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FBG MONITORING OF A COMMUNICATION PATHS AND ROADWAYS WITH A GEOSYNTHETIC SYSTEMS ON MINING HEAPS

Janusz JURASZEK[1], Monika GWOZDZ – LASON[1,*], Filip GAGO[2], Roman BULKO[2]

[1] Department of Civil Engineering, Faculty of Materials, Civil and Environmental Engineering, University of Bielsko-Biala, Bielsko-Biala, Poland.
[2] Department of Geotechnics, Faculty of Civil Engineering, University of Zilina, Univerzitna 8215, 010 26 Zilina, Slovakia.
[*] corresponding author: mgwozdz@ath.bielsko.pl

Abstract

In civil engineering geosynthetics play the role of reinforcing the ground and strengthening the foundation structures of engineering facilities. This paper shows the possibility of using a geotextile, a geonet and a geogrid for the design of walking, cycle and quad-bike paths in the investigated mine waste dump sites. The functions of the solutions designed for linear investments in areas affected by mining activity and rehabilitated into a sports and recreation area must be monitored. The paper discusses the scope and the method of FBG monitoring, the data of which illustrate the behaviour of structures with embedded geosynthetic materials with regard to variables such as the structure service life and durability and the need to meet all limit states. The impact of the choice of designs with geosynthetics in sustainable development can be quantified in terms of the carbon footprint. A site-rehabilitation working design can also be analysed economically by estimating the market, investment and replacement values of a construction investment. In addition to key technical aspects, the discussed solutions in anthropogenic areas also ensure significant sustainable development of the Benefits system.

Keywords:

Geosynthetics;
Civil engineering;
Roadways;
FBG monitoring;
Market value.

1 Introduction

Areas affected by mining activities and post-mining areas are characterized by non-standard physical and mechanical parameters of the subsoil for design purposes and a significant degree of environmental degradation and deformation. Thanks to remediation and rehabilitation, the areas investigated and analysed for investment purposes become attractive to the environment. Mining heaps disappear gradually or get new life through development and modernization of land use functions. In Poland, the first step related to the development of this type of wasteland is to minimize its negative impact on the environment, then determine the path of change in the use of land in the local zoning plan, to finally create a suitable innovative project that is consistent with current trends in the construction sector [1, 2, 3, 4].

Geosynthetic materials, which have been used since the mid-20th century, are continually developing their form, function and use through applications in a modernized and upgraded form in many new fields of civil engineering, including road structures. The non-woven and woven fabrics used for the first applications [2, 4] originated from the textile industry. There are a number of studies with empirical justifications to determine the properties of various innovative geosynthetic materials intended for use in civil engineering investments [4, 5]. Guidelines for the performance of earth structures and designs of elements connecting an engineering facility to the construction subsoil using various types of geosynthetics are common. The guidelines for proper identification of the material that could be used in geotechnical applications and civil engineering are being continually expanded and updated [3, 6]. Geosynthetics are effective in reinforcing various types of aggregate layers making up the pavement for road solutions, laid, for example, on anthropogenic subsoil with unusual and nonuniform physical and mechanical characteristics. The results of the conducted research and analyses indicate that monolithic geogrids are very effective when designing traffic pavements in mining areas. Geosynthetics laid at the interface of the outer layer of the mining heap and the layer of the traffic pavement structural scheme stabilize the subsoil-traffic structure cooperation and make it possible to substantially extend the life of the construction investment, as well as to obtain a suitable working platform during the construction of the traffic pavement for non-standard input guidelines. The effect of securing and reinforcing the structure on mining soils qualifying for geotechnical category III, as well as the structural ability to absorb the tensile stresses arising at the bottom of the aggregate layer under load, depend on the type and manner of the geosynthetic cooperation with the anthropogenic layer formed by mining waste on the mining heaps under analysis. The main mechanisms of the subsoil strengthening using geosynthetics exposed to the load due to the weight of vehicles, which are distinguished prior to the implementation of a traffic project, include improving the aggregate layer shear strength, the stretched-membrane effect and lateral fixing of aggregate grains [7, 8, 9, 10].

For the analysed properties of geosynthetic materials, appropriate design models are selected for the investigated engineering application which, after analysis and design modelling, enters the working design phase and then the phase of acceptance and monitoring. All the time, new structures, optimized for the set purpose of implementation, are created with geosynthetic elements from different groups with different characteristics and functions. According to the PN-EN ISO10318:2007 standard, geosynthetics are divided into geotextiles, geotextile-related products, geosynthetic barriers and geocomposites, Fig. 1.

