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THE APPLICATION OF A HEXAGONAL GEOGRID AS A REINFORCEMENT ELEMENT OF THE BASE OF A ROAD EMBANKMENT

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SUMMARY

For stability calculations, one of the most important factors is the strength of the material used in the role of reinforcement. In the case of hexagonal geogrids, strength results can be obtained according to the manufacturer's recommendations – radially tensile or in accordance with the standard – using the wide-width strip specimen tensile method. It was decided to compare the strength results obtained using the radial stiffness to those resulting from tests conducted according to the standard. This article presents the utilisation of geosynthetic materials, specifically hexagonal geogrids, as reinforcement elements for soil. The article showcases the methodology and results of strength tests conducted on samples of hexagonal geogrids using the wide-width specimen method, as well as stability analysis of a representative road embankment using the aforementioned geogrid. The objective of the research was to determine the strength parameters for stability calculations of the embankment. The obtained parameters were compared with the manufacturer's specifications.

Keywords: hexagonal geogrid, tensile strength, reinforced soil, embankment, stability analysis

INTRODUCTION

The construction of embankments on weak soils often requires costly and time-consuming replacement of the subsoil or the implementation of pile or column foundations (Duszyńska & Szypulski, 2012). One solution to this problem may be the use of reinforcement at the base of the embankment, preventing excessive soil deformations and ensuring the stability of the structure (Duszyńska, 2016). Geogrids are classified as geotextile-related products (GTP) according to the PN-EN ISO 10318 standard (Polski Komitet Normalizacyjny [PKN], 2015b). The main functions of hexagonal geogrids (Fig. 1) include reinforcement of aggregate layers, steep slopes and retaining walls (Pisarczyk, 2020). In terms of reinforcement, two parameters for hexagonal geogrids are crucial: radial stiffness and isotropic stiffness coefficient.

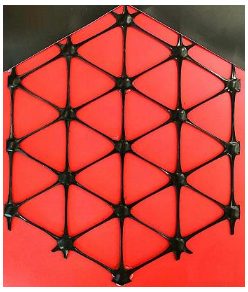

Fig. 1. Hexagonal geogrid

Source: own work.

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Radial stiffness is understood as the ratio of stress achieved at a small deformation (0.5%) and measured in all stress directions. The value of radial stiffness is the minimum value among all measured values in the range of 0–360°. This parameter determines the stiffness within the range of small, approximate deformations like those occurring under real conditions (Gołos & Woloniecki, 2013). However, the coefficient of isotropic stiffness determines the ability to achieve similar stiffness values in all directions. In the case of hexagonal geogrids, the value of this parameter ranges between 0.75 and 0.80. It can be determined based on the results of radial stiffness measurements as the ratio of the minimum and maximum stiffness, calculated from the appropriate number of measurements conducted (Gołos & Woloniecki, 2013). Additionally, the PN-EN ISO 10319 standard (PKN, 2015a) provides a testing method for determining the tensile strength of hexagonal geogrids, although it should be noted that the manufacturer does not declare the tensile strength test using this particular method.

As a result of loading, there is an 'interlocking' effect, causing the wedging of aggregate particles within the rigid geogrid. Due to the stiff structure, lateral confinement of the aggregate particles occurs, and this effect is visible not only directly around the geogrid but also at a certain distance from it. In practice, three zones of influence (Fig. 2) of the hexagonal geogrid can be distinguished:

1. Zone of full confinement: complete interlocking of particles occurs in this zone, leading to significant wedging of the aggregate particles. Displacement is practically non-existent in this zone.
2. Intermediate zone: in this zone, the interlocking of particles gradually diminishes.
3. Unconfined zone: in this zone, the interlocking effect between particles is minimal, and the influence of particle wedging is not noticeable.

