INFRASTRUKTURA I EKOLOGIA TERENÓW WIEJSKICH
INFRASTRUCTURE AND ECOLOGY OF RURAL AREAS

Nr IV/1/2014, POLSKA AKADEMIA NAUK, Oddział w Krakowie, s. 1089–1099
Komisja Technicznej Infrastruktury Wsi

DOI: http://dx.medra.org/10.14597/infraeco.2014.4.1.080

TEMPORARY MONITORING OF AREAS PRONE TO LANDSLIDES ILLUSTRATED WITH THE EXAMPLE OF THE KŁODNE VILLAGE

Paweł Ćwiąkała, Paweł Drwal, Monika Daroch, Paulina Grabek
AGH University of Science and Technology in Krakow

Summary

Mass wasting processes are very dangerous phenomena, mainly due to their unpredictability. Moreover, their tumultuous and rapid character has led to attempts of predicting the places of occurrence of such phenomena and to assess the possible threat. Unfortunately, it is not possible to monitor all potentially unstable areas, however, temporary monitoring of such areas, that are already activated, is legally required. Monitoring the area prone to mass movements is essential to assure the safety of its inhabitants and their possessions. The article presents the example of a surveying solution which was applied to monitor the landslide areas as well as their surroundings.

The subject of the research was the landslide that occurred within the area of the Carpatians flysch in the village of Kłodne. Its activation, disastrous in its effects, occurred in 2010 and was caused by an intense rainfall.

The first described stage of the research was the design and stabilisation of a control network. This resulted in the stabilisation of 68 points creating an observational network. The next stage, described in the article, was conducting two observational series using both satellite and classic measurement techniques. In the following part of the article, the results of the field measurements were discussed. The analysis of the results started with the calculation of coordinates of all points stabilised on the researched area in reference to the national spatial reference system. The calculations were made for each measurement series separately. After the conduction of works aimed at detecting fixed points in the created surveying network, a slight horizontal displacement of several points located in the landslide area has been noticed. The determined displacements slightly exceed the values of measurement errors. In order to verify the obtained results, it is necessary to conduct more measurement series

Key words: landslides, displacements monitoring, control networks

INTRODUCTION

Recently in Poland, the awareness of both people and public administration units related to the threats resulting from surface mass movements is raising. The example of this tendency is the creation of the Anti-Landslides Protection System (SOPO). It is also worth noticing that the issues related to defining such threats occur in the Environment Protection Law Act. The mentioned act also regulates the obligation to register the areas threatened by mass movements as well as the areas on which the movements have already occurred. The register should be prepared by the district governor. Moreover the land use planning and development act obliges the commune to concern the natural geological threats as well as the areas endangered with flood or landslides at the stage of preparing the study of conditions and trends in land use development of particular areas. The local zoning plan should define the boarders and methods of development for areas or objects that are under protection, determined on the basis of separate regulations, including both mining areas and ones threatened by floods or mass movement landslides. Another document is the regulation of the Minister of Environment from 20th June 2007 concerning the information related to the mass movement of soil. The regulation introduces the obligation to monitor the areas, in which the mass movement landslides have occurred. Such monitoring should be based on displacement measurements aimed at defining the speed and character of the occurring phenomenon. The above-mentioned regulation also defines the minimum frequency of surveying. It is recommended to conduct the surveys twice a year in March/April and September/October as well as every time after the occurrence of extreme natural phenomena that influence the increase of soil mass activity. The regulation obliges a person who performs the monitoring of landslide areas to observe the technical guidelines included in it. The area covered by the survey should include the objects located both within the landslide-influenced area and the neighbouring grounds. The appropriately conducted monitoring may help to define the occurrence of the real threat during the next soil destabilisation. The following study presents the subject matter of the beginning of the landslide monitoring after the mass movement activation. The conduction of survey with proper accuracy characteristics, within a short period of time and on a vast area requires properly adjusted surveying methods and equipment as well as the organisation of survey and integration of the surveying team. In the instruction issued by the National Geology Institute which describes the preparation of maps of landslides and areas threatened by mass movements in the 1:10000 scale, four phases of landslide areas monitoring were defined, namely: “The monitoring covers the following phases: the project phase, the field works and the system installation, the survey and the documentary phase” (Grabowski et al., 2008). All of the monitoring phases were described in the following study.

