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TRIAXIAL GEOGRIDS IN ROAD TECHNOLOGY PROGRESS

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Abstract

The paper deals with the design and construction of unpaved access roads where large quantities of triaxialgeogrids have been incorporated. In the last 5 years in Romania big wind farms were set up in order to increase the national production of green energy. Tens of kilometers of unpaved access roads have been executed for the establishment, operation and maintenance of the wind farms. Geosynthetic materials and, specifically, triaxialgeogrids, brought important benefits in the construction of these roads: a decrease of the execution period, a decrease of construction costs and a better quality of the completed works.

Key words**:** *congruence, durability, isomorphism, strength, topology.*

INTRODUCTION

Soils, as material for foundations, absorb the actions defined by Newton as vectors, meaning moments of a force, only after their conversion into unit stresses as tensors, meaning surface forces. There are only two types of such unit stresses: 1) Normal unit stresses, marked with σ, originating from the fundamental mechanical phenomena of axial extension, axial compression and pure bending and 2) Tangential unit stresses, marked with τ, originating from pure shearing and free twisting mechanic phenomena. There are no other types of unit stresses in any other construction material and the two defined above are always perpendicular on each other. In the equilibrium equations, written based on Newton's reciprocal actions 'law, the two unit stresses σ and τ never occur explicitly and independently of the surfaces on which they operate. Since these equations are vectorial, to these actions, which are external forces and moments, are opposed the sectional stresses which are internal forces and moments and thus creating the products of the unit stresses with the surfaces they occur on (Timoshenko, 1951). Morphologically, soils for the construction foundations are of two types: 1) cohesive or aluminous and 2) non-cohesive or granular as sand, aggregate and ballast. What distinguishes them is their way of yielding in compression in the gravitational field under their own weight. The cohesive soils yield through cutting after curved cylindrical surfaces of hyperbolic type, while the granular soils yield in shearing or sliding, after plane surfaces assigned to Coulomb as recognition for the Law of friction. Cohesive soils have large compaction accompanied by transversal plastic deformations and reduced bearing capacities, while the non-cohesive soils have low compaction and high bearing capacity. To increase the mechanic performance of soils, both cohesive and non-cohesive, in time several consolidation procedures with fill mass were tried, but composites were never obtained. Nowadays, composites are seen as a mix or association of two materials with complementary physical-mechanical characteristics which obey the principle of geometric continuity of deformations formulated by Saint Venant (Feodorov, 1997). Practice proved and history also retained only the reinforcement of the non-cohesive or granular soils. The reinforced soil was invented by the French Henri Vidal and patented in London in 1962. Vidal's reinforcement Principle is based, for the transfer of unit stresses between the soil and reinforcement, on the "anchorage effect" which uses the tensile strength of the reinforcement through the σ normal unit stresses. Reinforced soil is a composite material and is essential different from the reinforced concrete. The latter was invented in 1867 by the French gardener Joseph Monier from Versailles to protect the flower vases made of concrete with English cement. However, reinforced concrete is a composite material which is based, for the transfer of unit stresses between concrete and reinforcement, on the “grip vice effect” which uses the resistance to shearing obtained through the tangential unit stresses τ from the interface between concrete and steel metal reinforcement. It is interesting to note that at less than 20 years from the patenting in London, in 1981, at Politehnica Iasi from Romania, Prof. Tudor Silion initiated and guided the doctoral thesis "Contributions to the dimensioning of reinforced soil works" of Anghel Stanciu engineer who afterwards became university teacher at the same University (Stanciu, 1981). Both French inventors, Monier and Vidal, from different eras, separated by almost one century, had the same inspiration source for their inventions and namely the interaction between the plant roots and granular soil. But they considered the same truth from two different perspectives that can be symbolically called σ and τ. As a matter of fact, there is no third solution.

