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Influence of Parameters the Wall on Reinforced Soil Segmental Walls

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Abstract

The behaviour of retaining walls in geosynthetic reinforced soil is complex and requires studies and research to understand the mechanisms of rupture, the behaviour of the reinforcements in the soil and the behaviour of the main elements of the system: reinforcement-wall-soil. Several researches have been done on the use of geosynthetics as backfill massive reinforcement material (experimental studies, numerical analysis, reduced models ...). This parametric study was conducted to investigate the influence of numerical parameters of the wall which confront us in the projects, on the behaviour of walls on reinforced soil segmental walls. A 3.6 m high wall is composed of modular blocks of earth sand reinforced with four geogrids layers was modelled. The properties of materials, the wall geometry, and the boundary conditions will be explained later. The finite difference computer program FLAC3D was used in this study. The results of this numerical study allowed to deduce the importance of each parameter of the wall selected for the behaviour of retaining walls in soil reinforced by geogrid. The inclination of wall "W" is of great importance for the calculation of retaining walls in modular blocks and can provide an important contribution to the horizontal balance of this type walls. The value of lateral displacements of the facing tends to continuously decrease with the increase of "W". More the wall is inclined plus the horizontal stresses behind the wall and values of the tensile stress in the layers of geogrid "T" decrease in an expressive manner. The dimensions of modular blocks (types) and the mechanical characteristics of modular blocks (category) have a remarkable effect on the calculation of retaining walls in modular blocks reinforced with layers of geogrid.

Keywords: Parametric Study; Retaining Walls; Modular Block; Reinforced Soil; Geogrid; FLAC3D.

1. Introduction

Retaining walls reinforced by geosynthetics and constructed with concrete block (modular) are spreading in recent years because of their good performance, aesthetics, the value and the swiftness of construction... The three main principal components of a retaining wall on reinforced soil are: Backfill the soil, the reinforcement elements and the wall.

The flexible nature of the segmental retaining wall systems and the small size of the modular blocks allow building walls to complex geometry, at different heights and several levels under adverse conditions of the site.

For a clearer understanding of the behavior of the wall's system, the numerical modeling is an excellent method which is permitted to take into account the soil properties, the geosynthetic reinforcement and the wall which also allow analyzing the stability, deformation and the influence of several parameters at any point of the model within a reasonable time. Several researches have been done on the use of geosynthetics as backfill massive reinforcement material that we quoted hereafter some examples of studies based on numerical modeling:

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Bathurst. R. J and Hatami. K [1a] Examined numerical modeling work of other authors who were focused on the walls in soil reinforced by geosynthetic. Their survey focused on numerical approaches that have used the finite element method (FEM) and the finite difference method (FDM). Of the many studies based on FEM are those by [2a-6]. Examples of the FDM applied on soil reinforced walls which have used the program (FLAC) are: [3- 8].

Most of the studies reviewed by the authors are the answer to wall models reinforced soil (eg [6- 9, 2b]). The numerical results were compared with measurements from physical models including the walls of the appliance field. In the rare cases where direct comparisons are reported, there are often significant differences in the magnitude and trends between predicted and measured values.

The majority modeling reinforcing elements included in the soil has been done by the use of linear elastic models with a yield of failure criterion to simplify the numerical simulations (eg [2a, 7]). In some studies, a constant value of linear rigidity from rapid tests of traction in laboratory was used to define the reinforcement of load stress properties. However, the response of geosynthetic reinforcement products from a rapid tension test is unlikely to be representative of field conditions, the speed of loading, or loading time reinforcing layers in actual terrain structures Walter & all [10].

The influence of the face type, the rigidity of the panel, and the method of construction were numerically controlled by [2a, 11-14] especially. However, the authors' experience is that the quality of the construction of the wall and variability in the construct as built for nominally identical designs are difficult or impossible to quantify, and therefore the use of numerical models to accurately predict performance wall during construction becomes a formidable challenge to Bathurst. R. J and Hatami. K [1b].

Chungsik. Y and Hyuck-Sang. J [15] numerically studied a new system of modular blocks reinforced soil by geosynthetic, this system has two levels of wall offset one meter wide. This study aims to present the effect of this configuration on horizontal deformations in the wall face and deformations in the reinforcement, the results represent a good agreement with large-scale studies are on the same system at Sungkyunkwan University in Korea. There are other researchers as Chungsik. Y and Sun-Bin. K [16] who also made numerical studies on this type of system, and the results are compared to experimental studies; they also reached an agreement in the processed results.

Bathurst. R. J and Hatami. K [1b] compared the results of numerical simulations to three segmental retaining walls in soil reinforced with measured results from physical tests. The walls are valid only on the type and number of polymer reinforcement layers. They used the Duncan-Chang model combined with a rupture criterion Mohr-Coulomb and the linear model elastoplastic Mohr-Coulomb to the soil in the simulations. The numerical results have been shown to be in good agreement with measured forces toe border, the vertical pressure of foundation, the movements of face, connection charges and deformations of the reinforcements. Bingquan. H et al. [17] did a thorough numerical study to investigate the influence of different constitutive models of soil to forecasts the characteristics performance of the walls with other reinforcement materials also to compare these predictions to results measures.

The numerical results using the linear model elastoplastic Mohr-Coulomb to the soil also gave a good agreement with the measured displacements of the wall, the forces of the point, and strains in the reinforcement layers.

Abdelkader. A et al. [18] studied the behavior of a mechanically stabilized earth walls reinforced with two types of reinforcements (metallic and geosynthetics) by numerical analysis. This work aims to study the influence of soil parameters, the parameters of reinforcement (type and modulus of elasticity), the behavior of soil models, the interface parameters soil / reinforcement, the compacting effect soil and the influence of the wall height. [18] Concluded that the modeling by different types of reinforcements shows that the use of synthetic bands two times larger than the metal bands leads to greater stability of the wall and increases the adhesion. This stability is even higher with the use of the new synthetic reinforcements of high adherence (GS HA). Bingquan. H et al. [19] numerically study the influence of the stiffness of the interface blocks in combination with various reinforcing materials, on the behavior walls reinforced soil with modular facing different heights. Three reinforcement materials were considered: a geogrid woven polyester (GWP), high density polyethylene geogrid (HDPG) and welded wire mesh (WWM). The program of finite difference FLAC2D was used for this study. The results presented in this study demonstrate the sensitivity of the relative displacements of the facing misaligned profiles, fillers connections and deformations of the reinforcement (load) to the magnitude of the stiffness of the interface blocks.