Figure. 1. The landslide niche and gully (author: Wróbel A.).

THE CHARACTERISTICS OF THE KŁODNE LANDSLIDE

The heavy rainfalls in May and June in 2010 caused disastrous floods and reactivation of the existing landslides and emergence of many new ones in the South of Poland. The analysed landslide is located in the Middle Carpathians in the area of Beskid Wyspowy in the village of Kłodne, the Limanowa commune. Its activation took place on 1st June 2010 and was caused by not only atmospheric conditions, but also by geological structure. The precipitation water which overburdened and saturated the ground significantly, created optimal conditions for the occurrence of slide plane on the layer of the magura slates (Kleczkowski, 1955). The landslide developed on the southern slope of the Kleń ridge. The displacement of the soil masses was relatively fast and rapid, although small cracks were noticed the day before the landslide (Wójcik et al., 2011). The area influenced by the movement is estimated to be of 50 ha. The scale of the phenomenon is best described by its span, that is the (approximately meridional) length of 1050 m and breadth that reaches 455 m in the maximum scope of the landslide (Fig. 1., Fig. 2).

The vertical span, that is the difference between the minimum and maximum height of the landslide is 184 m. The gradient of the landslide slope is 18°, whereas the azimuth of the descent direction is 185°. The height of the main slope is about 5 m, and its gradient measures about 50°. The length of the colluvium is respectively shorter than the length of the landslide that includes the area of the main slope. The meridional span of the area covered by the landslide material is 1030 m with the average gradient of about 12°. The height of the head of the landslide is slightly shorter than that of the main slope and measures 3 m. The thickness of the colluvium is estimated to measure about 30 m (Drwal et al., 2013).

Figure 2. The inter-landslide uplifts (author: A. Wróbel).

NETWORKS AND SURVEY TECHNOLOGIES IN THE AREAS INFLUENCED BY LANDSLIDES

The methods commonly used to landslides monitoring are classic surveying methods: tacheometric surveying, trigonometric levelling, precise levelling, precise GNSS positioning, photogrammetric surveying, surveying rosettes (Góral and Szewczyk, 2004; Sitek and Mierzwa, 1987; Gargula, Kwinta and Siejka, 2012; Szafarczyk, 2011). The new technologies ofdisplacement surveying such as laser scanning (Maciaszek and Ćwiąkała 2010) and radar interferometry (Szafarczyk, et al., 2013) are also worth noticing. The displacement surveying can also be conducted by means of geological methods, using the following devices: piezometers, inclinometers and feeler gauges. The precision characteristics of the mentioned surveying methods is very diverse. The possible errors in measuring horizontal displacements are about 2 – 5 mm. The elevation of the measured points can be defined with 1 mm accuracy. Landslides, as phenomena covering vast areas, require using the surface monitoring method and therefore angular-linear and linear networks, networks and singular traverses, modular networks and others may be used as measurement control networks.

THE DESIGN OF SURVEY CONTROL NETWORK AND THE DESCRIPTION OF SURVEY TECHNOLOGY

The design of the landslide measurement control network has to be individual and especially carefully adjusted to the specifics of the observed area. The location of points in the area is of extreme importance. In the discussed case it was done through the irregular location of points as well as through the local adjustment of groups of points to the area. The consecutive points in the designed traverses have to fulfil the condition of mutual visibility in order to allow the creation ofmeasurement network. Moreover, it was assumed that some points have to fulfil the requirements of the GNSS survey. The area of the landslide was divided into four parts and there was a different location of surveying points planned for each of the parts (Fig. 3).

The first part covered the area above the landslide niche. The aim of setting the measurement control network there was to monitor the areas located over the landslide slope which allows reacting in the situation of the slope destabilisation above the landslide niche. In this area, above the landslide, 6 points marked with 102-108 numbers were stabilised as well as 4 other points located to the north-east from the landslide, marked with 201-204 numbers. The landslide niche and gully make the second part of the landslide (fig. 1). This area is covered by numerous cracks, rifts, secondary slopes and other forms of the landscape features characteristic of landslides. For this part a network consisting of 13 surveying points (points 301-313) was designed. Furthermore, 4 additional points (901-904) were located on the inter-landslide uplifts (Fig. 2).The third part of the landslide is its bottom part. In this part 15 control points were located (points 504-512,514, 517-521). The points were designed in the way that renders the shape of the head of the landslide. In order to estimate the influence of the landslide in neighbouring areas, the so called foreland area was also defined. The stabilisation of observation points in these areas is aimed at checking the stability of region in the neighbouring areas. The areas are located at every side of the landslide. Ten points numbered: 401 – 405, 501-503 as well as 601 and 604 were stabilised to the west from the boarder of the landslide. Another network consisting of 10 points (602, 603, 605-612) was designed along the road below the landslide. 6 observation points (513, 515, 516, 522, 523, 613) were located to the east from the landslide.

