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GEOGRID AS AN EFFECTIVE REINFORCEMENT OF NATURAL AIRFIELD PAVEMENTS

Geokrata jako skuteczne wzmocnienie naturalnych nawierzchni lotniskowych

Abstract: *The load-bearing capacity of natural airfield pavements is crucial for air operations safety. Taking into account the insufficient load-bearing capacity of natural airfield pavements, which is confirmed by the conducted tests in this field, the article presents a tangible impact of the application of geocells (geogrids) as an efficient way of their reinforcement with particular emphasis on the improvement of their load-bearing capacity. The recovery time of airfield operational capability compared to the currently applied reinforcement methods of natural pavements, such as mechanical or chemical surface stabilization or surface replacement, was showcased.*

Keywords: geogrid, reinforcement, natural airfield pavement

Streszczenie: *Parametr nośności naturalnych nawierzchni lotniskowych ma istotne znaczenie w aspekcie bezpieczeństwa wykonywania operacji lotniczych. Mając na uwadze niedostateczną nośność naturalnych nawierzchni lotniskowych, co potwierdzają dotychczas przeprowadzone badania w tym zakresie, w artykule przedstawiono wymierny wpływ zastosowania geosyntetyków komórkowych (geokrat) jako skuteczny sposób ich wzmocnienia ze szczególnym uwzględnieniem poprawy ich nośności. Zwrócono także uwagę na zaletę geokrat, jaką jest czas przywrócenia zdolności operacyjnej lotniska, w porównaniu do aktualnie stosowanych sposobów wzmacniania nawierzchni naturalnych, jak np. stabilizacja mechaniczna i chemiczna gruntu czy wymiana gruntu.*

Słowa kluczowe: geokrata, wzmacnianie, naturalne nawierzchnie lotniskowe

1. Introduction

Natural airfield pavements play a significant role in air operations safety. They serve as runways on lower class airfields: aeroclubs, sports or external use airfields. At the airports with artificial pavements used for aircraft operations, natural pavements are mainly applied on working runways and rear and front safety lanes. Compliant with NO-17-A503:2017 [1], a working runway is part of a runway intended for take-off and detachment of military aircraft during take-off, touchdown and landing roll. Rear safety lanes are part of a runway adhering to the rear edge of the working runway. They are intended to ensure safety during the excursion of military aircraft from the runway.

One of the fundamental operational features of airfield pavement or road is its load-bearing capacity. According to [2], load-bearing capacity of pavements is the ability of a structural system (e.g. set of layers making up a pavement structure) to transfer loads from aircraft or mechanical vehicles. The load-bearing capacity of the soil subbase is the ability of the soil to transfer loads from higher structural layers. According to [1], load-bearing capacity of airfield pavements is the ability of pavements to transfer loads from aircraft to ensure their lack of damage, as expressed by the California Bearing Ratio (CBR).

The load-bearing capacity of natural pavements has to be high enough that a potential aircraft excursion from the runway will not result in its damage, failure of the underground airfield infrastructure (e.g. devices that are part of power supply landing support system, installation of electro-light devices, power cables, telecommunications cables), and to ensure quick restoration of operational capability of the airfield by the efficient removal of aircraft from the natural pavements by the airport services [3].

The insufficient load-bearing capacity of airfield pavements can run a risk for air operations [4]. Figure 1 shows the image of an aircraft that skidded off after touchdown and excursed the runway. Due to this, both parts of the main undercarriage were broken, resulting in wing failure and fuel leakage [5].

Fig. 1. Runway excursion [5]

It is necessary to maintain the appropriate load-bearing capacity of airfield pavements To maintain operational capability and ensure safety during air operations. To this end, they should be subjected to maintenance and reinforcement procedures [6].

Maintenance comprises agrotechnical and biological services, which include, e.g. a gradual increase and restoration of organic matter in the soil, thanks to which the level of fertility of turf-bearing vegetation increases. Moreover, maintenance treatments include regular mowing of natural airfield pavements, rolling pavement, supplementing areas with reduced turf cover with grass mixture, fertilizing turf and chemical sprays [7].

