Improving Weak Soils Bearing Capacity by Using Gravel Cushion Reinforced with Geosinthetic Materials

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Replacing weak soil layer by a gravel cushion is a usual consolidation method, wich has been improved lately by inserting in the gravel cushion reinfocements, analogical to concrete reinforcement, aiming to increase the bearing capacity of the foundation soil. This paper presents some aspects regarding geosinthetical materials behaviour used to reinforced the gravel cushion as much as the effect on stresses distribution and displacements in gravel and surrouding soil. This study has been conducted trough experimental tests and numerical analysis. The conducted analysis is statical and nonliniar. The calculus of the study consists of: displacements of the soil, the values of the stresses in inner part of the gravel layer and in the geosinthetic materials. Noticing that the disposal of the reinforcements leads to decrease stresses and displacements values at the foundation level but also at the gravel layer base.

Keywords: geosinthetic materials, gravel cushion, reinforced soil

Geosynthetic materials term is general and includes the entire domain of products made from synthetic polymers such as polypropylene, polyester, polyethylene, nylon, PVC which are used with the aim to solve geotechnical problems. This materials have high resistance to chimical and biological degradation and can be processed to attain the resistance requirements, tensile strain, to provide a good adherence with the reinforced soil.[17, 18]

The currently research activity of the reinforced soil used as foundation soil aims to specify the arrangement of reinforcement elements, the reinforced soil computation methodes to be determined but also ways of errection taking into account: the model and physical-mechanical characteristics of the geosinthetic materials, soil characteristics used as foundation cushion and the load type that applies to the foundation system.

This method involves the development of improved soil pads foundation, consisting of a material with high strength characteristics and low deformability, pads that can take the loads from the foundation system in condition of resistance and stability.

Having at the base the principle of reinforced concrete in which reinforcement is arranged in directions where the stresses exceed the tensile strength of concrete, the geosynthetic reinforcement layers are disposed on the same principle.

Through the reinforcement mechanism the tensile stresses are absorbed or dissipated by the flexible reinforcement that will take tensile deformations in the core as far as its rigidity characteristics. Thus the tensile deformation is transferred from the soil to the reinforcement by contact between them [17].

The interaction between the two materials depends on the soil and reinforcement characteristics, and the reinforcement arrangement influencing their relationship.

Choosing the geosynthetics will take account of long-term loads of the future structure and soil characteristics that will be used. Usually geosynthetic reinforcement materials are used in the form of tapes, geomembranes, geogrids or geocells. The connection between geogrid reinforcement type or geocell is controlled by the shear inner mechanism within the soil at the interface between soil and reinforcement. The developing connection force increase as the soil shear resistance increase but also with the increase of the reinforcement roughness.

Using geocells for reinforcing soils presents the advantage that after their arrangement inside the soil, the mechanism of cooperation has three aspects [16, 5]:

- the effect of lateral resistance (confinement) - the geocells are materials with 3 measures which confines, retains and reinforce various materials in the alveoli structure, thus preventing lateral spread of the materials they contain and increasing of the resistance to shear fillers;
- dispersion effect of vertical loads - geocells mattress reinforcing acts as a platform for immediate redistribution role of vertical efforts on a larger area, which involves their reduction;

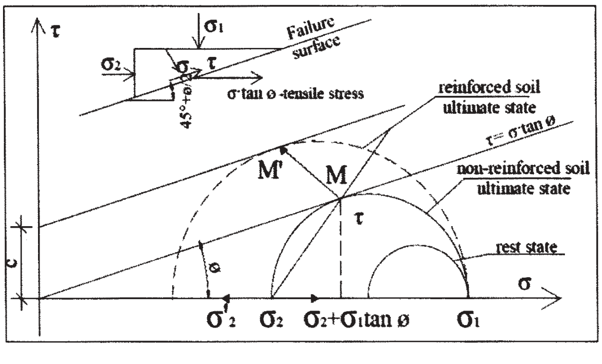

Fig. 1 Tension state in point A [14]