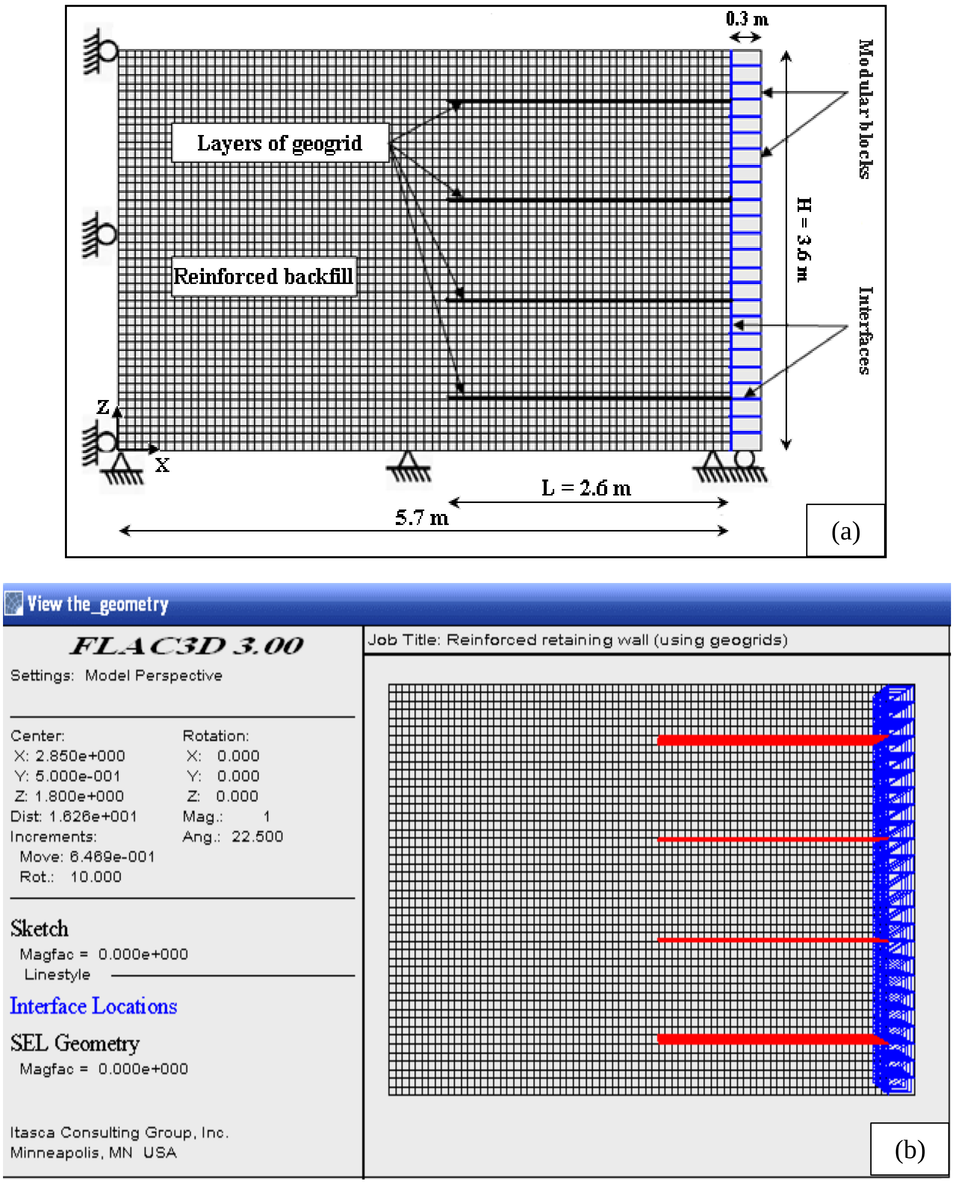
Some other researchers has been studied this type of walls dynamically in the case of an earthquake, and studied the behavior of these walls in this case [20- 23].

In this article our interest is related to the use of software FLAC-3D (Fast Lagrangian Analysis of Continued) to evaluate and analyze numerically the behavior of a retaining wall in modular block reinforced by horizontal layers of geogrid: horizontal displacements of the wall "Ux", the horizontal stresses behind the wall "σ_h", vertical stresses in the soil base "σv" and the tensile stress in the layers of geogrid "T". This analysis relates to the essential parameters of the wall: The inclination of the wall, type and Category modular blocks.

2. Presentation of the Numerical Model

The studied wall was constructed with a facing of solid modular units concrete columns of 3.6 m high (details modular blocks shown in Figure 2.) and the backfill is clean uniform sand on a rigid foundation 3.6 m high and 5.7 m in length. The layers reinforcement of the soil are geogrids elements of L= 2.6 m length. (Figure 1.)

In our study the reinforcement geogrid length is fixed to L / H = 0.7 according to conventional design methods [eg: 24, 25] and the comparison established by Zornberg. J and Leshchinsky. D [26] which showed that the typical uniform length of geosynthetic reinforcement in segmental retaining walls is about 0.5-0.7 times the height of the wall.



Job Title: Reinforced retaining wall (using geogrids)

Settings: Model Perspective

Center:
X: 2.850e+000
Y: 5.000e-001
Z: 1.800e+000
Dist: 1.626e+001
Increments:
Move: 6.469e-001
Rot.: 10.000

Rotation:
X: 0.000
Y: 0.000
Z: 0.000
Mag.: 1
Ang.: 22.500

Magfac = 0.000e+000
Linestyle

Magfac = 0.000e+000

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Figure 1. Presentation of the studied model

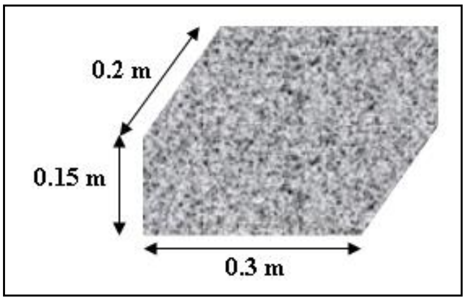


Figure 2. Detail modular block

3. Mesh and Boundary Condition

The mesh of a geotechnical structure is determined by the geometrical data of the project and geotechnical characteristics of the terrain. The following aspects should be taken in consideration during the mesh generation:

- The number and elements that will give good results;
- The adopted boundaries are sufficient for the rupture mechanism does not catch.

The mesh must satisfy as complete a description as possible of geometry, time calculation reasonable and acceptable results (speed and accuracy of calculation). The mesh adopted for simulation in this study is shown in Figure 1a.

The boundary conditions considered in this calculation are:

- Zero horizontal displacements in the x direction on the lateral faces of the soil mass;
- Vertical and horizontal displacements zero at the bottom of soil mass;
- Displacement in the y direction is blocked to treat the problem in plane deformation.

