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EFFECT OF GEOSYNTHETIC STIFFNESS AND SURCHARGE LOAD ONSTABILITY OF REINFORCED EARTH SEGMENTAL WALLS

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ABSTRACT

Geosynthetic-Reinforced soil wall with modular blocks have been extensively employed in the construction of highways and railways due to its good performance, convenient construction, and easy quality control. The service limit-state design requires accurate estimation of the lateral facing displacement at the end of construction as well as after years of creep. The lateral deformation of reinforced soil zone is largely governed by reinforcement stiffness, and spacing. On the other hand, the wall surface surcharge, density of the retained soil, also affect the lateral displacement and stability of such segmental wall. This paper investigated the influence of these factors using 2-D numerical Plaxis software, and recommendations proposed for the limitation of each factor were also provided. The results of this study indicate that, to achieve the stability of the reinforced segmental retaining wall (RSRW) the geogrid stiffness should not be less than 1000 kN/m^2, and spacing not more than 0.60 m. On the other hand, the surcharge load has significant effect on stability of (RSRW).

Keywords: 2-D Plaxis program, segmental wall, geogrid stiffness and spacing, surcharge load, backfill unit weight and shear strength, Facing horizontal displacement.

تأثير جسأة التسليح بالمصناعات الجيوتكنيكية والحمل الاضافي علي اتزان الحوائط الساندة المركبة للتربة المسلحة

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الملخص:

تم استخدام حوائط التربة المسلحة بالمصنعات الجيوتكنيكية مع البلوكات الحجرية على نطاق واسع في بناء الطرق السريعة والسكك الحديدية نظرًا لأدائها الجيد ، وسهولة البناء والتحكم في الجودة. يتطلب التصميم دقة في تقدير الإزاحة الجانبية للواجهة في نهاية البناء وكذلك تأثير الزحف بعد سنوات من البناء. وتخضع الإزاحة الجانبية لمنطقة التربة المسلحة إلى حد كبير إلى جسأة التسليح والمسافات البينية ، من ناحية أخرى فإن الحمل الإضافي لسطح الجدار، وكثافة التربة المحتجزة ، تؤثر أيضًا على الإزاحة الجانبية والاتزان الكلى للجدار. وتم في هذا البحث دراسة تأثير هذه العوامل باستخدام برنامج (بلاكسس ثنائي الأبعاد)، كما تم تقديم التوصيات المقترحة لحدود لكل عامل من هذه العوامل. تشير نتائج هذه الدراسة الي انه لتحقيق اتزان الحائط الساند المركب للتربة المسلحة يجب الأ تقل جسأة التسليح عن ١٠٠٠ كيلو نيوتن/ متر المربع، ولاتزيد المسافات البينة في الآتجاه الرأسى عن ٠,٦ متر. من ناحيه اخري الحمل الاضافي له تأثير كبيرعلي الاتزان الكلى للحائط.

الكلمات المفتاحية : برنامج بلاكسيس ثنائي الأبعاد ، حائط مركب ، جسأة التسليح والمسافات البينية ، قيمة الحمل الإضافى ، وزن وحدة الحجوم وقوة القص للتربة المحتجزة ، الإزاحة الجانبية للواجهة.

1. INTRODUCTION

Reinforced segmental retaining wall (RSRW) is a combination of modular block wall and geosynthetic reinforcement, it provides an integrated wall system that could be constructed to heights far exceeding the limits of simple gravity walls. The concepts of soil reinforcement are not new, the ziggurats of ancient Babylon and the Great Wall of China use similar soil reinforcing techniques [1]. SRW are used commonly and successfully in a range of applications, including residential landscaping, bridge abutments, stream channelization, waterfront structures, tunnel access walls, wing walls and parking area support [2-3]. They can be constructed with either a single depth of unit or with multiple depths [4].

The live load surcharges are considered to contribute to destabilizing forces, with no contribution to stabilizing the structure against external or internal failure modes [4]. Wade and Stephen (2004) [5] found that, the factor of safety under surcharge of 250 psf (12 kN/m^2) reduced the stability safety factor by about 17%. Spencer (2015) [6] investigated the effect of surcharge load on the stability of SRW and found that, the stability safety factor significantly decreased from 1.973 to 1.279 by about 55%, when surcharge load increased to 70 kPa.

The required length (L) of reinforcement layer to achieve the minimum pullout capacity should not be less than 0.6H, and the absolute minimum value for *L* be 1.20 m [4]. In case of the RSRW is expected to subject to seismic excitation, the length of the uppermost layer(s) is locally extended to provide adequate anchorage (pullout capacity) for the geosynthetic layers [7].

Vertical spacing between geosynthetic layers should be limited to prevent bulging of the wall face between geosynthetic connection points. Maximum vertical spacing between reinforcement layers 0.60 m is suggested to reduce construction stability issues. The maximum vertical spacing of the reinforcement layers be no more than twice the depth of the modular block unit. The reinforcement mode is tension and can also resist in bending and shear, providing additional stability to the reinforced soil structures [8].