Popular reinforcement procedures which aim at improving the load-bearing capacity of airfield pavements include mechanical/chemical stabilization (Fig. 2), reinforcement with polymer fibres (Fig. 3) or replacement of soil (Fig. 4).

Fig. 2. Chemical stabilization of the soil subbase [8]

Fig. 3. Soil reinforcement with polymer fibres [8]

Fig. 4. Replacement of low-bearing capacity soil [8]

The application of geocells (geogrids) can be an alternative way of reinforcing natural airfield pavements. Geogrid, which is classified as a geosynthetic, is used especially in transport engineering. According to [9], a geosynthetic is a general term which defines a product for which at least one component was created from a synthetic or natural polymer, taking the form of a sheet [10], grid or spatial element and used in contact with the surface and/or other materials in geoengineering and construction industry.

According to the *American Society for Testing and Materials* [11], geosynthetics are flat products made of polymer material, applied with the soil, rock or other materials related to geotechnical engineering as an integral part of the project, structure and system. The types of geosynthetics classified in PN-EN ISO 10318 [9] are shown in Fig. 5.

GEOSYNTHETICS			
GEOTEXTILES (GTX)	**GEOTEXTILE RELATED PRODUCTS (GTP)**	**GEISYNTHETICS BARRIERS (GBR)**	**GEOCOMPOSITES (GCO)**
▪ Woven Geotextiles (GTX-W)	▪ Geogrids (GGR)	▪ Polymeric Geosynthetics Barriers (GBR-P)	
▪ Non-Woven Geotextiles (GTX-N)	▪ Geonets (GNT)	▪ Clay Geosynthetics Barriers (GBR-C)	
▪ Knitted Geotextiles (GTX-K)	▪ **Geocells (GCE)**	▪ Bituminous Geosynthetics Barriers (GBR-B)	
	▪ Geostrips (GST)		
	▪ Geomats (GMA)		
	▪ Geospacers (GSP)		

Fig. 5. Types of geosynthetics classified in PN-EN ISO 10318:2007 [9]

Broadly understood geosynthetics are mainly applied in road construction, e.g. reinforcing a weak substrate and protecting the slope against erosion as a separation or drainage layer.

According to [9], Geocells (GCE) are polymer (synthetic or natural) products with spatial, permeable honeycomb structure or other cellular structure, made from interconnected ribs of geosynthetics. According to [11], geogrid is a geosynthetic consisting of interconnected parallel sets of ribs with an aperture of no more than 6.35 mm to allow meshing with the surrounding ground, rock, soil and other surrounding materials.

The key function of geosynthetics addressed in this manuscript is the reinforcement of natural airfield pavements, which increases their load-bearing capacity and durability.

In the case of wet, unstable or sensitive soils, the application of external load, e.g. aircraft strut, will result in soil deformation, which leads to rutting. The vertical force acting on the wheel results in shear or displacement of soil, which terminates in soil liquefaction (Fig. 6).

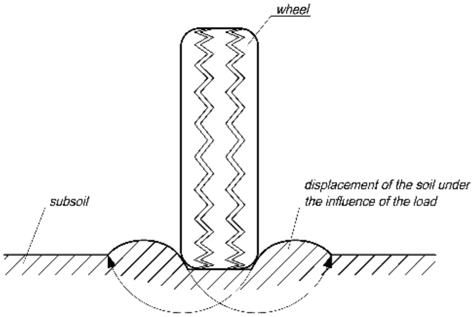

Fig. 6. Soil liquefaction due to loads applied to wheels

Under Regulation [12], which defines technical and operational requirements for exclusive use airfields and the method and procedure for performing inspection, it is allowed on runways to use the pavement reinforcement of turf and soil surface, also in some sections of these pavements. It is done to increase their durability and under the condition that their smoothness is maintained.

In domestic and foreign journals, laboratory experiments of studying a geocell applied in structural layers subjected to loads are addressed. Article [13] demonstrates the results of static and cyclic tests of applying the load on a surface reinforced with a geocell with different filler materials, e.g. poorly sorted Kansas River sand, quarry waste and asphalt pavement from recycling. The results showed increased bearing capacity after using a geocell, as shown in Fig. 7.