The main effects of reinforcing an unbound aggregate layer with the hexagonal geogrid are: achieving a higher density index, increasing the modulus of elasticity of the aggregate layer, enhancing the load-bearing capacity of the stabilised layer, prolonging the overall performance of the construction by extending the service life of the geogrid-reinforced layer, and providing greater resistance to deformation (Gołos, 2014). For the proper and reliable functioning of the embankment, the design of reinforcement requires adherence to the principles specified in Eurocode 7 (Duszyńska & Sikora, 2014), which are: determining the geotechnical category of the structure and its design service life, defining requirements regarding soil-water conditions and reinforcement material, specifying the construction conditions of the embankment, and conducting verification calculations considering ultimate limit state and serviceability limit state. Synthetic materials used for manufacturing reinforcement should possess appropriate strength parameters: tensile strength, chemical resistance, and be characterised by small rheological parameters (Duszyńska & Sikora, 2014). The soil material should exhibit suitable grain size distribution to facilitate easy compaction and achieve the desired mechanical and hydraulic properties. It should also demonstrate good permeability to allow water to drain from the structure and be free from chemical pollutants, with an appropriate pH value. According to the recommendations of Eurocode 7 in the case of reinforced geosynthetic road embankments, limit states are determined by checking the following events:

- overall stability loss of the terrain,
- destruction caused by surface erosion, internal erosion, or undermining,
- slope or crest failure of the embankment,
- deformations of the structure leading to loss of serviceability,

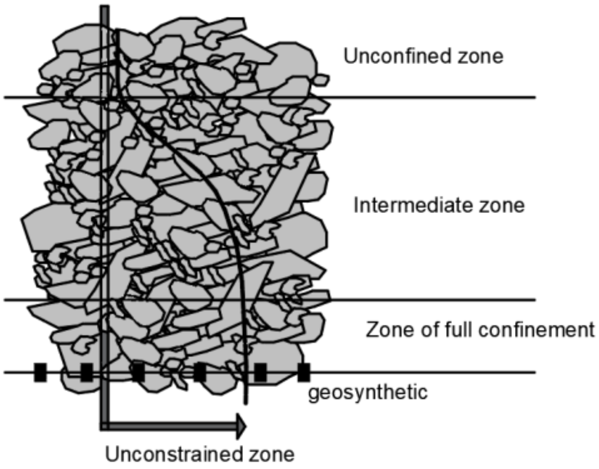


Fig. 2. Influence zones of a hexagonal geogrid

Source: own work.

- settlement and creep of the embankment affecting neighbouring structures,
- change in environmental conditions,
- high deformations in transitional zones of the embankment,
- creep of soils and road surfaces induced by temperature fluctuations,
- failure of the subgrade due to high traffic loads (EBGEO, 2011).

When performing verification calculations for the ultimate limit state and serviceability limit state, the recommendations of the EBGEO and the British standard BS 8006:2010 (British Standards Institution [BSI], 2010; Duszyńska & Szypulski, 2014) are primarily or supplementarily used. Internal stability is checked based on the assumption that a section of the structure separated by a slip line maintains equilibrium due to the strength forces of the soil and reinforcement. The calculation condition for not exceeding the limit state is generally accepted as follows:

$$E_d < R_d, \tag{1}$$

where:

E_d – the designed value of destabilising force acting on the section of the structure separated by the slip line,

R_d – the designed value limiting resistance of the embankment slope along the slip line, consisting of the resistance of the soil and the sum of the strengths of the reinforcement layers intersected by it (EBGEO, 2011).

According to the guidelines of the EBGEO, the analysis of serviceability limit states involves checking the position of the resultant force of the applied loads acting on the reinforced soil structure and analysing its displacements and deformations. The control of serviceability limit state involves considering the settlement of the subsoil, internal settlement of the backfill soil, horizontal displacements of the structure's face at different levels of the reinforcement layers, and shape deformations resulting from the deformation of the structural reinforcement (Duszyńska & Kieliszczyk, 2017).

The aim of the conducted research was to assess the behaviour of hexagonal geogrids as a reinforcement in the base of an embankment based on mechanical strength tests conducted in accordance with the PN-EN ISO10319 standard and comparisons of the results with the data provided by the manufacturer, as well as stability analysis of the slope using the GEO 5 software.

MATERIAL AND METHODS

For the strength tests using the wide-width sample method, eight samples of hexagonal geogrids were prepared by cutting them in the direction parallel to the roll axis, as well as eight samples cut perpendicularly to the roll axis. The dimensions of the samples were 200 mm in width and 200 mm in length, with a length of 100 mm between the jaws of the testing machine. The remaining part of the geogrid sample allowed for its secure attachment to the machine jaws. According to the PN-EN ISO 9862 the samples were cut from a roll, with the outer layers previously removed, to ensure that any potential manufacturing defects would not affect the test results (PKN, 2007). According to the PN-EN ISO 13251 for products intended for reinforcement, the manufacturer is obligated to provide specification of the material (PKN, 2016). Table 1 presents the specification of the tested material.