The type of backfill has a significant effect on the total displacement, Inappropriate backfill materials include expansive clays, organic soils, poorly graded sands, and soils with a plasticity index (PI) larger than 20 or a liquid limit (LL) larger than 40 [9]. Compaction also has a significant effect, but not as great as backfill type, particularly for granular backfill. Based on the Bowles information, the backfill component of deflection for a well-compacted fine-grained soil is approximately 3 times greater than marginally compacted granular soil [10]. The well-graded granular backfill has the advantage of convenient drainage, can improve the durability of the geogrid, and reduce the amount of reinforcement [11].

Geosynthetic reinforcement materials are high-tensile-strength polymeric materials. They may be geogrids or geotextiles, although current RSRW construction typically uses geogrids. High value of elasticity for geogrid did not significantly affect the failure of RSRW, because soil would fail sooner in the event of excessive strain [12]. The main function of reinforcement is to restrain the lateral deformation of the soil body, so that the ultimate strength of the soil body is improved, and the generation and development of the plastic zone are inhibited [11] On the whole, the smaller the reinforcement spacing, the greater the interface friction will be between the reinforcement and the soil and the more significant the reinforcement effect will be.

In this study using two-dimensional finite element program PLAXIS is used to investigate, the effect of variation of wall surface surcharge load, geogrid stiffness, vertical spacing of geogrid, as well as the unit weight of retained backfill on the wall deformation and stability safety factor.

Table (1) Soil Properties and Geogrid Parameters

Soil Properties					
Soil parameters	Natural	Fill	Soil parameters	Natural	Fill
Angle of friction (φ°)	36°	32°	Poison's ratio (ν)	0.25	0.30
Unit Weight (γ) kN/m^3	18.5	18	Elastic Modulus, E (kN/m^2)	4021	2298
Cohesion (c) kN/m^2)	1.00	1.00	$R_{interface}$	1.00	0.67
Permeability $K_x = k_y$ (m/day)	1.00	1.00	Dilatancy angle (ψ°)	6°	2°
Geogrid Properties					
Parameter		Value	Parameter		Value
Elastic Axial Stiffness (EA) kN/m^2/m		3000	Max. Axial Tension force (Np) kN/m^2/m		120

The geometry of the RSRW is shown in Fig. (1) with height (H) 6.00 m, and geogrid length (L) = 0.7H, spacing of (Sv) 0.60 m. The properties of the retained, natural and foundation, and geogrid parameters are listed in Tables (1)

