage elements during the pullouts. The maximum pullout resistances have occurred between 40.0mm displacement for the least normal stresses and 100.0mm displacement for the highest normal stresses; these were the optimum displacements which are significantly higher than those of the plain strip. Again, the displacement required to mobilize a strip can vary significantly depending on the normal stress; and once more, the pull out capacity was arrived at earlier for strip with lesser normal stress than for strip with higher normal stress. The pullout capacities of 3.81kN, 5.56kN, 7.49kN, 12.63kN and 16.73kN were respectively 210%, 168%, 157%, 131% and 126% of the pullout capacities of plain strip, correspondingly under the normal stresses of 1.61kPa, 2.93kPa, 4.40kPa, 8.80kPa and 13.20kPa. The gains in pull out capacity due to having anchorage elements were significant; furthermore, the gain was highest for the least normal stress and it reduces with increasing normal stress. The results also suggest that for such strips lightly embedded in the field, the potential pullout capacity lost would only be imminent once shifted by over 40mm, instead of only 6mm as in the previous case of plain strip.

3.4 Pullout force-displacement relationship for strip with anchorage elements of 2 cm deep

The pullout force-displacement relationships for strip with anchorage elements of 2.0cm deep are given in Figure 10. The curves corresponding to the lower normal stresses again show the curvilinear characteristics with no sharp peaks while those corresponding to the higher normal stresses exhibit the sharp peaks, again probably due to slips of the shear surfaces created by the anchorage elements during pullouts. The optimum displacements corresponding to the maximum pull out resistances were about 70.0 mm for the lowest and the highest normal stresses and about 40.0 mm for the median normal stresses which trend has somewhat departed from the earlier cases involving plain strips and strips with 1.0cm deep elements. Thus, the displacements required to mobilize a strip in this case were not as predictable as were with the earlier cases, nevertheless were larger than those of the plain strips. The pullout capacities of 5.41kN, 7.00kN, 9.24kN, 15.01kN and 18.92kN were respectively 299%, 212%, 193%, 156%, and 143% of the pull out capacities of plain strip, correspondingly under the normal stresses of 1.61 kPa, 2.93 kPa, 4.40 kPa, 8.80 kPa and 13.20 kPa. Again, the percent increase in pullout capacity of a strip with anchorage elements was highest under the lowest stress and it reduces with increasing stress.

3.5. Pullout force-displacements relationship for strip with anchorage elements of 3 cm deep

The pullout force-displacement relationships for strip with anchorage elements of 3.0cm deep are given in Figure 11. The results in terms of shape of curves and displacements at highest pullout force were quite similar to the previous case of 2.0cm deep elements indicating possible slips of the shear surfaces during pullouts which apparently have occurred only in the cases of deeper anchorage elements. Like in the previous case of strip with 2.0cm deep elements, the displacements required to mobilize the pull out capacity in this case again were not as predictable but in the region of 50 to 100mm, which were even higher than anything seen before. The pullout capacities of 6.62kN, 8.73kN, 10.36kN, 16.71kN and 21.59kN were respectively 366%, 265%, 217%, 173% and 163% of the pull out capacities of plain strip, correspondingly under the normal stresses of 1.61kPa, 2.93kPa, 4.40kPa, 8.80kPa and 13.20kPa. Again, the percent increase in pullout capacity of a strip due to having anchorage elements was highest under the least stress and it reduces with increasing stress.

3.6 Further commentaries on the pullout capacities

The percents increase in pullout capacity due to having anchorage elements were almost entirely reflected by the increase of the interaction coefficient value. This indicates that the merit in having anchorage elements under any particular normal stress is naturally evaluated by the interaction coefficient values. The sorting of interaction coefficient values by descending order resulted in similarly decreasing order of the normalized pullout capacity increases, which are increases in pullout capacity due to the various appointments of anchorage element divided by the pullout capacity of plain strip under the same stress, as given in Table 4.

The plot of pull out capacities against depths of anchorage element for the various normal stresses together with the least square regression lines are given in Figure 12. The almost parallel lines indicate similar increase in pull out capacity with each increase in normal stress, with any anchorage element appointment. The percents increase of pull out capacity with each increasing normal stress was greatest when the depth of anchorage elements was the least. However a higher pullout capacity could only be achieved via deeper anchorage elements.

