Slope Reinforcement with the Utilization of the Coal Waste Anthropogenic Material

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Abstract. The protection of the environment, including waste management, is one of the pillars of the policy of the Europe. The application which is presented in that paper tries to show a trans-disciplinary way to design geotechnical constructions – slope stability analysis. The generally accepted principles that the author presents are numerous modelling patterns of earth retaining walls as slope stabilization system. The paper constitutes an attempt to summarise and generalise earlier researches which involved FEM numeric procedures and the Z_Soil package. The design of anthropogenic soil used as a material for reinforced earth retaining walls, are not only of commercial but of environmental importance as well and consistent with the concept of sustainable development and the need to redevelop brownfield. This paper tries to show conceptual and empirical modelling approaches to slope stability system used in anthropogenic soil formation such as heaps, resulting from mining, with a special focus on urban areas of South of Poland and perspectives of anthropogenic materials application in geotechnical engineering are discussed.

1. Introduction

The basis of all efforts is to improve the stability of a well-made diagnosis of geotechnical ground in the area of the slope or the slope itself. Currently, available methods of research, analysis software and techniques to improve the implementation of various treatments stability create conditions for the safe design of cut and fill slopes. The field of slope stability encompasses the analysis of static and dynamic stability of slopes of subsoil and excavated slopes. Slope stability investigation, analysis (including modelling), and design mitigation is typically completed by geotechnical engineers. A geologist can determine relative slope stability by simply observing the site due to his knowledge about Earth's processes and their skills in interpreting geomorphology.

Now, in the period 2000-2020, all the problems that are associated with the design of the geotechnical link in are a very important issues that have a basis in: construction, soil mechanics, computer science, environmental engineering and economics - interdisciplinary teams take part in the project and they are able to find solutions for many problems on the spot. It is interdisciplinary and, in particular with regard to: a suitable description of the weak interaction with the engineering design of a small ground floor (rules and procedures for the selection of appropriate methods and technology to strengthen the reinforced subsoil); creation of corresponding numeric models for ground before and after strengthening and implementation of relevant experience; time and function analysis of the effect of the numeric costs associated with the strengthening of the substrate (design costs, material, a
robotics-hours workers and labour costs of specialized equipment), on its market value in the undeveloped real estate group.

In recent years in Poland, the road infrastructure is experiencing a great revival, mainly through funding those roads construction with funds from the UE. The protection of the environment, including waste management, is one of the pillars of the policy of the European Union. The application which is presented in that paper – coal waste used as a material for reinforced earth retaining walls as slope stabilization system, are not only of commercial but of environmental importance as well. Due to special regulations, which included extractive waste (Directive 2006/21/EC of 15.03.2006 PEiR) and the new obligations under which the companies generating those wastes from are, create a need to develop practical applications. Reinforced earth retaining walls are an essential element of every road design and usually are used for slope stabilization.

Not many years ago retaining walls were almost exclusively made of reinforced concrete, and were designed as gravity or cantilever walls. The cost of stability system increased rapidly when the subsoil's condition was deteriorating while the amount of soil on the slope was increasing. The slope stability system that was proposed in that paper regarding coal waste products from mine KWK Mysłowice-Wesoła located between geotextile and geogrid created reinforced soil retaining wall, (Figure. 1).

![Figure 1. The anthropogenic soil as waste product from coal mine KWK Mysłowice - Wesoła, Poland](image1)

A research has been conducted in order to broaden the understanding of processes that anthropogenic ground with geosynthetics undergoes when it is under the influence of strong internal and external forces. It’s objective is to use the available knowledge to build a number of various stabilization system models, with the idea of designing retaining wall of reinforced coal waste soil and to make those models both as simple as possible and as close as possible to the real (in situ) behaviour of this road slope stability characteristics [4], [7]. Reinforced soil techniques are very old subsoil improvement method applied for more than a thousand years. Different types of reinforcing materials have been used in various geotechnical constructions over the years. Nowadays, the modern reinforcement techniques provide durability, strength, and another complex approaches, such as sustainable waste management, which are presented in that paper.