The points were stabilised in the area in the form of metal bars with drilled centres. The length of the bars (100 or 50 cm) was selected in order to allow their complete hammering into the ground.

The concept of the surveys assumed the survey of some points by means of satellite techniques in order to create a reference for tacheometric surveys. 22 points, evenly located on the whole studied area, were chosen to the static GNSS technology survey. The points were marked on figure 3 by underlining their numbers. The survey was conducted by means of 5 Leica receivers (two System 1200 receivers and three System 500 receivers) during 7 surveying sessions. The observations on one of the points were taken during the whole time of the satellite surveys and were aimed at establishing the control network with reference to the ASG-EUPOS system.

The tacheometric survey consisted of observations from 29 stations. The observations were conducted by the Leica TCRA 1102+ total station by means of the three tripods method. In the bottom part of the landslide, a closed traverse was designed which included pairs of points with coordinates determined on the basis of satellite surveys. In the middle of the landslide the surveys were made from 4 points that created a surveying tetragon. From the node points of the tetragon, surveys were conducted to the rest of the points. Additionally, one of the node points was a starting point for the free traverse allowing the survey of the points located on the inter-landslide uplifts. In the upper part of the landslide, two groups of points were connected with each other by means of a survey basis, the ends of which were located on the stations of the instruments related to the particular group of points. The draft of the control network was presented on figure 3.

The reference of the surveys to the ASG-EUPOS system allows defining the absolute displacements occurring within the whole object. The accuracy of measuring the displacements by means of such solution is about 10 mm (Graszka et al., 2013). It is a favourable solution in case of more significant displacements of the landslide area as well as of the neighbouring areas. If there are no significant changes in the researched area, then the displacement analysis can be conducted on the basis of points located around the landslide. Such an analysis allows the increase of accuracy in determining the displacements of the points.

FIELD RESEARCH, CALCULATIONS AND ANALYSES

The surveys of the first two surveying series were discussed in the study. The first series called the initial survey was conducted on 17th and 18th May 2013. The second one, called the current survey was conducted from 3rd to 5th October 2013. The period of about half a year is a typical time for displacement surveys in landslide areas.

According to the data obtained during both surveying series, the coordinates of the points measured by means of satellite techniques were calculated for each series. Next, the rigorous adjustment of the tacheometric network was conducted. By these means, plane coordinates for both series were determined in the coordinate system PL-2000. The calculated mean errors of the plane coordinates in both cases did not exceed the level of 3 mm. In order to calculate the displacement of points, the obtained coordinates were compared. The comparison of the coordinates of points, calculated in relation to the ASG-EUPOS network did not allow determining points which were subject to displacement. Such a result indicates that no displacement exceeding the level of 10 mm occurred in the landslide.

Another stage was the analysis based on searching for mutually stable points in the studied area. In order to do that, a procedure called searching transformations was conducted (Lazzarini 1977; Prószyński, Kwaśniak, 2006) which allowed the identification of displacement points in the landslide area. The points were recognised as displacement when the calculated horizontal displacement exceeded the value of the mean error of horizontal displacement determination which was defined as 4 mm. As a result of calculations, significant, that is larger than surveying errors, horizontal displacements of the following points were determined: 106, 203, 301, 303, 305, 306, 309, 310, 311, 312, 313, 903, 502, 505, 507, 516, 518 and 607. The values of displacements of these points are slightly larger than the mean errors and range from 4 mm to 7 mm. In case of points 106, 203 (located over and to the east from the existing landslide) as well as points 301, 303, 305, 306, 309, 310, 311, 312, 313 and 903 (located in the upper part of the landslide) it can be assumed that the detected displacements are related to insignificant displacements of ground in the mentioned areas. The projection of the obtained horizontal displacements were shown on figure 4.

