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EFFECT OF SOIL FRICTION ON PERFORMANCE OF HYBRID MECHANICALLY STABILIZED EARTH WALLS WITH LARGE SPACING

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ABSTRACT

Recently, Mechanically Stabilized Earth Walls (MSEW) showed improved performance and acceptance among engineers and contractors, particularly when used to widen roads to handle large traffic or as bridge ramps. MSEW has a number of advantages over conventional concrete reinforcement walls, including; greater heights can be achieved at reasonable cost. The need for higher walls of retaining requires a desire for new techniques. The use of large geogrid spacing is one of these techniques. In this case, there are a number of solutions, including the use of wire mesh to avoid local failure on the wall due to the large spacing. In this scientific paper a study of the behavior of the MSEW was carried out through three forms which are: horizontal displacement, tensile forces in the wire mesh, and shear strain. The elastic model of geogrid which used to reinforcement the soil will be changed. To know the effect of this on the behavior of the MSEW through the three cases that I mentioned previously. There are three cases of Elastic Models used in this study 0.26E2, 0.26E6, 0.26E10. In addition to the experience of changing the friction angle of the reinforced fill, using three angles 42.9°, 33°, 24°. The results showed a reasonable and convincing performance of the study that was used for MSEW behavior at the angle 42.9°. Where made it clear that the MSEW does not need reinforced the soil by geogrid and can be dispensed with completely. On the contrary, the angle of friction was 24° and 33°, where the geogrid had a clear effect on its effect on MSEW behavior. The higher the Elastic model for Geogrid, the better the results for the three cases studied.

Keywords: MSE walls, reinforced soil, geogrid, numerical model, horizontal displacement, tensile force, friction angle.

INTRODUCTION

Mechanically stabilized earth walls (MSEW) are an old-fashioned technique that started to be used about 50 years ago. It was established in the eighties of the twentieth century and began to be involved in civil engineering projects in the USA. His main advantage of using reinforced earth instead of reinforced concrete in performing the function of retaining walls and bridge abutments was the need to develop this technology. This new MSEW technology made it possible for developers to build higher walls than the typical cantilever RC walls. [14, 3]

MSE is one of the most inexpensive and expedient methods of altering the existing material; mechanically stabilizing with kinds of reinforcements by soil mixing. If soil mixing is not feasible or suitable soil content is not made, geotextiles or chemical admixture stabilization may be taken into consideration. Mechanical stabilization allows compaction to interlock with soil-aggregate particles. The gradation of the soil-aggregate mixture must be such that a dense mass is produced when compacted. Geotextiles can be used to boost soil engineering characteristics. [9]

The first use of reinforced soil walls to develop the infrastructure, using mechanically stabilized earth walls [7] in the Unites States (1987), was in a transportation project for the California department of transportation [12].

These have been used as retaining structures and reinforcement components consist of geosynthetic material, metallic, and facing panels. In addition, soil stability and retaining capacity can be strengthened by reinforcement and the reinforced soil retaining walls can be known as composite structures [5].

Because it is made primarily of soil that is often more economical and due to its inherent flexibility the walls have been used more extensively in civil engineering projects over the past 30 years. These were a more attractive alternative to traditional retaining reinforced concrete walls. Therefore (MSEW) has several uses: most notably retaining walls, industrial storage walls, seawalls, and abutments of bridges (Mitchell and Christopher, 1990; Schlosser, 1990; Jones, 1996). To move the stresses between reinforcement and fill and over the interface during friction as well as the passive resistance of the façade particles or a combination of both, it depends on the type of reinforcement that provides tensile resistance and internal imprisonment components. [10, 11].

Considering the empirical knowledge accumulated over the past four decades, either instrumented full-scale prototypes or small-scale models were used to test and design reinforced soil improved by the classic soil plasticity principle (Rankine's and Coulomb'). [6] Several experiments were carried out based on numerical modeling to take into account the validity of idealized wall measurements more general approaches were then developed using numerical analysis than previous proprietary methods. [2] Such studies have helped to learn a lot about the effect of factors (such as compressibility, backfill shear strength, type of facing panels, reinforcement stiffness and geometry of walls) on the performance of reinforced soil walls as well as the knowledge of the performance aspects of interface

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interaction for this type of performance (MSEW) and the stress-strain distributions in it. [2]