4. Material Properties

4.1. Soil

The soil is modeled as a linear elastic perfectly plastic material using the Mohr-Coulomb in the FLAC library. The elastic behavior is expressed by the generalized Hooke's law with (Module Young's modulus (E) and Poisson ratio (υ) or characterized by a volume module (K) and a shear modulus (G)), and plastics parameters (friction angle (ϕ), cohesion (c) and dilation angle (ψ)). In this study we based on experimental studies of Bathurst. R. J and Hatami. K [1b] to choose the soil characteristics (Table 1)

Table 1. Characteristics geomechanics of the soil

Parameters	
Model behavior	Mohr Coulomb
Young's modulus (MPa)	60
Poisson's ratio	0.3
Density (kg/m3)	1700
Friction angle (°)	30
dilation angle (°)	0
Cohesion (kPa)	0

4.2. Interfaces

The interfaces between similar materials (block-block) and different materials (wall-ground) were modeled as of the systems with spring linear cursor, with the interface shear resistance defined by the Mohr Coulomb rupture criterion (Itasca 2005). The relative movement of the interface is controlled by the interface stiffness values in the normal direction (Kn) and tangential (Ks).

Table 2. Interface Properties

Parameters	
Bloc-bloc :	
Friction angle (°)	40
Normal stiffness (Pa/m)	10^9
Shear stiffness (Pa/m)	4.10^7
Soil-bloc :	
Friction angle (°)	30
Normal stiffness (Pa/m)	10^8
Shear stiffness (Pa/m)	10^6

4.3. Reinforcement

Soil reinforcement layers in this study were simulated using geogrids elements FLAC3D. The geogrid layers simulated in the calculation to a main property is the axial stiffness EA was taken equal to 285 kN/m. Other properties included in the model are shown in Table 3.

Table 3. Characteristics of geogrids

Parameters	Notation	
Isotropic elastic material :		
Young's modulus (MPa)	E	57
Poisson's ratio	ν	0.33
Thickness (mm)	t	5
coupling spring cohesion (Pa)	cs_scoh	0
coupling spring friction angle (°)	cs_sfric	30
coupling spring stiffness (Kg /m3)	cs_sk	$23\ 10^5$

4.4. The Wall (Modular Blocks)

The properties of modular blocks compounds the wall have been assigned the values presented in Table 4. The primitive forms quadrilateral "Brick" was used to model these units and the dimensions of the block were selected according to that available in the market ($300 \times 200 \times 150\ mm$).

Table 4. Characteristics of the wall

Parameters	
Modular Blocks:	
Young's modulus (MPa)	3000
Poisson's ratio	0.2
Density (kg/m^3)	2500

5. Results and Discussion

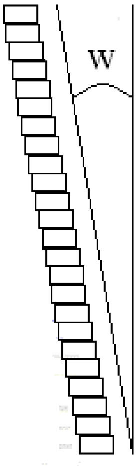
In this article our interest is related to the use of software FLAC-3D (Fast Lagrangian Analysis of Continued) in order to evaluate and analyze numerically the influence of several parameters of the wall on the behavior of a retaining wall in modular block reinforced by geogrids.

The numerical analysis is performed by varying several geometrical and mechanical parameters of the wall, to evaluate and study the lateral displacements of the wall "Ux", the horizontal stresses behind the wall "σ_h", the vertical stress at the base of the soil "σv" and the tensile stress in the layers of geogrids "T".

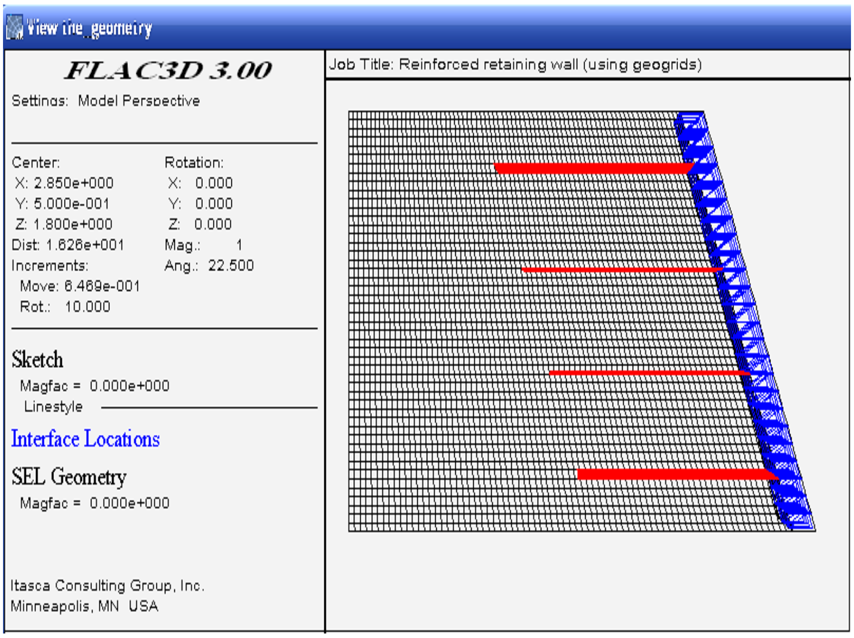
All simulation results obtained in this study are presented in graphs and curves are widely discussed.

5.1. The inclination of wall "W"

In this first part, we have studied the effect of the inclination of the wall (modular blocks) on the behavior of the system wall, varying "W" (0°, 8°, 15° and 22°) (Figure 3).



(a) Inclination of wall "W"



FLAC3D 3.00
Settings: Model Perspective

Job Title: Reinforced retaining wall (using geogrids)

Center:
X: 2.850e+000
Y: 5.000e-001
Z: 1.800e+000
Dist: 1.626e+001
Increments:
Move: 6.469e-001
Rot.: 10.000

Rotation:
X: 0.000
Y: 0.000
Z: 0.000
Mag.: 1
Ang.: 22.500

Sketch
Magfac = 0.000e+000
Linestyle

Interface Locations

SEL Geometry
Magfac = 0.000e+000

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(b)

Figure 3. Inclined retaining wall

5.1.1. Influence of "W" on the Lateral Displacement of the Wall "Ux"

The influence of the inclination of the wall on the calculation of lateral displacement "Ux" was investigated by analyzes carried out for four values of "W" (0°, 8°, 15° and 22°).