Table 1. Specification of the hexagonal geogrid used for calculations

Parameter	Value	Unit	Others
Surface mass	0.63	$kg \cdot m^{-2}$	–
Average rib length	60	mm	–
Radial stiffness	350	$kN \cdot m^{-1}$	–
Short-term tensile strength	18.91	$kN \cdot m^{-1}$	–
Raw material	–	–	PP
Type of nodes	–	–	rigid

Source: the manufacturer's data.

Embankments on weak soil foundations are often constructed using geosynthetics (Duszyńska, 2020). This allows for avoiding soil replacement and reduces the need for other more complex and labour-intensive ground reinforcement techniques. Placing geosynthetic material in the base of the embankment ensures stability during construction and enables better distribution of loads on weak soil (Alenowicz, 2009). The designed structure consists of a road embankment with a load of 25 kN·m^{-2}, a height of 5 m, a crown width of 9 m, and a base width of 31 m. The slope of the embankment is designed as 1 : 2.2. In the article, the embankment body consists of medium sand (MSa), while the base layer consists of silt clay (siCl) with fine sand (FSa) beneath it. Table 2 presents the geotechnical parameters of the soils used. Table 3 presents the technical parameters of the geotextile used for separation.

Table 2. Geotechnical parameters of soils used in the model

Type of soil	Thickness h [m]	Unit weight γ [kN·m^{-3}]	Internal friction angle φ' [°]	Cohesion c' [kPa]
MSa	5	19	32	0
siCL	5.5	20	15	20
FSa	6	19.5	26	0
Aggregate	0.2	20	30	10

Source: the manufacturer's data.

Table 3. Specification of the geotextile used for separation

Parameter	Value	Unit	Others
Surface mass	0.30	kg·m^{-2}	–
Tensile strength	100	kN·m^{-1}	–
Raw material	–	–	PES

Source: the manufacturer's data.

The design value of long-term strength is obtained by dividing the characteristic value by reduction coefficients and the partial material safety factor (Kiersnowska & Koda, 2018).

$$F_d = \frac{F_k}{(A_1\ A_2\ A_3\ A_4\ A_5\ A_6\ \gamma)}, \qquad (2)$$

where:
F_d – long-term strength value,
F_k – short-term strength value,
A_1 – the coefficient takes into account the deformation and damage during the creep of the reinforcement; it depends on the initial reinforcement material,
A_2 – the coefficient takes into account the mechanical damage to the reinforcement during transport, placement, and compaction of the soil. It is determined based on the fraction of the soil material,
A_3 – the coefficient takes into account the influence of connections and, in the case of the EBGEO guidelines (EBGEO, 2011), seams; it is determined based on reinforcement tests comparing tensile strength over time,
A_4 – the coefficient takes into account the influence of the ground environment,
A_5 – the coefficient takes into account the influence of dynamic actions (Instytut Techniki Budowlanej [ITB], 2008; EBGEO, 2011),
A_6 – the coefficient takes into account specific conditions of foundation for structures,
γ – partial material safety factor.

In Table 4, the values of reduction coefficients for the given case according to Instytut Techniki Budowlanej requirements are presented. The strength test of the triaxial geogrid was conducted at the Strength of Materials and Structural Engineering Laboratory of the Water Center at the Warsaw University of Life Sciences (SGGW). The testing was performed according to the PN-EN ISO 10319 standard using an Instron universal testing machine with a maximum capacity of 10 kN (Fig. 3).

Table 4. Reduction coefficients

A_1	A_2	A_3	A_4	A_5
1.53	1.10	1.00	1.00	1.00

Source: the manufacturer's data.

The tensile strength (*T*) of the tested geotextiles was calculated using the following formula, according to the PN-EN ISO 10319 standard:

$$T = F_{\max}\, c, \qquad (3)$$

where:
T – tensile strength [kN·m^{-1}],
$F_{\max}$ – maximum tensile force [kN],
$c = \frac{1}{B}$ – for geogrids,
B – nominal width of the sample [m].