On the other side, there is not enough evidence to show associations except for small-or full-scale physical experiments with numerical results from (mostly geosynthetic) reinforced soil walls. Basically, a few carefully prepared experiments were checked by numerical modeling for the walls of the real field [2]. Far from what we described above, the design methods were implemented with a semi-experimental approach to tackle ultimate resistance limits and limit equilibrium analysis in terms of internal and external stability [4.1]. The walls of the reinforced soil are used in highway transport projects, for example; traffic surcharge charges for construction are taken into account to maintain internal and external stability. In Hail City in Saudi Arabia, Figure-1 indicates a height of 9 m, a width of 13.5 m, and a MSEW of 150 m long. This project began in early 2019. In this study will focus on the behavior of the MSEW through the properties of the geogrid, especially the change in the elastic modulus of the geogrid by numerical modeling using FLAC; a FDM-based software. The importance of changing the properties geogrid through the elastic modulus is to know the effect of the impact of three cases: horizontal displacement in front of wall, wire mesh, and the shear strain to the MSEW through which the results are extracted by numerical study. Meixiang *et al*. (2017) presented a study that was used to validate the numerical model. Meixiang conducted an impact study of the MSEW reinforcement using soil reinforcement with two types of geogrid reinforcement and weir mesh with large distances between reinforcement. Given the spacing of the reinforcement between them, the results showed good efficiency; 2 meters long vertically, satisfactory agreements were reached between the numerical and measured results, giving confidence that the numerical models developed can be used to investigate other wall performance where field measurements are not available. The mechanically stabilized earth walls with a large vertical reinforcement spacing of 2 m show reasonable performance based on numerical analysis.

Figure-Error! No text of specified style in document.**.** Constructed MSEW at a highway, Hail Saudi Arabia.

NUMERICAL MODEL

The field study published by Meixiang Gu *et al*, (2017) [8] is utilized to verify the results of the finite difference-based numerical model used in this study.

GEOMETRY AND DEFINITION OF NUMERICAL MODELS

Figure-2 shows the model dimensions, and illustrates the layers of soil reinforcement applied. The structure elements dimensions in MSEW are shown in Table-1.

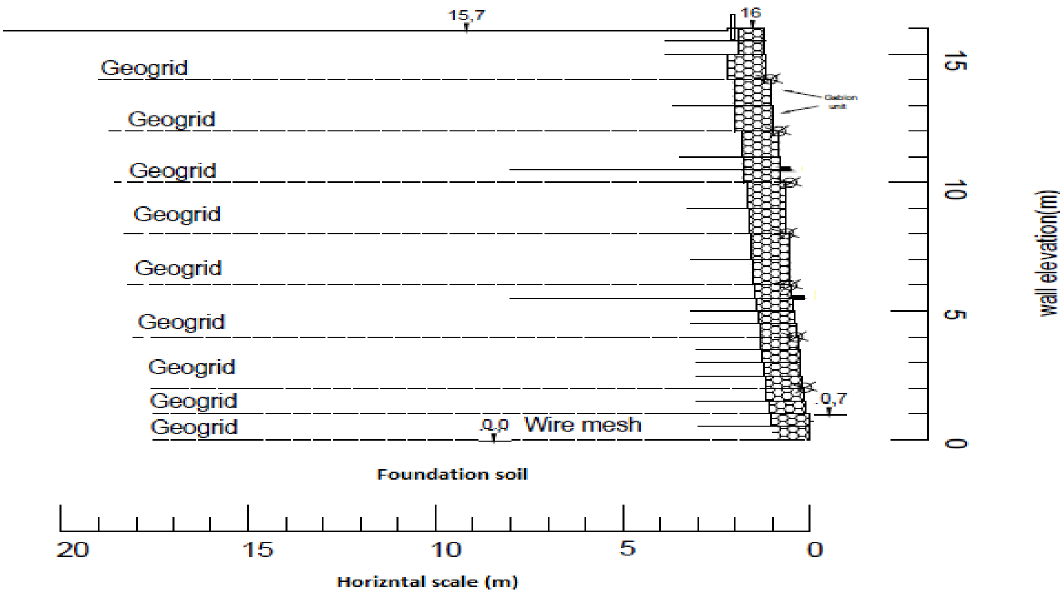

Figure-Error! No text of specified style in document.**.** Instrumentation layout MSEW with hybrid reinforcement.

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Table-1. Structural elements dimension in the MSEW.

Structural elements	Dimensions	Materials
Primary reinforcement	Length : 17.5 m	High strength Geogrid
Secondary reinforcement	Length : 3.0 m	Double twisted steel wire mesh
Gabion unit	0.5*1.0 m(thickness*length) in the ten bottom layers :1.0*1.0m (thickness*length) in the ten upper layers :0.5*0.5m(thickness*length) in the two top layers	Mesh basket filled with boulders

Soil and Reinforcement Properties

The properties of soil and reinforcement used in numerical modeling are shown in Table-2 and 3.