At the beginning metallic reinforcements were used, at first of steel and then of Aluminium. But steel oxidizes quickly in the ground and Aluminium is far too expensive for such works. That is why the definitive transition was made to synthetic, non-metallic reinforcements in less than two decades. In the mid 80s the use of synthetic reinforcements spread in all countries with earthwork advanced technologies, but especially England and Germany perform reinforced soil retentions. Being actually self-retentions, these works are much cheaper, may be performed in the cold season as well, after the ending of agricultural works, have remarkable draining qualities, do not affect the agricultural lands and preserve perfectly the environment. Still, for 33 years, the reinforced soil structures have been used cautiously because their behaviour to dynamic actions in general and seismic in particular was not known. Only from 1995 earthquake from Kobe consecrated their use in seismic areas and established them definitively and Japan's contribution in promoting these structures was remarkable. Immediately after this earthquake, the British standard BS 8006:1995 was issued and implemented opened the way for the application of reinforced soil without any restrictions throughout the world. Two years later, in 1997, the Romanian contribution to the composition concept of the reinforced and confined soil structure was recognized (Feodorov, 1997; Feodorov, 2003; Sofronie and Feodorov, 1995; Sofronie and Feodorov, 1998). Then followed attempts of 3D models at reduced scale, the first in Europe, on the seismic tables INCERC Iasi for geocells and at Bristol University, England, for reinforced soil retentions (Sofronie, 2000; Sofronie, Taylor and Greening, 2000; Sofronie, Taylor and Crewe, 2000). The only country after Romania that carried out trials at natural scale is Japan, but their results are according to some national standards, very different than the European ones.

Since they offer safety at the lowest price, in a relatively short time, of only of few decades ago, the reinforced soil found many applications, especially in the critical or vital structures. Among these, in order to establish the ideas, we remind only three types of works. The first type includes the retention works. These massive structures of granular soil become auto-retentions, miraculously, through reinforcement and under gravity's actions. But if the gravity is diminished by immersion or seismically, the effect of soil reinforcement with geogrids will weaken. Gravitational variable actives, applied usually on the crown, are small compared to the permanent ones, under own weight and active pushing of the upstream soil, but favourable when they have the direction of the gravity. Instead accidental actions from earthquakes are dangerous due to the high inertia forces developed because they increase the initial eccentricity with which, by construction, the reinforced soil retentions occur (Feodorov C., 2012; Feodorov, 1997; Feodorov, 2003; Feodorov, 2012). The second type includes the road systems. Here occur higher concentrated vertical forces which, in addition, are mobile. The conversion of these concentrated forces in unit stresses represents a classic problem of the mathematics Theory of elasticity solved theoretically by Boussinesq (Tensar, 2011). Actually, the first innovative step was taken by producing the geogrids with rigid integrated nodes. The second innovative step concerns the geogrids ribs while concur in nodes. The geogrids' level of conformation to the ribs has reached outstanding performance and, apparently, the development process is in progress. The functions of geosynthetic reinforcements in road systems are currently well known (Voinea, 1989). For this reason, this article is dedicated to this subject. Finally, the third type includes the geocellular systems. These are spatial structures of granular soil, gravitationally confined or self-confined. By geocells' confinement is obtained a triaxial compression state and thus their bearing capacity may be increased by up to five times compared to the monoaxial compression. By virtue of the logical relation between the part and the whole, the increase of the bearing capacity from the level of individual cells is extrapolated to the spatial structure in its entirety and thus safety and cost performance is obtained. Once the granular soil confinement's effects are proved, the procedure may be identified or, if applicable, reedited in other constructive versions.

The first part of the article, named *Materials and Methods*, presents successively the mono- and biaxial geogrids production of technology, their conformity, their final geometry, the transfer of the σ and τ unit stresses trough geogrids and finally what the innovation brought by triaxialgeogrids.

The second part of the article, named *Results and discussions*, presents three case studies and each of them is commented.

The conclusion of the article highlights the fact that the remarkable progress in the road technology was made possible only by correct the applying in practice of the scientific knowledge already existing at the date of their issuance.

MATERIAL AND METHODS

Triaxialgeogrids as reinforcing materials

1. Geogrids Producing

Appropriately selected and proportioned mixes of polyethylene and polypropylene are extruded into stripes of polymer. Then, holes are drilled in the stripes, arranged according to octagonal networks. The perforated stripes are heated and extended uniformly and uniaxial until the circular holes become rectangular meshes with rounded corners. If the extension is repeated furthermore, but this time crosswise, perpendicular on the movement's direction, the biaxial geogrids with square curvilinear meshes are obtained (Figure 1).