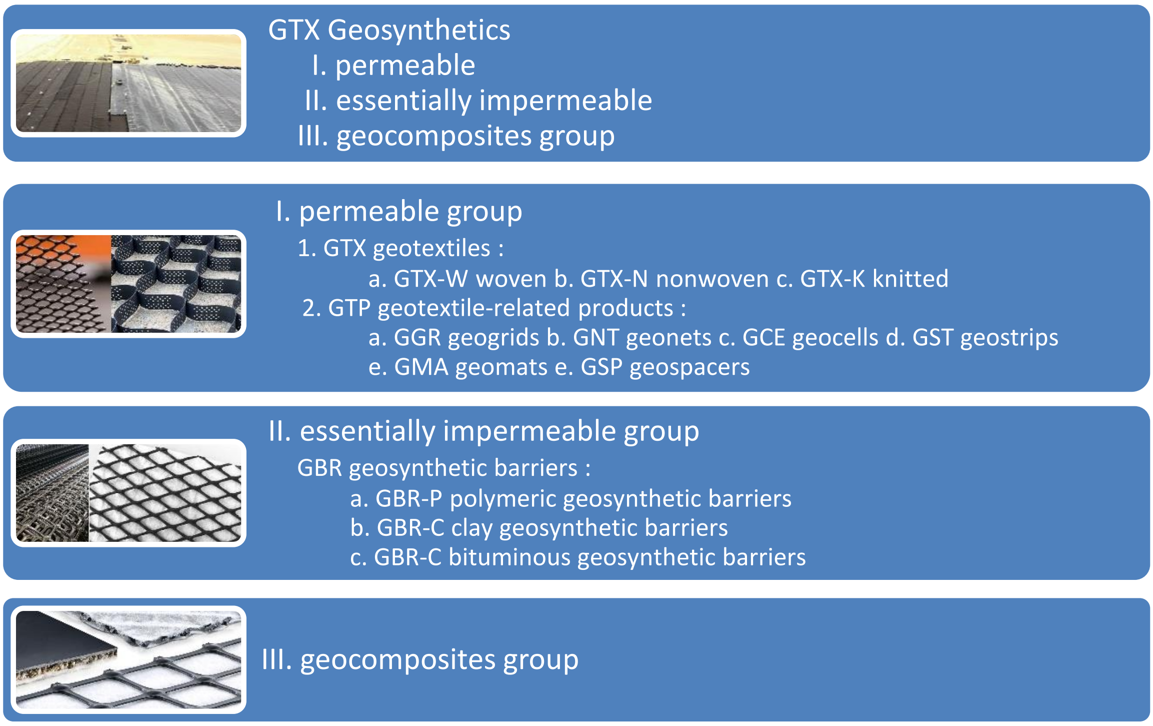

Fig. 1: Division of geosynthetics by form, features and applications in civil engineering.

Geosynthetics can play various roles in civil engineering. The function of reinforcement in earth structures is performed by geotextiles, geonets and geogrids. According to the classification, all these materials are included in the group of geotextiles and related products, but they are characterized by different properties and a different mechanism of cooperation with the soil. Geosynthetics serve the separation, filtration, drainage, anti-erosion, reinforcement, strengthening and securing function; they also seal and protect. In this paper we analyse geosynthetics whose main role is to reinforce the subsoil in mining areas, which improves the mechanical properties of the subsoil and the construction materials, and ensures optimal cooperation between the subsoil and engineering structures in the form of roads, paths and traffic sites.

Mining impacts manifest themselves on the ground surface in the form of cracks or deformation of building structures. Moreover, the characteristics of mining heaps also have their own chemical and physical interrelationships affecting the way in which structural loads are received from roads for sports and recreational equipment and from walking paths. The complexity of issues related to the effect of mining deformation on road structures requires a comprehensive approach to the assessment of the state of cooperation between the mining heap surface and the traffic project, along with appropriate protection against the anticipated adverse and abnormal impacts. Innovative conceptual and design works using modern state-of-the-art materials, including geosynthetics, with already-tested engineering properties are now a frequent subject of analysis and research of university projects in the Department of Civil Engineering [11, 12, 13, 14]. The complex geotechnical conditions needed to strengthen and stabilize the subsoil of mining heaps using geosynthetic reinforcement are still an unexplored issue, so the monitoring of completed pilot rehabilitation projects for the land development concept is a key complement to the task. Even in the case of walking paths, or roads for bicycles, quad-bikes, scooters or motorcycles generating slight loading forces, the prediction and design of the correct and optimal cooperation of a linear road structure with the heterogeneous system of the subsoil of a mining heap classified as geotechnical category III require appropriate studies and assumptions, as well as full monitoring of the cooperation and durability of the road pavement. Monitoring the ability of the heap subsoil to absorb the assumed maximum constant and variable loads of the road structure is of key importance in terms of current requirements and trends in the construction sector of the economy [16].

2 Subject and scope of the issue under investigation

The subject of the study is the analysis of the concept of rehabilitation of mine waste dump sites, i.e. mining heaps, for the variant of planning and designing walking, cycle and quad-bike paths in the area of the investigated mining heap. The scope of the research study includes the concepts and the design with the use of geosynthetics for the study of physical and mechanical parameters of an anthropogenic soil, along with an analysis of all current leading trends in construction in Poland and Europe. The working design of the task, according to the initial assumption of the study, includes a designed FBG monitoring system, the data from which are to be used to analyse the damage to the road structure in mining activity areas [15, 16, 17]. The monitoring data were the basis for the concept of creating a scoring model based on logistic regression, classification trees, and hybrid methods combining the two approaches. The last stage of the study is an economic analysis of the construction investment, which is a plan for a change in the purpose of a given area in the local zoning plan from wasteland to sports and recreational areas. The analysis of conceptual, design, execution and management costs of the facility with monitoring, as well as the analysis of potential risks presented to the project investor will provide a basis for the performance of calculations and estimates of the investment market and residual values [8, 13, 18-22].