Fig. 3. Instron universal testing machine

Source: own work.

RESULTS AND DISCUSSION

Tensile strength of geogrids by the wide-width specimen method

According to the PN-EN ISO 10319 standard, five specimens were tested in both directions, cut longitudinal and transverse to the roll axis. Figure 4 shows the relationship between strain and tensile strength.

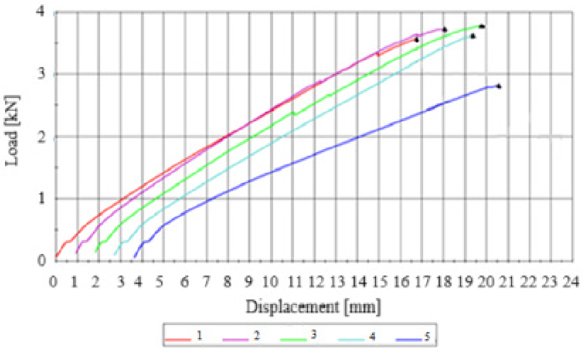


Fig. 4. The relationship between load and displacement for the specimen tested in the longitudinal direction of fabrication

Source: own work.

Based on the obtained results of the tensile strength test using the wide-width specimen method, it can be concluded that the tested hexagonal geogrid exhibits better strength properties when stretched along the roll axis. Considering the average results of the maximum force and deformations presented in Table 2, it should be observed that the hexagonal geogrid, when working along the roll axis under maximum load, can achieve a deformation that is 1.9% greater compared to the average strain value when working in the transverse direction to the roll axis. Furthermore, the average maximum load in this case reaches a value of 3.51 kN, which is nearly 131% of the maximum average value in the transverse direction. Based on the obtained results and with the use of Eq. (3), the tensile strength of 1 m of the tested geogrid was determined as five times the maximum tensile force (due to the width of the tested sample being 200 mm), resulting in $T = 18.91\ \mathrm{kN \cdot m^{-1}}$. Table 5 presents the results of the tensile strength test of the hexagonal geogrid using the wide-width specimen method.

Stability analysis of a road embankment

Using the GEO 5 software, stability analysis of the unreinforced road embankment was performed. The calculated value of the stability coefficient was $F = 1.42$, which indicates that the permissible value of $F = 1.50$ was not achieved. It was concluded that reinforcement is necessary to reach the allowable value of it. In the second case, reinforcement with a hexagonal geogrid was used at the base of the embankment (specifications in Table 1). The geogrid in the program was defined individually, considering the characteristic short-term ultimate strength based on the conducted tests as $T = 18.91\ \mathrm{kN \cdot m^{-1}}$, and the design long-term

Table 5. Tensile strength test results for a hexagonal geogrid using the wide-width specimen method

Direction of sample testing	Sample cut perpendicularly to roll axis			Sample cut parallel to roll axis		
	maximum load [kN]	deformation at maximum tensile force [%]	strain (standard) [%]	maximum load [kN]	deformation at maximum tensile force [%]	strain (standard) [%]
1	1.976	6.5	7.3	3.567	8.4	9.0
2	2.552	6.5	6.5	3.730	8.6	8.8
3	2.398	6.4	6.8	3.782	9.0	9.1
4	3.113	7.2	7.2	3.634	8.3	8.3
5	3.365	6.2	6.2	2.828	8.5	9.9
Average	2.681	6.6	6.8	3.510	8.5	9.0
Aberration standard	0.558	0.38968	0.47327	0.389	0.25882	0.54870

Source: own work.

strength as $F_d = 11.23$ kN·m^{-1} (using the reduction factors according to Table 4). The stability coefficient increased to $F = 1.87$, indicating that the allowable value was achieved and the specified reinforcement parameters were sufficient (Fig. 6).

In the next case, the stability of the slope was examined by using the same geogrid, but this time, an additional layer of 20 cm thick aggregate (specified in Table 2) and a geotextile (specified in Table 3) were also applied. The geotextile serves as a separation layer in the given project (Fig. 7).