Table-Error! No text of specified style in document.**2.** Properties for primary and secondary reinforcement.

Parameters	Wire mish mesh	Geogrid
Calculation width (m)	1.0	1.0
Number of strips per calculation width	1.0	1.0
Strip width (m)	1.0	1.0
Strip thickness (m)	0.0027	0.0024
Tensile stiffness (KN/m)	10000	6200
Tensile strength(KN/m)	51	412
Elastic modulus (MPa)	3700	2600
Interface normal and shear stiffness(KN/m/m)	90000	90000
Soil interface cohesion (KN/m)	4.0	4.0

Table-1. Soil properties used in the model.

Parameters	Gabion	Reinforced fill	Foundation and retained soil
Unit weight (KN/m^3)	17.0	20.5	18.0
Cohesion (KPa)	560	5	7500
Friction angle (degrees)	45.0	42.9	23.0
Dilation angle (degrees)	—	6.0	—
Elastic modulus (MPa)	20	40	20000
Poisson’s ratio	0.30	0.30	0.23

BOUNDARY CONDITIONS

The following summarize the boundary conditions considered in the model:

a) The left and right sides of the problem model are allowed to move only in the vertical direction.

b) The bottom of the problem model is not allowed to move in either horizontal or vertical directions.

VALIDATION OF NUMERICAL MODEL

In order to verify the results of the numerical model, two comparison-steps were conducted between the results of the numerical model to the field results published by Meixiang *et al*. (2017). Figure-3 shows the first comparison between the values of tensile forces recorded in the wire mish at an elevation 4m with different distance from the wall facing within the MSE wall and the values resulted from the numerical model. The figure shows that at 1.76 m distance from facing wall the value of field measure is 13.9 Kn while the numerical model is 12.77 Kn. At 2.5 m distance from facing wall, the value of field measure is 7.9 Kn while the numerical model is 8.3

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Kn These results show a good comparison with the difference ranging 4 % - 8%, which proves that the numerical model is able to simulate the behavior of that MSE wall in the field.

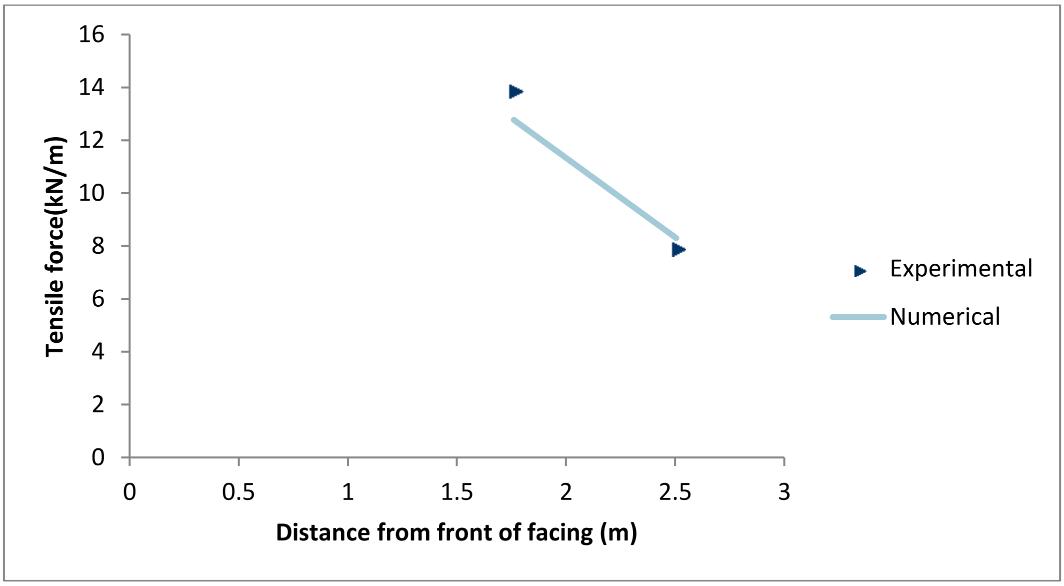

Figure-Error! No text of specified style in document.**.** Comparison of wire mish tensile force results in experimental test and numerical
model at 4.0m high.