Fig. 2 shows the concept analysed within this research approach for land development of a mine waste dump site located in the south of Poland in the Silesian Voivodeship. The entire project is divided into two trails with an easy and a difficult layout to ensure safe traffic on the mine waste dump site to be rehabilitated. The design of the site on anthropogenic soil reinforced with geosynthetics includes on the outer side of the slope of the mining heap first a walking path, then a higher-located area for rest and, further on, a complex of roads for skaters, bicycles, scooters and quad-bikes. The investment design anticipates soil strengthening with geosynthetics and full FBG monitoring [19, 22, 23]. The whole project is in line with the circular economy trend in civil engineering, ensuring the use of the strategy of sustainable development of the Benefits system.

The design of the reinforcement of the subsoil with geosynthetics to provide protection against possible adverse impacts of the mining heap anthropogenic soil assumes for the designed geomattress a mix of recycled aggregate as filling, along with substances that reduce the possibility of fire spreading. It includes the cross-section of a road with lanes for two-way traffic of vehicles, i.e. bicycles, electric scooters and personal transport devices, where the speed limit does not exceed 50 km/h. The design also assumes fencing along the roads for bicycles and bike-quads, especially in the sections bordering on the outside the secured slope of the heap.

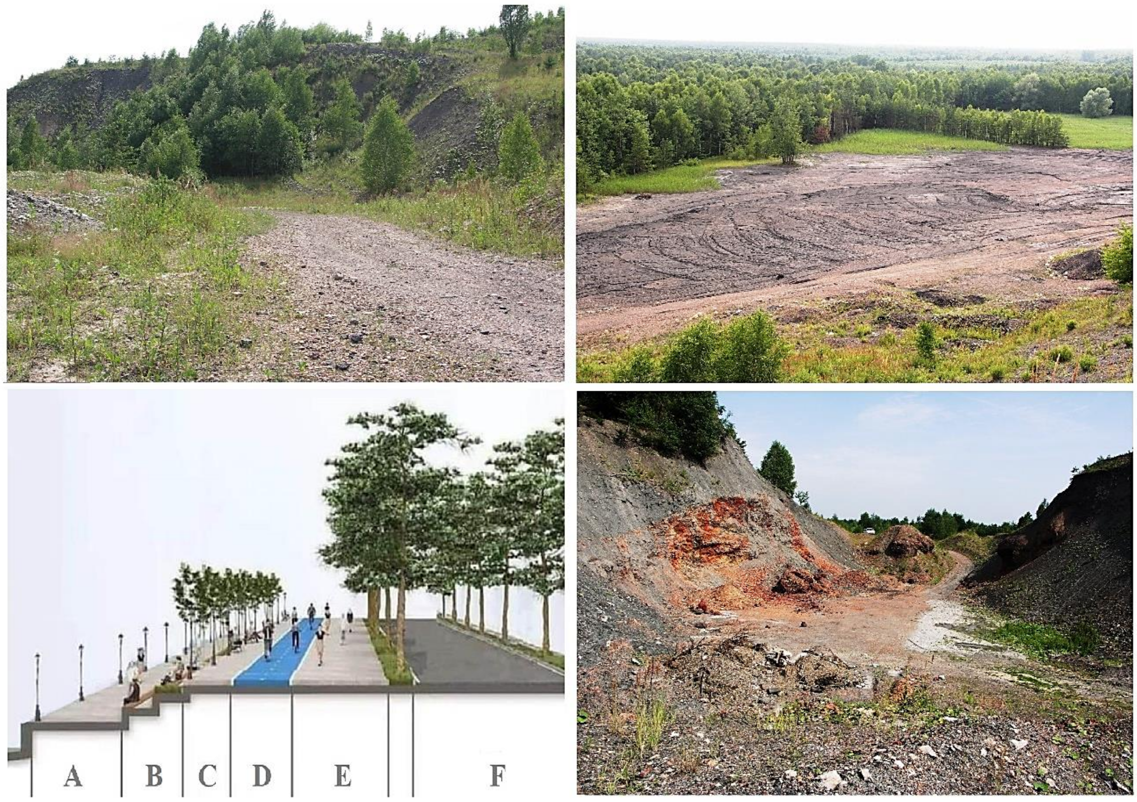

Fig. 2: Land development concept for a mine waste dump site in the Silesian Voivodeship through a project of a park with: A: walking paths, B: rest area separated from the part of the complex with L- and D-class roads for C: trails for skaters, D: bicycles, E: scooters, F: quad-bikes – on subsoil reinforced with geosynthetics and with FBG monitoring [photos and elaboration: own resources].

