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COMPARATIVE STUDY ON FINITE ELEMENT MODELING OF A ROAD STRUCTURE REINFORCED WITH BIAXIAL AND TRIAXIAL GEOSYNTHETIC MATERIALS

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Abstract

Geosynthetic materials are commonly used in designing modern road structures, thus a series of distinctive characteristics were developed, according to their field of application. Geogrids are planar geosynthetic materials, used for mechanical stabilization and soil reinforcement works. There are several different assortments of geogrids, ranging from monoaxial to biaxial, and triaxial forms. Their applicability is set by the scale and direction of the loads the earth structure is subjected to. The present study follows a series of experimental modeling (both virtual and scale models) of a road embankment, highlighting the difference and similarities between numerical and laboratory testing, as well as emphasizing the difference between using biaxial or triaxial geogrids.

Rezumat

Utilizarea materialelor geosintetice reprezintă o practică relativ comună în proiectarea structurilor rutiere moderne. Folosirea acestor materiale la scară largă a permis elaborarea unor caracteristici specifice domeniului lor de aplicare. Geogrilele, care fac obiectul prezentului studiu sunt elemente de armare plane, utilizate pentru stabilizarea mecanică a pământurilor. Folosirea diferitelor modele disponibile (monoaxial, biaxial, triaxial) este decisă în funcţie de solicitările la care va fi supusă structura de pământ armat. Studiul urmăreşte un experiment realizat prin modelare virtuală şi la scară a unui terasament rutier, care prezintă în paralel rezultatele obţinute prin armare cu modelul triaxial şi modelul biaxial.

Keywords: triaxial geogrid, biaxial greogrid, modern road embankment

1. Introduction. Justifying the conformation of the experimental model.

Numerical modeling is based on failure criterion of different materials introduced in the virtual model. Studying the bearing capacity of a full scale laboratory model, until failure occurs is a complex task, therefore the creation of a void was suggested. Cavern forming in road embankments is relatively common, due to hydrological factors, what leads to the formation of sinkholes, or different construction activities, such as pipeline leaking, or poor compaction of the base layer, that

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causes differentiated settlements. Figure 1 shows an example of a road service surface in Romania, located on DJ 108A.

Figure 1. Deformation of asphalt layer due to poor compaction after pipeline intervention on DJ 108A

A layer of geogrid reinforcement was proposed above the void created on the scale model. The geosynthetic reinforcement confines the superior layer (which is also the base layer of the embankment), by retaining the granular material in its meshing. It also takes over and dissipates the resulting stretch load above the cavern, by friction forces on its contact surface.

2. Triangular meshing or rectangular meshing

The study was conducted on models reinforced with biaxial geogrid and triaxial geogrid (an unreinforced model was also created). Triaxial geogrid was specifically developed for traffic loads, according to the producer – Tensar UK. Its triangular meshing increases the in-plain stiffness. The triangle is the most stable geometric form, and also the most used in engineering due to its sturdiness. The geogrid's triangular aperture displaced in multiple directions provides high radial stiffness, which is important in dissipating the pressure cone resulted from traffic loads.
Rectangular meshed geogrids, also called biaxial geogrids have traction resistance and stretching stiffness by two main directions. The triaxial geogrid has these characteristics on three main directions, providing higher efficiency in transferring stresses from the reinforcement to the surrounding granular material. Also, based on the data provided by the manufacturer, triaxial geogrid has a longer lifespan and reduces considerably the total costs of reinforced earth structures. The behavior differences between the two types of applied reinforcement will be discussed in the following parts of the study.