2. The anthropogenic subsoil as the material used in creating retaining walls

The term "anthropogenic subsoil” covers the types of subsoil created by various human activities. Mainly those are types of soil that are created during industrial activities. This groups of anthropogenic subsoil include waste associated with the different sectors of the economy [1], [10].
Table 1. Geotechnical parameters of four representative anthropogenic soil groups

\[ \gamma \] - unit weight, \( w \) – water content, \( \rho_{ds} \) – dry density,
\( \phi \) - friction angle, \( c \) – cohesion (in short or long term conditions),
\( \nu \) - Poisson ratio, \( M \) – compressibility modules

|             | \( \gamma \)  | \( w \) | \( \rho_{ds} \) | \( \phi \) | \( \nu \) | \( c \)  | \( M_0 \)  | \( M \) |
|-------------|----------------|--------|----------------|----------|--------|--------|----------|--------|
| A-          | 20.00          | 12.50  | 2.15           | 38.50    |        | 22.50  | 78.200   | 121.300|
| B-          | 21.00          | 13.00  | 1.90           | 32.00    |        | 27.50  | 62.800   | 110.200|
| C-          | 18.80          | 15.00  | 2.00           | 48.40    |        | 21.00  | 96.700   | 200.000|
| D-          | 19.50          | 15.50  | 1.95           | 22.00    |        | 28.50  | 28.500   | 42.500 |

Figure 2. The anthropogenic soil (A and C) from mine KWK chosen for this project

Studies regarding the soil suggest that it can and is used during construction of objects such as railroads, dams, flood shafts and road embankments. The construction of gravity retaining walls is a cheaper alternative to those made of soil and concrete. In our case, the retaining wall is made with the use of the gabion - welded wire baskets filled with coal waste products from coal mine. This solution provides a simple technique of installation and assembling of individual elements of the structure, along with satisfactory aesthetic, economical and results [10]. On the pictures presents anthropogenic subsoil from mine chosen for this project, which has a very good shear strength parameters that were examined in our laboratory (Fig.2). Based on the results of laboratory tests analyses, four of the representative groups was chose, which geotechnical parameters such as unit weight and density, Atterberg’s limits, oedometer tests, isotropic consolidated drained compression, flexible wall permeameter and compressive strength test. For develop the calculation models total stress and effective stress analysis was made. They approximates performance of undrained saturated soil conditions under either relatively quick or typical construction loading scenarios and approximates effective stress parameters and field pore pressures under very slow loading conditions or soil performance at very shallow depths was done.

An additional advantage of this type of gravity retaining walls with gabion is that they allow water flow and as a result, it has no negative effect on the environment, leaving the soil with very good properties. Since the walls with gabion solution can be adapted to the individual requirements and needs, along with adaptation to a specific environmental conditions, in many cases they can be a crucial structure. The advantages of using the construction of gabions construction gravitational the fact that in such a case, the solution is more economical compared to the traditional construction of walls of concrete and reinforced concrete, construction does not require specialized technologies or huge experience in their construction, since they do not require special foundations to be made. In addition, the gabions are flexible and adapt to the subsidence of the ground and gabion walls are permeable to water and do not cause the formation of hydrostatic pressure forces.
3. Characteristics of subsoil and anthropogenic subsoil

Between the two towns of Myślenice and Pcim, which are in the south of Poland, a huge slope with residential buildings can be found. The difference between its heights compared to the nearby road S-7 is 15 meters. The distance in a straight horizontal line from buildings to new express road is very close - about 22,00 m. The road following the slope with a residential building, descends at an angle of 35° to the local road. (Fig. 3)

The results of the geological research show 4 geotechnical layers. Layer I is saclSi, they have a variable thickness, from 2,00 m up to 2,70 m at the base of the slope. Layer I is the base of the layer II – SM soft and solid rock and the thickness of this layer varies from 1.80 m around the building to the 1,60 m at the foot of the slope. Empirical formulas for estimating the penetration rate is very simple and is based upon empirical formulas that were developed from field tests. They usually take into account the parameters which one of this group is compressive strength which can easily be determined in laboratory test. Compressive strength $R_C$ this rock is less than or equal to 5.000,00 kPa.

Layer II is on Layer III - ST hard rock solid and $R_C$ this layer is approximately 10.000,00 kPa. All of the tested parameters separated layers of soil and material intended for the construction of the wall of resistance are shown in Table 2.

![Figure 3. Schematic cross section of localization the road slope along express road S-7](image)

| Parameter * | $\gamma$ [kN/m³] | $\phi$ [°] | $\nu$ [-] | $E$ [kPa] | $R_C$ [kPa] |
|-------------|-------------------|-----------|-----------|-----------|-------------|
| Layer I /saclSi/ | 19.50 | 15.00 | 0.3 | 30.000 | - |
| Layer II /SM/ | 23.00 | 15.00 | 0.3 | 500.000 | > 5.000 |
| Layer III /ST/ | 26.00 | 35.00 | 0.3 | 5.000.000 | 10.000 |
| Anthropogenic subsoil | 18.80 | 48.40 | 0.3 | 200.000 | - |

* / $E$ - Young’s modulus, $R_C$ - Compressive strength, $\gamma$ - unit weight, $\phi$ - friction angle, $\nu$ - Poisson’s ratio

The analyzed layers of the slope's soil are parallel to the ground below it, which creates a possibility of landslides. Analyzed slope plies arranged accordingly, parallel to the plane of the slopes of what might be the cause of potential landslides. The most likely area to slip to one of the layers and groundwater
parameters seems to be the surface of contact between Layer I and the ground rock, additionally charged by filtering down the groundwater. Because the geotechnical parameters of subsoil for that location was rather not very good and additional loads caused by the execution of construction works on the upgrading of the express road, some methods of slope stability had to be proposed. The most satisfying way to build earth retaining structures from the economic and environmental perspective is to use coal waste- anthropogenic soil as filling between layers of geosynthetics which is a solution to meet aesthetic, budget and environmental needs.