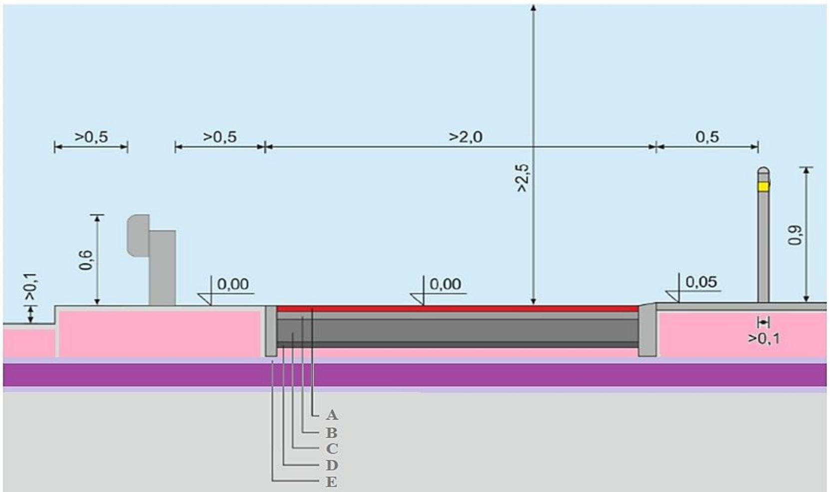

Fig. 3: View of the cross-section of a two-way bicycle road on the mining heap anthropogenic subsoil reinforced with geosynthetics: A: 5-cm-thick red bituminous wearing course, B: 5-cm-thick bituminous binder course, C: layer of crushed aggregate with an admixture of recycled soil with the total thickness of 15 cm, D: 1.5 MPa stabilization, E: subsoil reinforcement in the form of a geonet with a geogrid structure and sharp-edged ribs [own study].

3 Method of the study and analysis of the concept of mine waste dump site rehabilitation

3.1 Mining heaps and areas of mining activity

The negative impact of mining waste can be mainly related to the mechanical instability of the dumps, the water- and wind-erosion hazards, the formation of acid leachates and the increase in salinity. In the case of carbon waste, there is a threat of spontaneous auto-ignition inside the dump and dusting into the atmosphere of solid particles, which often contain potentially toxic elements – post-flotation precipitates of Zn, Pb and Cu ores. Dumps can be reclaimed for further use provided that the design and execution tasks, as well as the task related to the management of the investment with the monitoring system, are economically profitable. It is known that there are various possibilities and methods of purification of the subsoil affected by mining activities through chemical methods based on oxidation and reduction, extraction, precipitation in forms of hardly soluble chemical compounds and reaction stabilization. Biological methods are also applied: bioremediation (based on the activity of microorganisms) and phytoremediation (based on the activity of higher plants in the process of phytostabilization, phytoextraction or phytodegradation).

Using the waste material of a land heap for civil engineering projects, it is necessary to create an optimal algorithm for the geotechnical research quantity and quality to determine the input data for design computations and for the model of the engineering road structure cooperation with a non-natural subsoil with an adverse effect on the structure. Oedometric and triaxial tests, as well as direct shear testing, were carried out during the works for different optimized testing points established based on the optimization algorithm [26, 27]. The obtained results made it possible to determine compressibility parameters, i.e. the volume compressibility factor, oedometric and secant moduli, the slopes of the lines of primary and secondary consolidation, and to estimate cohesion and the internal friction angle as a function of the porosity index. The mining waste permeability was investigated and the possibility of swelling was checked. The testing results were used to determine the representative parameters based on the Eurocode 7 guidelines. This enabled calibration of constitutive soil models (the Coulomb-Mohr, the CAP and the Modified Cam Clay models), which helped in the analysis of the effective and economic use of land with mining waste for the designed scope of rehabilitation of the mine waste dump site.

Table 1: Summary of the results of in situ and laboratory testing for individual areas of the investigated heap as the results of the set of data meeting the assumptions of the adopted algorithm.

Representative group of the heap area	**Heap area**	**Volume density depending on the moisture content in representative samples from individual groups**	**Results of statistical analysis of the obtained strength parameters of the tested groups of representative soil samples from the heap as the project input values**		**Oedometric modulus of deformation as the median of the data of a representative group**	
-	**-**	**[g/cm^3]**	***c* [kPa]**	***Φ* [º]**	**M_0 [kPa]**	***M* [kPa]**
A	N-E 3,4; N 1,2,3,4; N-W 1,2;	2.141	22.504	38.501	78.20	121.31
B	N-W 3,4; W 1,2,3,4,5,6; E 1,2;	1.903	27.503	32.093	62.81	110.20
C	E 3,4,5,6; N-E 1,2; S-E 1;	2.011	21.001	48.401	96.70	200.15
D	S-E 2,3,4; S 1,2;	1.961	28.502	22.103	28.53	42.52
E	S 3,4; S-W 1;	2.254	23.116	29.101	77.03	111.01
F	S-W 2,3,4;	1.849	21.019	27.013	60.43	105.20

In each separated area of the heap (part N and S divided into 4 parts, part E and W – into 6, and part N-W, N-E, S-W, S-E – into 4), samples were taken and tested from minimum 3 points; for each sample, 3 tests were carried out for each testing. From such a pool of data, representative groups were separated, and the maxima, minima and the mean values, together with the medians and standard deviation were determined. The optimal values were taken as the input data for the design of the road structure and the strengthening of the anthropogenic subsoil on the mining heap.

Cohesion and the internal friction angle were estimated based on the testing results as functions of the porosity index. The compressibility tests in the oedometer for six representative groups followed typical standard guidelines. It should be noted that due to the high content of sand and gravel fractions, high values of compressibility moduli were obtained. The obtained results were confirmed by testing in a triaxial compression apparatus, where the soil was tested by means of various methods, and in the end the CD (consolidated drained) method turned out to be the optimal option for the initial assumptions concerning the function of the use of the analysed anthropogenic soil. The CD method involves very slow shearing of a pre-consolidated sample. During the testing, there is a continuous outflow of water from the sample, the test speed is adjusted so that the pore pressure value recorded in the sample is zero. This method is used when the expected operating load of the structure does not exceed 30 % of the total load, and the construction time is long enough to achieve full consolidation of the subsoil, which was one of the initial assumptions of the research.

