



# INTERNATIONAL SCIENTIFIC CONFERENCE

**CIBv 2010**

**12 – 13 November 2010, Braşov**

---

## **HYBRID SOLUTIONS FOR ACHIEVING HIGH SLOPES FOR ROADS**

Dorin Vasile MOLDOVAN, Daniela PETRIC

Technical University of Cluj-Napoca, Faculty of Civil Engineering, 25 Baritiu Street, Cluj-Napoca

Corresponding author: Dorin Vasile MOLDOVAN, E-mail: dorinvasilemoldovan@yahoo.com

*Abstract:* With increasing land prices and topographic complicated site conditions, structures made of reinforced soil with geogrids consistently represent an economic and ecologic alternative to conventional constructions methods like e.g. concrete retaining walls. The big flexibility of these structures, relating to the diversity of possible facing systems and the adaptability to in-site conditions is one of the major decision criterions for the geosynthetic construction technology. The presented project from Romania, "Bellevue Residence" Braşov represents a construction method which allowed a fast, economical and ecologic solution under the project specific conditions.

*Key words:* reinforced soil, geogrid, geosynthetic.

### **1. INTRODUCTION**

In accordance with ASTM D4439, geosynthetic materials are defined as follows:

Geosynthetic – a polymeric material used with different types of earth or other materials designed by humans to function as a whole or as a system.

The first construction material that mankind had at hand was the earth, of which constructions were made bold, but limited in size and performance due to physical and mechanical characteristics of this natural material.

Geosyntetics brought with them not only the possibility of developing new technologies and solutions, but allowed theoretical approaches in construction of land by bringing new concepts such as reinforcement and then containment, control water flow and thus the phenomenon of internal erosion, sometimes radical improvement of the fundamental features of the earth.

Use of geosynthetic materials proposes two basic elements: (a) better behavior considering the life of the structure (reduced degradation) and (b) savings compared with traditional solutions and materials (either low initial cost or reduced maintenance costs).

## 2. CALCULATION METHODS – FINITE ELEMENT METHOD (FEM)

- **Plane strain**  $\varepsilon_z = \gamma_{yz} = \gamma_{zx} = 0$ .

$$\mathbf{E} = \frac{E}{(1+\nu)(1-2\nu)} \begin{bmatrix} 1-\nu & \nu & 0 \\ \nu & 1-\nu & 0 \\ 0 & 0 & (1-2\nu)/2 \end{bmatrix} \quad (1)$$

$\sigma_z$  can be obtained from the relation

$$\varepsilon_z = 0 = (\sigma_z - \nu\sigma_x - \nu\sigma_y) / E \quad (2)$$

after  $\sigma_x$  and  $\sigma_y$  are known.

- **Plane stress**  $\sigma_z = \tau_{yz} = \tau_{zx} = 0$ .

$$\mathbf{E} = \frac{E}{1-\nu^2} \begin{bmatrix} 1 & \nu & 0 \\ \nu & 1 & 0 \\ 0 & 0 & (1-\nu)/2 \end{bmatrix} \quad (3)$$

### 2.1 The equilibrium equations

Figure 1 shows a plane differential element. The equilibrium equations are developed stating that the differential element is in equilibrium under forces applied to it. Forces come from stresses on the edges and from body forces.

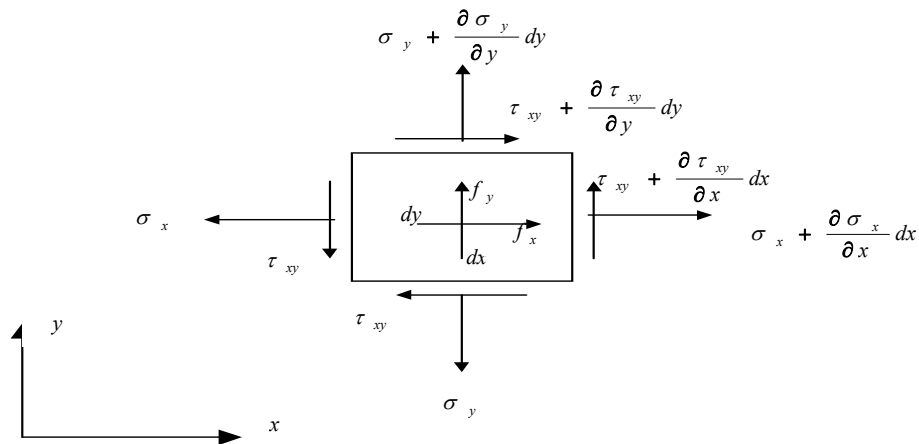


Fig. 1. Stresses and body forces that act on a plane differential element of constant thickness.