3. Scale and numerical modeling

The study was conducted on two directions. A series of 1:1 scale models were tested under traffic load conditions using the Lucas plate (according to STAS 8942-85), while their equivalent two dimensional finite element models were introduced in the GFAS program. The Lucas plate test is commonly used for testing the linear deformation modulus of road structures. Laboratory models were built in a box having the following dimensions: width 1.50 m; height 1.00; and length 1.00 m. The box was filled with an initial layer of 40 cm of clay, which was covered with another 40 cm of ballast material. In order to run the test until failure was reached on both physical and numerical models a void was created at the bottom-center of the span on both series of models. The cavern was 50 cm wide and 25 cm high, and was created on the laboratory models by using a retractable drawer. Testing consisted of placing a 300 mm diameter plate on the top center of the span, and applying consecutive load stages, starting from 50 kPa (with a 50 kPa step) until the structure fails. Load stages were only increased when the surface settlement was considered stabilized (settlement does not increase by more than 0.1 mm for 30 minutes under the applied load stage). The influence of geosynthetic reinforcement was determined by testing an unreinforced scale model. The study also reflected a different failure type for the two types of geogrids used: the triaxial model failed through material failure, while the biaxial model failed by sliding between the ballast material and clay layer, until it touched the bottom of the void, as shown in figures 2 and 3.

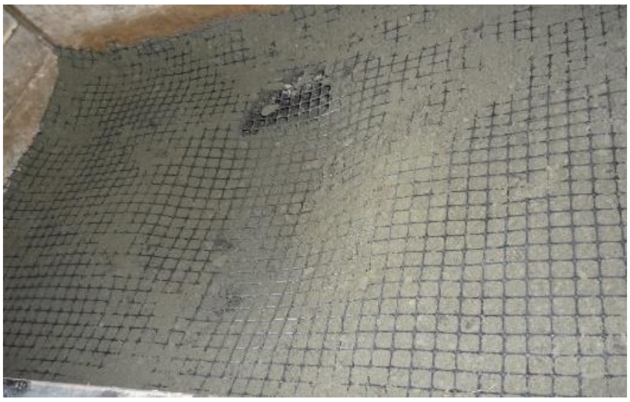

Figure 2. Shape and size of the collapse surface, when using biaxial geogrid reinforcement. Note the settlement in the center of the failure area, where the geosynthetical reinforcement touched the bottom of the cavern

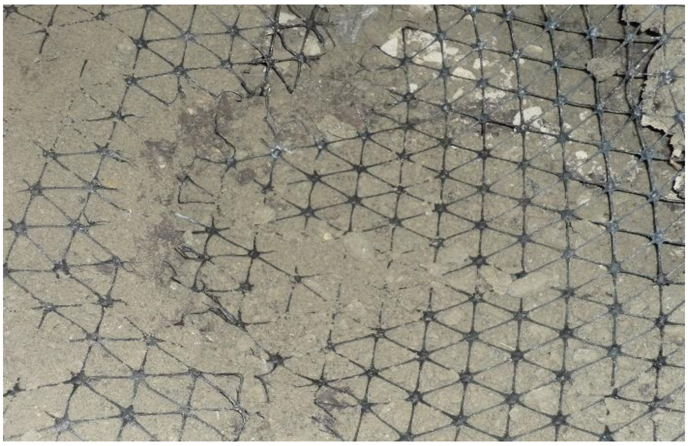

Figure 3. Shape and size of the failure surface when using triaxial geogrid reinforcement. Note the failed ribs of the geosynthetical material, and also the significantly smaller size of the failure surface

For the numerical modeling part GFAS software was used. The finite element method was considered suitable for the numerical modeling, because it allows interaction between earth layers and reinforcement material. It can also model failure through conditions dependent or independent of the hydrostatic pressure (inside the soil pores), which is an important aspect, considering the fact that the simulated structure consisted of both cohesive (the initial layer of clay) and non cohesive (base layer of ballast material) soil types. Finite element modeling determines the stress domain corresponding to the applied load stage, and geometry of the given structure. Using a predefined failure criterion, the software indicates if the flowing occurs at any given point of the model. Failure criteria define the linear – elastic behavior limit of materials. The road foundation layers were introduced using their geometrical characteristics, while the geosynthetical reinforcement was modeled as a linear element featured by its physical and mechanical properties, such as density, traction resistance, and modulus of elasticity. The GFAS software can use the following failure criteria: Mohr – Coulomb, von Mises and Drucker – Prager (suited for sandy soils). Von Mises failure criterion was chosen for the bottom layer of clay, as it can consider the influence of hydrostatic pressure. The natural humidity of the clay used in the scale model was 40%, determined in laboratory conditions. Cohesion and internal friction angle values were considered under drained conditions, and were determined as in laboratory shear tests. The ballast material base layer would have been more accurately defined by the Mohr – Coulomb failure criterion, but it was stored outdoors, in rainy weather, and as a consequence it accumulated a high amount of water. As the primary objective of the study was to correlate scale and numerical modeling results, von Mises criterion was chosen for this layer too. The von Mises perfectly plastic models is based on the assumption that plastic deformation begins when the potential energy required for changing the shape of the finite elements (noted with W_d) reaches a critical value specific to each type of material introduced in the numerical model.

