VOL. 15, NO. 5, MARCH 2020 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

EFFECT OF SOIL FRICTION ON GEOGRID MAXIMUM TENSILE FORCE IN HYBRID MECHANICALLY STABILIZED EARTH WALLS WITH LARGE SPACING

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ABSTRACT

Mechanically Stabilized Earth walls (MSEW) have been showing improved performance and acceptance level among engineers and contractors recently particularly when used to widen roads to accommodate large traffic or as ramps for bridges. MSEW have a number of advantages over traditional reinforcement concrete walls among which; it can reach more heights at a reasonable cost. The need for higher retaining walls requires the tendency for new techniques. One of such techniques is the use of large geogrid spacing. In such a case there is a number of solutions, among which is the use of wire mesh to prevent local failure at the face of the wall due to the large spacing. This paper investigates the maximum tensile force in hybrid MSEW over the height of the wall as well as along the geogrid length for different soil friction angles. Finite difference analysis is used to model a 16 m height instrumented MSEW. Mohr-Coulomb is used to model the soil as well as the gabions face panels, interface elements were used between the geogrids and the soil. Verification was done using instrumented readings from the field. Five friction angles, Ø=22° Ø=26° Ø=32° Ø=36° Ø=42.9° were used for the parametric stud, and a traffic load of 20 KN was included in the investigation. Results of the study show that the maximum tensile force in the geogrids increases as the strength of the soil is reduced by decreasing the friction angle. The maximum tensile force in the geogrid varies with the geogrid vertical position within the wall. The maximum tensile force in the geogrid was found to be at around one-third of the wall height. The position of the maximum tensile force in a geogrid tends to move away from the face of the wall as the angle of friction decreases.

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

INTRODUCTION

The mechanically stabilized earth walls (MSEW) is an old-new technology that started to be utilized more than 50 years ago. It was developed and started to be involved in the civil engineering projects in the USA in the eighties of the twentieth century. The need to develop this technology came up became of its main advantage of using the reinforced earth in place of reinforced concrete in performing the function of retaining walls and bridge abutments. This new technology of MSEW allowed developers to construct higher walls than the typical cantilever RC retaining walls. [14, 3]

MSE is one of the most economical and expedient method of altering the existing material; mechanically stabilizing through soil mixing with sorts of reinforcements. If soil blending is not feasible or a satisfactory soil material is not produced, geotextiles or stabilization of chemical admixture maybe considered. Mechanical stabilization causes soil-aggregate particles to be interlocked by compaction. The soil-aggregate mixture grading must be such that when compacted, a dense mass is produced. Geotextiles can be used to enhance the characteristics of soil engineering. [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].

They were used as retaining structures, so reinforcement elements are made up of geosynthetic material, metallic, and facing panels. Moreover, soil stability and retain backfill capacity can be improved through reinforcements and considering the reinforced soil retaining walls to be composite structures [5].

Because it is made mainly of soil which is often more economical and because of its inherent flexibility; over the past 30 years, the walls have been more widely used for civil engineering projects. They have been a more attractive alternative to usual reinforced concrete retaining walls. Therefore, (MSEW) have several uses: most notably retaining walls, industrial storage walls, seawalls, and bridges abutments (Mitchell and Christopher, 1990; Schlosser, 1990; Jones, 1996). In order to transfer the stresses between reinforcement and fill and over the interface during friction as well as the passive resistance of the facade particles or a combination of both, it depends on the kind of reinforcement which provides components of resistance to tensile and internal imprisonment. [10, 11]. Given the empirical knowledge formed over the past four decades, the analysis and design of reinforced soil enhanced by classic theory of soil plasticity (Rankine's and i.e., Coulomb's) were based on either instrumented full-scale prototypes or small-scale model. [6] Many studies have been conducted depending on numerical modeling of taking into account the validity of measurements of idealized walls. Then, more general methods have been developed than earlier previous proprietary methods using numerical analysis. [2] These studies have helped learning a lot about the effect of factors (such as the compressibility, the backfill shear strength, the type of facing panels, the reinforcement stiffness, and the geometry of wall's) on the performance of reinforced soil walls as well as the knowledge of the interface interaction aspects of performance for this kind of (MSEW) and the stress-strain distributions in it. [2]