The stresses in the structure must satisfy the following equilibrium equations:

$$\frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + f_x = 0 \quad (4)$$

$$\frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \sigma_y}{\partial y} + f_y = 0 \quad (5)$$

$$\tau_{xy} = \tau_{yx} \quad (6)$$

where  $f_x$  and  $f_y$  are body forces, such as gravity forces, per unit volume. In the finite element method, these equilibrium equations are satisfied in an approximate sense.

## 2.2 Constant strain triangle (T3)

The two-dimensional simplex element is a triangle as shown in Fig. 2, it has two degrees of freedom at each node. It is also called *linear triangular element*. This element, has three nodes at the vertices of the triangle, which are numbered around the element in the counterclockwise direction. Each node has two degrees of freedom (can move in the  $x$  and  $y$  directions).

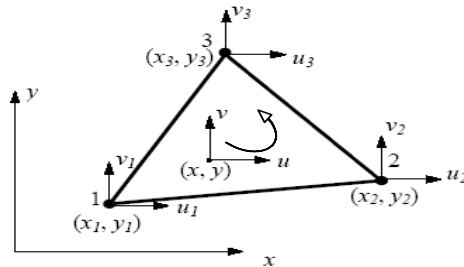


Fig. 2. Linear triangle finite element (T3).

The displacements  $u$  and  $v$  are assumed to be linear functions within the element that is:

$$u = \alpha_0 + \alpha_1 x + \alpha_2 y \quad (7)$$

$$v = \beta_0 + \beta_1 x + \beta_2 y \quad (8)$$

The constants  $\alpha$  and  $\beta$  are determined imposing the nodal conditions. Solving the system of equations we can find the coefficients in terms of nodal displacements and coordinates.

## 2.3 Stress calculation

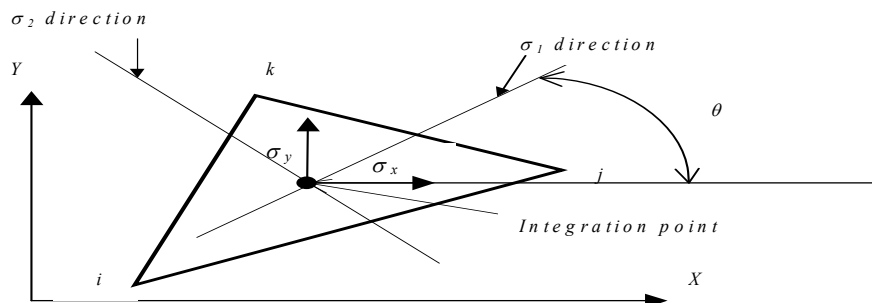


Fig. 3. Principal stresses.

## 3. COMPARATIVE STUDY ON THE SLOPES OF THE "BELLEVUE RESIDENCE" BRASOV

This study aims to follow in a comparative study the influence of geosynthetic materials, precisely the geogrids, on stresses, displacements and safety factor for the hybrid systems build in "Bellevue Residence" complex, in Brasov.

Thus were taken into account two types of typical profiles:

- A) reinforced soil structure
- B) two overlapped concrete support walls with reinforced soil behind them, in both cases it is present an 25KN/mp overload from the traffic.

Each profile was examined across two hypotheses:

- A.1) unreinforced soil slope;
- A.2) reinforced soil slope;
- B.1) overlapped support walls with unreinforced soil;
- B.2) overlapped support walls with reinforced soil;