The required value of the stability coefficient was obtained, which was higher than in the case without the layer of aggregate, $F = 1.93$. The above calculations of the hexagonal geogrid were based on its short-term characteristic strength obtained from the tensile strength test using wide specimens. The technical specification of the tested sample includes the value of radial stiffness characteristic of the triaxial geogrid. Therefore, it was decided to re-calculate the model by replacing the strength value obtained from the test with the radial stiffness value declared by the manufacturer, which is 350 kN·m^{-1}. Since the hexagonal geogrid has already been defined in the GEO 5 software, only the strength value changes, while the reduction coefficient values remain unchanged. The calculations showed that using the radial stiffness value allows the safety coefficient to be increased to $F = 2.78$ (Fig. 8).

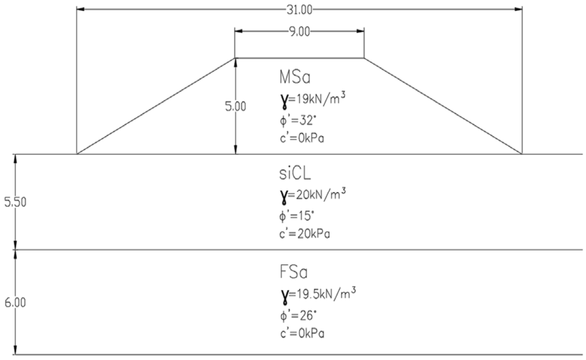
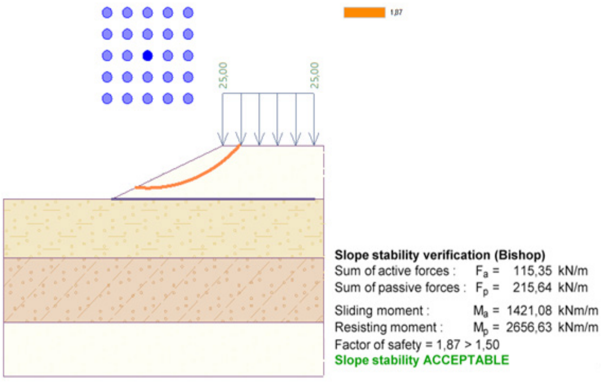


Fig. 5. Analysed cross-section

Source: own work.



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Slope stability verification (Bishop)
Sum of active forces :     Fa =   115,35  kN/m
Sum of passive forces :    Fp =   215,64  kN/m
Sliding moment :           Ma =  1421,08  kNm/m
Resisting moment :         Mp =  2656,63  kNm/m
Factor of safety = 1,87 > 1,50
Slope stability ACCEPTABLE
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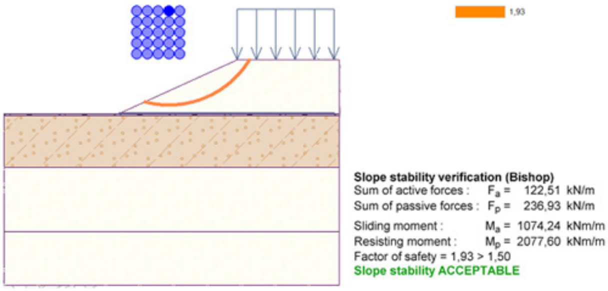
Fig. 6. Slip curve with the stability coefficient

Source: own work.



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Slope stability verification (Bishop)
Sum of active forces :    Fa =   122,51  kN/m
Sum of passive forces :   Fp =   236,93  kN/m
Sliding moment :          Ma =  1074,24  kNm/m
Resisting moment :        Mp =  2077,60  kNm/m
Factor of safety = 1,93 > 1,50
Slope stability ACCEPTABLE
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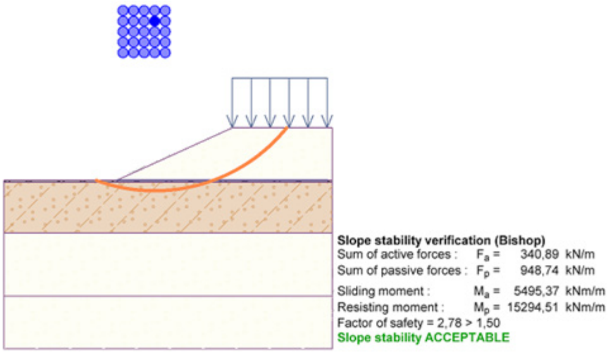
Fig. 7. Slip curve with the stability coefficient

Source: own work.