On the other hand, there is no sufficient evidence to show comparisons except the small- or full-scale physical experiments of (mostly geosynthetic) reinforced soil walls with numerical results. At the end, a few carefully prepared experiments which were validated for the walls of the real field used by numerical modeling [2]. Far from what we have mentioned above, the design methods have been adopted to address ultimate limits of resistance and limit equilibrium analysis in terms of internal and external stability using a semi-experimental approach [4.1]. The walls of the reinforced soil are found in highway transporting projects. For example, traffic surcharge loads are taken into account for construction to maintain internal and external stability. Figure-1 shows a 9 m height, a 13.5m width, and a 150m length MSEW in Hail City in Saudi Arabia. This project was started at the beginning of 2019. In this study will focus on the behaviour of the MSEW through the properties of the soil, especially the change in the angle of friction of the soil by numerical modeling using FLAC; a FDM-based software. The importance of changing the properties soil through the angle of friction is to know the effect of the impact of soil compaction to the MSEW through which the results are extracted by numerical study. The study presented by Meixiang *et al.* (2017) was used to verify the numerical model. Meixiang conducted a study of the impact of the reinforcing MSEW by using soil reinforcement with two types of reinforcement geogrid and wair Mesh with large distances between reinforcement. The results showed good efficiency despite the spacing of the reinforcement between them, 2 meters long vertically, satisfactory agreements have been 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. Based on numerical analysis, the mechanically stabilized earth walls with a large vertical reinforcement spacing of 2 m show reasonable performance.

Figure-1. 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 dimension in MSEW is shown in Table-1.

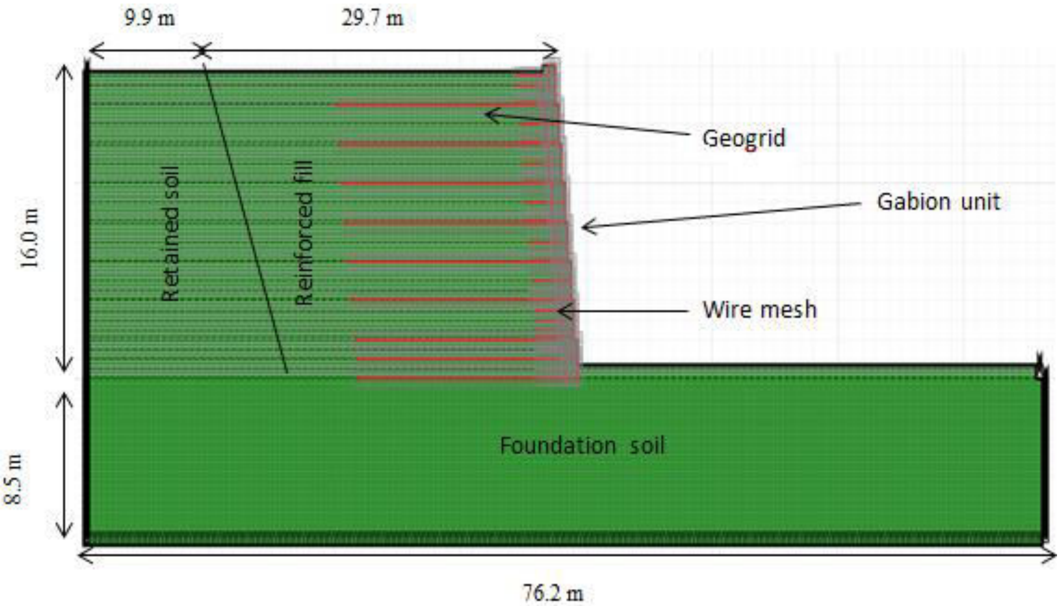

Figure-2. Schematic of the MSEW with hybrid reinforcement.