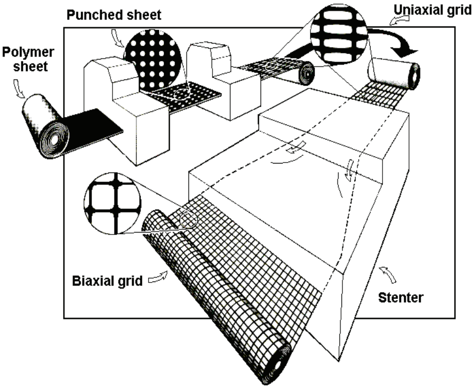

Figure 1. Manufacturing procesof geogrids

2. Geogrid conformation

The extension process with a constant axial N force is produced according to the equilibrium Law

$$N = \int_A \sigma dA \qquad (1)$$

Considering that all geogrid's ribs have technologically identical cross sections, it is acknowledged that the normal unit stress σ from the ribs is constant across the entire cross section A. Under these circumstances, the Bernoulli formula is obtained through integration

$$\sigma = \frac{N}{A} < f \ (2)$$

where$f$ is the tensile strengthPa If the tensile axial force N remains constant, which is perfectly possible from a technological point of view, and even convenient, between A cross section area and the normal unit stress σ is established a relation of reverse proportionality, expressed in Bernoulli hyperbole (Figure 2)

The constancy of the tensile force expressed by the relation,

$$Af = const., (3)$$

denotes the fact that the solution used is the most economical. Furthermore, as the t thickness of the geogrid is constant and the ribs have rectangular sections, results the widths b of the ribs are still variable, so that:

$$p = bf = const.,(4)$$

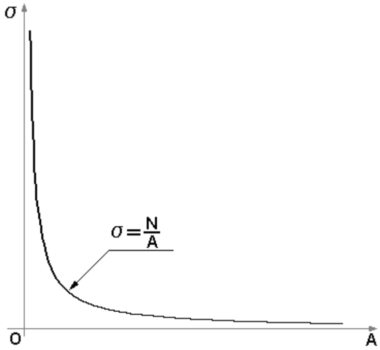

Figure 2. Bernoulli's equilateral hyperbole

What defines the *p* constancy of the tension flux constancy in *N/m* of the fins. This remarkable characteristic had not been yet identified in any reinforcing metallic or synthetic material. For this reason the producer defines the geogrids according to tension flux *p*named the quality control resistance. For example, *biaxial geogrids* means *p=20kN/m.*
Then, the polymeric geogrids were conformed to the same tension flux law. It is a natural self-confirmation process. Indeed, through the successive congruence or mirroring of the Bernoulli's hyperbole, after the two coordinate axes is obtained the image of an integrated node of the geogrids described above (Figure 3). Then, through repeated successive mirroring of the obtained nodes, and operation called auto Topology or iso-morphism, the mono and biaxial geogrid images are obtained (Figures 4 and 5)

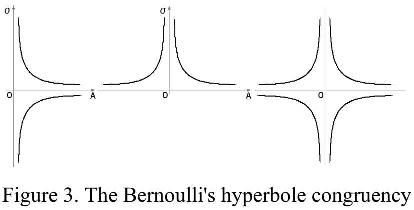

Figure 3. The Bernoulli's hyperbole congruency

3. Geometry of the grids

Practically, polymeric geogrids consist of flexible fins and rigid nodes. The connection between the nodes and fins follow continuous curves.

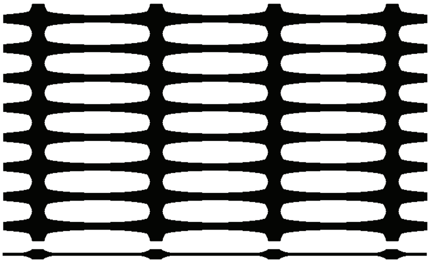

Figure 4. The geometry of the monoaxial grid

The lack of discontinuity excludes the local concentrations of efforts and ensures the stress flow fluency. Monoaxialgeogrids have two symmetry axes while biaxial geogrids have four axes.