The plot of pull out capacities against normal stresses for the various appointments of anchorage element together with the least square regression lines are given in Figure 13. These lines only differ slightly on their inclinations, therefore also indicating an almost equal increase in pull out capacity with each increase in the depth of anchorage elements, with any normal stress appointment. However, the percent increase in pullout capacity with each increasing amount of anchorage elements were greatest under the lowest normal stress, which is obvious due to the very small capacity that the plain strip had in the first place.

The lines of Figure 13 are of comparable steepness to the lines of Figure 12, indicating comparable change in pullout capacities with changing normal stress as with changing depth of anchorage elements. Therefore the percents increase in pullout capacity with increasing normal stress were as pronounced as with increasing depth of anchorage elements, for the given range of parameters considered in this study.

Table 4 Pullout capacity over pullout capacity of plain strip versus interaction coefficient

Depth of anchorage elements, cm	Normal stress (kPa)	Pullout capacity (kN)	Pullout capacity divided by pullout capacity of plain strip under the same stress (%)	Interaction coefficient
3	1.61	6.62	366	9.432
2	1.61	5.41	299	7.708
3	2.93	8.73	265	6.835
2	2.93	7.00	212	5.480
1	1.60	3.81	210	5.429
3	4.40	10.36	217	5.401
2	4.40	9.24	193	4.817
3	8.80	16.71	173	4.356
1	2.93	5.56	168	4.353
2	8.80	15.01	156	3.913
1	4.40	7.49	157	3.905
3	13.2	21.59	163	3.752
1	8.80	12.63	131	3.292
2	13.2	18.92	143	3.288
1	13.2	16.73	126	2.907
plain	2.93	3.30	100	2.584
Plain	1.61	1.81	100	2.579
Plain	8.80	9.64	100	2.513
Plain	4.40	4.78	100	2.492
plain	13.2	13.24	100	2.301

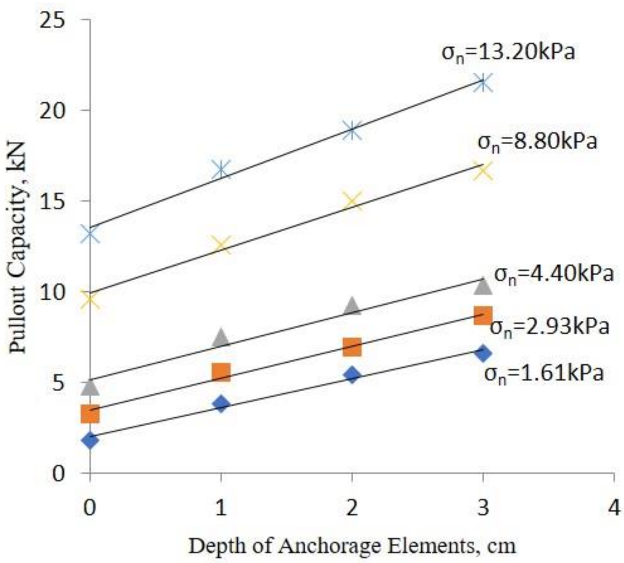


Figure 12 Pullout capacities versus depths of anchorage elements for strips under various normal stresses