Influence of geogrids over the stresses of the unreinforced/reinforce slope soil

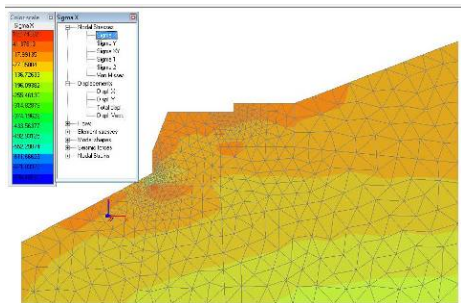


Fig. 4. Case A.1 Sigma X

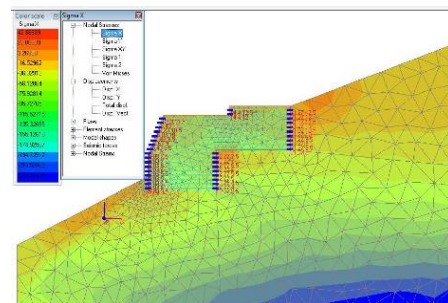


Fig. 5. Case A.2 Sigma X

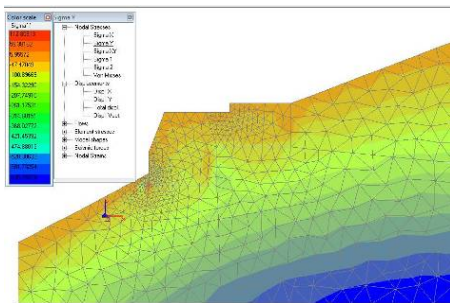


Fig. 6. Case A.1 Sigma Y

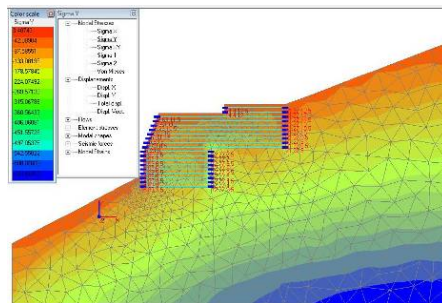


Fig. 7. Case A.2 Sigma Y

Influence of geogrids over the displacements of the unreinforced/reinforced slope soil

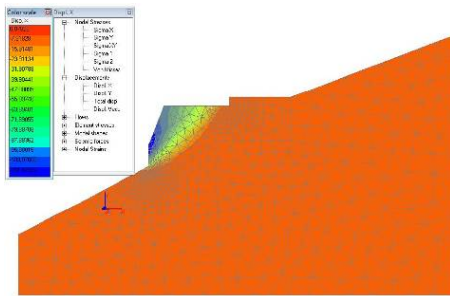


Fig. 8. Case A.1 Delta X

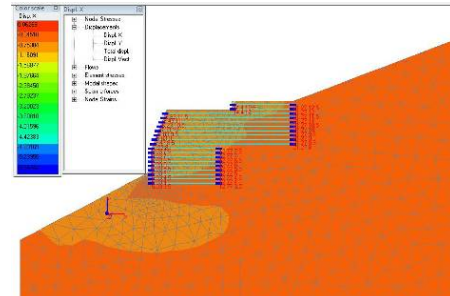


Fig. 9. Case A.2 Delta X

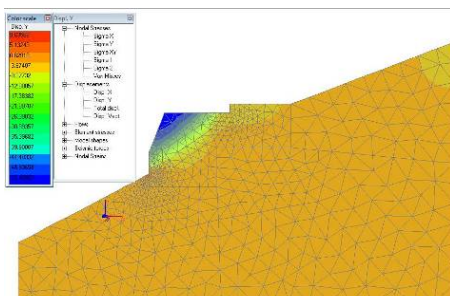


Fig. 10. Case A.1 Delta Y

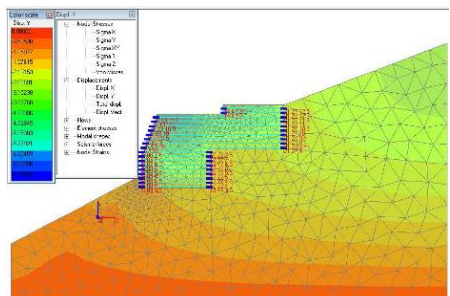


Fig. 11. Case A.2 Delta Y

Influence of geogrids over the stresses of the unreinforced/reinforced slope soil system