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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-2. Properties for primary and secondary reinforcement.

Parameters	Wire mesh 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-3. 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 the wall displacement recorded in the field and the displacement values resulted from the numerical model. The figure shows that at a height of 1.5 m, the wall displacement was recorded as 9.76 mm in the field while the numerical model resulted in a value of 10.9 mm. At a height of 3.0 m; the wall displacement was recorded as 27.44 mm in the field while the numerical model resulted in a value of 30 mm. At a height of 8.6 m the field displacement was recorded as 32.20 mm while the numerical model showed a displacement of 35.33 mm. These results show a good

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comparison with the difference ranging 8.5 % - 11.2%, which proves that the numerical model is able to simulate the behaviour of that MSE wall in the field.

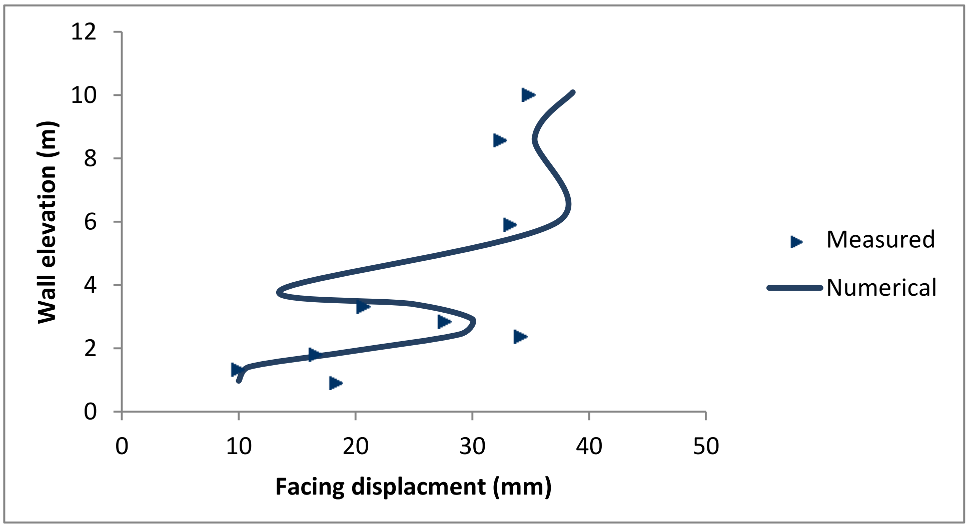

Figure-3. Experimental and numerical horizontal displacements of the wall facing.

Figure-4 shows the second comparison between the values of tensile forces recorded in the geogrid at an elevation 2 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 2 m distance from facing wall the value of field measure is 8 Kn while the numerical model is 6.86 Kn. At 4 m distance from facing wall the value of field measure is 14.9 Kn while the numerical model is 11.71 Kn. at 6 m distance from facing wall the value of field measure is 2.8 Kn while the numerical model is 6.1 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-4. Geogrid tensile force results in experimental test and numerical model at 2.0m high.

	Distance from front of facing (m)		
Type of test	**2**	**4**	**6**
Tensile force in experiment (kN)	8	14.90	2.80
Tensile force in numerical model(kN)	6.86	11.71	6.1