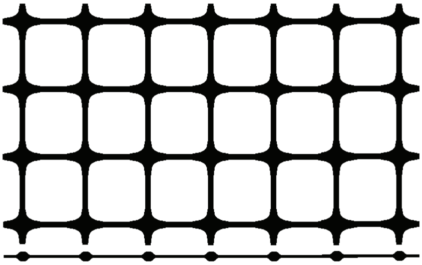

Figure 5. The geometry of the biaxial grid

By this geometry, the geogrids state Bernoulli's hypothesis regarding equal and small deformations in both directions, which entails an uniform state of unit stresses.

4. Unit stress transfer

Polymeric geogrids with integrated nodes are used to reinforce non-cohesive granular soils by the interlocking mechanism. The reinforcement is passive and the transmission of the unit stresses from the soil to the geogrids is performed in discontinuous manner through the rigid nodes. These nodes convert the normal unit stresses in sectional stresses. These are tensile stresses and make the connection of each node with the nearby nodes (Figure 6). Due to their thinness, the ribs never take compressions. Otherwise, they have a certain cross stiffness and that's why when through the redistribution of the unit stresses around nodes cutting forces occur these are taken from ribs (Figure 7).

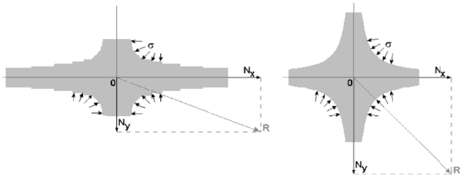

Figure 6. The transfer of the unit stresses in the integrated nodes from axial forces

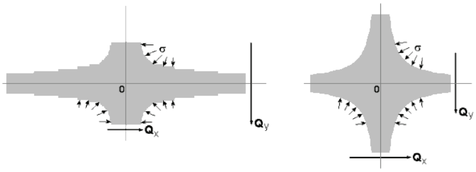

Figure 7. The transfer of the unit stresses in the integrated nodes from cutting forces

In all loading cases, the reinforcement from the polymeric geogrid becomes deformed. The deformations occur both in nodes and ribs and they are always elastic and plastic at the same time. The elastic stresses and deformations form together the potential energy, which, upon discharge converts into mechanical work. On the other hand, plastic stresses and deformations form together part of the induced energy which is dissipated through heat. Through this energetic mechanism, due to the polymeric grids' ductility, the reinforced soil is protected against local concentrations of unit stresses. This is a spontaneous and self-adjustable mechanism, typical for the geogrids with rigid, integrated nodes. Indeed, if the ribs weren't being fixed on the nodes and would move freely, then the creation of the stresses wouldn't occur as in figure 6 and the movements in both directions would be larger. Furthermore, if the grids would be perfectly elastic, without ductility qualities as fibres, then the amount of accumulated elastic energy would be much greater and upon discharge it would become dangerous due to the sudden occurrence of damages or even dislocations.

5. Triaxial Geogrids

It was natural that after uniaxial and biaxial geogrids the innovative thinking of the producer would provide an increased capacity to cover the efforts and deformations plan. Maintaining the same topological congruency and automorphism rules, but also the rigid character of the nodes, by arranging the geogrids according to three directions at a distance of 60°, the so-called *triaxialgeogrids* are obtained (Figure 8). The performance is technological because a few centuries ago, the simultaneous extension on two perpendicular directions was a problem.

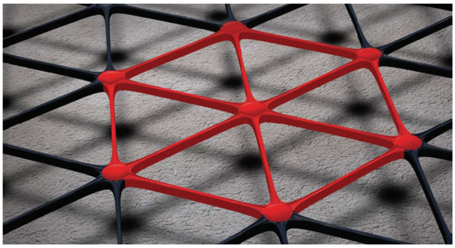

Figure 8. The perspective geometry of triaxial geogrids

The mechanic performance is illustrated suggestively by the comparison between the bearing capacity under concentrated force of the biaxial geogrid in blue and that of the triaxialgeogrid in red. It is about the coverage capacity which is greater in triaxialgeogrids than in biaxial geogrids (Figure 10). The consequence of this innovation is economical. For road works, where the concentrated forces are dominant, the triaxialgeogrids are cost effective than the biaxial ones. For retention works, uniaxial geogrids continue to remain the most efficient.