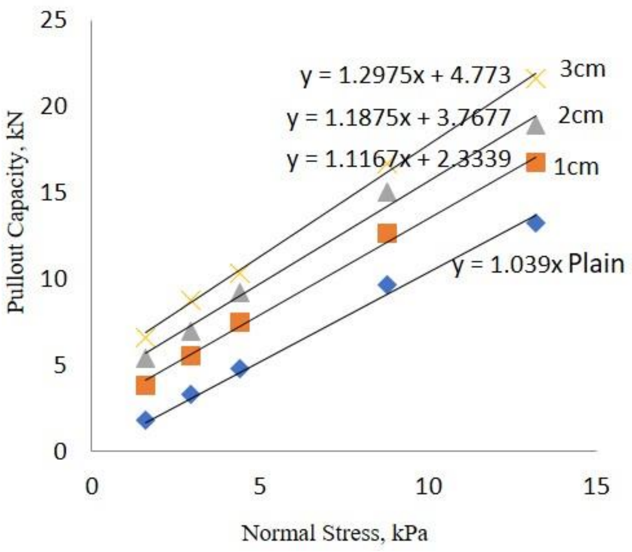


Figure 13 Pullout capacities versus normal stresses for various strips

The plot of apparent shear strengths, which were directly worked out from the pull out capacities, against normal stress for the various appointments of anchorage elements together with the least square regression lines are given in Figure 14. Apparent shear strength is pullout capacity in each case divided by the contact area of a plain strip, regardless of the fact that a strip with anchorage elements would have an increased contact area. The corresponding shear strength equations are given in Table 5 – for the plain strip, the corresponding equation represents the actual strip-sand shear interaction; however, for strips with anchorage elements, these would be the equivalent, apparent, or simplification of the more complex interaction involving the anchorage elements. The anchorage elements have provided an extra pullout capacity due to shear resistances within the sand whereas the capacity of a plain strip had only come from friction along the strip-sand interface.

4. CONCLUSIONS

The pullout tests were carried out on 4 strips. The first was standard, plain metal as commonly used in the MSE structure. Each of the rest was attached with 6 anchorage elements of equal depth and spaced equally on the strip; the depths were 1cm, 2cm, and 3cm. With anchorage elements introduced to the strips, the pullout capacities were found increased by very high percentages, more so under the lower normal stress than under the higher one. Under a normal stress of 1.61 kPa, for the strips attached with 3cm, 2cm, and 1cm deep anchorage elements, the pullout capacities were respectively 3.7, 3.0, and 2.1 times as much as the pullout capacity of the plain strip. On the other hand, under a normal stress of 13.2 kPa, for the strips attached with 3cm, 2cm, and 1cm deep anchorage elements, the pull out capacities were respectively only 1.6, 1.4, and 1.3 times as much as the pullout capacity of the plain strip. Thus the percentage gains in pullout capacity under the low normal stresses were higher than under the higher normal stresses, for any depth of the anchorage elements. The given figures also indicate significant pull out capacity increase with increasing depth of the anchorage elements throughout the whole range of stresses. The results suggest that the pullout capacity a strip in a MSE structure can be enhanced by introducing the anchorage elements, more so for the ones under shallow overburden than for the ones under deeper overburden. Thus attaching anchorage elements to strips destined for shallow embedment could remedy the problem of insufficient pullout capacity that have resulted in compromised quality of existing MSE structures.

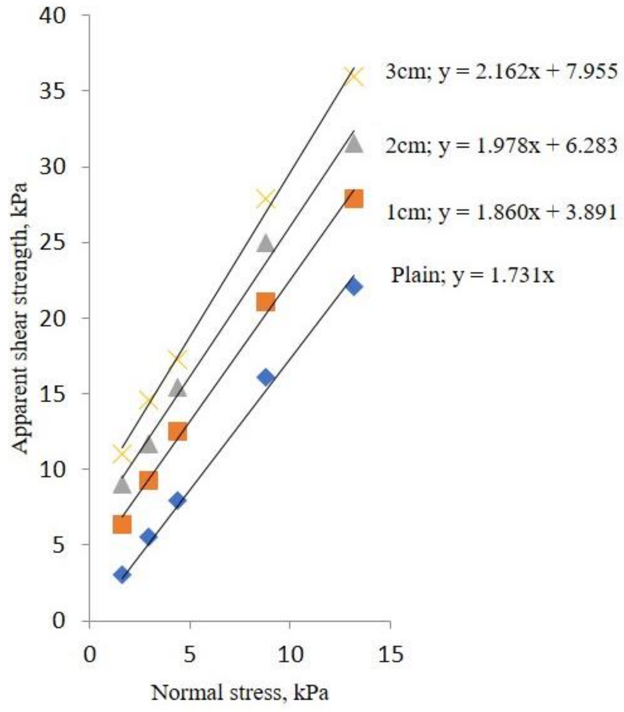


Figure 14 Normal stress versus apparent shear strength

Table 5 Apparent shear strengths of various strips derived from the pullout test results

Strip	**Equivalent shear strength (kPa)**
Plain	$\sigma_n tan60.0° + 0.0$
Attached with 6 anchorage elements, 1cm deep	$\sigma_n tan61.7° + 3.9$
Attached with 6 anchorage elements, 2cm deep	$\sigma_n tan63.2° + 6.3$
Attached with 6 anchorage elements, 3cm deep	$\sigma_n tan65.2° + 8.0$

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