Figure-4 shows the second comparison between the values of tensile forces recorded in the geogrid at an elevation 8 m with different distance from the wall facing within the MSE wall and the values resulted from the numerical model. The figure shows that at 2m distance from facing wall the value of field measure is 12 Kn while the numerical model is 11.2 Kn. At 7m distance from facing wall the value of field measure is 5.5 Kn while the numerical model is 6.8 Kn. at 10 m distance from facing wall the value of field measure is 5 Kn while the numerical model is 5.8 Kn. For different distance from the face of the wall. Results show good agreement between both results this strength verification of the numerical model.

Table-Error! No text of specified style in document.**.** Geogrid tensile force results in experimental test and numerical model at 8.0m high.

	Distance from front of facing (m)		
Type of test	**2**	**7**	**10**
Tensile force in experiment (kN)	12	5.5	5
Tensile force in numerical model(kN)	11.2	6.8	5.8

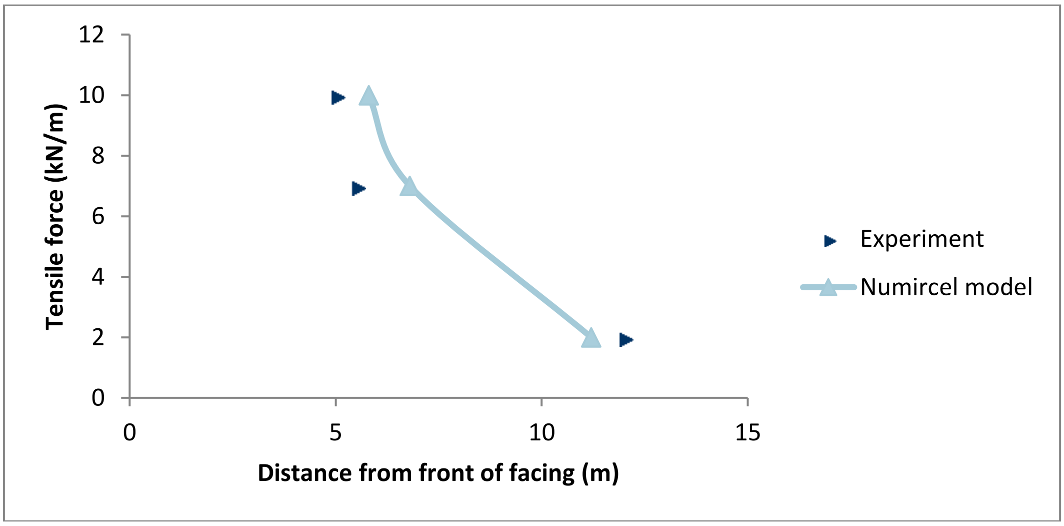

Figure-4. Comparison of geogrid tensile force results in experimental test and numerical model at 8.0m high.

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RESULTS AND DISCUSSIONS

Horizontal Displacement

The main objective, in this case, is to measure the state of the horizontal displacement toward the front of the wall. This is by changing a type of geogrids properties, which is an elastic modulus, too weak, medium, and strong. Also, three friction angles were used for the reinforced fill soil and knowing how the front wall was affected by these changes, and is the wall needed to use geogrid in all cases of changing friction angles. Three cases of elastic modulus were used for geogrid 0.26E2, 0.26E6, and 0.26E10 all of them were tried with three friction angles 24°, 33°, and 42.9°. Figure-5 shows the shape of the Horizontal displacement, and the effect of the clear wall facade is shown in blue.

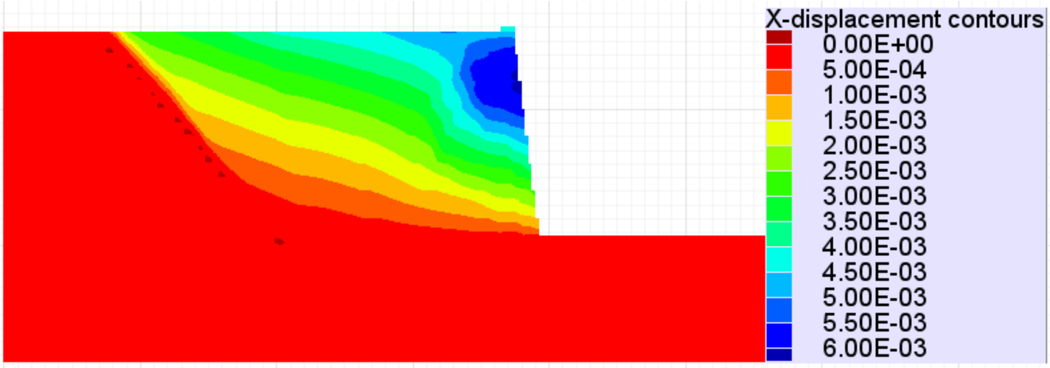

Figure-5. Horizontal displacement using friction angle = 42.9° and Elastic modulus = 0.26E10.