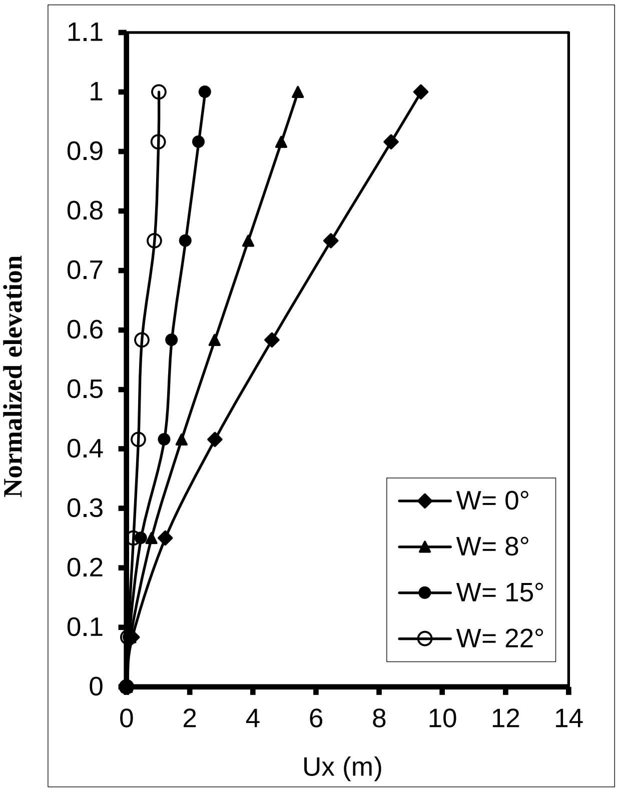

Figure 4. Lateral displacements of the wall

Figure 4. shows the results of simulation for the retaining wall with different inclinations of the wall. The horizontal displacements were normalized to the wall height. Is can be observed that each time the inclination of the wall "W" increases with respect to the vertical, lateral movement "Ux" decrease in a significant way.

It can be seen clearly that the inclination of the wall is very influential on the lateral displacement, an inclined wall at an angle W = 8° relative to the vertical (W = 0°) causes a decrease in "Ux" about 41.79% (at the summit wall), this reduction is 73.28% when the inclined wall at an angle W = 15° with respect to W = 0° and 88.98% if W = 22° with respect to W = 0°.

5.1.2. Influence of "W" on the Horizontal Stresses Behind the Wall "σ_h"

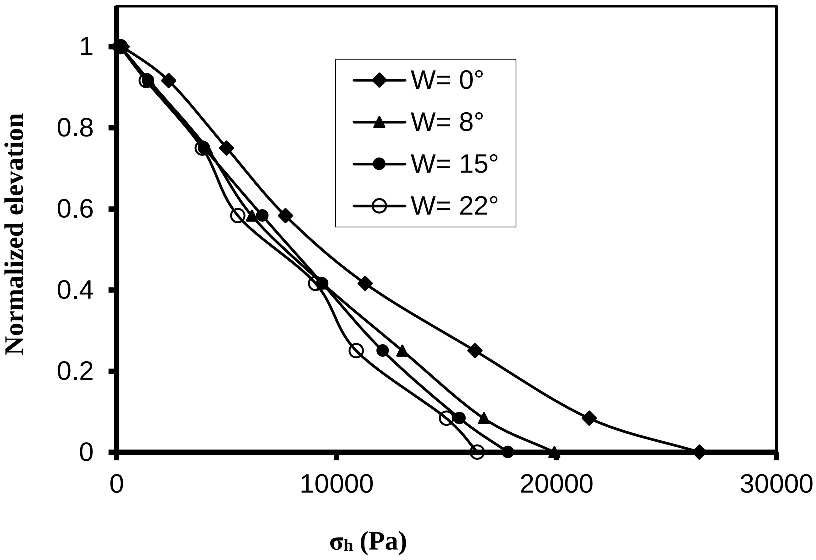

Figure 5.Horizontal stresses behind the wall

Figure 5. illustrates the effect of the inclination of the wall "W" on the calculation of horizontal stresses "σ_h" over the entire height of the wall. It may be noted that the values of "σ_h" decrease significantly when the angle "δ" increase (at the base of the wall).

It may be noted that for an angle of inclination W = 8° to the vertical, the horizontal stresses "σ_h" reduced an expressive way, this reduction can be up to 26% H = 0m. For an angle of inclination W = 15° relative to the vertical, "σ_h" decreases to 29%, and for an angle of inclination W = 22° relative to the vertical, "σ_h "decreases to 31%.

5.1.3. Influence of "W" on the Vertical Stress at the Base of Soil "σv"

The distribution of the vertical stress calculated at the base of the soil is presented in Figure 6, the values of "σ_v" were normalized with the vertical pressure due to the own weight of the soil (γ.H).

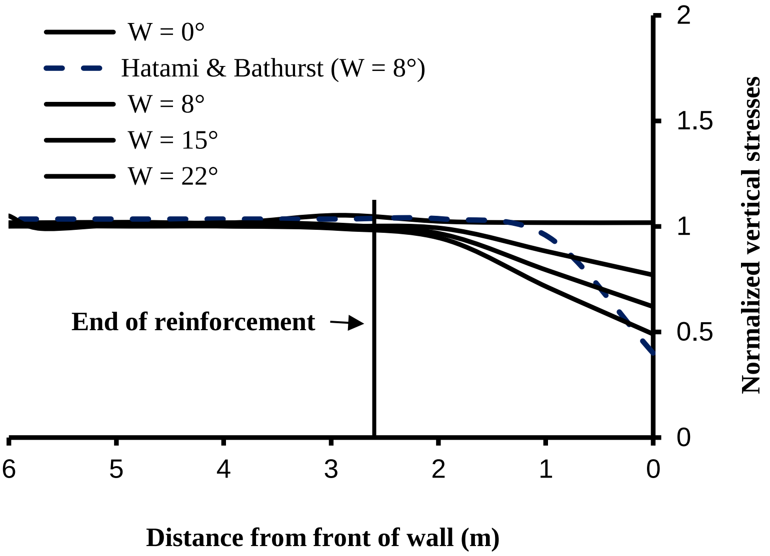

Figure 6. Distribution of vertical stresses at the base of soil

From this figure we can conclude that the inclination of the wall has no effect on the calculation of "σ_v ", the ratio of vertical stress is almost equal to unity (σ_v / γ.H≈1) except for the first two meters after the wall σ_v / γ.H <1 due to the contribution of the weight of the wall units in the calculation of vertical restraints "σ_v" in this part, the results of this study are excellent agreement with those of Bathurst. R. J and Hatami. K [1b] for an inclined wall W = 8°.