$$W_d = \frac{1+\upsilon}{6E}\left[(\sigma_1-\sigma_2)^2+(\sigma_2+\sigma_3)^2+(\sigma_3+\sigma_1)^2\right] \quad (1)$$

where E is the Young modulus, υ is the Poisson ratio, respectively σ_1, σ_2 and σ_3 are the normal stresses on the main directions.

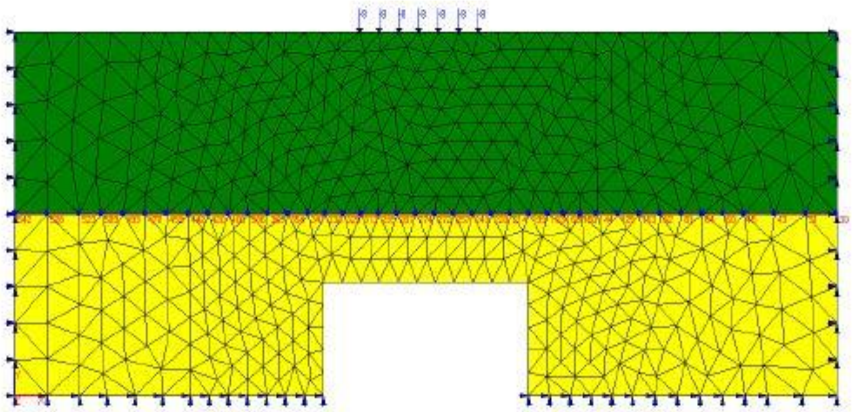

Figure 4. Numerical model created in GFAS

Boundary conditions were set by defining the coordinates of the points. The boundary conditions consist of prescription of displacement and of stress. We separated two zones with different characteristics. After defining the numerical model, the software runs the mesh generation. Mesh generation is a procedure of generating data of the elements and their nodes. The nodes make the connection between these elements. The mesh generation is very important procedure in the finite element modeling.

Results from the numerical analysis confirmed the values obtained from the scale model testing. A failure occurred at pressures of 500 kPa on the unreinforced model, 650 kPa on the model reinforced with biaxial geogrid, and 750 kPa on the model reinforced with triaxial geogrid. On the scale models subjected to the Lucas plate test the corresponding values were 550 kPa, 700 kPa and 800 kPa. The constant difference of 50 kPa is due to the principles of calculation applied in the finite element method. Load bearing capacity of earth structure is increased by the arch effect of the cohesive soil used, also on the scale models small or medium size earth lumps collapsed during testing, thus altering the load distribution in the structure. These aspects cannot be simulated in GFAS, as one of the principles of finite element modeling relies on constant contact of the elements generated by meshing. However, overlapping the displacement – load stage diagrams show how close the mathematical model comes to the practical reality (figures 5.a and b).