4. Numerical analysis for concept of geotechnical slope stability design

In regards to the numerous models of subsoil, advanced devices are used, capable of complex calculations needed for the construction with finite methods. FEM models software can become our indispensable calculation instrument but we need more information about foundation behaviour. Predicting reinforcement soil behaviour is difficult and requires application of sophisticated constitutive models incorporated into numerous procedures. In addition, it used to be difficult to separate forces influencing the soil and its response to them [3], [8], [16], [17].

Before a model can be adopted for general use it has to be verified using techniques known as verification. During the development phase a computational model is often modified and reformulated with higher accuracy. With each model component having a considerable influence on the outcome of testing, the development process was broken down into a number of stages. An ‘actual configuration’ is understood as a space containing a continuous medium and technical objects located within it. In this case this is ground with retaining wall and reinforcement material. Any theoretical investigation aiming to understand the behaviour of such ground medium under internal and external influences demands a mind-model complete with a set of formulae describing its properties, assumptions and simplifications, all of which together would constitute a mathematical or computational model. A mathematical model should be understood as a set of mathematical data describing the examined physical phenomenon with certain accuracy. Mathematical modelling is the formulation of the mathematical process description. Various mathematical models can be made for each examined object, depending on the adopted simplifications that make the object description easier, but also affect the accuracy of the solution. While a far-reaching simplification may lead to the omission of important features of the actual object overly complex mathematical model could lead to errors in the solution because of the overly complicated computational process. Normally, mathematical modelling employs partial differential equations. Digitisation of a continuous mathematical model involving the application of a numerical method leading to a system of algebraic equations (full digitisation), or ordinary differential equations, typically with time derivatives (partial digitisation) [10], [14]. Digital modelling of a discrete system involves a selection of a numeric algorithm to solve the equations of the discrete model, while numerical solving of the discrete equations of the model follows the adopted model-testing plan. Figure 4 shows a diagram of the analysis of the section with the original surface relief of the terrain. The length of the escarpment in the level is 21 m. Seeking the optimal geometry of resistance includes grading geometry, surface and slip the likely course of the distribution of external impacts on proposed construction. With the proposed total amount of H = 7.5 m obtained values were adjusted to optimize the solution. The structure is divided into two parts: the lower part, with the largest share in the prevention of landslide, in the wide cross-section of Lₙ = 6 m, with a width of the upper part of the Lₚ = 4 m. This these things are continuations of earlier publication [3], [4], [5], [7], [10]. When utilising FEM mechanics to complete the task, one has to develop a detailed (computational) model corresponding to a mathematical model of a continuous medium The process of building the model involves a number of steps, beginning with dividing the studied area V into subareas Ve – components; and adoption of nodal points so as to be able to approximate the function sought within the Vearea using approximation functions and independent nodal parameters. The following steps involve the determination of matrix structures describing the properties of a given model at each nodal point and working out matrixes for the entire system. Next comes the determination of boundary conditions and loading of the body followed by the solving of the basic
system of equations and computation of functions derived using the determined nodal parameters. Mathematical issues arising during model development and application often require a determination of state parameters \([5], [12]\). By setting restrictions to such mathematical issues they are transformed into numerical issues: computer models can be applied to determine their set points, as long as the mathematical relationships, equations, inequalities and numerical data are known. Numerous mathematics and numerical data processing covers designing, analysis and application of computer-aided problem solving A combination of a mathematical problems (of a constructive nature) and objectives pertaining to outcome accuracy are referred to as a numerical problem. If the forces available to resist movement are greater than the forces pushing the soil, the slope is considered stable. A safety factor is calculated by dividing the forces opposing the movement by the forces pushing the soil. The analysis is, in most cases, run for static conditions and pseudo-static conditions, where the seismic forces from an earthquake are assumed to add static loads to the analysis. This these things are continuations of earlier publication \([3], [4], [13]\). Soil nailing is an efficient, effective and economical method of ground reinforcement, which allows a controlled improvement of the natural stability of the soil. Soil nails provide friction, shear and tension strength in loose materials, combining all into a new monolithic structure. Soil nailing consists of three basic elements: the soil or weathered rock, rotary grouted, self-drilling soil nails and surface treatment with reinforced shotcrete, geotextile mesh or tensioned wire nets on slopes to 75 degrees \([7], [10], [11]\).