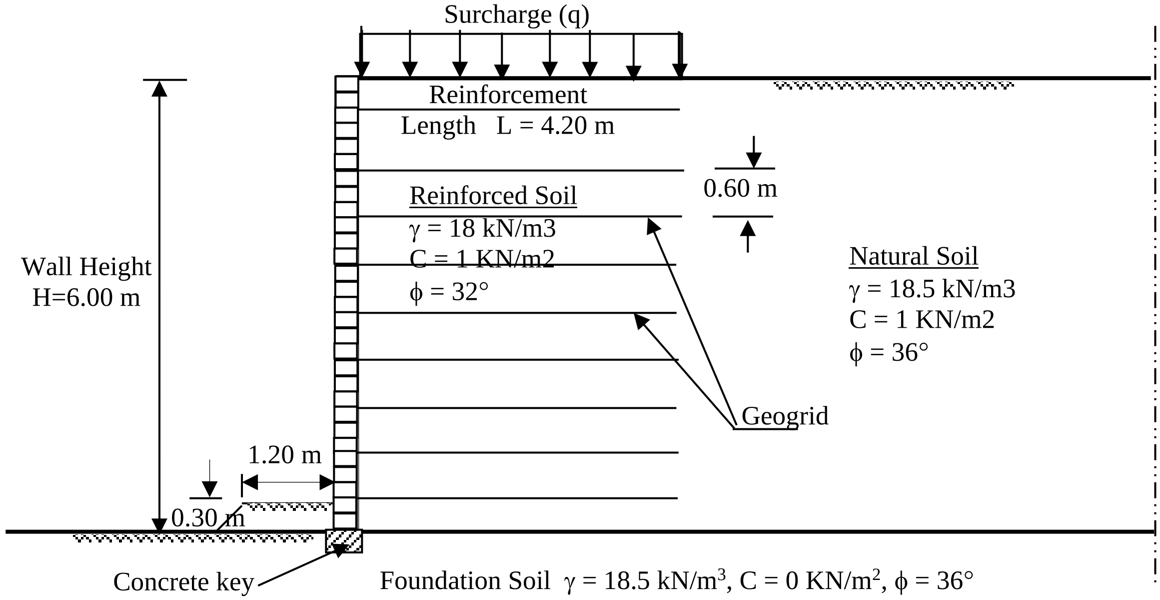


Fig. (1) Geometry and Soil Properties of Segmental Wall under Study

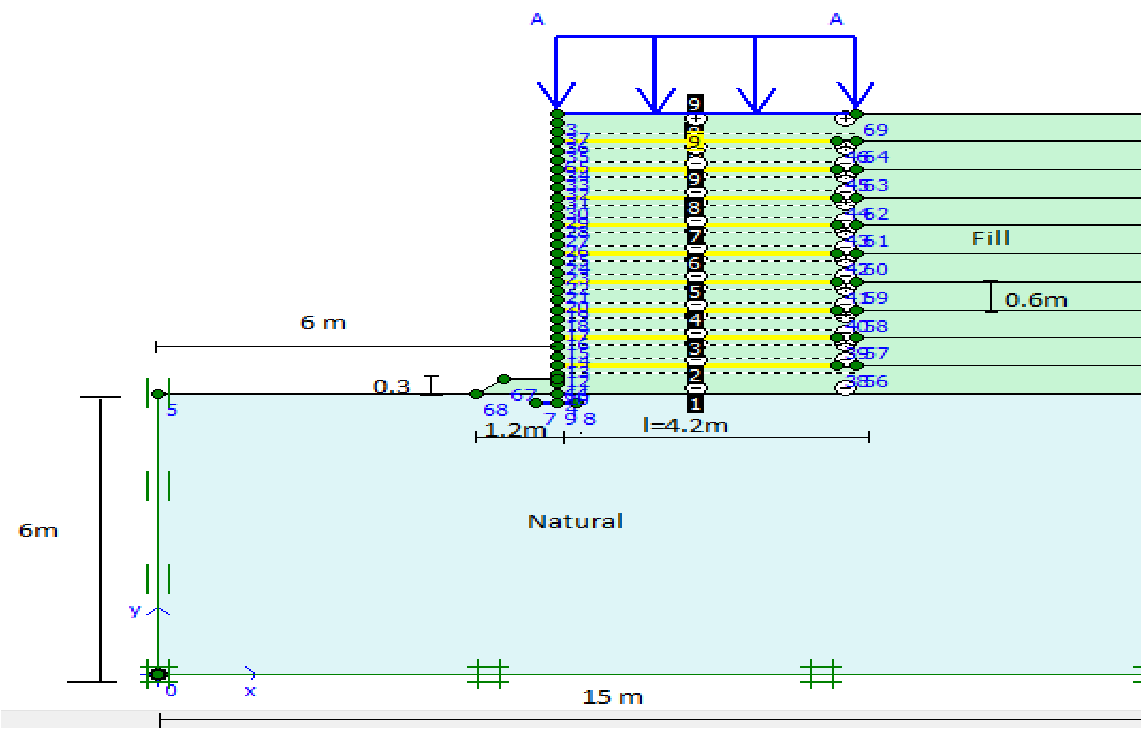


Fig. 2 2-D model for the segmental wall under study

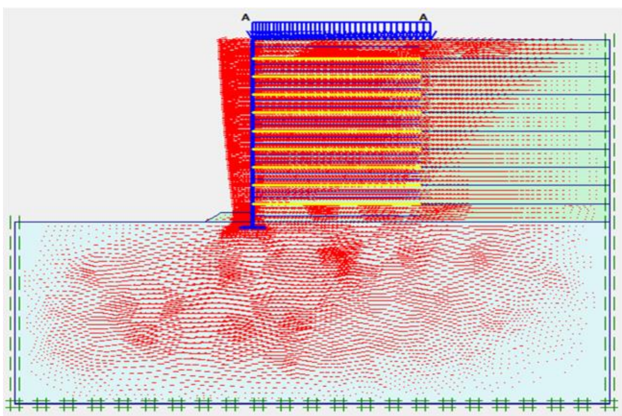
2. NUMERICAL MODEL

The two-dimensional finite element program PLAXIS was used to perform the numerical modeling and analysis of the segmental wall shown in Fig. (2) The finite element modeling comprised of two-dimensional plane strain analysis. The well-known Mohr-coulomb model has been considered as approximation of real soil behavior. Finite elements used were triangular 36 elements with 15-nodes. Due to the stress concentration in and around the wall, a finer mesh used in these areas and mesh became coarser in the zones away from the wall. Vertical space 0.60 m and 9 layers of geogrids. The concrete modular blocks were 0.35m x 0.40 m with height of 0.20 m.

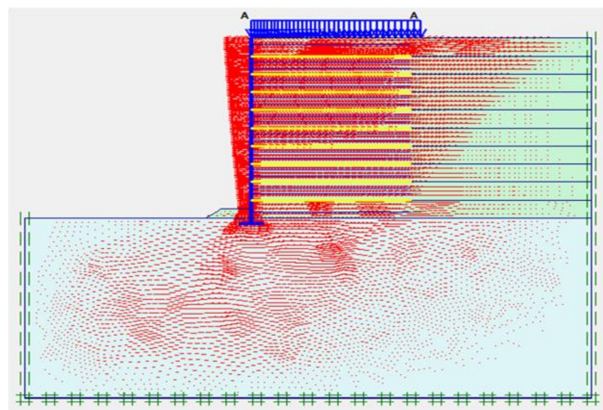
3 **PARAMETERIC STUDIES**

3.1 Surcharge Load

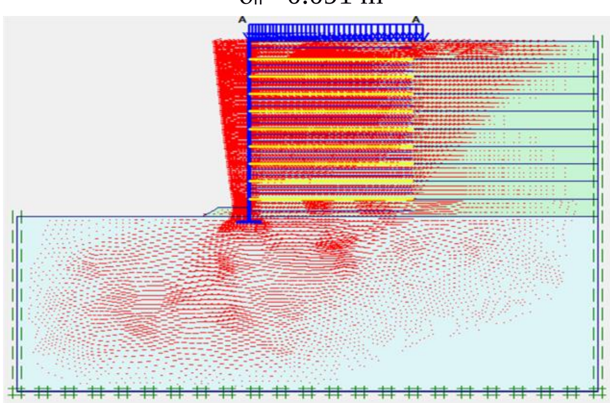
Live load surcharges are considered to be transient loadings that may change in magnitude and may not be continuously present over the service life of the structure. Examples of live load surcharges are vehicular traffic and bulk material storage facilities.