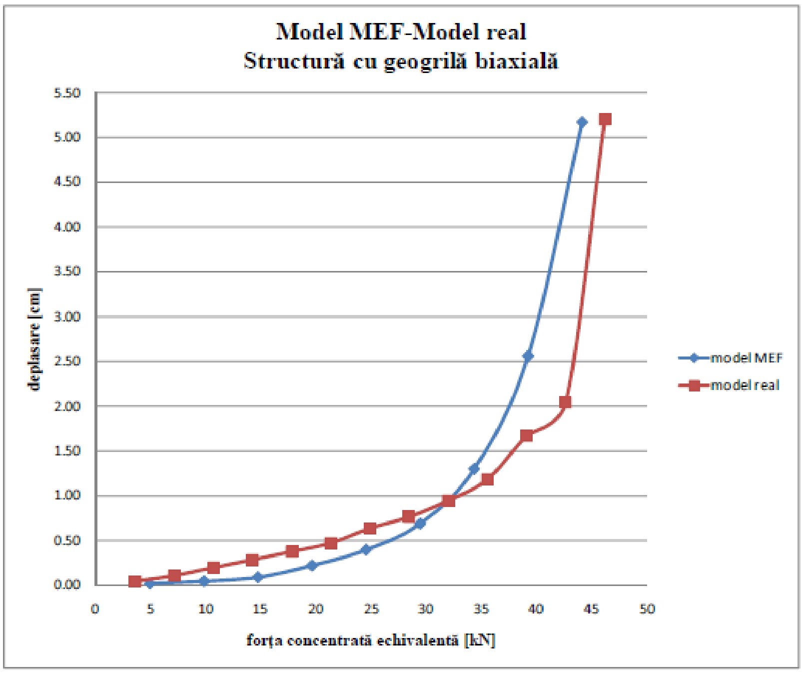

Figure 5.a. Displacement – equivalent concentrated load (on the 300 mm Lucas plate surface). Model reinforced with biaxial geogrid

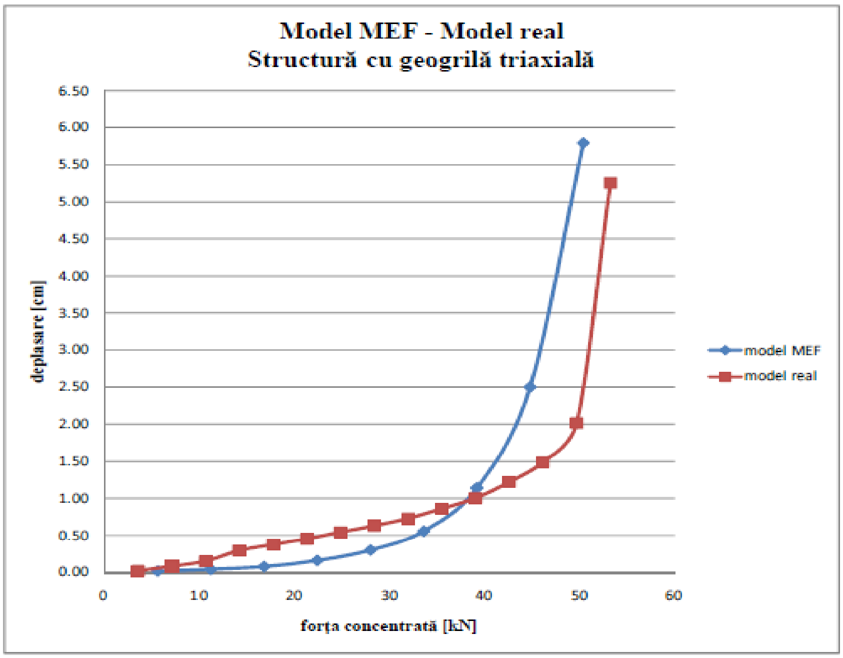

Figure 5.b. Displacement – equivalent concentrated load (on the 300 mm Lucas plate surface). Model reinforced with triaxial geogrid

Admitting the similarity of the behavior of the scale and numerical models, the GFAS software offers a stress diagram from inside the earth layers (figures 6.a and b).