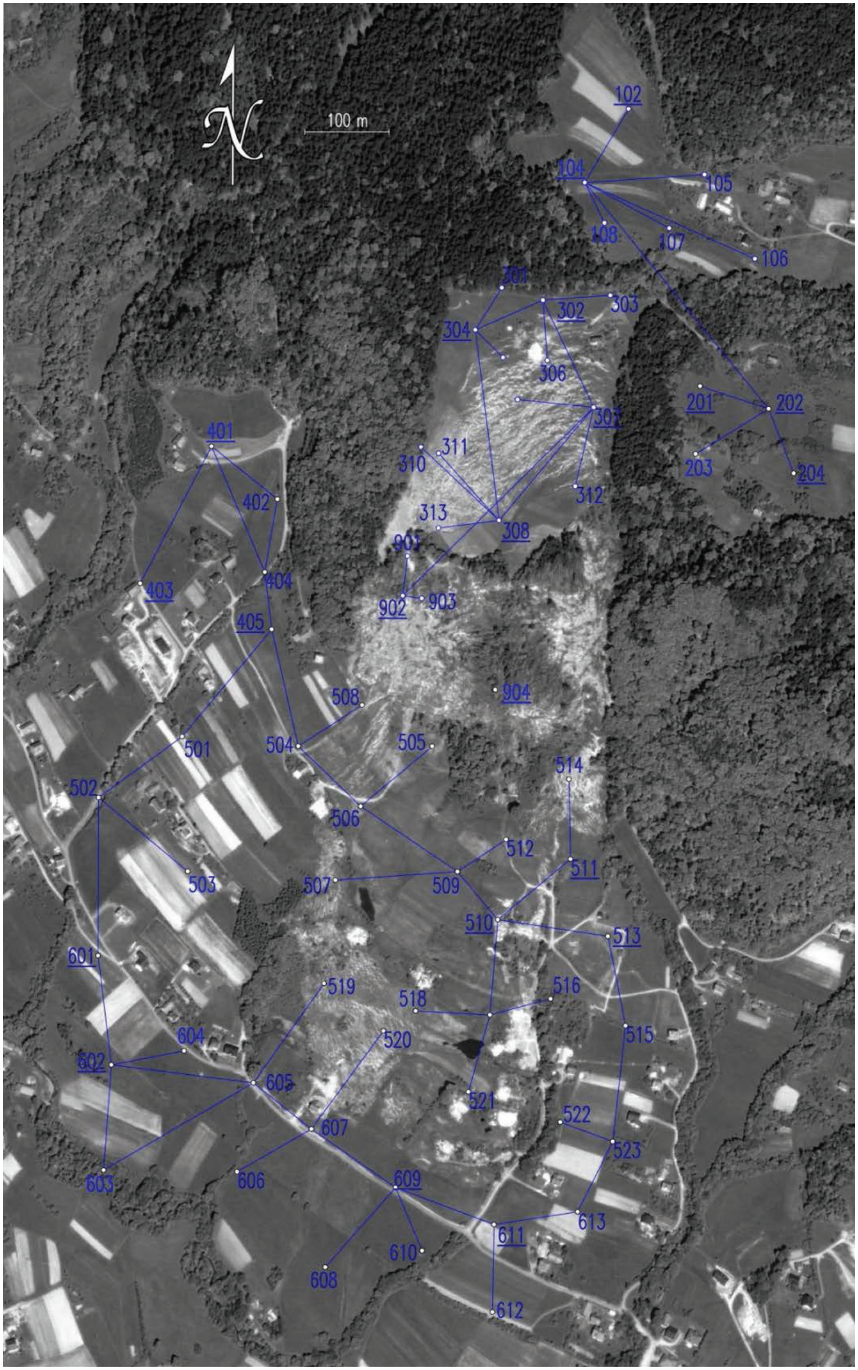

Figure 3. The draft of the measurement control network (https://maps.google.pl/).

In case of 502, 505, 507, 516, 517 and 607 points, the directions of the defined displacements are of chaotic character and should not be recognised as soil mass movements. Significant displacements of points 201, 202, 602 and 610 were also detected. Their values exceeded the level of 10 mm. The on-site inspection has proven that the displacements were the result of disturbance of points caused by human activity.