In Table-4 all the results obtained in the study were included for the sake of comparisons. In Figure-6, a comparison of two angles of friction 42.9°, 33° was made The blue graph expresses 42.9° and indicates that the wall facade was not affected by the displacement in a manner that calls for the use of geogrid. This means that the friction angle of 42.9° did not need to use geogrid with all its properties. Quite the opposite, the angle of friction 33°, which began to use geogrid very important, and with certain properties, as the horizontal displacement increases when the geogrid properties are weakens. This indicating the need for friction angle 33° for the geogrid, and that is more safety principle.

Table-Error! No text of specified style in document.**.** Horizontal displacement results with different angles and elastic modulus.

Friction angle	Horizontal displacement using Elastic modulus = 0.26E2	Horizontal displacement using Elastic modulus = 0.26E6	Horizontal displacement using Elastic modulus = 0.26E10
42.9°	0.014 m	0.014 m	0.006 m
33°	0.24 m	0.275 m	0.00475 m
24°	17 m	30 m	0.009 m

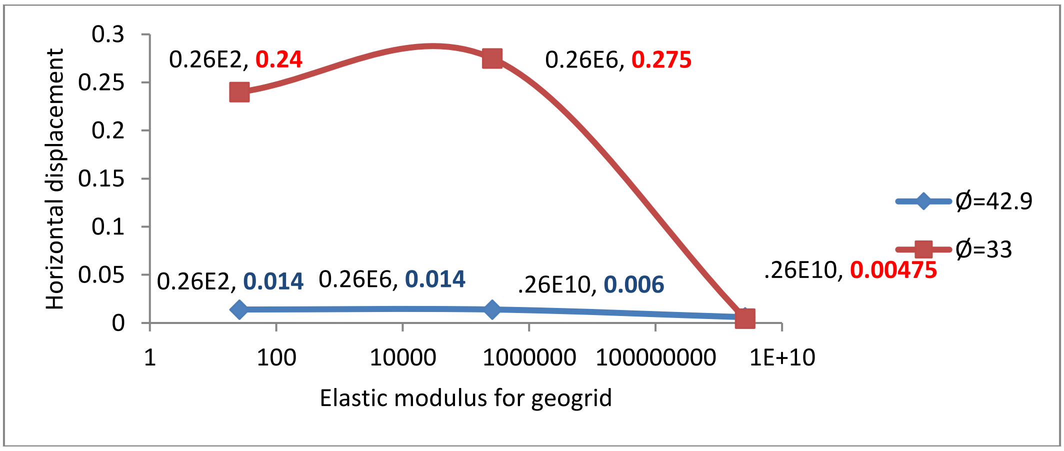

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Figure-6. Compression of horizontal displacement results with different elastic modulus using Ø=42.9°, Ø=33°.

In the following Figure-7, the comparison of the angle of friction 24°, which we could not add with the previous comparisons, is due to the high displacement amount until it reaches 17 M in the case of using the elastic modulus = 0.26E2 for geogrid. In the case of elastic modulus = 0.26E6 is 30 m. In the case of elastic modulus = 0.26E10 the amount of displacement was very small compared to Previous cases which is 0.009 m. Based on these results, the effect of the use of geogrid is evident in the last case, in which the elastic modulus is high, which limits the displacement amount very high.