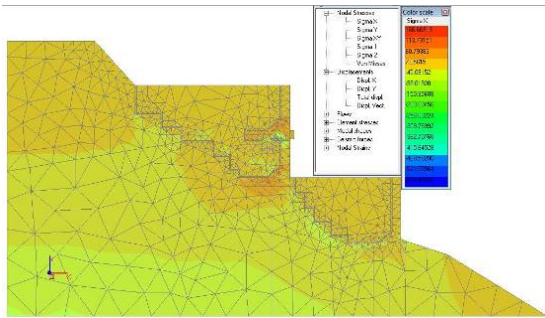


Fig. 12. Case B.1 Sigma X

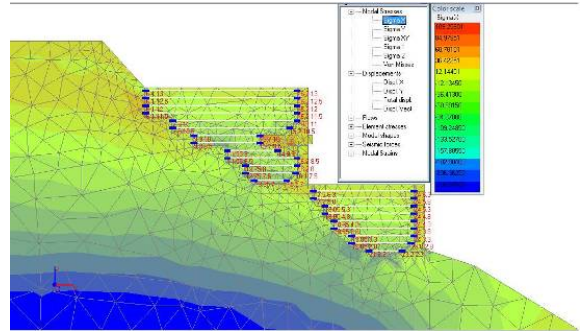


Fig. 13. Case B.2 Sigma X

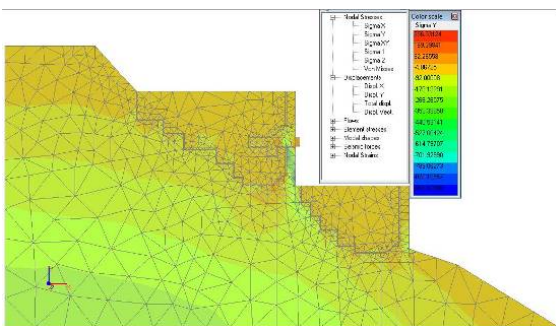


Fig. 14. Case B.1 Sigma Y

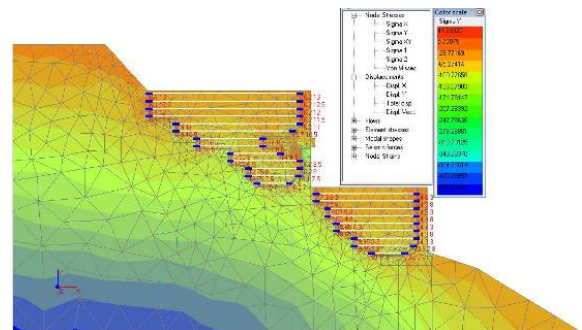


Fig. 15. Case B.2 Sigma Y

Influence of geogrids over the displacements of the unreinforced/reinforced slope soil system