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Slope stability verification (Bishop)
Sum of active forces :    Fa =     340,89  kN/m
Sum of passive forces :   Fp =     948,74  kN/m
Sliding moment :          Ma =    5495,37  kNm/m
Resisting moment :        Mp =   15294,51  kNm/m
Factor of safety = 2,78 > 1,50
Slope stability ACCEPTABLE
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Fig. 8. Slip curve with the stability coefficient

Source: own work.

DISCUSSION AND SUMMARY

Geosynthetic materials used in road construction play an important role in the construction of earth structures. They are used in reinforcing embankments and retaining walls, allowing them to be constructed at steeper angles, even up to a right angle (Gajewska, Grzegorzewicz, Kłosiński & Rychlewski, 2003). They are also used in reinforcing the base of road embankments, preventing excessive deformation and loss of stability during the construction phase and consolidation of weak subsoil (Duszyńska, 2020).

Based on conducted research, analysis, and calculations, the influence of reinforcing the base of an embankment with a hexagonal geogrid on the stability of the structure was examined. It was found that the initial stability coefficient (obtained without reinforcement) $F = 1.42$ increased to the allowable (sufficient) value in each of the conducted calculations. The reinforcement with a triaxial geogrid without a gravel layer is $F = 1.87$, with a gravel layer is $F = 1.93$, and taking into account the radial stiffness, $F = 2.78$. In the case where gravel was used, it is presented the influence of a characteristic mechanism of action of the hexagonal geogrid – wedging. The difficulty in designing reinforcement with the investigated geogrid arises from the discrepancy between the manufacturer's recommendations and the standard regarding the testing method and determination of the strength of triaxial geogrids. Comparing the results of calculations from different studies, a significant difference in the effects of reinforcement can be observed when using strength values determined according to the standard versus the radial stiffness specified by the manufacturer. Standardising the method for examining the properties of this material would increase the design possibilities of reinforcements with hexagonal geogrids. The presented research and stability analysis demonstrate the potential use of hexagonal geogrids for reinforcing the base of an embankment. The conducted studies serve as a basis for suggesting that strength parameters should be derived from appropriate laboratory tests for specific engineering scenarios. The comparison of tensile strength results and the performed stability analysis in various cases highlight this issue, indicating discrepancies in obtained values compared to manufacturer data.

Authors' contributions

Conceptualisation: A.K. and W.S.; methodology: W.S.; validation: M.D. and W.S.; formal analysis: M.D., A.K. and F.K.; investigation: A.K.; resources: W.S.; data curation: W.S.; writing – original draft preparation: W.S. and F.K.; writing – review and editing: W.S. and A.K.; visualisation: F.K.; supervision: M.D. and A.K.

All authors have read and agreed to the published version of the manuscript.

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ZASTOSOWANIE GEORUSZTU HEKSAGONALNEGO JAKO ELEMENTU WZMOCNIENIA PODSTAWY NASYPU DROGOWEGO

STRESZCZENIE

Znajomość wytrzymałości materiału użytego jako zbrojenie jest jedną z najważniejszych danych koniecznych do obliczeń stateczności konstrukcji. W przypadku georusztu heksagonalnego wyniki wytrzymałości można uzyskać zgodnie z zaleceniami producenta (rozciągane radialnie) lub zgodnie z normą (metodą szerokich próbek). Wyniki wytrzymałości ze sztywnością radialną postanowiono porównać do tych wynikających z badań według normy. W niniejszym artykule przedstawiono wykorzystywania materiałów geosyntetycznych (georusztów heksagonalnych) jako elementu wzmocnienia gruntu. Zaprezentowano także metodykę oraz wyniki badań wytrzymałościowych próbek georusztu trójosiowego oraz analizę stateczności przykładowego nasypu drogowego z zastosowaniem przedmiotowego georusztu. Celem badań było określenie parametrów wytrzymałościowych w aspekcie wykorzystania ich w obliczeniach stateczności nasypu. Uzyskane parametry porównano z parametrami podanymi przez producenta.

Słowa kluczowe: georuszt heksagonalny, wytrzymałość na rozciąganie, wzmocnienie gruntu, nasyp, analiza stateczności