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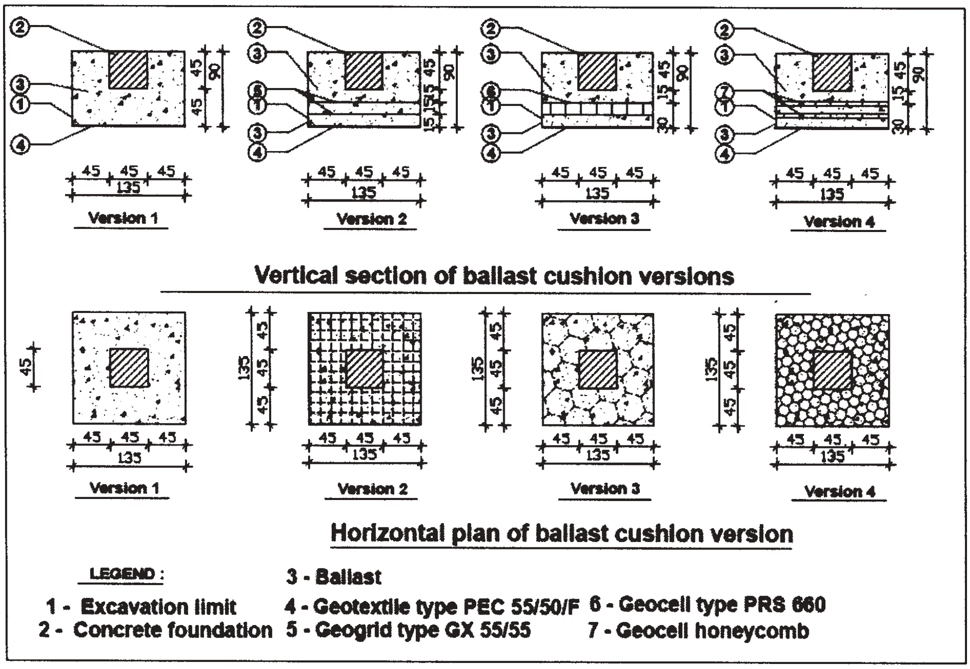

Fig. 2 Ballast cushion reinforced versiones studied analitical and experimental

- membrane effect - the extent of load application, foundation and soil under the foundation moves down and bends reinforcing layers being subjected to tensile stresses. As the depth of the rabbets prevent deformation of the layer with the geocells, the valve further provides the tensile stress. The reinforcement must be stretched tight and rigid to avoid tearing or exceeding the pull tensile strength.

Numerical computation. Finite element method

Materials and methods

The software using finite elemnt method is TNO Diana.

Geometric model involves the development of a cohesiveless soil cushion (ballast) with dimensions of 1.35 x 1.35 x 0.90 m within a cohesive soil (sillty clay).

We analyzed four numerical calculation models with the following options (fig. 2):

- non reinforced granular materials cushion;
- granular material cushion reinforced with two geogrid;
- granular material cushion reinforced with one geocell;
- granular material cushion reinforced with two geocells;

After studying literature in the field [1-4, 7-12, 15, 18] and the conclusions resulting in a previous research [13], reinforcement with geosynthetic materials, the length of the foundation denoted B = 0.45m, was disposed as:

- the distance between the layers of reinforcement in the vertical direction is 15 cm representing 0.33 B;
- distance between the surface of the foundation and first layer of reinforcement is 15 cm representing 0,33B;
- lateral extension of the reinforcement from the foundation layer is 45 cm representing 1B.

Numerical computation on behavior of cushion ballast to static vertical loads are presented in figure 3, was carried out in four stages corresponding to calculation load on the foundation surface: 2, 3, 4 and 5 daN/cm^2.