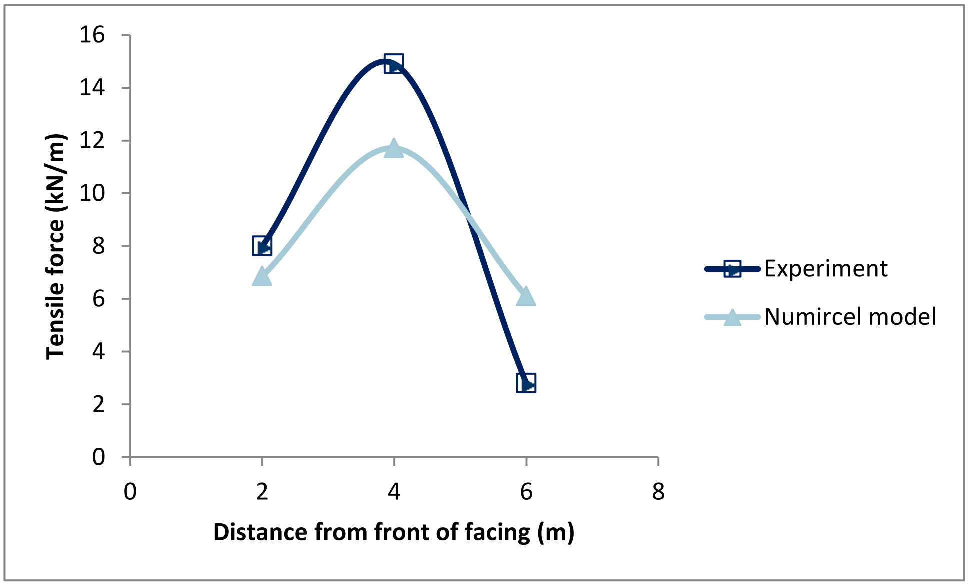

Figure-4. Comparison of geogrid tensile force results in experimental test and numerical model at 2.0m high.

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RESULTS AND DISCUSSIONS

The main objectives in this section are to show the performance of the geogrid in the MSEW. As well as comparing the results of tensile forces with different friction angles for two cases one without any surcharge and another case for 20KN/m^2 traffic loading. Five different friction angles was used in this study, 42.9^o, which was the same for the field model case that was used in this study for the verification of the numerical model, the other four friction angles were, 36^o, 32^o, 26^o, and 22^o, the five cases were chosen to present five different sandy soil strengths.

In Figures-5and-6, a comparison is be made between the friction angles of 22° and 42.9°, to see the effect of the tensile forces on geogrid. In both angles it is evident that the tensile forces did not affect geogrid # (1) due to the dredge. Also, in both angles, the tensile forces begin to increase from geogrid # (2) and # (3) until one third of the wall is raised to geogrid # (4). The tensile force values differ between the two angles, with the max values being at angle 22° and the lowest at angle 42.9°. The max tensile value at angle 22° is 99 Kn and is 65% precent lower at friction angle 42. °9 until it reach 34.65. The max tensile values are located near the wall façade of the two angles in all geogrids except for 8 and 9 geogrids where the tensile forces begin to move slightly away from the wall facade. It is possible to dispense with the last part of the geogrid 1 to 4 due to the presence of a clear effect of the tensile forces. On the contrary, geogrid # (5) to # (9), where the effect of the tensile forces along the entire geogrid.