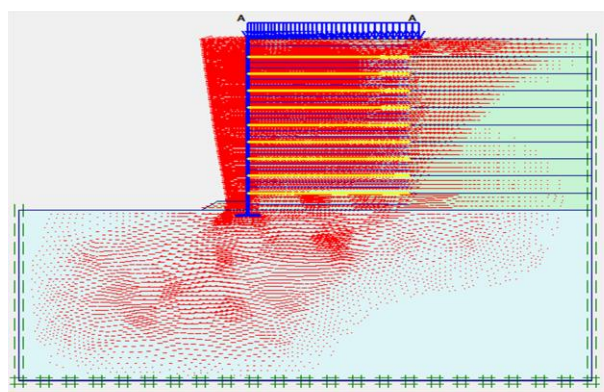
Horizontal displacement (q=20kN/m^2)
δ_h= 0.091 m



Horizontal displacement (q=50kN/m^2)
δ_h= 0.147 m



Horizontal displacement (q=70kN/m^2)
δ_h= 0.188 mm



Horizontal displacement (q=100 kN/m^2)
δ_h= 0.25 m

Fig. 3 Lateral displacement and wall face blocks panel, and RSRW deformed shape

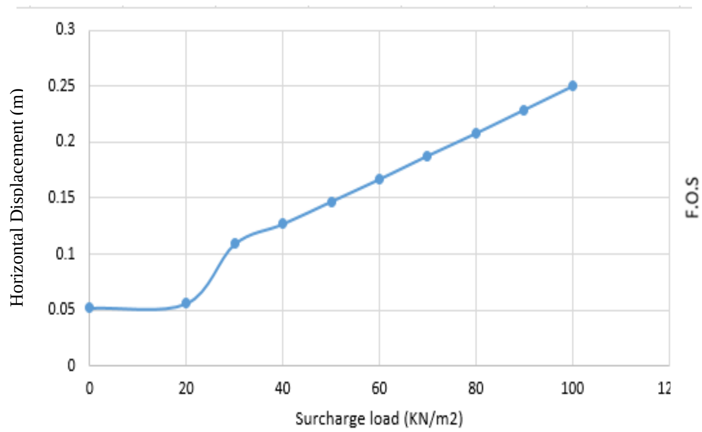


Fig. 4 Surcharge load and wall maximum top Horizontal displacement

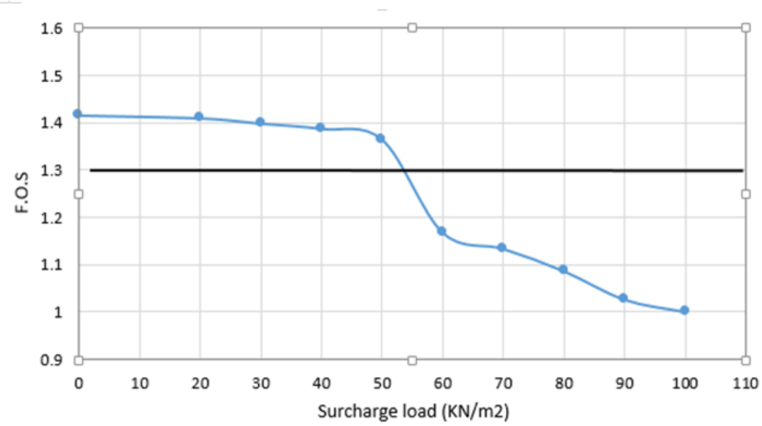


Fig.5 Relationship between surcharge load and factor of safety

In this study the effect of surcharge with magnitude in the range of 20 kN/m^2 to 100 kN/m^2 was investigated for wall reinforced by geogrid with stiffness (EA) = 3000 kN/m. Figure (3) shows the numerical deformed shapes of the wall face panel for surcharge loads 20, 50, 70 and 100 kN/m^2. The maximum lateral displacement for the facing was found to be at the top at the end of construction, as also observed by [7]. Figure (4) shows the relationship between the variation of surcharge load and the wall maximum lateral displacement. The effect of variation of surcharge load on the wall stability of safety factor (F.O.S.) is plotted in Fig. (5). The normalized horizontal displacement (δ_h /H) and stability of safety factor are listed versus the applied various surcharge load in Table (2).

Table (2) Surcharge load versus normalized horizontal displacement (δ_h /H) and F.O.S.