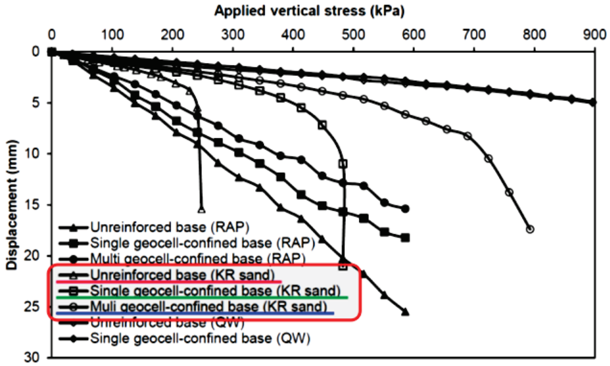

Fig. 7. Stress curves in the displacement function for static load testing [13]

The results of experimental works [14] that study the impact of applying geocells filled with river sand as reinforcement of soil subbase can be another example.

Based on performed tests, it was found that the applied cellular confinement system improved load-bearing capacity of the studied layer by 1.75 as compared to the unreinforced soil (Fig. 8).

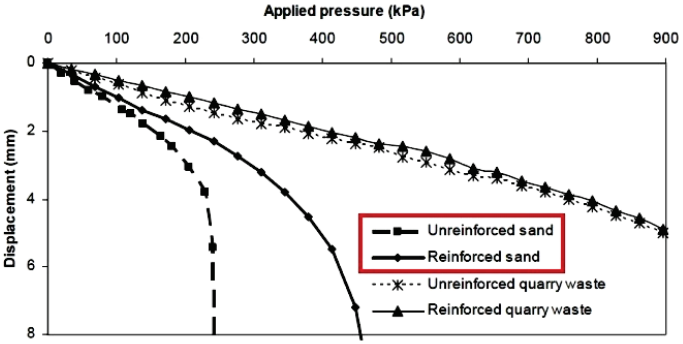

Fig. 8. Stress-displacement diagram for geocell-reinforced soil and unreinforced under static load [14]

2. Application of geocell in practice

The roots of geocells date back to the late 1970s when the US Army Corps of Engineers Waterways Experiment Station (WES), in collaboration with Presto Products (currently Presto Geosystems, Appleton, WI, USA), developed Cellular Confinement Systems, i.e. geocells, which transferred high loads onto lower laying surfaces.

Initially, geocells were made from wax-coated craft paper, paper-thin hexagonal glued aluminium (that was in the case of the American Army) and recycling materials with low and moderate density. Figure 9 presents an image of testing the efficiency of plastic and aluminium cellular confinement systems.

Fig. 9. Testing the efficiency of geocells made of plastic and aluminium (WES, Vickburg, Missouri, 1979) [15]

Only a few companies worldwide offer reinforcement of grass airfield pavements using geocells. The examples of the works presented below prove that using geocells on grass airfields and other pavements is effective in many respects.

GEOTERRA Construction Mats®

GEOTERRA mats® were invented by Presto GeoSystems (USA). They are made of HDPE (High-Density Polyethylene), resistant to industrial chemicals and with a high elastic modulus.

The advantages of GEOTERRA® mat include high flexural strength, suitability to transfer loads even over poor soils, low weight that enables installation without heavy overhead handling equipment, and it is easy to remove it with the possibility of re-use (more economical). GEOTERRA® system used on turf provides its reinforcement, protects from rutting caused by vehicles thanks to an open area in the mat (87% of open area is biologically active) by which turf growth is not endangered [16].

GEOTERRA® system is used on access roads to construction sites, helicopter pads, and drilling platforms. What is more, it can be applied as temporary or long-term solutions [16].

Geokrata TERRA-GRID® E 35

Novus HM (Germany) offers the reinforcement of grass airfield pavements by using TERRA-GRID® E 35.