3.2 Geosynthetics in mining heap rehabilitation projects

Reinforced soil can be strengthened with a layer of geonet when the purpose of the reinforcement is to prevent displacement of aggregate grains under load. Due to this design solution, grains become stuck and their lateral fixing is stabilized, which increases the modulus of the "restrained" aggregate layer laid on the anthropogenic subsoil. The correct performance of the geosynthetic in the road pavement-ground subsoil system ensures protection against damage during construction and operation. The conducted research and to-date publications confirm the assumptions that the highest stresses in the geosynthetic arise during construction, totalling for geogrids up to 5 %, while during the pavement operation they are less than 0.5 % of strength.

In the case of the construction of a linear engineering structure in the form of a class L and class D road in the area of a mining heap, the reinforcement of the subsoil cooperating with the structure is recommended and should be monitored during the entire life of the structure due to the non-standard effect of mining waste. The ground subsoil in a heap converted to a construction site requires protection with at least several geonet layers. In the project under analysis, in one case the design focuses on the reinforcement of the zone under the road and path structure, and in another case – the design takes account of the way in which the geosynthetic reinforcement should be distributed for a given volume of the ground on the designed roadside slopes. Considering the variety of the subsoil parameters, the reinforcement intended for the designed traffic structure generates averaging of the traffic route characteristics. One element represents certain properties of the reinforced ground, resulting from the coexistence of the two components that make it up: the so-called representative or elementary cells.

Analysing the "material 1, material 2" system response to the compressive load in the direction perpendicular to the contact surface, in the case of a perfectly smooth contact surface, there will be a mutual displacement (slip) of the components, which is due to the difference in their deformation properties. If the components are bonded together, their displacement across the contact surface is equal. This results in interaction forces (stresses) which arise in both components. Compressive stresses will occur in the material demonstrating higher deformability, whereas in the material characterized by smaller deformability tensile stresses will be the case.

The basic attribute of the ground deformation mechanism is mutual displacement of the structure skeleton particles. This results in the occurrence of deformation, which is irreversible in most cases. This situation occurs in practically every range of stresses, including the state before the exhaustion of the ground bearing capacity. In ground mechanics and its application in broadly understood geotechnics, there are issues for which a useful solution is obtained using a model that ignores the history of stress and strain states before the plastic flow state is reached. One of the most common and best-known models of the ground medium is the rigid-plastic model. Within this description, it is assumed that the ground medium does not deform under external loads until the load-bearing capacity is exhausted. When this limit is exceeded, the medium enters the plastic flow state. This means that unlimited and irreversible (plastic) deformations occur. The following are examples of important issues that are solved using the rigid-plastic model: the foundation limit load-bearing capacity, embankment and slope stability, and earth pressure. Such a model is applicable for the reinforced ground solution [15, 17].

Ground plasticization is a state in which irreversible (permanent) deformations arise and develop. This state is described quantitatively by the plasticity condition that binds together the quantities describing the stress state. The most common basic description of the state of the ground plasticity in geotechnics is the Coulomb-Mohr (C-M) criterion, ruling that the maximum value of the shear stress must not exceed the ground shear strength, i.e.

$$|\tau| \leq \tau_f \ , \qquad (1)$$

where: τ – shear stress τ_f – ground shear strength. The shear strength description proposed by Coulomb, and assuming the ground medium isotropy, is of the following well-known form

$$\tau_f = \sigma_n \cdot \mathrm{tg}\varphi + c\ , \tag{2}$$

where σ_n – stress normal to the shear plane; ϕ – internal friction angle; c – cohesion. The given form of the C-M condition is convenient and useful when the position of the slip surface is known and the normal and shear stresses on the surface are defined. The stress states will be represented by stress tensors:

- in the (x,O,z) system of coordinates

$$\begin{pmatrix} \sigma_x, & \sigma_{xz} \\ \sigma_{xz}, & \sigma_z \end{pmatrix}, \tag{3}$$

- in the (1,O,2) system of coordinates

$$\begin{pmatrix} \sigma_{11}, & \sigma_{13} \\ \sigma_{13}, & \sigma_{33} \end{pmatrix}, \tag{4}$$

- by principal stress

$$\begin{pmatrix} \sigma_1, & 0 \\ 0, & \sigma_3 \end{pmatrix}. \tag{5}$$

In the general case of two-dimensional problems, it is convenient to express the Coulomb-Mohr condition in principal stresses σ_1 and σ_3; it then takes the following form

$$\sigma_1 - \sigma_3 = (\sigma_1 + \sigma_3) \cdot \sin\varphi + 2c \cdot \cos\varphi, \tag{6}$$

$$\sigma_1 - \sigma_3 = (\sigma_1 + \sigma_3 + 2k) \cdot \sin\varphi, \tag{7}$$

where $k = c \cdot c\mathrm{tg}\varphi.$ (8)

Taking account of equations: (1) - (8), after simple rearrangements, a commonly used form of the Coulomb-Mohr plasticity condition is obtained

$$f = (\sigma_1 - \sigma_3)^2 - (\sigma_1 + \sigma_3 + 2k)^2 \sin^2\varphi = 0. \tag{9}$$