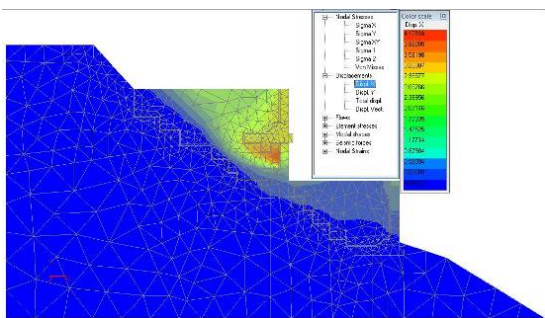


Fig. 16. Case B.1 Delta X

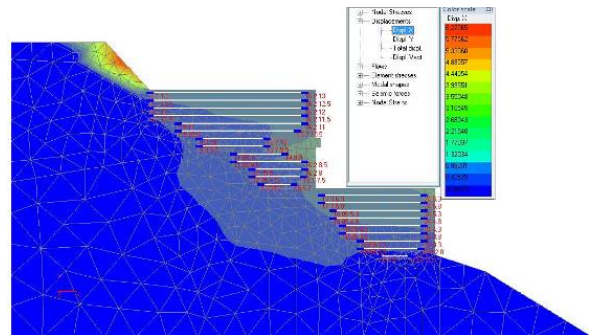


Fig. 17. Case B.2 Delta X

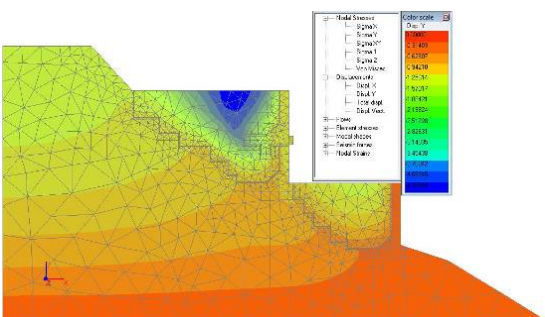


Fig. 18. Case B.1 Delta Y

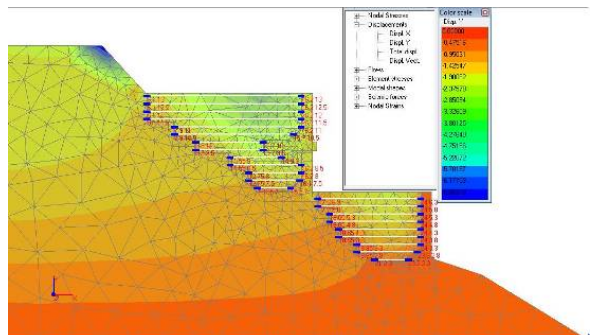


Fig. 19. Case B.2 Delta Y

Influence of geogrids over the safety factor F.S.

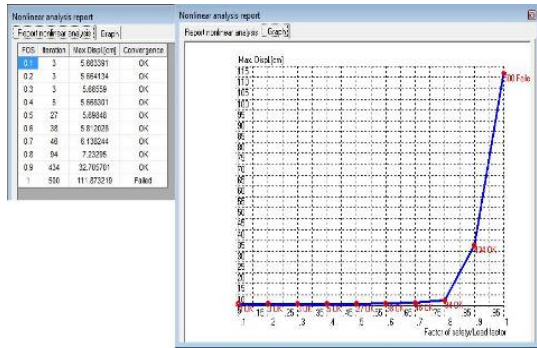


Fig. 20. Factor of safety case A.1 F.S=1

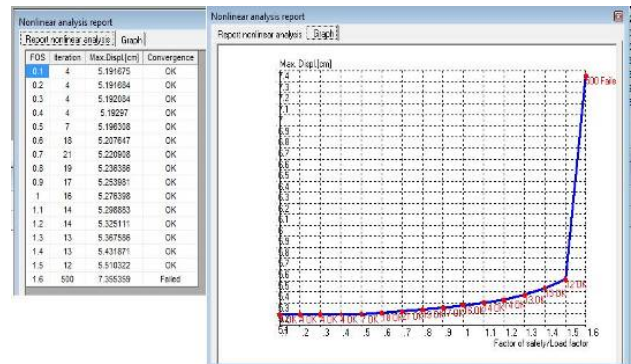


Fig. 21. Factor of safety case A.2 F.S=1.6

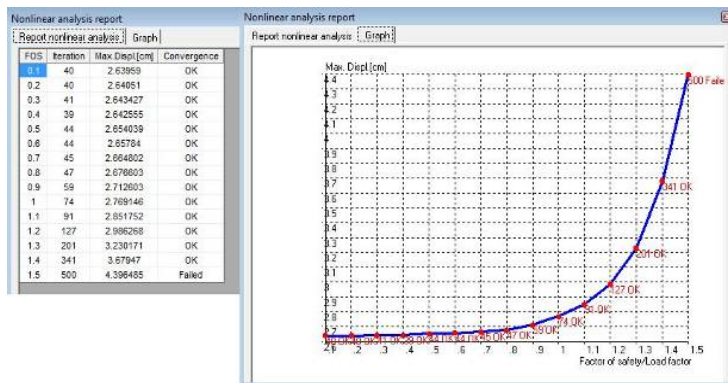


Fig. 22. Factor of safety case B.1 F.S=1.5

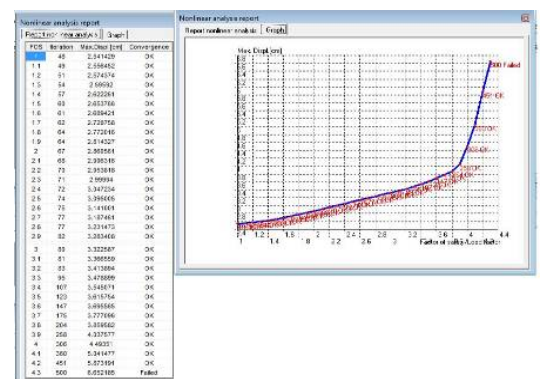


Fig. 23. Factor of safety case B.2 F.S=4.3

Table 1. Table of displacements

	Reinforced soil		Retaining walls	
	Case I	Case II	Case I	Case II
Delta X min [cm]	-7,91	0,06	-0,02	-0,003
Delta X max [cm]	-111,87	-5,64	4,15	6,22
Delta Y min [cm]	5,13	-0,52	-0,31	-0,47
Delta Y max [cm]	-53,4	-7,36	-4,39	-6,65