5.1.4. Influence of "W" on the Tensile Stress in the Layers of Geogrid "T"

The analysis of curves in Figure 7, which show the variation of the tensile stress "T" in the geogrid layers, allows drawing the following interpretations:

- For different cases of "W" study, the maximum values of "T" found in the top layer (at the summit of the wall) and these values decrease when the rigidity of lower geogrid layers.
- For each value of "W" selected one can observe that the curves of "T" are the same shape and the values of the tensile stress decrease gradually by one layer to other top to the bottom of the wall.
- The maximum value of "T" for each ply is obtained at a distance of 1m from the wall for intermediate layers; this value is obtained at a distance of 1.35 m (half-length of the layers) for the upper layer.

Through these remarks, one can conclude that every time we increased "W" (W = 0° to W = 22°) the maximum values of the tensile stress increases and always found in the upper layer. So the increase in "W" has a significant effect for decreasing max values of "T".

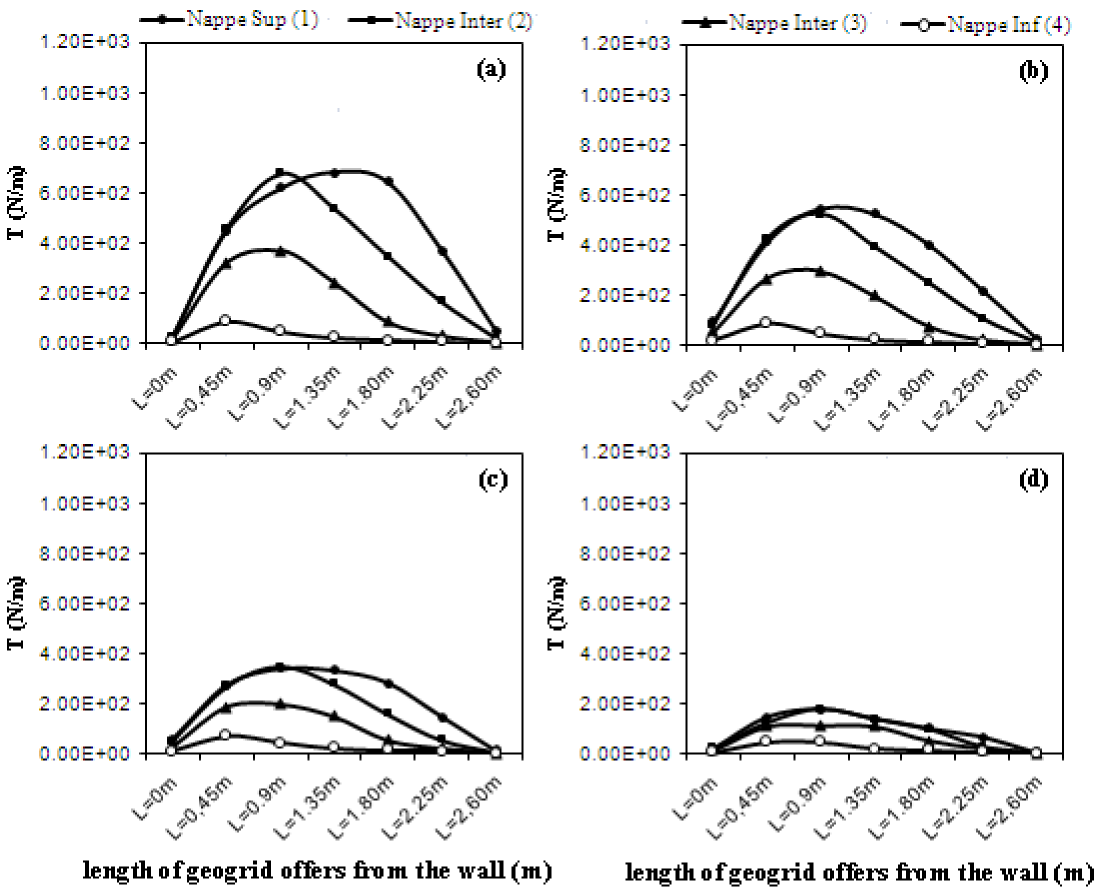

Figure 7. The tensile stress in the layers of geogrids, (a) W = 0°, (b) W = 8°, (c) W = 15° and (d) W = 22°

To conclude this section, the inclination of the wall is of great importance for the calculation of retaining walls in modular blocks and can provide an important contribution to the horizontal balance of this type walls.

5.2. Type Modular Blocks

The influence of the modular blocks type is studied using four types of blocks depending on their dimensions (Table 5). The modular blocks were deliberately chosen from a wide range of types available in the market according to our model and to facilitate modeling between the wall and the layers of geogrid.

Table 5. Type modular blocks used in modeling

Type blocks	A (cm)	B (cm)	C (cm)
Type 1	20	30	15
Type 2	50	30	15
Type 3	50	30	30
Type 4	100	30	30

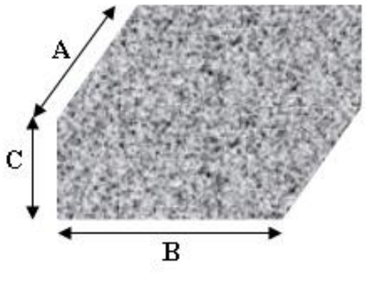

Figure 8. Detail of modular block

5.2.1. Influence Type of Blocks on Lateral Displacements of the Wall "Ux"

Figure 9. shows the influence of modular blocks type to the lateral displacements of the wall for the four type selected. The simulation results show that dimensions of the blocks composing the wall played a very important role for calculation of displacements "Ux".

It may be noted that the lateral displacements obtained for type 1 and type 2 are almost the same, this observation also applies to the type 3 and type 4.

Lateral displacements for the type 3 and type 4 are smaller compared to the other two types. The maximum displacements decreased about 24.65%, which meant that the wall in the case of type 3 and 4 is stiffer and has a higher resistance than the wall types 1 and 2.