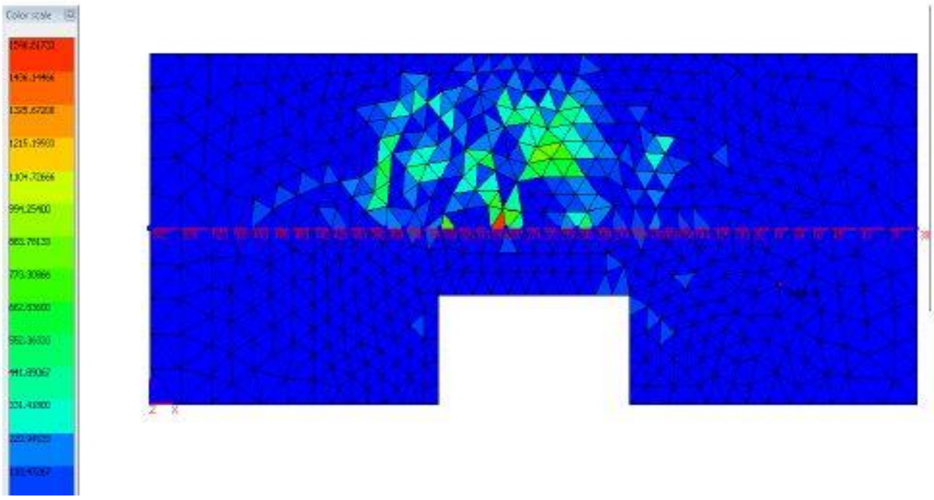

Figure 6.a. Normal stress in the ballast material and clay layer, results from the nonlinear analysis of the structure including biaxial reinforcement

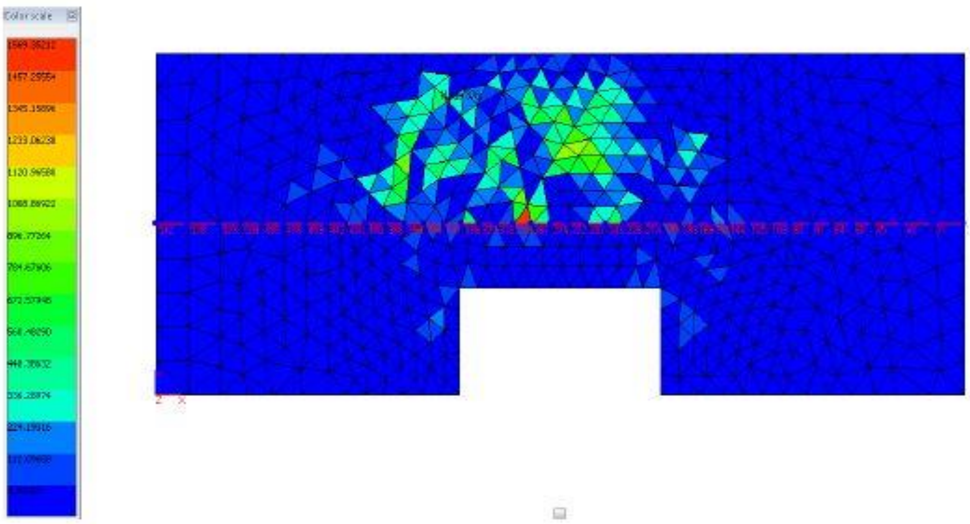

Figure 6.b. Normal stress in the ballast material and clay layer, results from the nonlinear analysis of the structure including triaxial reinforcement

A close look at the graphics reveals a roughly equal value for the peak stress, respectively 1560 kPa on the biaxial model, and 1580 kPa on the triaxial model.

4. Conclusions

The study reflected on the modeling differences between scale and numerical modeling on a particular case of road structure with a cavern. Based on the experimental values obtained with both methods, the following conclusions can be drawn:

- if failure criterion is chosen correctly the behavior of the numerical model comes very close to the behavior of the scale model
- finite element method however cannot match the scale model exactly due to the constrictions set by the continuous contact of elements
- the two types of geogrid fail in distinct ways, the biaxial reinforcement fails by slipping, while the triaxial reinforcement fails by material failure, the failure surface is significantly larger in the first case; this aspect cannot be approached in the finite element method

- peak stress values from inside the earth structures are very similar, careless of the reinforcement type chosen
- triaxial geogrid increases the bearing capacity of the structure by 31 %, while biaxial geogrid increases the bearing capacity by 22% as against the results obtained on the unreinforced structure
- the unreinforced scale model fails suddenly, while the reinforcing models fail slowly make them less hazardous for traffic

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