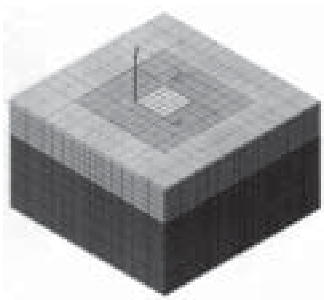

Fig. 3 Geometrical model and meshing

Table 1

NON-REINFORCED BALLAST CUSHION TENSION AND STRAIN TABLE

Variant reinforcement	Loading step on surface [daN/cm^2]			
Non-reinforced ballast cushion	**2**	**3**	**4**	**5**
ballast cushion settlement [mm]	0.119	0.45	0.85	1.76
principal stress s3 ballast cushion [N/mm^2]	-0.10	-0.25	-0.42	-0.64
maximum settlement [mm]	0.64	1.80	3.41	5.64

Table 2

TWO GEOGRID BALLAST CUSHION TENSION AND STRAIN TABLE

Variant reinforcement	Loading step on surface [daN/cm^2]			
Two geogrid ballast cushion	**2**	**3**	**4**	**5**
upper geogrid settlement [mm]	0.34	1.12	1,82	2.54
lower geogrid settlement [mm]	0.15	0.73	1.18	1.91
superior georgrid axial force [N]	0.63	1.44	2.76	4.34
inferior georgrid axial force[N]	0.58	1.35	2.71	4.34
ballast cushion settlement [mm]	0.10	0.34	0.78	1.46
principal stress s3 ballast cushion [N/mm^2]	-0.11	-0.25	-0.39	-0.64
maximum settlement [mm]	0.32	1.44	2.23	3.35

Variant reinforcement	Loading step on surface [daN/cm^2]			
One geocell ballast cushion	**2**	**3**	**4**	**5**
geocell settlement [mm]	0.45	1.2	2.5	4.02
geocell axial force [N]	0.44	0.51	0.90	1.37
tasare perna balast [mm]	0.15	0.503	1.17	1.63
principal stress s3 ballast cushion[N/mm^2]	-0.10	-0.23	-0.55	-0.64
maximum settlement [mm]	0.59	1.61	3.14	5.21

Table 3
ONE GEOCELL BALLAST CUSHION TENSION AND STRAIN TABLE

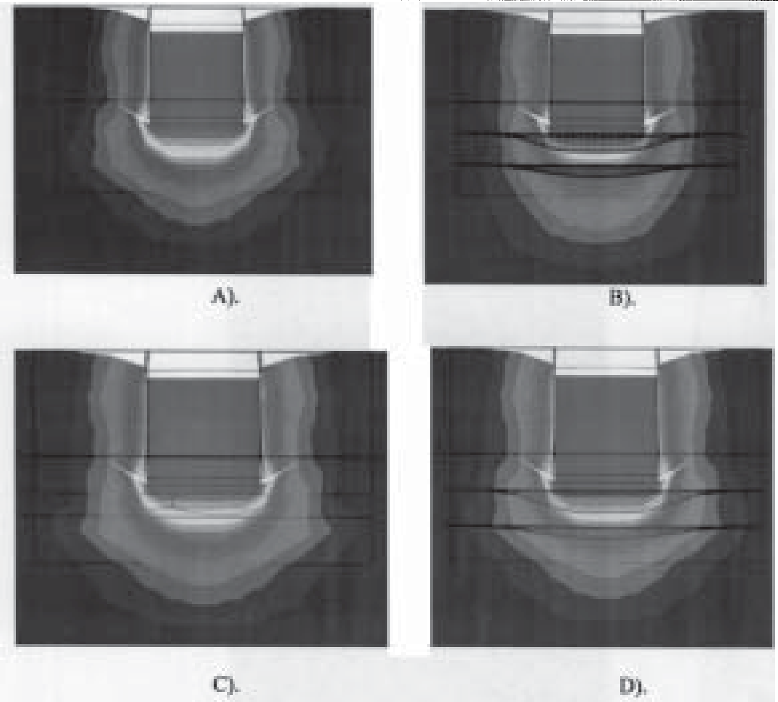

Fig. 4. A) Non-reinforced ballast cushion displacement. B) Two geogrid ballast cushion displacement. C) One geocell ballast cushion displacement. D) Two geocell ballast cushion displacement