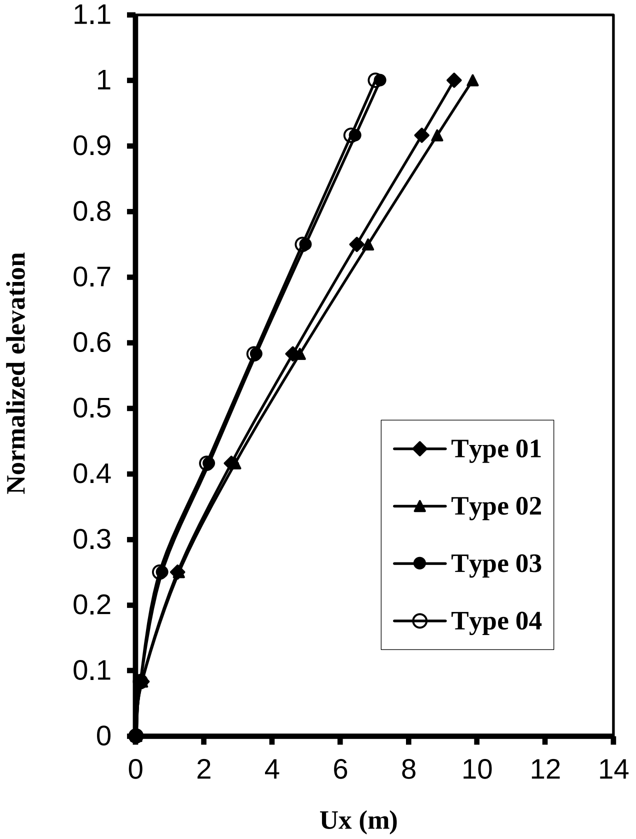

Figure 9. Lateral displacements of the wall

5.2.2. Influence Type of Blocks on the Horizontal Stresses behind the Wall "σ_h"

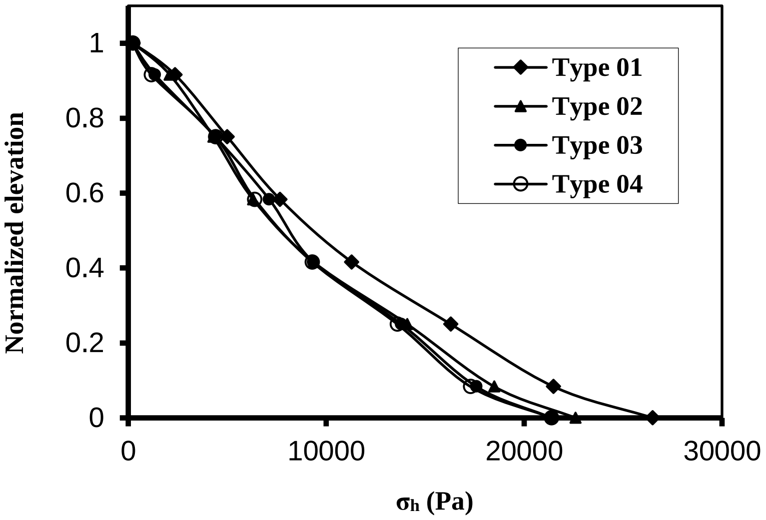

Figure 10. Horizontal stresses behind the wall

Figure 10. shows the variation of the horizontal stresses behind the wall "σ_h" a function of different types of modular blocks selected.

By analyzing this figure we see that the curves of the types selected in the same pace, in the upper 1/3 of wall negligible variation for horizontal stress values behind the wall. In the lower 2/3 of the wall variation for horizontal stress values behind the wall for the three types of blocks 2, 3 and 4, the values of "σ_h" decreased by 10% compared to type 1.

5.2.3. Influence Type of Blocks on the Vertical Stress at the Base Soil "σv"

The distribution of the vertical stress calculated at the base of the soil under different types of modular blocks is presented in Figure 11.

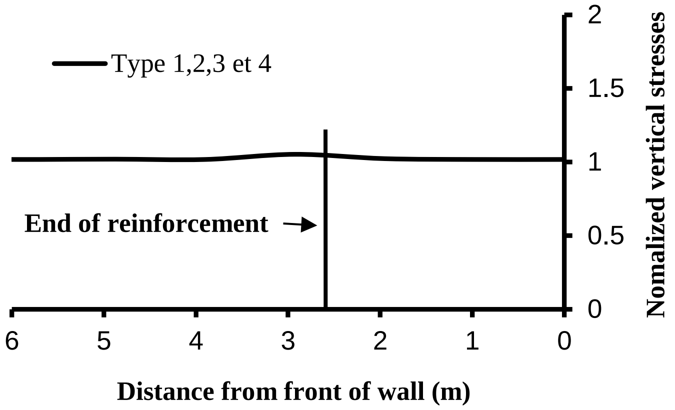

Figure 11. Distribution of vertical stresses at the base of soil

The values of "σ_v" were normalized with the vertical pressure due to the self-weight of the soil (γ.H). From this figure it can be concluded that the type of modular blocks has no effect on the calculation of "σ_v", the ratio of vertical stress is almost equal to unity ($\sigma_v / \gamma.H \approx 1$).

5.2.4. Influence Type of Blocks on the Tensile Stress in the Layers of Geogrid "T"

Figure 12. shows the tensile stress on the geogrid reinforcement for four different types of modular blocks, It is noted that:

- For the different types of cases modular blocks study, the maximum values of "T" found in the top layer (at the summit of the wall), one can also notice that the values of "T" obtained for type 1 and type 2 are almost the same, this observation also applies to the type 3 and type 4.
- For each type blocks, the same shape of the curves of "T" and the values of the tensile stress gradually decreases from top to bottom of the wall.