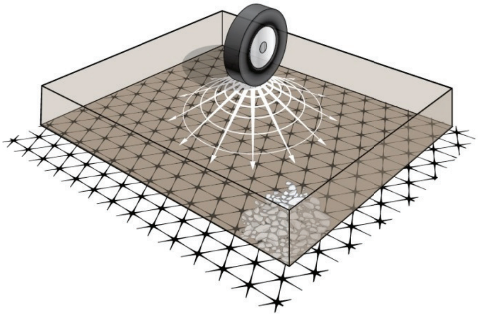

Figure 9. Load distribution at 360 degrees

Load distribution is 3-dimensional in nature and acts radially at all levels in the aggregate (Figure 9). For a stabilised layer to be effective it must have the ability to distribute loads through 360 degrees. To ensure optimum performance, the geogrid reinforcement in a mechanically stabilized layer should have a high radial stiffness throughout the full 360 degrees. Biaxial geogrids have tensile stiffness predominantly in two directions. TriAxgeogrids have three principal directions ofstiffness, which is further enhanced by their rigid triangular geometry. This produces asignificant different structure than any othergeogrid and provides high stiffness through 360 degrees. A truly multi-directional productwith near isotropic properties (Tensar, 2011).

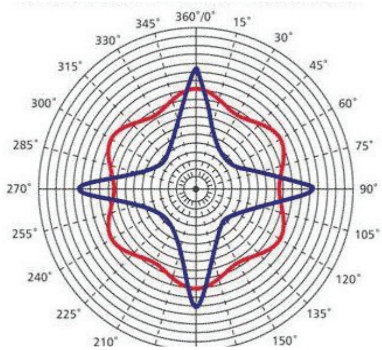

Figure 10. Radial coverage at biaxial geogrid with blue and radial coverage at triaxial geogrid with red

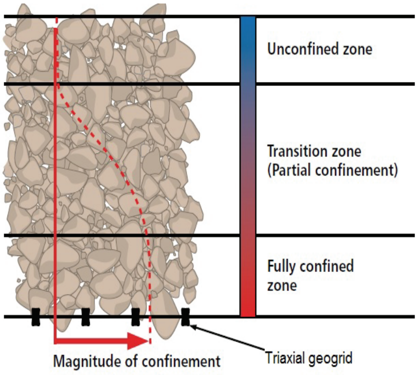

Figure 11. Interlock and confinement of triaxial geogrid

In a mechanically stabilized layer, aggregate particles interlock within the geogrid and are confined within the apertures, creating an enhanced composite material with improved performance characteristics. The structural properties of the mechanically stabilized layer are influenced by the magnitude and depth of the confined zones. The shape and thickness of the geogrid ribs and the overall structure of triaxialgeogrid has a direct influence on the degree of confinement and efficiency of the stabilised layer (Figure 11).

Triaxialgeogrid increases the magnitude of confinement and increases the depth of the confined zones (Tensar, 2011).

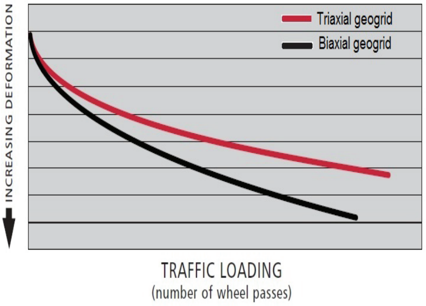

Figure 12. The advantage of triaxial geogrid compared to biaxial geogrid regarding performance.