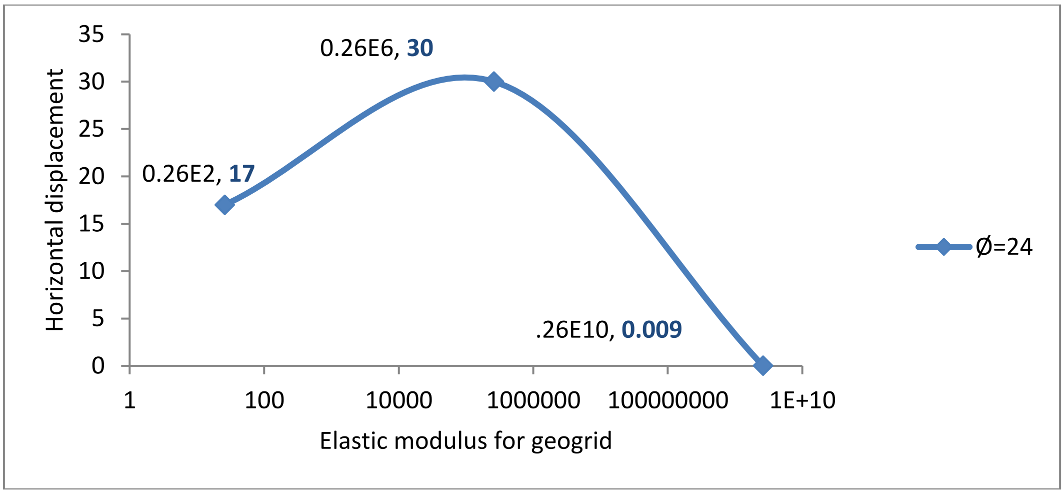

Figure-7. Compression of horizontal displacement results with different elastic modulus using Ø=24°.

Wire Mesh

Wire mesh is used in the wall to resist local failure caused by geogrid spacing. The tensile force in the wire mesh is much less than the tensile forces in the geogrids, due to the geogrids resistance in addition to its high properties. In this study, comparisons of the tensile forces in the wire mesh by changing the elastic modulus in geogrid to 0.26E2, 0.26E6, and 0.26E10. Three friction angles of the reinforced fill soil, 24°, 33°, and 42.9° were also tried. In the following Figure-8, the location of the wire mesh is indicated at the front end of the wall.

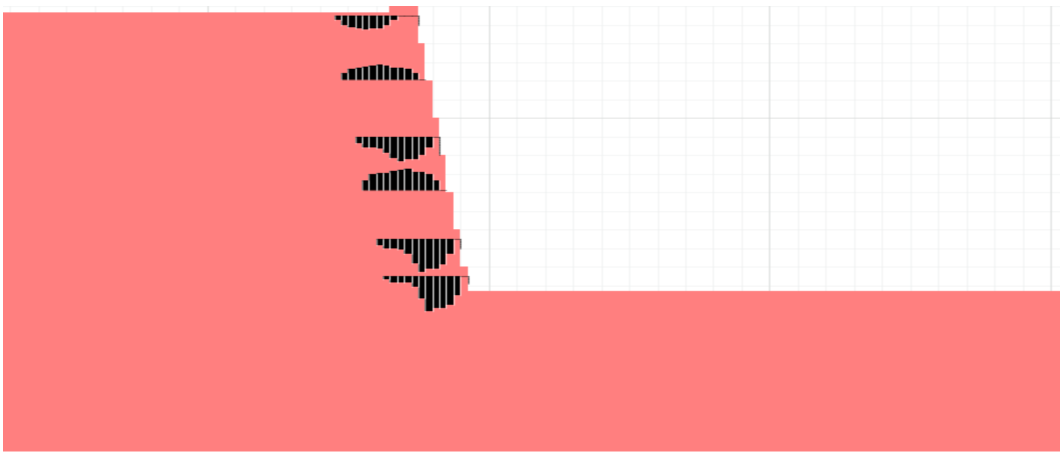

Figure-8. Maximum tensile force using friction angle = 42.9° and Elastic modulus = 0.26E10.

In Table-5 the results obtained in this comparison are illustrated. Figure-9 shows the diagram on the friction angle 42.9°, it is clear that the result similar for the wire mesh tensile forces is evident despite the variation in geogrid. This is because of the high friction angle of the soil. Whereas in the two cases in which the friction angle is used 24° and 33°, the tensile strength increases up to 120% in cases where the elastic modulus is weak at 0.26E2, 0.26E6. While in the elastic modulus 0.26E10, the results are very close to the results of the friction angle 42.9.

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Table-6. Maximum tensile force results with different angles and elastic modulus.

Friction angle	Maximum tensile force using Elastic modulus = 0.26E2	Maximum tensile force using Elastic modulus = 0.26E6	Maximum tensile force using Elastic modulus = 0.26E10
42.9°	51.81 kn	51.78 kn	33.23 kn
33°	109.7 kn	112.1 kn	42.43 kn
24°	123.8 kn	141.1 kn	56.73 kn