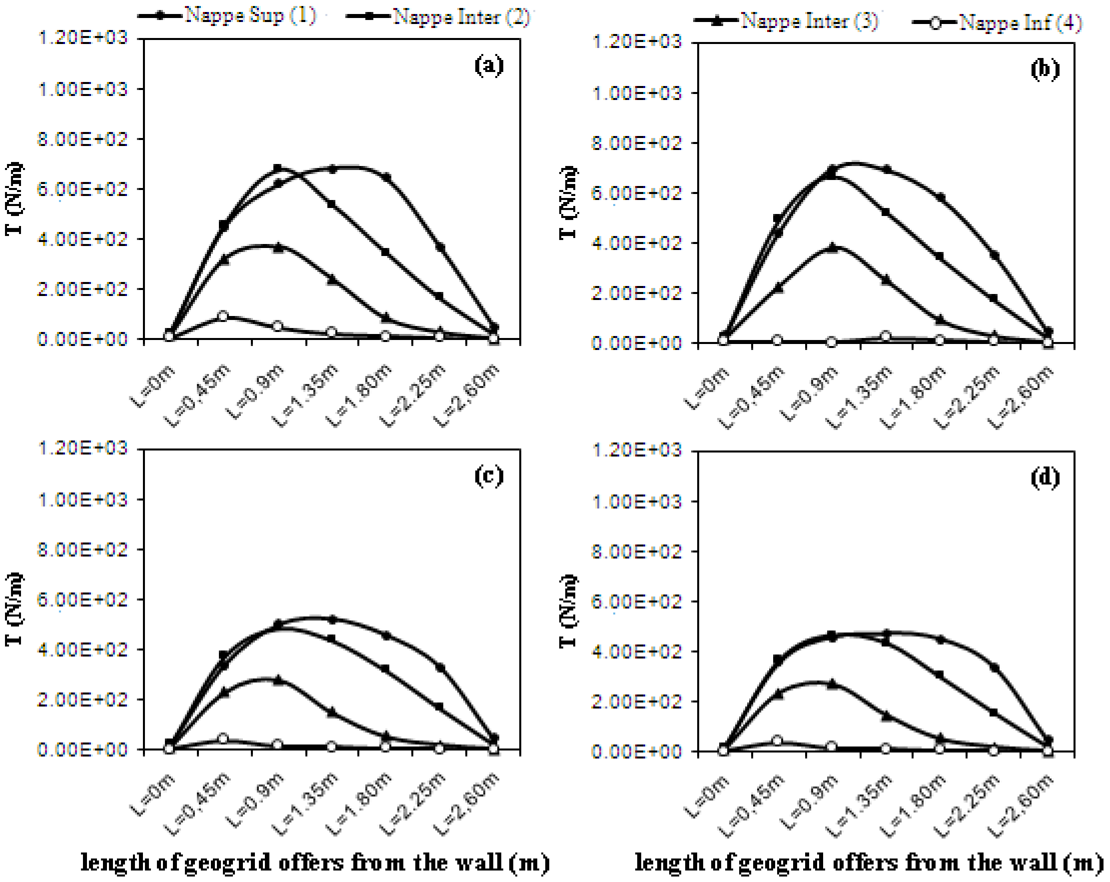

Figure 12. The tensile stress in the layers of geogrid, (a) Type 1, (b) Type 2, (c) Type 3 and (d) Type 4

The results of this part can be deduced that the type of the blocks is an essential parameter for the calculation of retaining walls in modular blocks reinforced by layers of geogrid.

5.3. Categories Modular Blocks

We present in this part of the numerical results of modeling of a retaining wall in soil reinforced to facing in blocks to different categories manufactured of concrete to different resistance classes (Table 6).

Table 6. Mechanical properties of modular blocks

	Hollow blocks		Full and Perforated blocks	
	Light aggregates	**Current aggregates**	**Light aggregates**	**Current aggregates**
Categories blocks	C5/700	C12/1350	C7/850	C20/2200
ρ (Kg/m^3)	700	1350	850	2200
E (MPa)	2750	6000	3500	10250

5.3.1. Influence of the Category of Blocks on the Lateral Displacements of the Wall "Ux"

Four different categories of modular blocks were used in our numerical model of reinforced soil retaining wall. Figure 13. shows the lateral displacements of the wall obtained from the selected categories.

It may be noted that the lateral displacement of the wall for the case where the facing block to current aggregates much lower than those observed in the case of block light aggregates.

The results clearly show that the more elastic modulus of concrete blocks is high plus reduced lateral displacements, to the wall of the class C20 / 2200 where the blocks are full and perforated at current aggregate lateral displacements "Ux" decrease about 69.32% compared with the calculation performed with a hollow blocks facing to light aggregates C5 / 700.

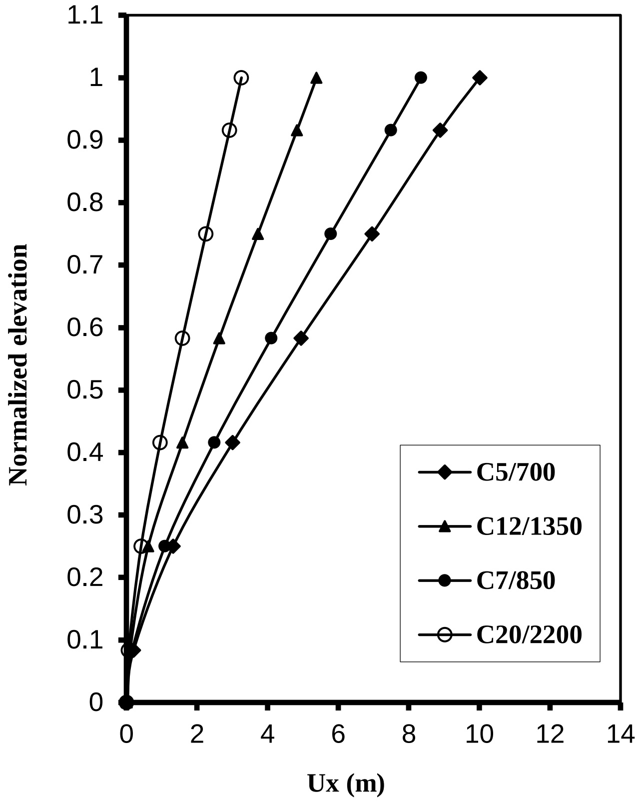

Figure 13. Lateral displacements of the wall

5.3.2. Influence of the Category of the Blocks on the Horizontal Stresses behind the Wall "σ_h"

The effect of the category of modular blocks is shown in Figure 14.

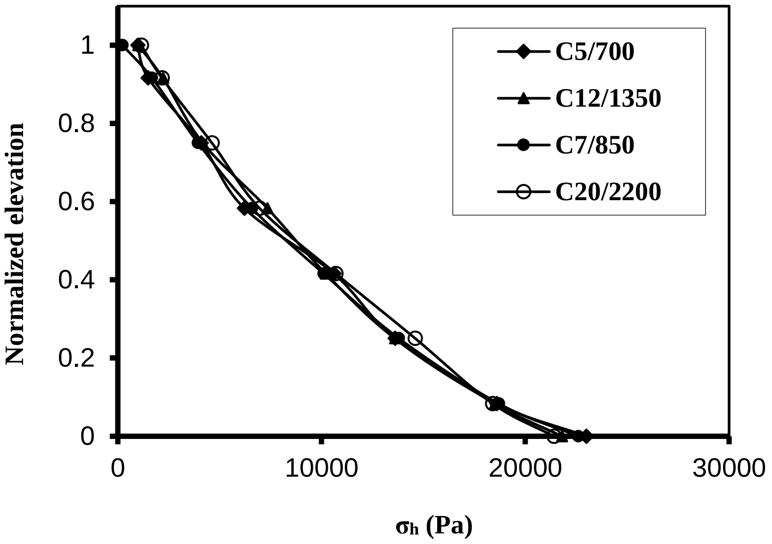

Figure 14. Horizontal stresses behind the wall

By analyzing this figure we see that the curves of the categories chosen in the same pace, and we also note that the values of "σ_h" practically the same in different cases, so we can say that the variation of the category of blocks does not affect the horizontal stresses behind the wall.

5.3.3. Influence of the Category of Blocks on the Vertical Stress at the Base Soil "σv"

The distribution of the vertical stress calculated at the base of the soil at different categories of modular blocks is presented in Figure 15.