Surcharge Load (q) (kN/m^2)	Horizontal Displacement δ_h (m)	Normalized Lateral displacement (δ_h /H)	Factor of Safety (F.O.S.)	Remarks
0	0.052	0.009	1.415	Stable
20	0.056	0.009	1.409	Stable
30	0.109	0.018	1.398	Stable
40	0.127	0.021	1.387	Stable
50	0.147	0.025	1.366	Stable
60	0.167	0.028	1.168	Unstable
70	0.188	0.031	1.134	Unstable
80	0.208	0.035	1.087	Unstable
90	0.229	0.038	1.027	Unstable
100	0.250	0.042	1.001	Unstable

Table (2) indicates that, for the RSRW under study with geogrid stiffness of 3000 kN/m the maximum surcharge load should not exceeds 50 kN/m^2. On the other hand, the results of wall without surcharge reveal that, recommended surcharge load of 20 kN/m^2 has insignificant effect on the wall displacement and FOS. The FOS decreased by only about 4.00%, and lateral displacement increased by about 160% when the load increased from 20 kN/m^2 to50 kN/m^2. The lateral wall top displacement is found to be about 0.010 to 0.025 of the wall height (H) under surcharge load from 20 to 50 kN/m^2.

3.2 Geogrid Stiffness

Effect of Stiffness of Geogrid is investigated on stability of safety factor and displacement for wall height (H) = 6.00 m, surcharge load (q) = 20 kN/m^3, angle of internal shear friction of retained backfill (Φ) =32°, unit weight (γ) =18 KN/m^3, cohesion (c) = 1 kN/m^2. The studied stiffness of geogrid is in the range of 500 kN/m^2 to 3000 kN/m^2. The maximum lateral displacement at the top of the wall versus the geogrid stiffness is shown in Fig. (6), and the corresponding stability of safety factor is shown in Figure (7).

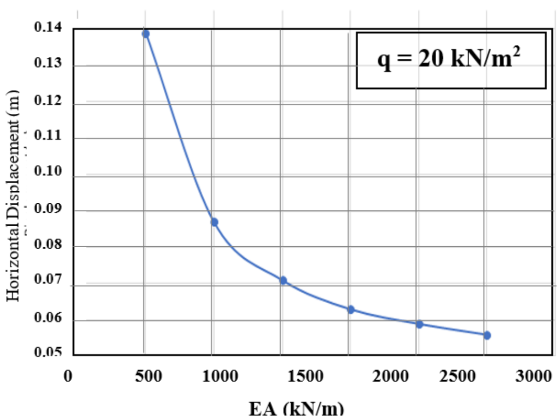


Fig. 6 Geogrid stiffness and wall maximum top Horizontal displacement.

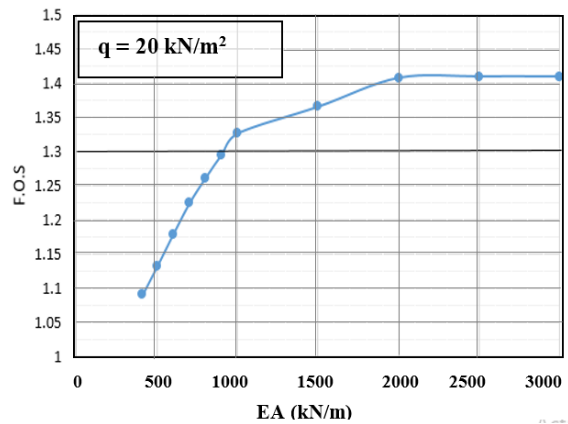


Fig. 7 Relationship between surcharge load and factor of safety

Table (3) Geogrid stiffness versus normalized horizontal displacement, and F.O.S. under surcharge load (q) = 20 kN/m^2

Geogrid Stiffness (kN/m)	Horizontal Displacement δ_h (m)	Normalized deflection (δ_h /H)	Decrease In (δ_h) (%)	(F.O.S.)	Remarks	Increase in F.O.S (%)
500	0.139	0.023	----	1.132	Unstable	-------
1000	0.087	0.015	37.41	1.326	Stable	17.13
1500	0.071	0.012	48.92	1.365	Stable	20.59
2000	0.063	0.011	54.68	1.407	Stable	24.29
2500	0.059	0.010	57.55	1.409	Stable	24.47
3000	0.056	0.009	59.71	1.409	Stable	24.47

The results of numerical analysis for the effect of geogrid stiffness on the wall panel horizontal displacement (δ_h), and the stability of safety factor (F.O.S.) are shown in Fig. (6& 7) respectively. The listed results in Table (3) indicate that, with the increase of geogrid stiffness the factor of safety increases, and to achieve the minimum factor of safety (F.S.)

= 1.30 the geogrid stiffness should not be less than 1000 kN/m^2. In spite of increasing the geogrid stiffness from 1000 kN/m^2 to 3000 kN/m^2 has decreased the lateral deflection (δ_h) by about 22%, while the increase the factor of safety (F.S.) by only 7%. Therefore, the increase of geogrid stiffness has significant on the wall displacement rather than the wall global factor of safety.

3.3 Geogrid stiffness and Surcharge Load

The wall displacement at each geogrid-face block connection are plotted for various geogrid stiffness, and surcharge load of 30, 50, and 70 kN/m^2 in Figure (8).