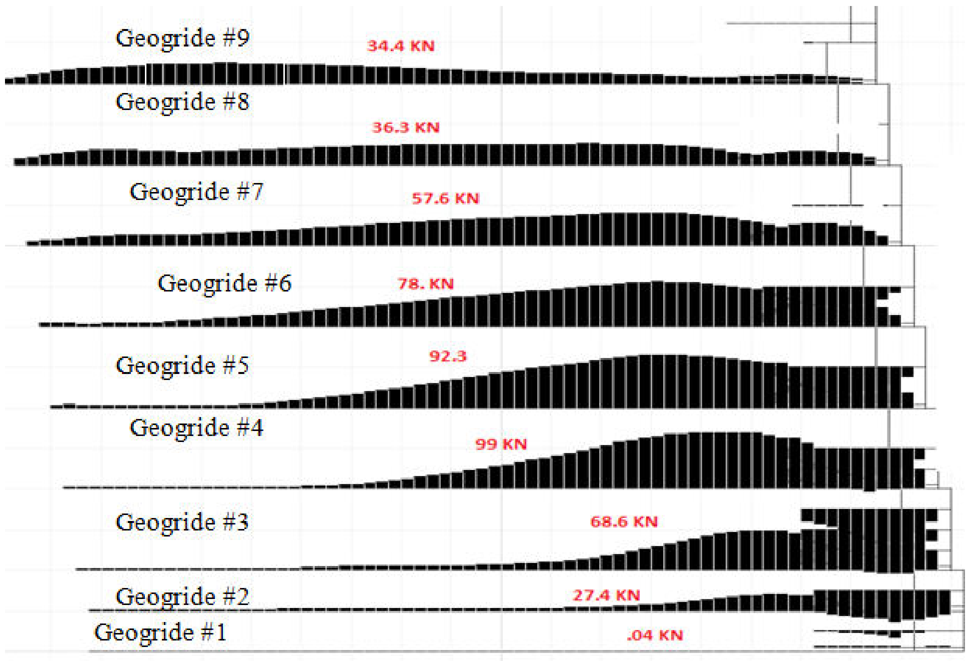

Figure-5. Maximum tensile force in the geogrids for friction angle = 22°.

ISSN 1819-6608
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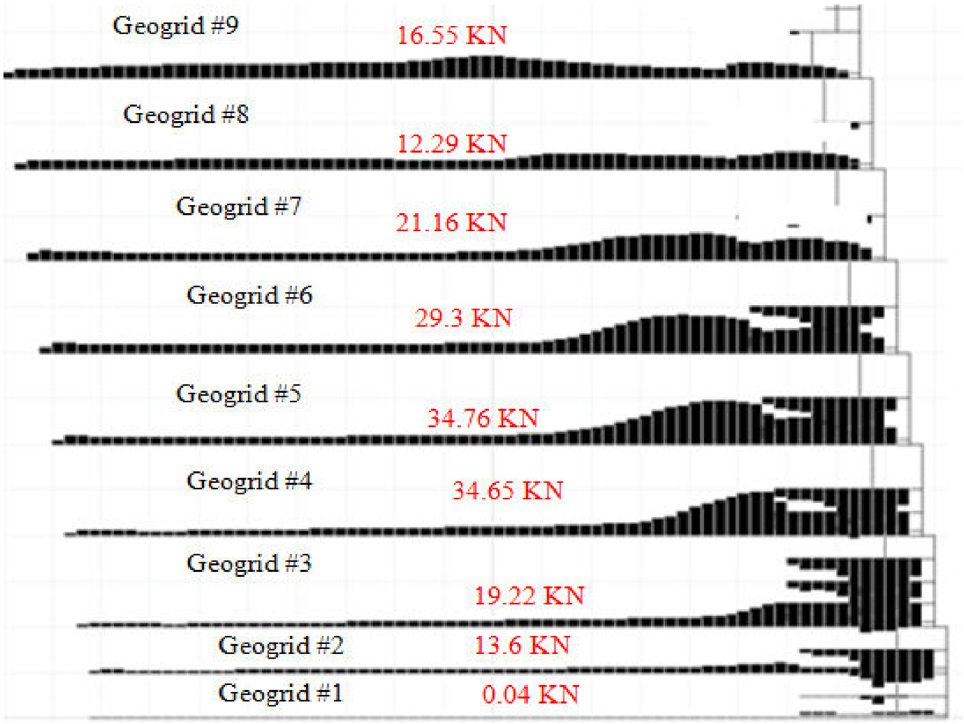

Figure -6. Maximum tensile force in the geogrids for friction angle = 42.9°.

Table-5 shows the results of the first case which is no surcharge is applied and only own weight is demonstrated in this case. The results are for the maximum tensile force in the different geogrids for each friction angles at the different elevation for the same wall configuration. Geogrid 1 was completely ineffective at all friction angles as it is below the dredge level. The tensile forces present in the geogrid decrease as the friction angle increases as shown in both Table-5 and Figure-7 Tensile forces increase in geogrid with the increase in its elevation within the wall, until it reaches 4m height about one third of the clear height. The tensile force will gradually decrease after that. The results showed that the last part of the length of the geogrid can be dispensed with in geogrid one to four. On the other hand more development length is recommended in the upper geogrids. This could be due the less soil that these upper layers are experienced.