For example, selected for this project Titan soil nails are installed by simultaneous drilling and grouting, which enhances the diameter of the grout body and maximises shear value at the grout/ground interface. Correct design of the nail positioning grid across an embankment and soil nail lengths, results in a monolithic structure capable of supporting required loads, (Figure 4).

![Figure 4](image1.png)

**Figure 4.** Scheme of geotechnical slope stability construction from gravity wall, plastic polymer product and three rows of soil nails. Two reinforced slopes were the subject of numerical analyses by FEM.

Numerical models take into account two possible ways of creating of reinforcement: by beam elements and by truss elements. Attention has been focused on safety factor values determined in each
case. The numerical analyses were based on geological and geotechnical research results, as well as the documentation that was gathered and analysed [3], [6], [9]. Methods employed during numerical computation of factor of safety consisted of classic procedures based on the limit equilibrium theory, however deformation calculations and stress distribution in the subsoil of designed structures, were conducted with a use of modified Cam-Clay and Drucker-Prager which is very convenient from the point of view of numerical and technological efficiency. The main assumption for the adopted numerical model was made of using continuum medium and by accepting the elastoplastic character of materials and we accepted a plane strain model. The computer program Z_SOIL, which offers an attractive alternative to traditional approaches to geotechnical problems was used to solve one of problems of the main task [6], [9], [15], [18].

![Figure 5. Calculation model of FEM; SF - safety factor](image)

The method presented in the paper is quite simple because its main purpose is to be a simple, economic and ecological method of securing the slopes. Therefore, on the basis of the basic parameters of geotechnical and engineering and using a simple computational model received quite good results.

The computations results allowed introducing reinforcement of slope with gravity wall and three rows of soil nails, and drainage system of structures. As a result of the carried out analyses yielded the desired safety factor equal to 1.51 in Figure 5 shows the probable area of slip and deformation of slope in the event of loss of stability.

The surface of the slip is in this case is mainly on the border between the first and second geotechnical layers. On the deformation is still primarily the Summit slope, you can clearly see how the degradation of the ground will go if the load exceeds the carrying capacity of the nails. Design of resistance may be distorted. The safety coefficient of 1.51 indicates very small probability of landslides in the secured area of the slope. Researches, simulations and empirical experiment are closely related and none of these cognitive methods should be applied separately. A simulation, i.e. analytical or numerical solving of model equations, can generate full and credible results only if it is theoretically and empirically verified. In order to arrive at the best possible model of the actual system further testing is necessary to determine the impact of the various assumptions and simplifications adopted on the end result of the investigation, which should be followed by a selection of a
computational model that is both as simple as possible and provides results that are the nearest to real-life [2].

5. Conclusions
The concept of grading security provides support for its thrust wall made of reinforced land and strengthens its peak nails ground roads. A combination of two methods of stabilization due to the geological terrain, economic aspects and transferred the burden seems to be a hit. The proposed project will give you satisfactory results for both assessing the analytical method that is compatible with the guidelines of the PN-EN 1991-1 and-2, and using numerical analysis of FEM. An additional advantage is the use of concept presented as a design thrust of anthropogenic land, which is consistent with the objectives and sustainable spatial management. This clearly points to the possibility of using former coal mining waste in the design of geotechnical structures with good endurance characteristics, which in the light of new EU directives makes them sought - after solution on the market.

The results of monitoring gave some information which were used to check out the accepted numerical model. Safety coefficient of the numerical model slope stability construction from gravity wall and three rows of soil nails was about 18,582% bigger than the real of this subsoil located along the motorway bypass. In spite of assumed the results may be successful.

Another aspect which our paper touches upon involves to model better cooperation between construction elements and the soil, even though in soil mechanics, the material nonlinearity and its computer implementation in the finite element analysis have been treated in great efforts.

The cost of such security is less than 25% because of the wheel due to appropriate coal waste anthropogenic material to reinforcement this slope. This profit not take into account the value management of trash to the surface of the real estate and mining, where are mine heaps

On the basis of the carried out calculations and design variants presented solution is very economical and ecological. Information about time and cost that investor need to start build express road on the plot of land may be used for estimate real market value of plot of land with commercial use because only in the case when the cost of every reinforced works is known the residual method of estimate market value can be used. So the residual method is the most appropriate tool to estimate the value of an undeveloped land real estate taking into account the influence of its load-bearing capacity on the market value.

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