Table 4
TWO GEOCELL BALLAST CUSHION TENSION AND STRAIN TABLE

Variant reinforcement	Loading step on surface [daN/cm^2]			
Two geocell ballast cushion	**2**	**3**	**4**	**5**
upper geocell settlement [mm]	0.51	1.50	2.90	3.58
lower geocellsettlement [mm]	0.27	0.85	1.87	2.25
superior geocell axial force [N]	0.47	1.28	2.56	3.17
inferior geocell axial force [N]	0.24	0.81	1.27	1.76
ballast cushion settlement [mm]	0.18	0.32	0.83	1.73
principal stress s3 ballast cushion[N/mm^2]	-0.10	-0.24	-0.42	-0.63
maximum settlement [mm]	0.63	1.17	3.32	5.53

The main characteristics of the materials used are: elastic modulus of the ballast $E_b=8*10^7$ N/mm^2, internal friction angle $\Phi_b=32^o$ Poisson's $\nu_b=0.277$, specific weigth $\gamma_b=2100$N/mm^3. Clay layer characteristics: $E_a=2.65.10^8$ N/mm^2 $\Phi_a=16^o$, $\nu_a=0.361$, cohesion $c_a=30000$N/mm^2, $\gamma_a=1800$ N/mm^3. Geosynthetic material: $E_g=1.99*10^9$, γg = $\gamma_g=860$ N/mm^3.

For modeling the interface between the concrete block foundation and ballast cushion was opted for Coulomb Friction model with the following properties: normal stiffness Kn = 2.26E8, shear stiffness Kt = 2.26E8 and Φi = 22^o. The values of these parameters were determined by laboratory tests (to determine mass density) and ν Poisson's ratio, cohesion and internal friction angle were taken from the literature [8, 6]. Materials behavior laws are nonliniar.

Ballast and clay has Mohr-Coulomb's behaviour law and the geosynthetic material constitutive model is elastic.

Meshing the model was made with prismatic elements.

Results of numerical analysis

Following the numerical analyzes were obtained the following results presented in tables 1-4.

In the figure 4 are presented the deformed shape of the ballast cushion and the sourrounding soil.

Experimental tests

Used materials

The foundation system used consists of four concrete, C16 / 20 , foundation blocks with nominal size 30x30x30 cm.

The filling material is ballast with the following characteristics:

- Dry density $\rho_{d\ max}=2.19$ g/cm^3;
- Optimum compaction moisture $w'_{opt}=4.1$ %

1. Geotexil type PEC 55/50 / F product of Polyfelt Geosynthetics (with separation role between the natural terrain of the site and ballast) with the following technical characteristics:

- Product type - geocomposite continuous filament nonwoven mechanically linked / PET fiber high strength,

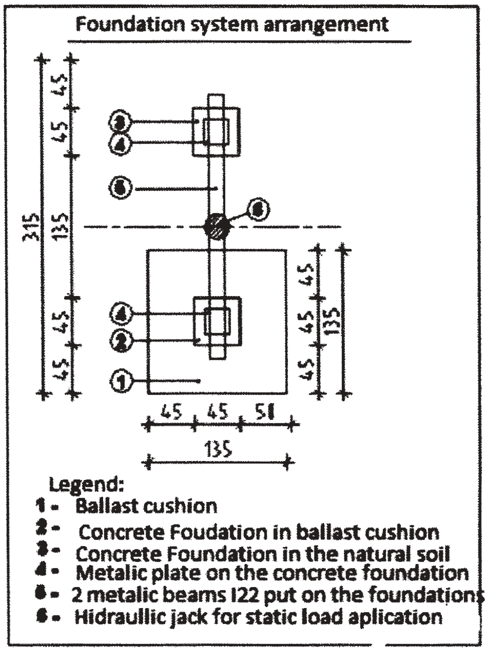

Fig. 5 Foundation system plan

Table 5
DISPLACEMENT TABEL FROM EXPERIMENTAL TESTS

Loads	Non reinforced cushion	Two geogrid reinforced cushion	One geocell reinforced cushion	Two geocell reinforced cushion
[daN/cm2]	[mm]	[mm]	[mm]	[mm]
0	-	-	-	-
1	0.3	-0.5	-1.7	-0.4
2	-0.2	-1.7	-3.6	-1.3
3	-2.2	-2.3	-4.7	-2.3
4	-4.1	-2.9	-5.6	-3.3
4.5	-4.7	-3.4	-6.0	-3.4
5	-5.6	-3.9	-6.7	-4.1
0	-4.0	-2.2	-4.7	-2.5

the reinforcement direction - biaxial , maximum tensile strength long. / Transverse. - 58/53 kN / m, elongation at break long. / Transverse. - 12 / 11.5%, permeability normal to the plane - 55 mm / s, thickness - 2.6 mm.