Table-5. Table showing the results of tensile forces by changing the friction angles.

Order of geogrid	Elevation of geogrid (m)	Ø=22°	Ø=26°	Ø=32°	Ø=36°	Ø=42.9°
1	0	0.04 KN	0.04 KN	0.04 KN	0.04 KN	0.04Kn
2	1	27.4 KN	22.9 KN 1	18.3 KN	16.8 KN	13.6 KN
3	2	68.6 KN	54.8 KN	38 KN	30.2 KN	19.22 KN
4	4	99 KN	76.7 KN	54.5 KN	44.4 KN	34.65 KN
5	6	92.3 KN	70.6 KN	51.8 KN	43.6 KN	34.76 KN
6	8	78 KN	60.6 KN	44.7 KN	37.4 KN	29.3 KN
7	10	57.6 KN	44.5 KN	33.8 KN	28.3 KN	21.16 KN
8	12	36.3 KN	28.5 KN	23.19 KN	18.7 KN	12.29 KN
9	14	34.3 KN	28.1 KN	23.11 KN	20.13 KN	16.55 KN

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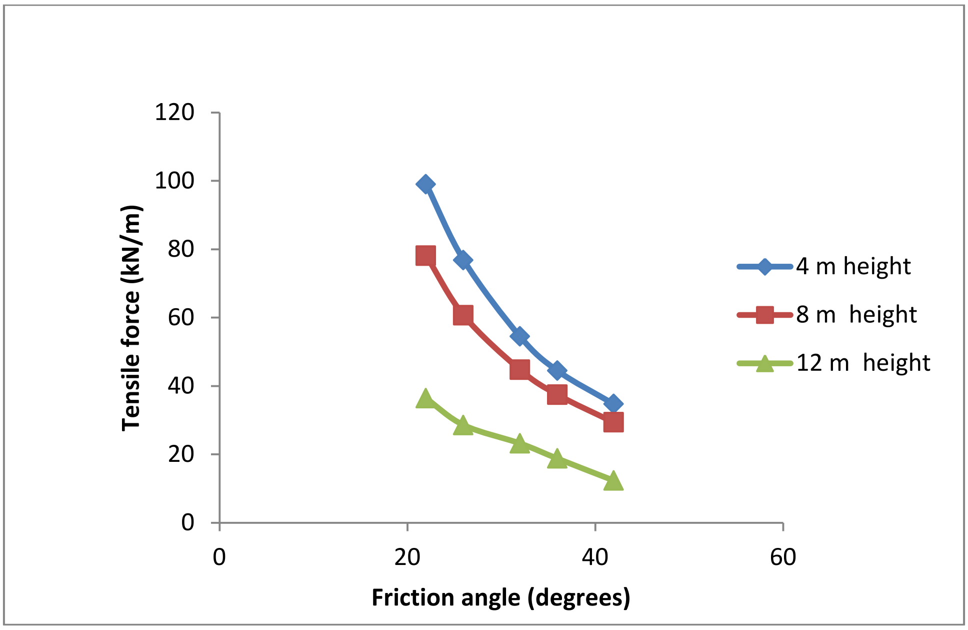

Figure-7. Maximum tensile force in geogrid for different friction angles at different heights.

Figures-8 through-10 and Table-6 shows the results for the second case of the MSEW used in this study. In this case 20KN/m2 was applied as uniform load on the top of the retained and the reinforced portions of the soil. All other parameters and dimensions are the same as for the no surcharge case. Overall the increase in all geogrids in all elevations was less than 20% with respect to the case of no surcharge. Away from this all three figures and the table have the same trends as for the case of no surcharge.