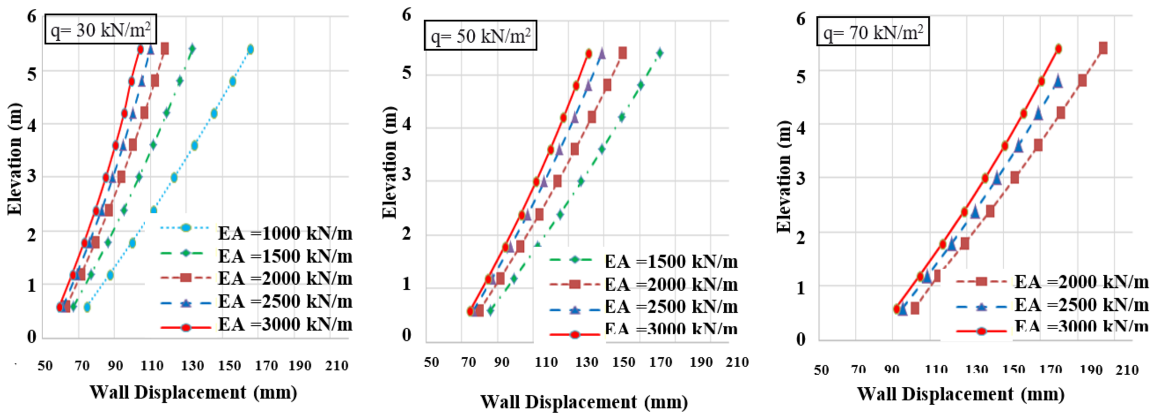


Fig. 8 Horizontal displacement of geogrid – block face panel connections with variation of surface surcharge and geogrid stiffness.

Table (4) Maximum Lateral Displacement at geogrid wall blocks panel connection for various geogrid stiffness and surcharge load, and the corresponding F.O.S.

Geogrid	Surcharge Load (q) = 30 kN/m^2				Surcharge Load (q) = 50 kN/m^2				Surcharge Load (q) = 70 kN/m^2			
Stiffness EA (kN/m)	Max. δ_h (m)	δ_h/H	F.O.S.	Increase In FOS (%)	Max. δ_h (m)	δ_h/H	F.O.S.	Increase In FOS (%)	Max. δ_h (m)	δ_h/H	F.O.S.	Increase In FOS (%)
1000	0.175	0.029	1.174	-----	Failed	-----	-----	-----	Failed	-----	-----	------
1500	0.140	0.023	1.307	11.33	0.191	0.032	1.204	------	Failed	-----	------	-------
2000	0.123	0.021	1.389	18.31	0.169	0.028	1.302	8.14	0.215	0.036	1.119	------
2500	0.115	0.019	1.397	18.99	0.159	0.027	1.354	12.46	0.199	0.033	1.125	0.54
3000	0.109	0.018	1.399	19.10	0.147	0.025	1.366	13.46	0.188	0.031	1.134	1.34

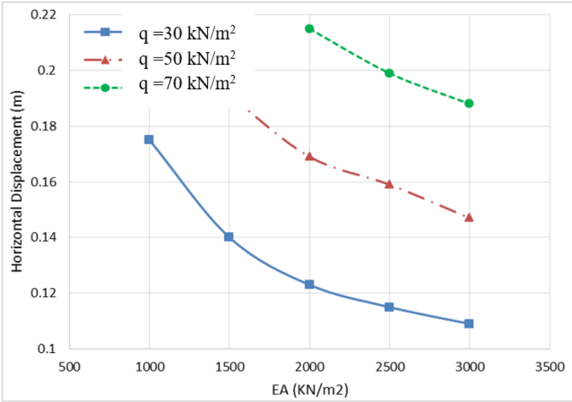


Fig. 9 Geogrid stiffness and wall Horizontal displacement under surcharge load

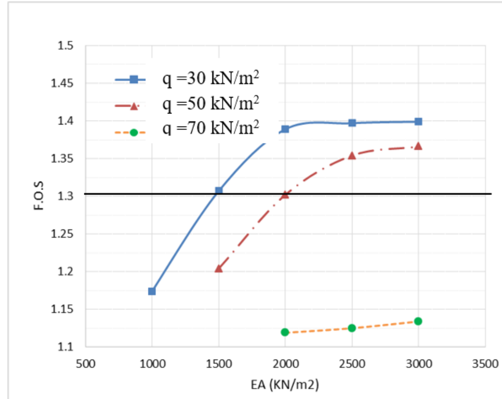


Fig. 10 Relationship between Geogrid stiffness and surcharge load on factor of safety

The numerical results listed in Table (4) and plotted in Figures (9 &10) indicate the following observations:

- Under surcharge load of 70 kN/m^2 the SRW was unsafe even in case of reinforcing the retained backfill with geogrid with stiffness of 3000 kN/m.
- Under surcharge load of 30 kN/m^2 and 50 kN/m^2, the minimum geogrid stiffness should not be less than 1500 and 2000 kN/m^2 respectively.
- Under Surcharge Load of 30 kN/m^2, increasing the geogrid stiffness from 1500 to 3000 kN/m^2 had decreased the maximum lateral displacement by 22%, while the increase in F.O.S. was only about 8 %. On the other hand, under surcharge load of 50 kN/m2, increasing the geogrid stiffness from 2000 to 3000 kN/m had decreased the wall top displacement by about 13%, and the increase in F.O.S. was only about 5%.
- Bowles (2006) [13] suggested that, for conventional retaining earth walls without reinforcement, the movement required to develop active earth pressure for dense cohesive backfill is in the range of 0.001H – 0.002H, where H is the wall height, this limit does not take into account- among other factors- the case of soil reinforcement, reinforcement stiffness and surface surcharge load of SRW. In this study, the amount of translation required to develop the active earth pressure may be more than 0.02H -0.04H depends on the combination effect of geogrid stiffness and surcharge load.