It is a product made of Polyethylene/ Polypropylene) that ensures load-bearing capacity of up to 160 t/m^2 (depending on soil conditions and soil preparation). Novus HM declares that TERRA-GRID® E 35 is resistant to UV, frost, oil, solvents, acid and road salt.

The experience of this company in using geogrids for reinforcing grass (natural) airfield pavements indicates that this solution is effective.

Grids were employed for the reinforcement of natural runway pavements and taxiways. When the problem was the inadequate drainage of the runway, TERRA-GRID® E 35 were also installed, which made it possible to use this runway all year round. The following airfields were reinforced with TERRA-GRID® E 35: general use, private and medical air rescue airfields. The helicopter towing path was also reinforced.

PERFO-SD Geogrid

PERFO (United Kingdom) invented a ground reinforcement system in the form of geogrids applicable in reinforcing different pavements, including turf airfield pavements. PERFO-SD is recommended to be used on airfield facilities.

PERFO-SD is made of PE/PP plastic and can withstand loads of at least 60 t/m^2 (depending on sub-base conditions and preparation). The single element is 405 x 405 x 37 mm. PERFO states that PERFO-SD geogrid is resistant to UV, frost, oil, solvents, road salt and most acids [17].

Geogrids by PERFO were successfully used on many airfields to improve the safety of air operations. Problems that needed to be solved using PERFO geogrids were wetlands with water puddles characterized by poor sub-base and water conditions that shut down a given airfield during the wet season, molehills and terrain roughness. PERFO geogrids were used on runways and taxiways (Compton Abbas Airfield, United Kingdom; Zürcher

Oberland Aeroclub, Switzerland; Völtendorf Airport, Austria; LSV Cloppenburg, Germany) and helicopter pads, aprons, aircraft hangars or parking areas [17].

Leszno-Strzyżewice airfield

In 2020, the Aeroclub airfield in Leszno reinforced the 23R-05L runway with a length of 700 m and width of 20 m using plastic geogrids made by the Polish company. The reinforcement of the runway in question used 14 000 m^2 of geogrids, and works lasted approximately three weeks. The aim of reinforcing the runway was to improve the safety of aircraft operations, especially larger aircraft in difficult weather conditions. The permissible maximum take-off weight at Leszno-Strzyżewice airport is 15 000 kg.

Narew 2 landing field

Narew 2 landing field belonging to Pronar Sp. z o. o. has a runway with grassy pavement reinforced with a plastic grid (Terra Grid) with a length of 1 500 m. The runway in Narew is the longest in the world among runways built with this technology.

3. Impact of the application of geogrids on the load-bearing capacity of natural airfield pavements

As part of the field tests, geogrids' efficiency in improving the load-bearing capacity of natural airfield pavements was verified. To this end, field measurements were conducted on five experimental plots located in different parts of Poland (Bagicz, Krywlany, Środa Wielkopolska and Warszawa).

Load-bearing tests were conducted on each field before and after the geogrid application. Tests aimed to determine the impact of the application of geogrid on the improvement of the load-bearing capacity of natural airfield pavements or lack of its improvement. The assumed test plan did not include the impact of the type of soil subbase on the adopted assumption.

3.1. Methodology of doing tests

The developed and adopted research methodology was based on the existing research methods, i.e. measurements with a VSS static plate (Fig. 10) and Heavy Weight Deflectometer HWD (Fig.11).

Fig. 10. VSS test [18]

Fig. 11. HWD test [18]

Load tests using a VSS static plate (Fig. 12) were conducted under PN-S-02205:1998 Roads. Earthworks. Requirements and tests [19]. Static Plate Load Test is done to determine the vertical strain (settlement) of the investigated layer under static pressure exerted on it using a circular steel plate with a diameter of 300 mm. A hydraulic jack with a pressure gauge applies the pressure on the static plate.

The primary deformation modulus E1 is determined from the first load, and the secondary deformation modulus E2 is determined from the second load. The modulus of deformation E is calculated from the following formula (1):

$$E = \frac{3\Delta p}{4\Delta s} \cdot D \tag{1}$$

where:
Δp – difference in pressure [MPa];
Δs – increase in settlements corresponding to this difference in pressure [mm];
D – plate diameter [mm].