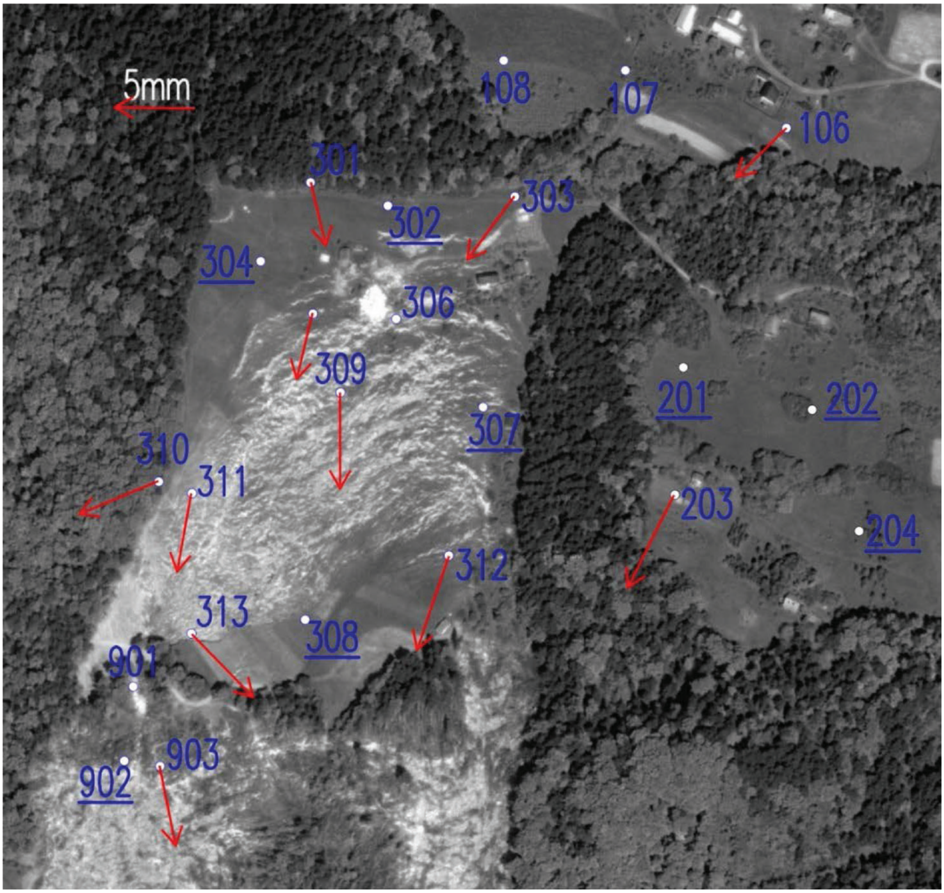

Figure 4. The sketch of vectors of points displacement in the upper part of the landslide(https://maps.google.pl/).

SUMMARY AND CONCLUSIONS

The character of displacements of rock masses in the Carpathians is diverse and influenced by many factors, such as geological structure of the ground, the conditions of movement activation as well as the depth and range of mass movements. Therefore, in the areas of various landslides, different surveying technologies are used to allow obtaining proper accuracy in defining the displacements, so that they render the character of the movement. The time-consumption of the process of data obtaining is also of significant importance. Each area endangered with the landslide movement requires individual approach in terms of the way of designing and setting the measurement control network as well as in case if surveying works conduction.

As the result of the analysis of the data obtained in the landslide area, insignificant movements of several stabilised points were detected. The determined displacements slightly exceed the value of surveying errors and equal from 4 mm to 7 mm. The displacement of points in the central part of the landslide may indicate insignificant movements of the area. The interpretation of the obtained results is difficult in this case and the conclusions will be verified by another surveying series.

The article was prepared with the support of the statutory fund of the Department of Engineering Surveying and Civil Engineering of the AGH University of Science and Technology in Krakow, number of research 11.11.150.005.

The article was written on the basis of the research conducted during the ‘Kłodne’ scientific project, prepared by the Dahlta Surveyors’ Scientific Club.

REFERENCES

Drwal P. i inni, Prace geologiczno – inżynierskie i geodezyjne na terenie osuwiska w Kłodnem. Sprawozdanie dla Wójta Gminy Limanowa, Kraków, 2013

Gargula, Tadeusz, Andrzej Kwinta i Zbigniew Siejka. Zastosowanie sieci modularnych zintegrowanych z pomiarami GPS do wyznaczenia przemieszczeń. Zeszyty Naukowe Politechniki Rzeszowskiej (2012): 95-107.