3.4 Geogrid Vertical Space

It is often cost efficient to maximize vertical spacing between geogrid layers as allowed by the stability factors of safety [4]. On the other hand, if the reinforcement spacing is excessively small, it is easy to cause "over reinforced soil", which not only increases the cost and the construction difficulty but also makes no sense in achieving a better reinforcement effect than the moderate reinforcement.

The geometry of the RSRW, and soil properties as previously illustrated in Fig. (1), with geogrid stiffness EA = 2000 kN/m, and surcharge load (q) = 50 kN/m^2. The effect of variation of geogrid vertical spacing (S_v) = 0.4, 0.6, 0.8, and 1.0 m on wall lateral displacement and stability of safety factor is plotted in Figures (11 & 12). The results are listed in Table (5).

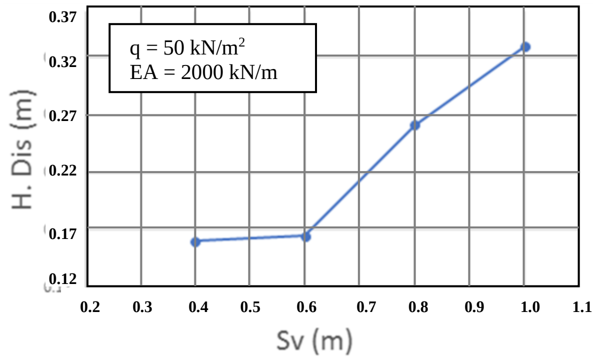


Fig. 11 Geogrid vertical spacing versus wall max. Horizontal displacement

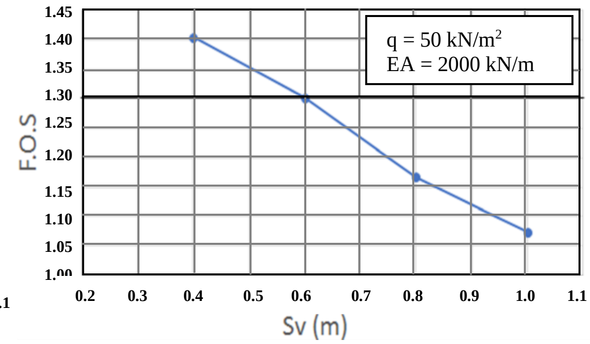


Fig. 12 Geogrid vertical spacing versus Factor of Safety

Table (5) Geogrid vertical Spacing and wall later deflection and Factor of Safety

Wall height (H) = 6.00 m, ϕ=32°, =18 kN/m^3, q = 50 kN/m^2, Geogrid stiffness = 2000 kN/m				
Vertical Geogrid Spacing ,S_v (m)	Wall Max. displacement (δ_h) m	Normalized Displacement (δ_h/H)	Factor of Safety (F.O.S.)	Decrease in F.O.S. (%)
0.40	0.162	0.027	1.405	-----
0.60	0.169	0.028	1.302	7.33
0.80	0.262	0.043	1.167	16.94
1.00	0.330	0.055	1.074	23.55

From Table (5) it can be observed that:
- To ensure the stability of the SRW the vertical geogrid spacing should not be more than 0.60 m, as also recommended by [4] to reduce construction stability issues.
- Reducing the geogrid vertical spacing to 0.40 m has no effect on the lateral deflection and increases the factor of safety by only about 7.00 %.
- The vertical geogrid spacing is also governed by the height of modular concrete blocks; [4] recommended that the maximum vertical spacing of the reinforcement layers be no more than twice the depth of the unit or 0.60 m which is higher.

3.5 Unit Weight of Backfill

Compaction of backfill has a significant effect, particularly for granular backfill. Based on the Bowles information, the backfill component of deflection for a well-compacted fine-grained soil is approximately 3 times greater than marginally compacted granular soil [10]. The effect of variation of unit weight (γ) = 17, 18, 19 and 20 kN/m^3 on wall lateral displacement and factor safety are investigated, under surcharge load of 50 kN/m^2 and with geogrid stiffness EA = 2000 kN/m. The geometry of the SRW is as previously illustrated in Fig. (1).
In this study the effect of increasing the backfill unit weight on the shear strength of the compacted granular backfill was taken into consideration. The unit weight of retained

backfill versus the induced wall lateral displacement and estimated stability of safety factor are plotted in Figures (13 & 14).