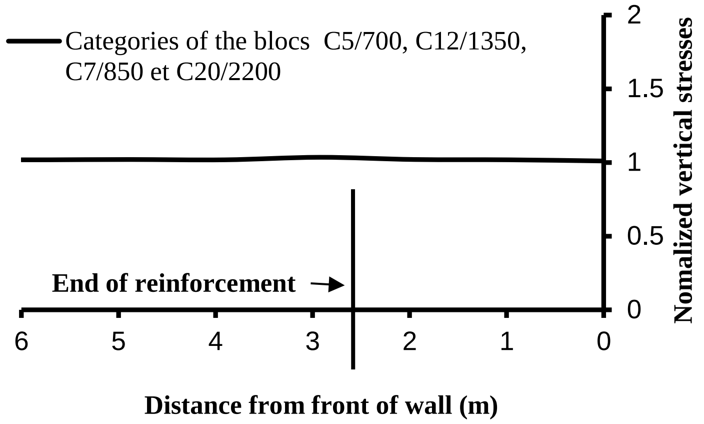

Figure 15. Distribution of vertical stresses at the base of soil

The values of "σ_V" were normalized with the vertical pressure due to the self-weight of the soil (γ.H). From this figure it can be concluded that the category of modular blocks has no effect on the calculation of "σ_V", the ratio of vertical stress is approximately equal to unity ($\sigma_V / \gamma.H \approx 1$).

5.3.4. Influence of the Category of Blocks on the Tensile Stress in the Layers of Geogrid "T"

Figure 16. (a, b, c and d) show the influence of the category of modular blocks on the tensile stresses in the geogrid layers to the different levels of the selected wall.

The simulation results show that the modulus of elasticity of the concrete blocks increases the tensile stress "T" decrease.

- For the different studied cases of category, the maximum values of "T" found in the upper layers (at the summit wall), and these values decrease as the modulus of elasticity of concrete blocks increases.
- For each category of cases studied, one can observe that the curves of "T" are the same shape and the values of the tensile stress decreases gradually from one layer to another up and down the wall.

Through these observations, one can conclude that whenever "E" increases (E = 2750 MPa to E = 10250 MPa) the maximum values of the tensile stress decreases and always found in the upper plies. So the increase in "E" has a significant effect for decreasing max values of "T".

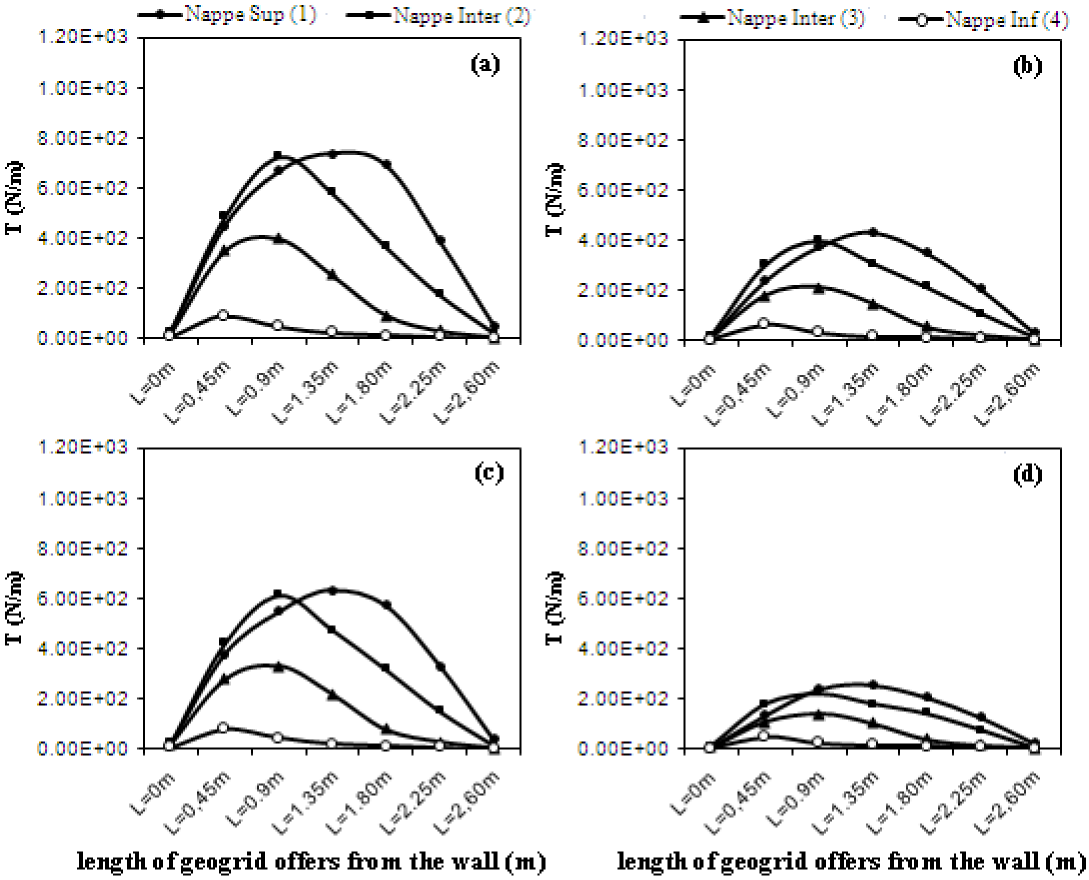

Figure 16. The tensile stress in the layers of geogrid, (a) C5 / 700 (b) C12 / 1350 (c) C7 / 850 (d) C20 / 2200

6. Conclusions

The results of this numerical study allowed to deduce the importance of each parameter of the wall selected for the behavior of retaining walls in soil reinforced by geogrid. The conclusions are derived:

- The inclination of wall is of great importance for the calculation of retaining walls in modular blocks and can provide an important contribution to the horizontal balance of this type walls. The value of "Ux" tends to continuously decrease with the increase of "W". More the wall is inclined plus the horizontal stresses "σ_h" and values of the tensile stress in the layers of geogrid "T" decrease in an expressive manner.
- This parametric study shows that the dimensions of modular blocks (types) and the mechanical characteristics of modular blocks (category) have a remarkable effect on the calculation of retaining walls in modular blocks reinforced with layers of geogrid. For a facing composed by blocks of Type 3 or Type 4 lateral displacements are reduced to approximately 24.65% as calculated in the case where the wall of type 1 or 2. The category of modular blocks a significant effect to decrease the values of lateral displacements of the wall "Ux" and decreased tensile stress values in the layers of geogrid "T".

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