Tabel 2. Table of stresses

	Reinforced soil		Retaining walls	
	Case I	Case II	Case I	Case II
Sigma X min [KN/mp]	100,74	42,87	166,66	109,25
Sigma X max [KN/mp]	-730,4	-234,32	-574,46	-230,64
Sigma Y min [KN/mp]	112,8	3,4	256,53	41,23
Sigma Y max [KN/mp]	-635,15	-633,54	-963,32	-455,8

#### 4. CONCLUSIONS

In the analysis by finite element method, namely by performing a linear analysis of plane stress condition and a nonlinear analysis (safety analysis, bearing capacity), there is noted an improvement in slope stability variant A.2 40% ( $SF = 1 > SF = 1.4$ ), a reduction of maximum stress value of approximately 53%, 7.5 times the vertical displacements and horizontal displacements of about 22 times.

In the case of retaining walls stacked with reinforced filling we noted that the presence of geogrid in filling determines a decrease of maximum efforts by 54% and an increase in safety factor of approximately 2.9.

In the A.2 case, we can notice the requirement to use geogrids in order to reinforce the slope of the ground whereas in the case A.1 it loses its stability to a factor equal to one.

More precisely, in case B.1 (unreinforced filler see Fig. 18) there is a concentration of displacements at the lower retaining wall, and in the case B.2 (reinforced filling, see Fig. 19) we can observe a small and evenly distributed displacements of the whole structure, consisting in reinforced filling and stacked elastic retaining walls.

In Figure 20 we observe the production of significant compaction of the unreinforced fill behind stacked walls, and the figure 21 shows that the presence of geogrids in filling causes an uniform and significant reduction of compaction of the filling material.

These issues found on the movement play an important role in choosing the type of structure, considering that above the filling it was planned to make all access roads within residential Bellevue Residence, which requires displacements as reduced as possible in order to give to the running surface a smoothness and continuity during the exploitation period.

On the terms of the safety factor determined by nonlinear analysis we might conclude that these retaining structures are oversized, but viewed in terms of allowable displacements, it is fully justified the rational use of geogrids, with role in reinforcement of earth filling.

At the end of this study, after analyzing the obtained data and time tracking of structures build on the field we can state that geogrids play an important role in the safety factor of slope stability, in the reduction of active pressure against the retaining walls and also in reducing compaction and horizontal displacements of reinforced filling.



Fig. 24 – Soil structure ( $H_e=7,00m$ )



Fig. 25 – Soil structure (He=10,00m)



Fig. 26 – Soil structure (He=13,00m)

## REFERENCES

1. CUELLAR, V., DAPENA, E., *Geotechnical Engineering in Urban Environments*, **Vol. 3**, 2007
2. FEODOROV, V., *Pământuri armate cu geosintetice*, 2003
3. KORNER, R. M., *Designing with geosynthetics*, 2003
4. AKIN, J.E., *Finite Element Analysis with Error Estimators*, Elsevier, 2005
5. ZIENKIEWICZ, O.C., TAYLOR, R.L., *The Finite Element Method*, McGraw-Hill, 2000
6. COOK, R.D, MALKUS, D.S., PLESHA, M.E., *Concepts and Applications of Finite Element Analysis*, John Wiley & Sons, 1996
7. Geostru software, *GFAS Finite Element Systems for Geotechnical applications*, Theoretical and User Manual 2010 [www.geostru.com](http://www.geostru.com)
8. CHIOREAN, C.G., *GFAS Theoretical and User manual*, <http://bavaria.utcluj.ro/~ccosmin>
9. CHIOREAN, C.G., *Aplicarea metodei elementelor finite in calculul geotehnic*, Aplicația GFAS, Curs online, <http://bavaria.utcluj.ro/~ccosmin>

*Received September 30, 2010*