The condition written in the stress tensor coordinates for any (x,O,z) system of coordinates is expressed as

$$f = (\sigma_x - \sigma_z)^2 - (\sigma_x + \sigma_z + 2k)^2 \sin^2\varphi + 4\sigma_{xz}^2 = 0. \tag{10}$$

Equation (9) presents in the system of coordinates of principal stresses two straight lines described by the following equations

$$\sigma_3 = \sigma_1 \cdot \frac{1+\sin(\varphi)}{1-\sin(\varphi)} + 2k \cdot \frac{\sin(\varphi)}{1-\sin(\varphi)}\ ,$$
$$\sigma_3 = \sigma_1 \cdot \tfrac{1-\sin(\varphi)}{1+\sin(\varphi)} + 2k \cdot \tfrac{\sin(\varphi)}{1+\sin(\varphi)}\ . \tag{11}$$

The rigid-plastic model of reinforced ground is a generalization of the classical model for a homogeneous and isotropic medium for the case of a two-constituent anthropogenic soil-geosynthetic-traffic structure composite. In order to analyse such a task, assumptions are made that make it possible to write appropriate relations, i.e.:

- the ground is reinforced using a two-constituent mixture made of two components: anthropogenic ground and reinforcement using geosynthetics
- the ground volume is equal to the sum of the volumes of its constituents
- the ground and the reinforcement are rigid-plastic materials
- the ground and the reinforcement are thoroughly mixed with each other, which means that it is possible to isolate the so-called representative volume (cell) which contains both components of the reinforced ground and which is much smaller than the entire structure

- the ground and the reinforcement cooperate perfectly, i.e. they do not separate and no slip occurs between them

- the reinforcement compressive strength is small compared to the ground compressibility and is omitted

- the placement of reinforcement in the ground results in the creation of a preferential direction which is the direction of the reinforcement, represented by directional vector *n.*

The description of stress states in an anthropogenic reinforced ground should take account of its complexity regarding the composite, the mixture of components, and the calculated design relations will then be the input data for the analysis of the results from the designed FBG monitoring [15, 28, 29].

3.3 FBG monitoring of structures on reclaimed mining heaps

The object of the testing was a pilot construction investment in the form of a bicycle road located on a mining heap. The FBG monitoring system is qualified for long-term monitoring of the deformation or temperature of a road structure on an atypical anthropogenic ground. The main unit of the proposed system is a two-channel FBG-800 optical interrogator, Fig. 4a. Continuous measurements were performed by means of FBG strain and temperature sensors attached to the geosynthetic reinforcement in the subsoil, Fig. 3. Dynamic measurements with the frequency of 2 kHz are also possible. Example results of measurements of changes in the geonet strain during dynamic loading with a force resulting from a running athlete are shown in Fig 4b. Own measurement results of the geonet strain during static loading are shown in Fig. 5. The load came from people riding a bicycle, a scooter or a quad-bike. The recorded strain values are within the range of 20 to 107 μstrain. Analysing the chart illustrating the geonet strain values depending on load, it can be noticed that the relation is non-linear.

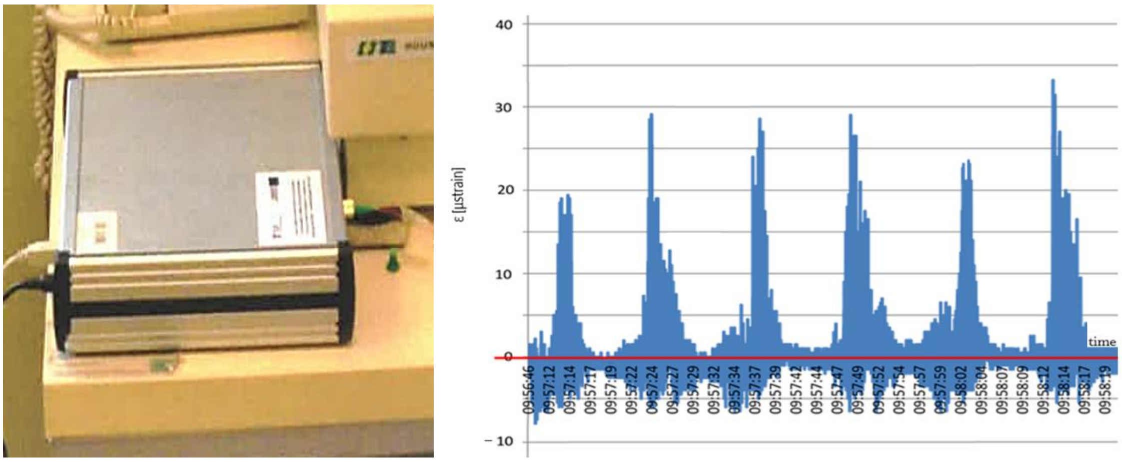

Fig. 4: a) FBG 800 optical interrogator; b) Chart illustrating strains in the geogrid based on an anthropogenic ground of a mining heap.