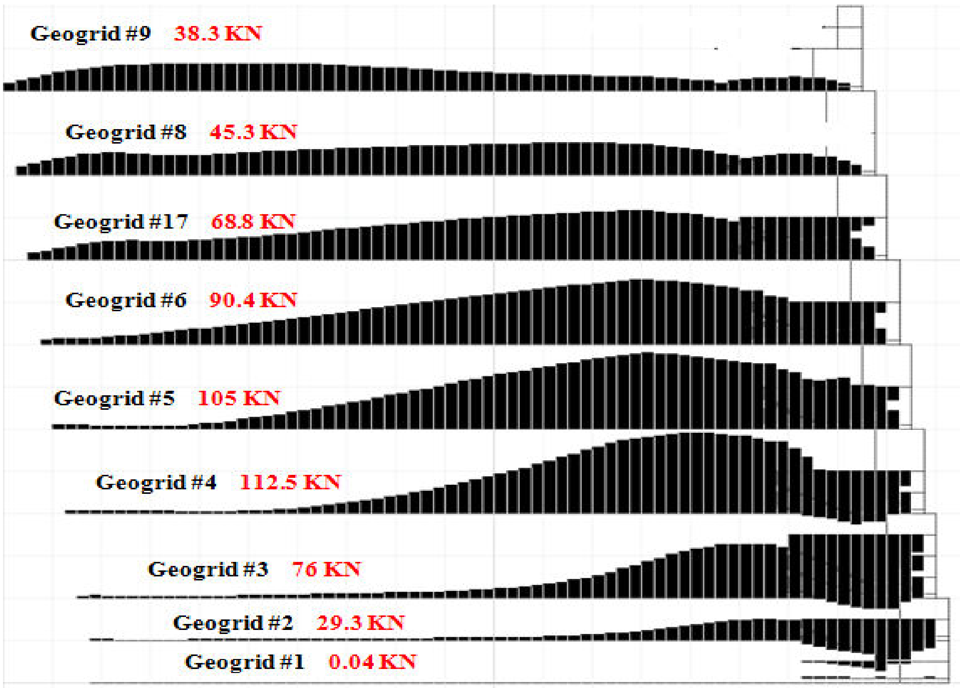

Figure-8. Maximum tensile force in the geogrids for friction angle = 22°
(Case of 20KN/m2 traffic load).

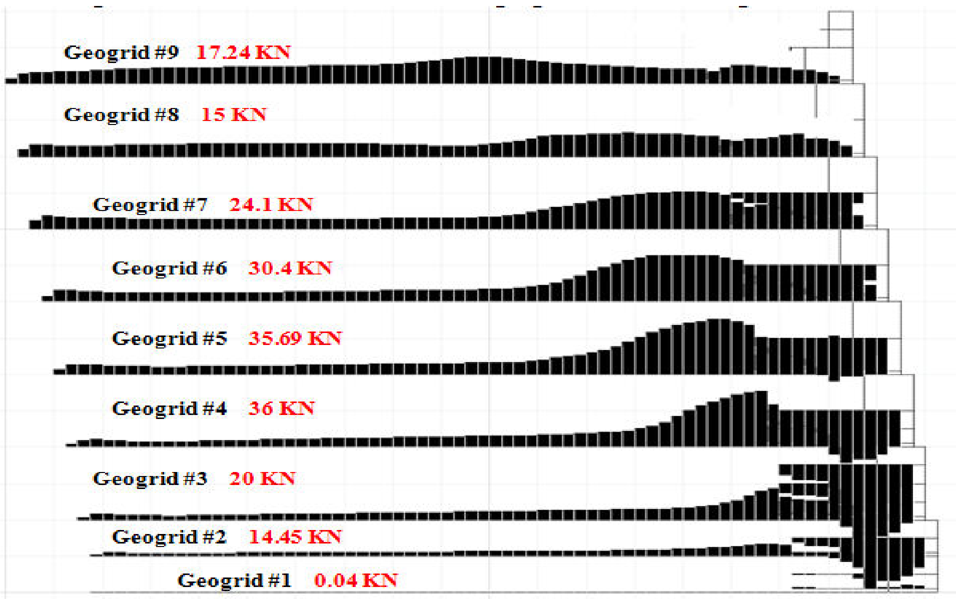

Figure-9. Maximum tensile force in the geogrids for friction angle = 42.9° (Case of 20KN/m2 traffic load).