Góral, Władysław i Jacek Szewczyk. Zastosowanie technologii GPS w precyzyjnych pomiarach deformacji. Kraków: AGH, 2004.

Grabowski D., Marciniec P., Mrozek T., Nescieruk P., Rączkowski W., Wójcik A., Zimnal Z., Instrukcja opracowania Mapy osuwisk i terenów zagrożonych ruchami masowymi w skali 1:10000, PIG – PIB, Warszawa, 2008.

Graszka W., Oruba A., Ryczywolski M., Wajda Sz., Poradnik użytkownika systemu ASG-EUPOS, wydanie 2 poprawione, Główny Urząd Geodezji i Kartografii, Warszawa, 2013.

Kleczkowski, Antoni. Osuwiska i zjawiska pokrewne. Warszawa: Wydawnictwa Geologiczne, 1955.

Maciaszek J., Ćwiąkała P., Badania możliwości zastosowania skanowania laserowego do monitoringu osuwisk zboczy wyrobisk odkrywkowych na przykładzie KWB „Bełchatów” (Laser scanning application for monitoring landslides and dislocations in open castmines – the “Bełchatów” Lignite Mine example), Przegląd Górniczy t. 66 nr 6 s. 52–57, 2010, ISSN 0033-216X.

Lazzarini T., Geodezyjne pomiary przemieszczeń budowli i ich otoczenia, Państwowe Przedsiębiorstwo Wydawnictw Kartograficznych, Warszawa, 1977.

Prószyński W., Kwaśniak M., Podstawy geodezyjnego wyznaczania przemieszczeń. Pojęcia i elementy metodyki. Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2006

Rozporządzenie Ministra Spraw Wewnętrznych i Administracji z dnia 9 listopada 2011 r. w sprawie standardów technicznych wykonywania geodezyjnych pomiarów sytuacyjnych i wysokościowych oraz opracowywania i przekazywania wyników tych pomiarów do państwowego zasobu geodezyjnego i kartograficznego (dz. U. 2011, Nr 263, poz.1572).

Rozporządzenie Ministra Środowiska z dnia 20 czerwca 2007 r. w sprawie informacji dotyczących ruchów masowych ziemi (dz. U.2007, N 121, poz. 840).

Sitek, Zbigniew i Władysław Mierzwa. Fotogrametria w górnictwie – możliwości, stan aktualny, prespektywy. Kraków: Zeszyty naukowe AGH Geodezja, 1987.

Szafarczyk, Anna. „Geodezyjne metody monitoringu osuwisk.” Infrastruktura i ekologia terenów wiejskich 2011: 293-300.

Szafarczyk A., Rybicki S., Woźniak H., Lenda G., Kaczmarczyk R., Ligas M., Krokoszyński P., Gawałkiewicz R., Tchórzewska S., Szymanowski R. Badania kinematyki powierzchniowych ruchów masowych z wykorzystaniem naziemnej interferometrii radarowej (Study of the kinematics of surface mass movements using ground-based radar interferometry), Wydawnictwa AGH, Kraków 2013, ISBN: 978-83-7464-648-2

Ustawa z dnia 27 kwietnia 2001 r. Prawo ochrony środowiska (Dz. U. 2001, Nr 62, poz. 627, z późniejszymi zmianami).

Ustawa z dnia 27 marca 2003 r. o planowaniu i zagospodarowaniu przestrzennym (Dz. U. 2003, Nr 80, poz. 840).

Wójcik, Antoni, i inni. „Zastosowanie danych teledetekcji lotniczej i satelitarnej do badania dynamiki czynnych osuwisk w 2010 roku na przykładzie osuwiska w Kłodnem koło Limanowej.” Współczesne technologie w świetle zabezpieczenia infrastruktury drogowej przed klęskami żywiołowymi. Zakopane, 2011. 111-120.

Paweł Ćwiąkała (pawelcwi@agh.edu.pl)
Paweł Drwal (pdrwal@student.agh.edu.pl)
Monika Daroch (monika.468@onet.eu)
Paulina Grabek (grabek.paulina@gmail.com)
Faculty of Mining Surveying and Environmental Engineering
AGH University of Science and Technology