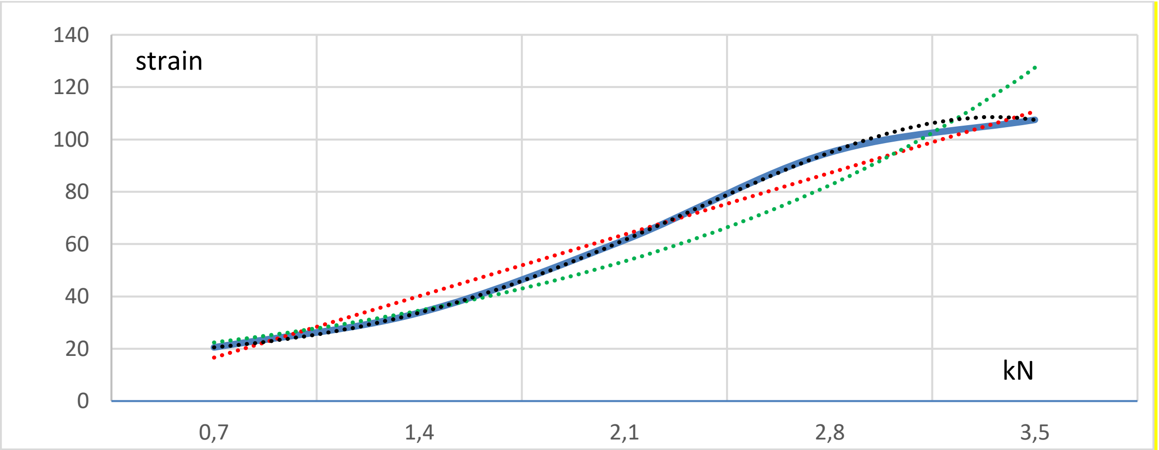

Fig. 5: Geonet load-dependent static strains.

Fig. 6 shows the results of the measurement of the temperature distribution in the near-ground layer and in the pavement performed with the use of FBG temperature sensors.

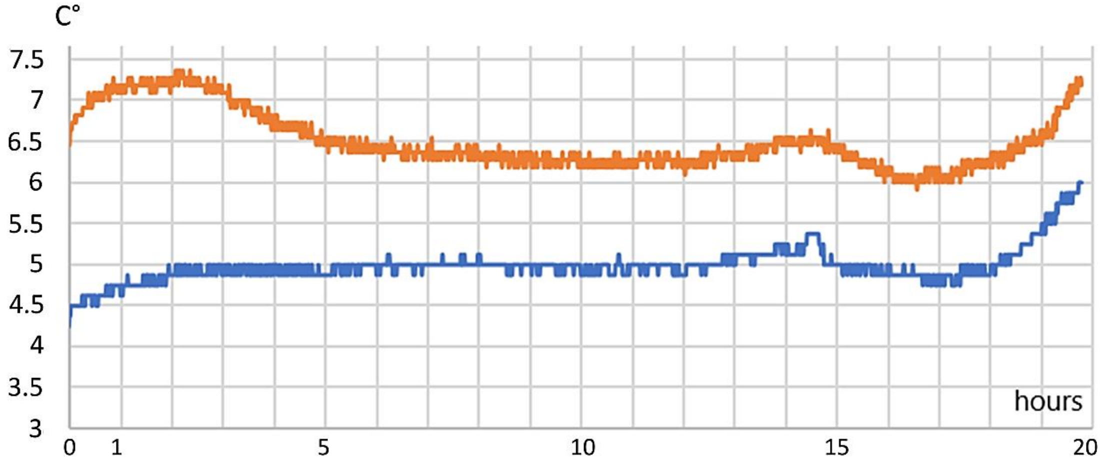

Fig. 6: Temperature monitoring during the observation.

The presented fibre-optic techniques enable simultaneous measurements of strain and temperature in selected areas of the structure. The measurements are characterized by significant accuracy compared to classical measurement methods, reliability, time stability and resistance to electromagnetic interference. The monitoring will make it possible to analyse possible destruction of the subsoil.

4 Attributes affecting values of rehabilitation of mine waste dump sites

The design of new linear structures using geosynthetics in areas to be rehabilitated generate a lot of research and design work, as well as execution and monitoring costs, which has a substantial impact on investment and as-built cost estimates, which in turn are the basis for the price of the market and replacement values of such a new investment. The technical characteristics of the analysed road structures generate new attributes of the property derived from the functions of the variables included in the Circular Economy (CE) and sustainable development processes in construction, which affect the property value.

At the very beginning, the site with the subject of the analysis – the mining heap – is excluded from use (brownfield). There are now no mining heap sales, so the market value of the real property cannot be estimated in the project. In order to reclaim the area for its assumed sports and recreation purposes, at first the real property market is studied for this property type and the future market value of the assumed and designed form of the site is established. Then the replacement value is determined, together with the worth of all the investment works that are necessary for the realization of the assumed project, taking account of the use of new building materials and new geotechnical and civil engineering solutions setting new trends in construction in Poland and Europe. Details of the model, the algorithm and the principles can be found in [13] and in the papers to be published soon. In the project, the type and the function of the applied geosynthetics constitute the variables describing the technical wear and tear of the structure, the optimal way of the repair management of the rehabilitated areas and the investment management model in terms of the current trends created by the construction market. The use of geosynthetics performing the functions of the infrastructure reinforcement, drainage or barrier to improve the road line stabilization also provides indirect financial benefits. This is indirectly related to the time variable, which significantly reduces the construction time, and thus has a substantial effect on the investment value. The appraisal of the investment, a real property with a traffic function in the form of a road structure in this case, is an individual act governed by its own laws adapted to the investor's basic initial assumptions with a variant option, for different types of geosynthetic materials, for different service life times and different degrees of investment risk [10, 15].