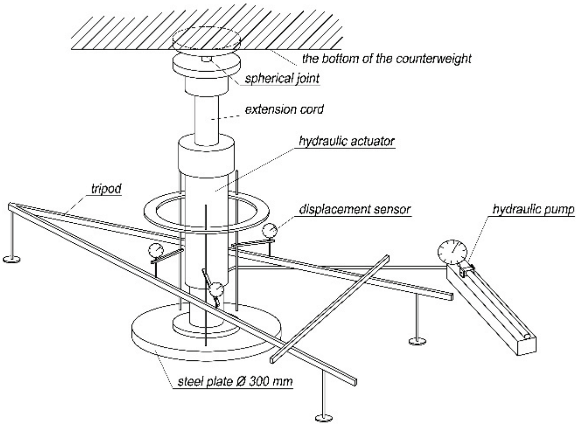

Fig. 12. Diagram of a VSS static plate based on [19]

Tests with Heavy Weight Deflectometer (HWD) (Fig. 13) were done in accordance with NO-17-A500:2016 Airfield and road pavement - test of load-bearing capacity [20]. It is used to determine elastic deflection formed under the dynamic load of 200 kN on the pressure plate with a diameter of 0.30 m or 0.45 m situated on the pavement. During the test, deflections of the investigated pavement are recorded by geophones mounted on the measuring plate and centrally under the loading plate. The results are presented on the computer with the simultaneous display of the deflection and stress waveforms over time. Apart from HWD, Fig. 13 also illustrates the exemplary diagram of the deflection basin and quantities which characterize particular construction layers of the pavement (the example concerns an artificial pavement).

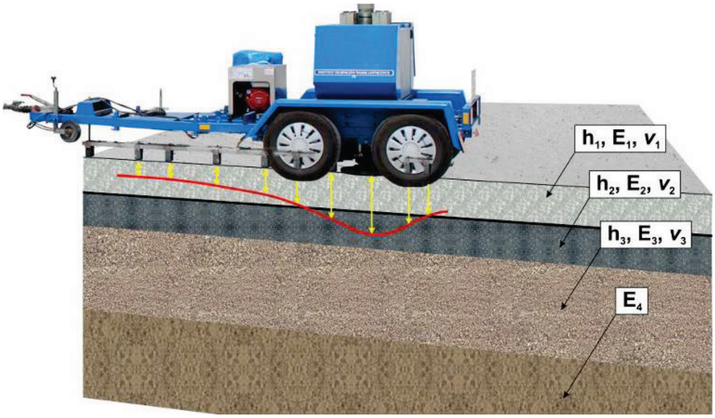

Fig. 13. Measurement diagram of elastic deformations by HWD

The knowledge of the deflection basin and the thickness of structure layers and material characteristics from which these layers are made to determine the elastic modulus of individual layers [2].

Load measurement results can be exhibited as elastic deformations, deformation modulus, replacement modulus, PCN index (Pavement Classification Number) or the permissible number of aviation operations for the adopted testing aircraft.

Elastic modulus, depending on the distance from geophones to the centre of the loading plate, are determined from the following equations (2) and (3):

$$E_o(0) = \frac{2 \cdot (1 - \nu^2) \cdot q \cdot a}{u(0)} \tag{2}$$

$$E_o(r) = \frac{(1 - \nu^2) \cdot q \cdot a^2}{r \cdot u(0)} \tag{3}$$

where:

$E_0(0)$ – elastic modulus under a loading plate [N/m^2];
$E_0(r)$ – elastic modulus in the distance r from the centre of the loading plate [N/m^2];
a – plate radius [m];
ν – Poisson's ratio [-];
u – deflection in the investigated point (0 – below a loading plate) [m];
q – stress under a loading plate [N/m^2].