Table-6. Maximum tensile forces in Geogridswith different friction angles(Case of 20KN/m2 traffic load).

Order of geogrid	Elevation of geogrid (m)	Ø=22°	Ø=26°	Ø=32°	Ø=36°	Ø=42.9°
1	0	0.04 KN	0.04 KN	0.04 KN	0.04 KN	0.04Kn
2	1	29.3 KN	25.04 KN	19.91 KN	18.15 KN	14.45 KN
3	2	76 KN	60.74 KN	41.93 KN	32.96 KN	20 KN
4	4	112.5 KN	86.04 KN	60.77 KN	48.33 KN	36 KN
5	6	105.7 KN	81.87 KN	58.7 KN	47.8 KN	35.69 KN
6	8	90.4 KN	71.66 KN	52.35 KN	43.21 KN	30.4 KN
7	10	68.8 KN	55.36 KN	41.47 KN	34.65 KN	24.1 KN
8	12	45.34 KN	37.78 KN	29.25 KN	24.06 KN	15 KN
9	14	38.32 KN	33.58 KN	26.94 KN	23.34 KN	17.24 KN

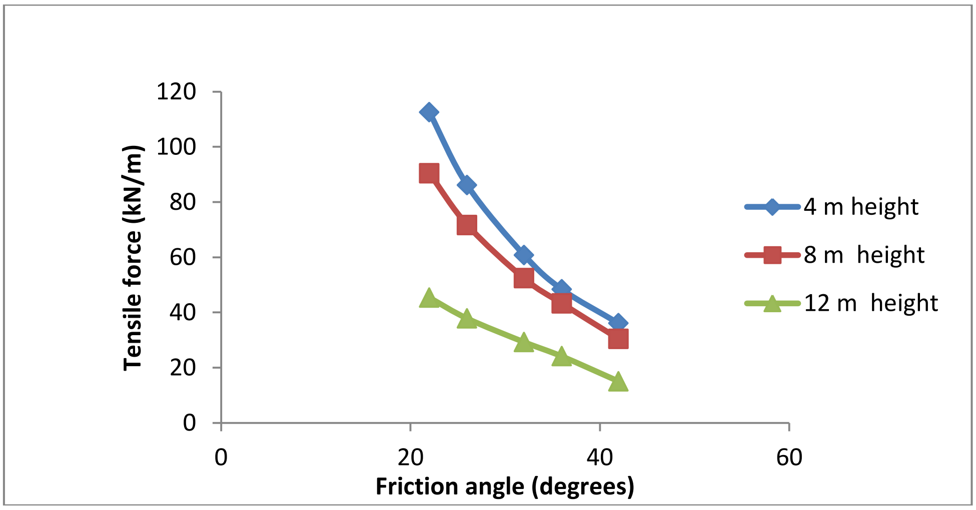

Figure-10. Maximum tensile force in geogrid for different friction angles at different heights (Case of 20KN/m2 traffic load).

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CONCLUSIONS

The numerical results that were verified utilizing field results highlight the values of the tensile force in the geogrids 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 geogrid. As the friction angle increases, the tensile force decreases. Also, the level of reduction of the tensile force in the geogrid decreases as the friction angle increases. The effect of reduction varies with the vertical position of the geogrid within the wall. The maximum tensile force in the geogrid was found at one third of the wall height. The position of the maximum tensile force within the geogrid moves away from the wall-facing Gabions as the friction angle decreases. Rankine failure surface angle with the facing panels increases as the friction angle decreases. The tensile force increases along the full length of the geogrid as the friction angle decreases showing that the geogrid tends to be fully utilized along large portions of it.

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