2. Geogrid of type TenCateMiragrid GX 55/55produced by TenCateGeosynthetics (with reinforcing role) with the following technical characteristics:

- Product Type - geogrid made from high strength polyester fibers covered with a coating polymer, the reinforcement direction - biaxial; mesh sizes - 20mm (transverse) and 35 mm (longitudinal) tensile resistance longitudinal / transverse (minimum) - 55/55 kN /m

3. Geocells type PRS 660, produced by IRIDEX GROUP PLASTIC (with reinforcing role) having the following technical characteristics:

- Product type – geocell with cellular structure made of polymer alloys , direction of reinforcement - triaxial, cell dimensions (recommended opening) - 500 mm x 420 mm, secant modulus - 480 kN / m, elongation at break -> 600%;

Description of the test

Ballast cushion dimensions were established taking into account the following:

- the distance between the foundations in the longitudinal direction is 1.35 m (corresponding to a size 3B) so as not to influence the behaviour of the field for each variant of the foundation, and the distance between the edge of the foundation and excavation is 0.45m in both directions, resulting in a length of 3.15 m in the longitudinal direction;

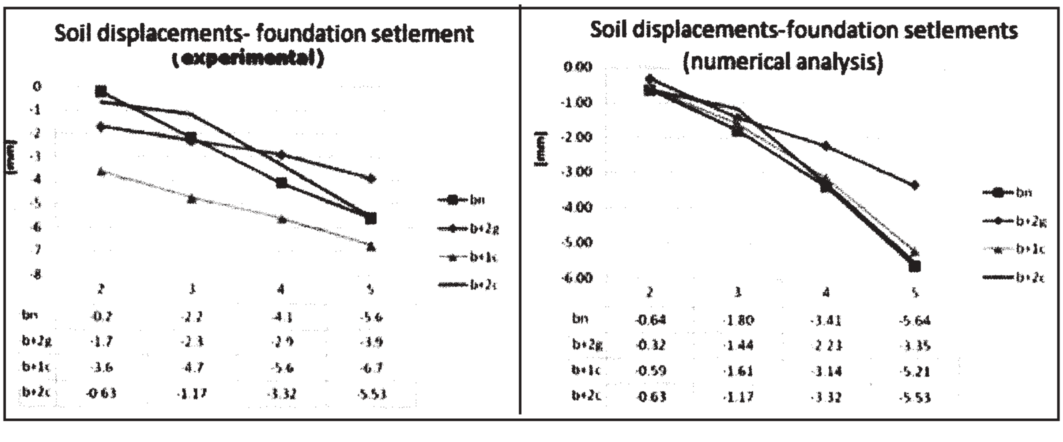

Fig.6 A) Displacement reprezentation from experimental test:
B) Displacement reprezentation from analytical analysis

- the depth was established by summing the thickness of all layers, namely the depth of 0.45 m from concrete blocks,the first layer to the first reinforcement layer with the thickness of 0.15, te second layer to the second reinforcement layer of 0.15 mand the layer to the separation geosynthetic material 0.15 m resulting depth of 0.90 m from ground level.

Errection of the ballast cushion was made according to the following steps:

- foundation excavation to the depth -0.90 from ground level;
- arrangement of the separation geosynthetic of type PEC 55/50/F;
- making a compacted ballast layer of thickness of 15 cm, until to foundation level -0.75 m below ground level;
- layout first GX geogridgeosynthetic material type 55/55 in foundations;
- making a compacted ballast layer thickness of 15 cm to 0.60 m elevation foundation to ground level;
-arrangement of the second GX geogrid geosynthetic material type 55/55 in foundations;
- making a compacted ballast layer thickness of 15 cm to 0.45 m elevation foundation to ground level;
-laying the foundation;
- adding compacted ballast to the top of the concrete foundation;
- each ballast bed was soaked until the moisture for optimum compaction previously calculated;
- after each layer has been carried out dynamic plate checks in order to determine the degree of compaction.