To estimate the replacement modulus E_z of the tested airfield pavement, the shortened versions of equations (2), (3) and (3) are applied.

$$E_z = \frac{2 \cdot q \cdot a}{u(0)} \tag{4}$$

3.2. Analysis of results from field tests

Results collected from the field tests have shown that geogrids used on natural airfield pavements improve their load-bearing capacity. In Table 1 and Figs. 14–16, we can observe the comparison of the elastic modulus values of airfield pavements reinforced with grid and unreinforced that were obtained based on field measurements with VSS static plate and Heavy Weight Deflectometer (HWD).

One test was conducted on each of the experimental plots. Natural pavements on all experimental plots were reinforced with the same geogrid type.

Table 1

Results of the load-bearing capacity of unreinforced and reinforced natural airfield pavement

Experimental plot	Passive elastic modulus E_2 [MPa] (VSS measurement)		Elastic modulus E [MPa] (HWD measurement)	
	before reinforcing with geogrid	after reinforcing with geogrid	before reinforcing with geogrid	after reinforcing with geogrid
Bagicz	79	86	117	139
Poletko I (ITWL)	38	43	128	145
Poletko II (ITWL)	35	38	110	140
Krywlany	45	87	109	157
Środa Wielkopolska	59	132	65	119

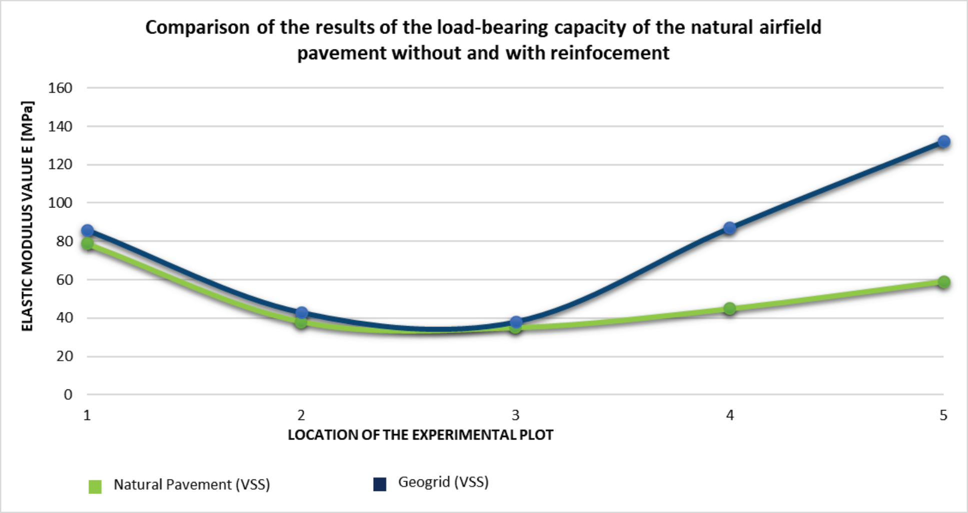

Fig. 14. Diagram of the load-bearing capacity values of natural airfield pavements without and with reinforcement – tests with VSS static plate