In construction investments, the purpose of appraisal reports is very often to secure an investment loan or determine the insurance value. In addition, more and more often appraisals are prepared for the purposes of the zero investment stage (ZIS) [9], in the form of valuation taking account of geotechnical and design aspects of the investment [8, 13, 15]. Considering the new aspects of investment appraisals, which recently have very often been determined for construction investments, an analysis is conducted of all the attributes that affect the time, the quality, the service life and the type of materials used for the analysed design and construction method and technology. In other words, the class of the investment is analysed. The option of the valuation of different variants of geosynthetic materials for the analysed project is more and more often realized using appropriately adapted property valuation methods in mixed approaches. In such analyses, the residual method is a frequent tool. It is used for known impacts of mining activity [11, 12], in the area under investigation and for a specific construction design involving structural reinforcement or protection of the structures discussed in [14]. Subsequent estimates show that the selection of an appropriate material is one of the key attributes in the calculation of the investment costs for the assumed service life of the structure and for its assumed reliability. Very often the use of appropriate geosynthetics, also in areas affected by mining impacts, significantly reduces the scope of works related to road repairs.

After an analysis of the construction costs for individual traffic categories from TC1 to TC7 for isolated flexible and rigid pavements, a group is formed of representative data which are the basis for comparisons and appraisals of the investment options. The model analysis is described by a function of design, execution, material and cost-related variables [10, 13]. The sum of all the performed comparative analyses indicates much lower whole life costs, i.e. the sum of design and material costs of the analysed geotechnical solution, the costs of the geosynthetic reinforcement, modernization and repair costs, which accurately illustrates the cost of the entire construction venture for a single investor (the assumptions that the investor builds and sells result in minimal costs of the materials and designs because the aspect of repairs and modernization and the current “No Waste” aspects no longer apply to a given road investment). The prices of construction materials needed to realize a construction project are continually changing, and their prices are difficult to estimate due to the numerous random variables of the task, i.e. inflation, energy crisis, the situation of the neighbouring country in the state of war, economic slowdown, etc. Nevertheless, the trend of economic profitability in the implementation of investments from geosynthetic materials is generally comparable to the estimates from the years 2015-2020. At the same time, solutions using geosynthetics are now the subject of a lot of research studies. Analyses are made of the results of comparative testing of sustainable development by increasing the presence of geosynthetics in typical and innovative material solutions. The investment economics stage analyses the costs of the application of geosynthetics for various isolated functions. The number and the type of main functions vary, but for all cases the function that is analysed is the one involving extension of the service life of the designed or modernized roads. In addition, analyses are made in all variants of the results of the estimation of the market and replacement values of geosynthetics, whose function is to significantly improve the performance of the roadway, which has a huge impact on the investment management model, the investment monitoring and the scope of the investment repair management. The investigated function includes different types and kinds of geosynthetics, the purpose of which directly or indirectly affects the investigated function.

In this case study, economical analysis was not an aim of our effort. Detailed economic analysis will be elaborated in further research.

5 Conclusion

The article signals some issues related to the preparation and implementation of a new infrastructure investment in the aspect of rehabilitation of mining heaps, in terms of the anthropogenic subsoil identification, as well as of the design and execution in various contractual formulas – taking particular account of the ordering party’s experience in the range from the stage of the technical-economic-environmental study, through the design brief, the building permit design, the working design, and implementation, to the stage of guarantees and litigation. The paper presents the results of geotechnical studies with an architectural and structural design proposal including different types and kinds of geosynthetics, as well as the necessary monitoring of the investment, and the methodology of the economic analysis algorithm [24-25]. The project included the selection of the right type of plants, making it possible to reduce dusting from the surface of the mining heaps, and the complement to the designed function of the rehabilitation of sites degraded due to mining activity in the form of changing them into friendly sports and recreation areas. Owing to the analysed concepts and designs for the creation of huge safe and monitored rehabilitated recreational areas with walking paths, bicycle, scooter and quad-bike roads, as well as with a viewpoint and space for a sports field, a playground, a toboggan slope, the scope, the characteristics, the costs and the economic approach are determined for such projects.

Designing new linear structures with the use of geosynthetics generates investment or as-built cost estimates, which is the basis for the valuation of the market and replacement values of the construction investment. The technical characteristics of the analysed road structures generate attributes of the real property that affect the property value. The type and the function of geosynthetics generate different variables of the function describing the technical wear and tear of the structure, the optimal way of the structure repair management and the investment management model in terms of the current trends created by the construction market. The use of geosynthetics to improve the road line stabilization also provides indirect financial benefits.

Heaps are also rehabilitated through successive dismantling, and the purpose of the reclaimed levelled land is changed in the local development plan to industrial or residential use. The analysed project demonstrates that dismantling is no longer the most effective method of heap rehabilitation. The dismantling and waste management costs have risen greatly and the analysis of the market values and comparisons between the designed project and the option of removing the heap is itself at a comparable level. The analysis of the new market attributes, which are the basis for certification of investments in terms of the current construction criteria and trends, and the social aspect bring the discussed concept to the forefront. The material from the works related to the building of roads and paths on mining heaps has its use in new methods of creating recycled building materials which perfectly fit into the CE options in the construction industry. The data from the analysis of the next stages of the project research works, as well as the information from the monitoring of the pilot construction investment on the rehabilitated mining heap, will be described in future publications.

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