The test stand consisted of two frames interconnected by a rigid metal floor plan with dimensions of 3.00 x 3.00 m. On this floor was ordered a total weight of 2.5,00 kg and 2,500 daN, made of concrete slabs and metal.For the distribution of the load on the foundation have been used two longitudinal beams 2I22 welded section that has a length of 2.70 m on which was arranged the hydraulic jack.The longitudinal beams are supported on concrete foundations through a central hole in the metal plate that ordered a round metallic element to pick up any spins. To establish the computational loads it aimed to reach on the foundation sole pressures that can develop normally in the soil. Respecting Romanian standards NP 112-2013 and STAS 3300/2-85 calculation of bearing capacity of the foundation soil is by conventional pressure calculation method, according to the conventional calculation of soil pressure corrected according to foundation width and depth. Conventional pressure for calculation uncorrected for sandy gravel p_{conv}=550 kPa = 5.5 daN/cm^2. To study the behaviour of soil the uploading of foundations was done in steps from 1daN/cm^2 up to 5 daN/cm^2. The load calculation took into account the weight of the concrete block and lightweight metal beams used for the test stand. After uploading in each step after the consumption of displacements interval of 5 min were carried out on each foundation surveying, as well as to a landmark existing on the platform, in order to establish the deformation of the soil.

After reaching the final load step was done the foundations downloading and a survey was carried out to determine the residual deformations

Used Equipment

The static loading system of the foundation consists of the following elements:

- 2 I22 metal beam located on two foundations;
- Hydraulic jack mounted on steel beams;
- Weight of 2.5 t, as a counterweight for the hydraulic jack;
- Hydraulic hand pump;
- Data acquisition station with electronic display connected to the hydraulic pump and pressure sensor.

Data recording

Topographic measurements were made with electronic digital level SPRINTER 100 / 100M / 200 / 200M and level instruments

Results

Comparison of the two analyzes (experimental and numerical tests):

Conclusions

Numerical analysis using the finite element program Diana TNO conducted on the behavior of reinforced foundation pads, with static vertical load applied, followed highlighting developments in field of strains (both on the surface of the foundation and the foundation cushion base contact with weak material foundation). Figures 4A to 4D shows diagrams of settlement in the central section of each of the four embodiments foundation cushion. It is noted that the arrangement of reinforcement causes a decrease in the distribution of compressive stresses or deformations of the foundation soil both vertically and horizontally. The plots in figure 6A and 6B and tables 1 to 5, comparing the three versions of reinforcement, is observed that the strains recorded values are significantly close together but apart from the value of non-reinforced version.

The best behaviour, presenting a variant of the arrangement of two layers of geogrid, their use leads to:

- 20% reduction (1.44 mm to 1.80 mm) in maximum deformations at static loads on the contact surface between the foundation and cushion and reduced by 24% (0.34 mm to 0.45 mm) of maximum deformation at static loads and maintaining constant values of stresses at the top ground level (at the base cushion foundation) upon to 3daN/cm^2;
- 40% reduction (3.35 mm to 5.64 mm) of maximum deformations at static loads on the contact surface between the foundation and cushion and reducing by 17% (1.46 mm to 1.76 mm) of maximum deformation to static loads and 4% decrease of stresses (6.18 to 6.42 kN/m^2), at the natural ground level (at the base of the foundation cushion) to a load of 5 daN/cm^2.

The presented results clearly indicates that the introduction of reinforcement in ballast cushion lead in all cases to substantially lower deformations of foundation soil, in a more even distribution of effort within the core and reduce the spread of efforts to the cushion granular material, resulting in a decrease of deformations at all levels of reinforcement but also at contact area with the low bearing capacity soil.