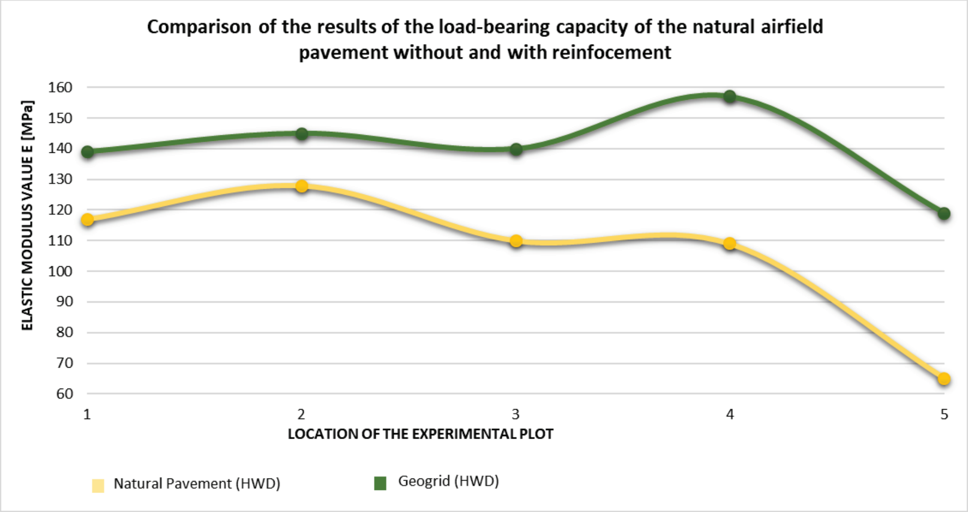

Fig. 15. Diagram of the load-bearing capacity values of natural airfield pavements without and with reinforcement – tests with HWD

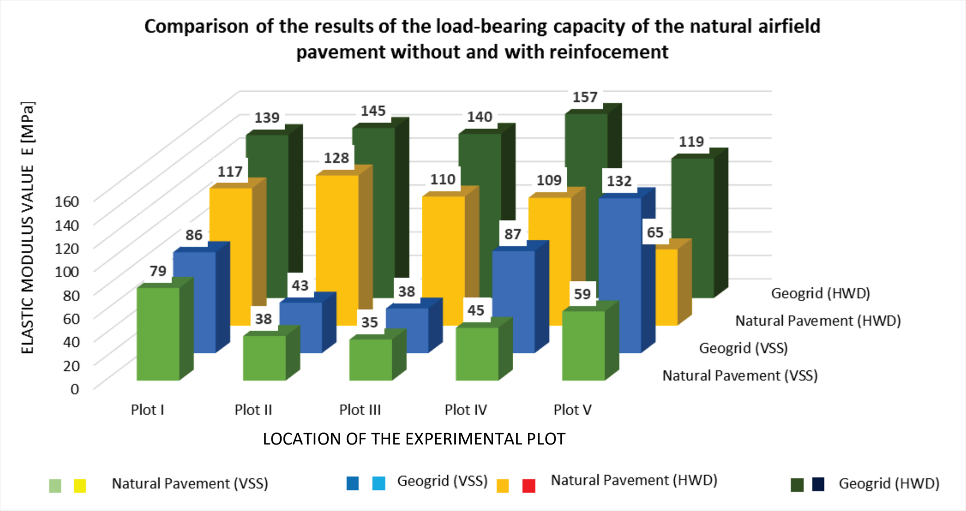

Fig. 16. Diagram of the load-bearing capacity values of natural airfield pavements without and with reinforcement

The analysis of results from the static load test (VSS) indicates that the elastic modulus of natural airfield pavements increased on average by 37% after the installation of geogrid reinforcement. In the case of tests done by Heavy Weight Deflectometer (HWD), elastic modulus increased on average by 50%. The differences in values of elastic modulus in relation to VSS and HWD are due to the specificity of the tests. A test with a VSS loading plate is static, while a test with heavy weight deflectometer is dynamic.

4. Summary

The application of geogrid to reinforce the natural airfield pavements of civilian and military airfields is intended to enhance aircraft operations safety. The unprecedented advantage of using geogrids over other reinforcement methods, such as mechanical and chemical soil stabilization and soil replacement, is the time regime to restore the airfield operational capability. The literature review showed the lack of works in which the authors would raise the subject matter in a manner similar to the one presented in this manuscript. Therefore, the analysis of the research results was limited only to those obtained by the authors.

The test results show that reinforcing natural airfield pavements with geogrid improves their load-bearing capacity. In addition, the unprecedented advantage of geogrids over other reinforcement methods used so far, such as mechanical and chemical stabilization of the soil or soil replacement, is undoubtedly the time regime for restoring the airport's operational capacity. Furthermore, applying geogrids on natural airfield pavements prevents the formation of water puddles by maintaining the appropriate drainage and rutting on wet surfaces due to vehicle movement. Thanks to these properties, natural airfield pavements can be used all year round for aircraft operations by military aircraft. It is a considerable advantage compared to the currently used approach in the operation process of natural airfield pavements.

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