A number of tests and trials have been conducted to prove the performance benefits of the triaxialgeogrid compared with conventional biaxial geogrids. Tests included trafficking trials at the University of Nottingham and, on a large scale, at the Transport Research Laboratory (TRL). Installation damage assessment, bearing capacity and field tests were also conducted as part of the comprehensive and rigorous testing programme (Figure 12).

Facilities at the Nottingham Transportation Engineering Centre (NTEC) at the University of Nottingham was used to identify the design features required for improved performance and to help shape and define the triaxialgeogrid. Trafficking trials were conducted on a much larger scale at the Transport Research Laboratory. Both triaxialgeogrid and biaxial geogrids were tested across varying aggregate depths each up to 10,000 wheel passes. The results showed that wheel track deformations were consistently smaller for triaxialgeogrids and proved conclusively the structural benefits of geogrid. The trafficking test facility at NTEC was used to produce a large quantity of trafficking data across both triaxialgeogrid and biaxial geogrids, confirming the much improved performance benefits of the triaxialgeogrids compared with biaxial geogrids (Tensar, 2011).

TRIAXIAL GEOGRIDS IN WIND FARM

Access to a wind farm site, often in a remote location, can be a challenging part of any wind energy project. Roads and crane lifting platforms are often constructed over poor soils and are frequently subjected to extreme weather conditions. Add to that the enormously heavy loads that they are expected to carry, and then traditional solutions can be costly, time consuming and not environmentally friendly. These roads are usually required for the construction, maintenance and ultimately the dismantling phases of a wind farm project.

The structural contribution made by triaxialgeogrid is to reinforce the unbound layers of roads and trafficked areas in order to create a mechanically stabilized layer. Aggregate particles interlock with the geogrid and are confined within the stiff geogrid apertures, creating an enhanced composite material with improved performance characteristics.

The greatest challenge when the wind farm is being constructed can be when the large turbine components are unloaded and lifted into position using a crane. The load spreading capability of a triaxialgeogrid layer increases the bearing capacity of working platforms for heavy-duty plant, cranes and piling rigs. For the contractor this means that less natural aggregate is required to construct the platform which can result in quicker construction and less cost when compared with a traditional unreinforced construction (Tensar, 2011).

Figure 13. Easy to install triaxialgeogrid.

WIND FARM ACCESS ROADS

Geogrids have been used since the early 1980's to stabilise aggregate in access roads constructed over compressible peat. Such 'monolithic' geogrids were used to provide safe access over soft ground in public roads in the Shetland Islands and infrastructure works on the Falkland Islands. The first recorded UK wind farm access road to use geogrids was Ovenden Moor near Halifax, UK in the mid-1980.

In Romania we start to use triaxialgeogrid for wind farms project since 2008, the first big project was Wind Farm Fantanele.

Since that time, numerous wind farms projects have been constructed with triaxialgeogrid.

A typical contemporary wind farm (Figure 13) consists of primary access roads such as the roads from the site entrance. These join secondary roads containing arrays of turbines. In turn, these lead to spurs, which are relatively short lengths of roads containing perhaps only one or two turbines (Figure 14).

The primary function of these roads is to provide safe, reliable access for materials, turbine components and the passage of cranes to the turbine locations. However, the most intense traffic is usually the aggregate delivery vehicles which are used in the road construction itself (Tensar, 2011).

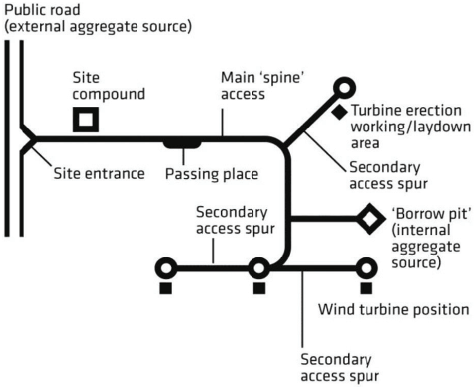

Figure 14. Schematic of the salient features of a wind farm layout

The required thickness of the road is most strongly influenced by the traffic activity that has to be supported during the road construction stage and which is engaged in the act of importing the fill for further construction activity along the route. The in-service-traffic generated by the importation of concrete and steel, the delivery of the turbine components and the passage of the turbine erection crane is usually a design check on bearing capacity and edge stability rather than the principal determinant of the designed thickness. The triaxialgeogrid will create a mechanically stabilised layer to provide the benefit of minimising the road thickness (Tensar, 2011).