This phenomenon can be explained by the fact that the reinforcement arrangement of geogrids has the advantage to achieve good ballast compaction, the same as that in the case of non-reinforced cushion, also offers the advantage of clenching the granular material due to friction forces, slowing down the movement of bulk materials and the deformation is decreased as the material work together as a whole thereby increasing the transverse modulus of deformation or increase the shear strength of the material.

Reinforcement layout as geocells has the disadvantage of low possibility of compacting the granular material inside geosynthetics cells (geocells). Granular material with a lower degree of compaction than the other variants recorded a deformation (subsidence) higher than the version with geogrids.

This work was partially supported by the strategic grant POSDRU/159/ 1.5/S/137070 (2014) of the Ministry of National Education, Romania, co-financed by the European Social Fund – Investing in People, within the Sectoral Operational Programme Human Resources Development 2007-2013.

References

1.ALAMSHAHI S., HATAF N., Bearing capacity of strip footings on sand slopes reinforced with geogrid and grid-anchor, Geotextiles and Geomembranes 27 :217–226, 2009

2.BOUSHEHRIAN A. ET AL., Modeling of the cyclic behavior of shallow foundations resting on geomesh and grid-anchor reinforced sand, Geotextiles and Geomembranes 29:242-248, 2010

3.CICEK E., YETIMOGLU T. GULER E., Effect of reinforcement type on the settlement of a strip footing under static loads, 5th European Geosynthetics Congress, Valencia 2012, pp 109-113, 2012

4.DASH S. K. ET AL, Performance of different geosynthetic reinforcement materials in sand foundations, Geosynthetics International 11(1):35-42, 2004

5. GOUVES R., REIFFSTECK P., VIGNON J. F., Study of confinenment effect in geocells, I-th European Geosynthetics Conference Eurogeo, 455-458, Balkema 1996

6 HAIDA V., MARIN M., MIREA M., Mecanica pãmânturilor, Orizonturi Universitare, Timiºoara, pp. 287-312, 2004.

7. HATAF N., BOUSHEHRIAN A. H., GHAHRAMANI A., Experimetal and numerical behaviour of shallow foundations on sand reinforced with geogrid and grid anchor under cyclic loading, Civil Engineering, vol.17, no.1, pp.1-10, 2010

8.IFRIM M., Dinamica structurilor ºi inginerie seismicã, Editura D.P.Bucureºti,1984

9. KOLAY P. K., KUMAR S., TIWARI D., Improvement of Bearing Capacity of Shallow Foundation on Geogrid Reinforced Silty Clay and Sand, Journal of Construction Engineering: 1-10, 2013

10. LING ZHANG, MINGHUA ZHAO, CAIJUN SHI, HENG ZHAO, Bearing capacity of geocell reinforcement in embankment engineering, Geotextiles and GeomembranesJournal, vol28, pp 475-482, 2010

11. LUNGU I., STANCIU A, BOTI N., Probleme speciale de geotehnicã ºi fundaþii, Editura Junimea, Iaºi, 2002

12. MAHBOUBI A.R., KEYGHOBADI M. H., Numerical modeling of bearing capacity of a strip foundation on geogridreinforced sand, EUROGEO 5 Conference, 5:395-402, 2012

13 NICULESCU-ENACHE F., SCARLAT C. A., TIRTEA A. M., GRUIN A., Foundation solution for buildings located in seismic zones, using geosynthetics reinforced granular materials cushions 149-156, 13th International Multidisciplinary ScientificGeoconference SGEM 2013, Albena, Bulgaria, 2013

14. STANCIU A., LUNGU I., Fundaþii, Editura Tehnicã, Bucureºti, 2006

15. VITO A. ET AL., Comparison of geogrid and geotextile reinforced earth slabs, Canadian Geotechnical Journal, 23(4): 435-440, 1986

16. ZHANG L. ET AL., Bearing capacity of geocell reinforcement in embankment engineering. Geotextile and Geomembranes 28:475–482, 2010

17. *** NP 075-02 Normativ pentru utilizarea materialelor geosintetice la lucrarile de construcþii Buletinul Construcþiilor, 2002

18. *** GP 093-06 – “Ghid privind proiectarea structurilor de pamant armat cu materiale geosintetice si metalice”

Manuscript received: 22.01.2015