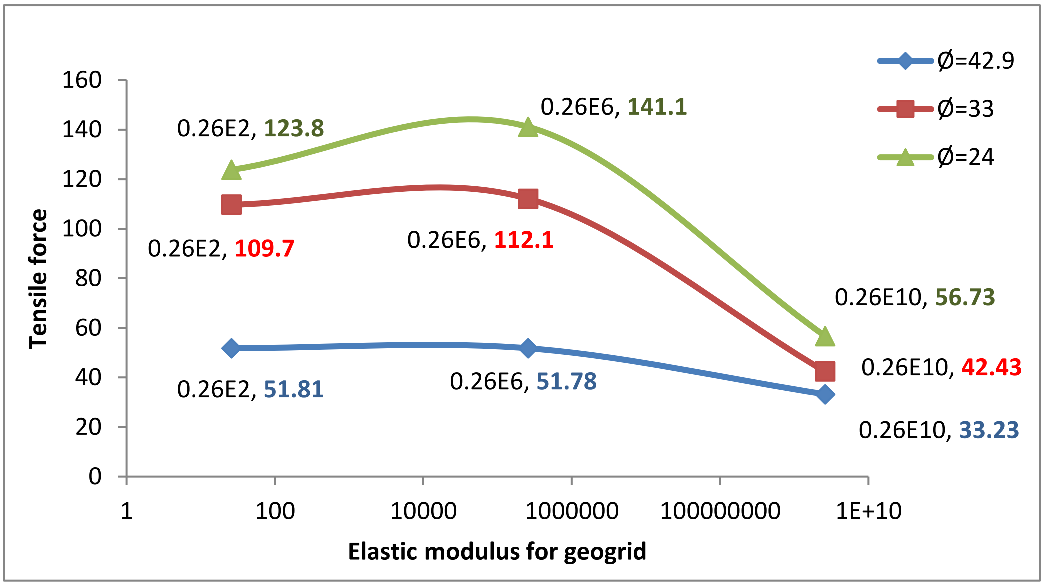

Figure-9. Compression of maximum tensile force results with different elastic modulus using Ø=42.9, Ø=33, Ø=24.

Shear strain increment

Knowing the wall shear strain is one of the important situations in behavior of MSEW, as it always exists in two different locations. The sites where shear strain is located at the front of the wall which take #1 in Figure-10, as well as between the reinforced fill and retained soil which take #2. A study was made to know the effect of geogrid on shear strain and to know the effect of this on them. Three cases of modulus Elastic were used they are 0.26E2, 0.26E6, and 0.26E10 with a difference in the friction angles of the reinforced fill 24°, 33°, and 42.9°.

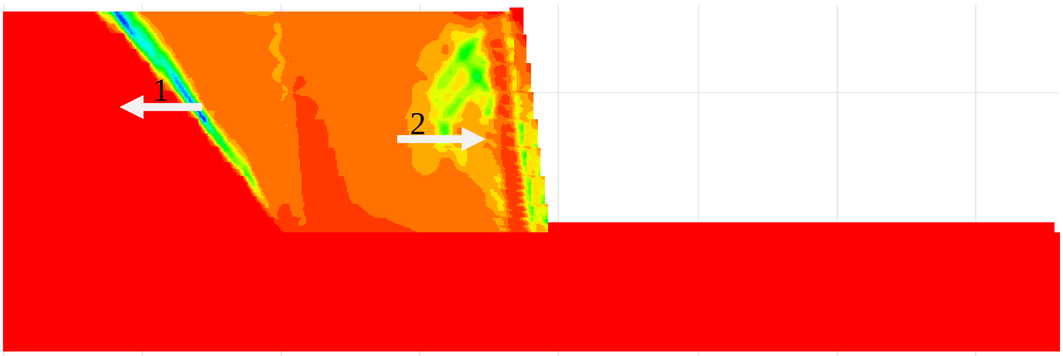

Figure-10. Shear srtain increcment using friction angle = 42.9° and Elastic modulus = 0.26E10.

Table-7 reviews the results obtained in this study. It is evident in Figure-11 that the change in geogrid properties does not affect shear stress due to the use of high friction angle 42.9°. Whereas in the friction angle 33°, the difference of the geogrid properties change on the shear strain. The less the properties of geogrid, the greater the stresses of strain, except in the case when the

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efficiency of geogrid was high, as the shear stresses were 0.001.

Table-7. Shear srtain increcment results with different angles and elastic modulus.