RESULTS AND DISCUSSIONS

WIND FARM FANTANELE, Constanta County, Romania

West Fantanele Wind Farm with 139 wind turbines, each turbine having a power of 2.5 MW. Existing tracks had to be widened and new access roads built over the site which soil (loess). Using thick stone layers to accommodate site traffic would have involved large numbers of vehicle movements and excessive road settlement. Instead, one triaxialgeogrid layers was installed and combined with crushed stone. This solution delivered excellent trafficking performance and achieved a significant carbon emissions saving over an unreinforced solution (Figures 15,16).

Figure 15. Relevant photos during the execution Wind Farm Fantanele

Road execution phases:

I. Natural soil after 20 cm uncovering
II. 250 g/sqm Geotextile
III. 5 cm repartition layer of split or natural sand
IV. Triaxialgeogrid
V. 25 cm crushed stone 25-63 graded, compacted
VI. 15 cm crushed granite 16-25 graded, compacted and bituminous treated

Figure 16. The road of Wind Farm Fantanele after the execution

WIND FARM PESTERA, Constanta County, Romania (Figure 17).

The site for wind farm Pestera was located a long distance away from the nearest source of suitable granular fill material. Access roads were needed for construction traffic, as well as the heavy turbine delivery vehicles and cranes which initially required large thicknesses of granular fill. Working platforms were also required to support the heavy crane operational loads and once again large amounts of granular fill were going to be needed.

Figure 17.Relevant photos during the execution Pestera Wind Farm

Triaxial geogrids was designed to form the new access roads and working platforms for the wind farm site, which took into account the low strength soils and anticipated high trafficking loads and produced thinner and therefore more cost effective construction (Figure 18).

Figure 18. The road Pestera Wind Farm after the execution

Execution phases:

I. natural soil after 20 cm uncovering
II. 300 g/ sqmGeotextile
III. Triaxialgeogrid
IV. 30 cm crushed stone 25-63 graded, compacted
V. 20 cm crushed stone 0-25 graded, compacted

WIND FARM Chirnogeni, Constanta County, Romania

The triaxialgeogrid it was used in Wind Farm Chirnogeni to stabilise well-graded aggregate over low soils to allow stabilised access onto the areas in question. The access roads support 100 kN standard axeles. The project involved the erection of 32 wind turbines. There will be access roads to separate working platforms required for lifting operations. The road width at the top of the road construction is 4,0 - 4,5m.

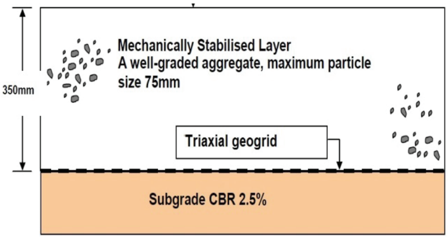

Figure 19. Section of the access roads, ChirnogeniWind Farm

Assessment of these granular layers is based on direct trafficking of the aggregate layers by construction vehicles (Figure 20).

Figure 20. Relevant photos during the execution road Chirnogeni Wind Farm

CONCLUSIONS

Since Romans times, roads and bridges were classified in the category of engineering works of art. In their turntriaxialgeogridsare produced bytheperformancerequirements of the XXIst century. The performance is, firstly, an intellectual one. Their conformity responds in a precise manner to the confinement function which needs to be met by putting them into practice. The triaxial geogrids have thus become the quality of functional aesthetics. Secondly, these geogrids have been fabricated through a technological performance. The simultaneous stretching on three directions, along with the conservation of all the physical and mechanical properties of isotropy and uniformity, is without precedent at this scale and industrial conditions. Finally the ease of installation of the triaxial geogrids as well as their reversibility offers them unmatched qualities. It was a privilege for the wind farms in Dobrogea to be serviced by an operational network of high-class roadways with solid durability guarantees.

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