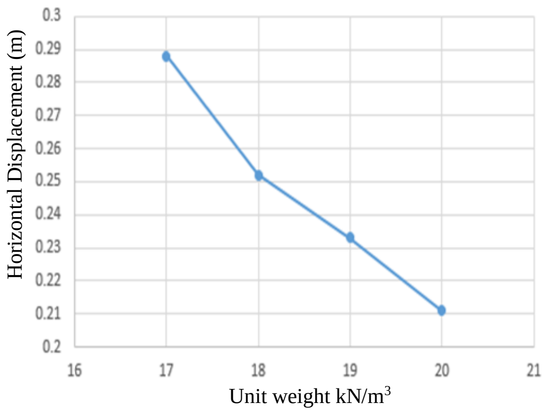


Fig. 13 Relationship between unit of retained backfill and wall top displacement.

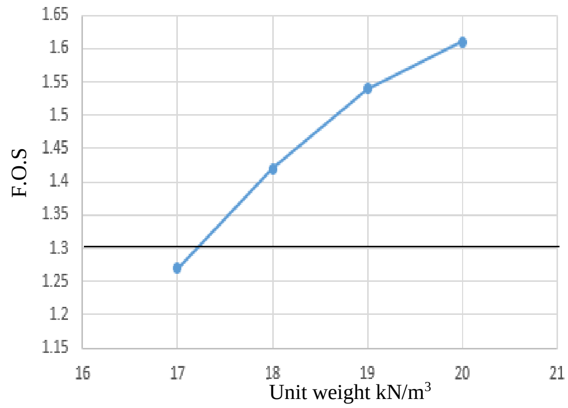


Fig. 14 Relationship between unit of retained backfill and wall Factor of Safety.

The effect of unit weight and corresponding assumed angle of internal friction on the wall displacement and stability of safety factor are listed in Table (6).

Table (6) Unit weight of retained soil and wall lateral displacement and Stability of safety factor

Wall height (H) = 6.00 m, q = 50 kN/m^2, Geogrid stiffness = 2000 kN/m					
Retained soil unit Weight (kN/m^3)	Assumed Angle of friction (ϕ°)	Wall max. Top displacement (δ_h) m	Normalized Wall Deflection (δ_h/H)	Factor of Safety (F.O.S.)	Increase In F.O.S. (%0
17	31	0.288	0.048	1.270	-----
18	35	0.252	0.042	1.416	11.50
19	40	0.233	0.039	1.543	21.50
20	45	0.211	0.035	1.612	26.93

From the results of Table (6) it can be concluded that:

- To ensure the stability of SRW the unit of the retained compacted retained backfill should not be less than 18 kN/m^3, and angle of internal friction not less than 35° to achieve dense backfill developing adequate shear resistance with the geogrid sheets.
- Increasing the unit of the backfill from 18 kN/m^3 to 20 kN/m^3 had increased the factor of safety by about 15% and reduced the wall displacement by has significant effect on the stability of safety factor about 16%.

4- CONCLUSIONS

In this paper a parametric study was carried out using 2-D Plaxis program, to investigate the effect of surcharge load, geogrid stiffness and vertical spacing, and unit weight and corresponding angle of internal friction on the stability of segmental retaining wall. The wall height was 6.00 m, and stability of the RSRW was evaluated based on global stability factor = 1.30 [4]. From this study the following conclusions are drawn:

1- The wall lateral displacement should be accompanied with the corresponding stability of safety factor, to evaluate the limit of lateral deflection at which the wall will be still stable.

2- For the RSRW under study with geogrid stiffness of 3000 kN/m, the maximum surcharge load should not exceed 50 kN/m^2. The lateral displacement increased by about 163 % and FOS decreased by only 4.00%, when the load increased from 20 kN/m^2 to 50 kN/m^2. On the other hand, the wall top lateral displacement is found to be 0.01- 0.02 of the wall height (H), with higher lateral displacement for higher surcharge load.

3- To achieve the stability of the RSRW the geogrid stiffness should not be less than 1000 kN/m^2. On the other hand, increasing the geogrid stiffness from 1000 kN/m^2 to 3000 kN/m^2 had decreased the lateral displacement (δ_h) by about 22%increased, while the factor of safety (F.S.) increased by only 7%, while. Therefore, the increase of geogrid stiffness has significant on the wall displacement rather than the wall global factor of safety.

4- Under surcharge load of 70 kN/m^2 the SRW was unsafe even in case of reinforcing the retained backfill with geogrid with stiffness of 3000 kN/m. Under surcharge load of 30 kN/m^2 and 50 kN/m^2, the minimum geogrid stiffness should not be less than 1500 and 2000 kN/m^2 respectively.

5- To ensure the stability of the RSRW the vertical geogrid spacing should not be more than 0.60 m, as also recommended by [4]. Reducing the geogrid vertical spacing to 0.40 m has no effect on the lateral displacement and increases the factor of safety by only about 7%.

6- The unit of the retained compacted retained backfill should not be less than18 kN/m^3, and angle of internal friction not less than 35° to achieve dense backfill developing adequate shear resistance with the geogrid sheets. Increasing the unit of the backfill from 18 kN/m^3 to 20 kN/m^3 had increased the factor of safety by about 15% and reduced the wall displacement by has significant effect on the factor of safety about 16%.

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