Friction angle	**Shear strain increment using Elastic modulus = 0.26E2**	**Shear strain increment using Elastic modulus = 0.26E6**	**Shear strain increment using Elastic modulus = 0.26E10**
42.9°	0.009	0.009	0.0019
33°	0.22	0.25	0.001
24°	15	24	0.00325

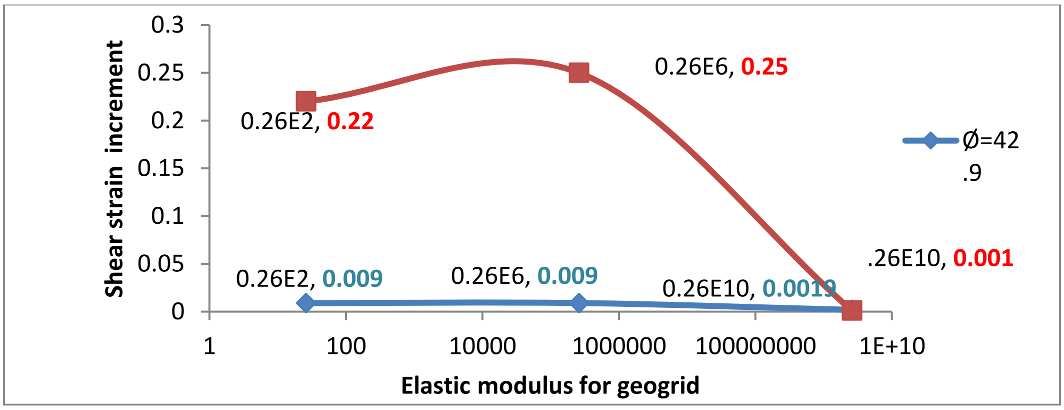

Figure-11. Compression of Shear srtain increcment results with different elastic modulus using Ø=42.9°, Ø=33°.

In Figure-12 a comparison of shear strain using the friction angle 24°. The results showed that there is high shear strain in the two cases where the effectiveness of the geogrid was low at elastic modulus 0.26E2, 0.26E6. As for the case of elastic 0.26E10, the shear strain was very low compared to the previous two cases.

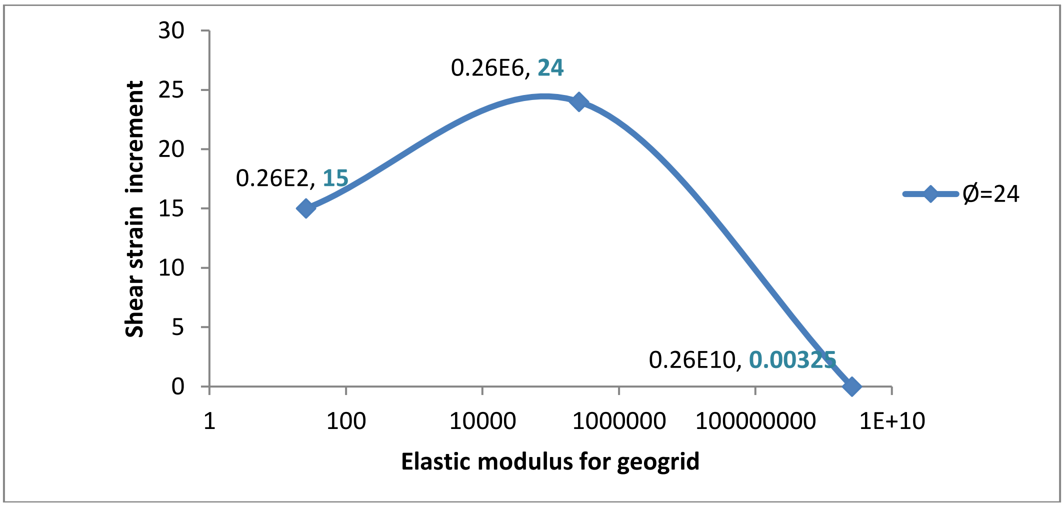

Figure-12. Compression of Shear srtain increcment results with different elastic modulus using Ø=24°.

CONCLUSIONS

The numerical results that were verified utilizing field results, highlight the Horizontal displacement in front of the MSEW, values of the tensile force in the wire mesh, shear strain in hybrid mechanical stabilized earth wall with the variation of the strength of the reinforced fill. This study shows that the soil friction angle affects the tensile force in the behavior of MSEW. Also the effect of the amount of Elastic model for geogrid was evident. The more effective the Elastic model, the better the results.

The friction angle 42.9° not needs geogrid, as the results showed very reasonable performance without using it. It became clear the effect of the Elastic model for geogrid on friction angle 33° and 24°. If the elastic modulus of geogrid is weak, the effect on the two angles increases. The horizontal displacement in the face of

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MSEW was not affected except in the 33°, 24° angles in which the geogrid was ineffective. Also, the wire mesh tensile forces could bear up to 120% in case the geogrid was ineffective in the 33°, 24° angles. Finally, the results showed the need for shear strain for geogrid at 33°, 24°angles.

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