ASSESSMENT OF CLIFF STABILITY AFTER THE DEMOLITION OF THE ENGINEERING FACILITIES

Artur Janowski[1]

Agnieszka Jurkowska[2]

Dawid Lewczuk[3]

Jakub Szulwic[2]

Aleksandra Zaradny[3]

[1] University of Warmia and Mazury, Faculty of Geodesy and Land Management, Institute of Geodesy, Olsztyn, **Poland**
[2] Gdansk University of Technology, Faculty of Civil and Environmental Engineering, Department of Geodesy, Gdansk, **Poland**
[3] Gdansk University of Technology, Faculty of Civil and Environmental Engineering, Department of Geodesy, Geodetic Circle Hevelius, Gdansk, **Poland**

ABSTRACT

As a part of an experiment, cliff in Gdynia Redlowo (southern coast of Baltic Sea, Gdansk Bay) was measured using terrestrial laser scanner. The main reason for taking up the subject of the Orlowo Cliff's stability was a decision about controlled removal one of the war fortification elements. The main purpose of that analysis was to specify suitability of laser scanning in determination of slope's stability after a violent event.

Location of the bunker and the cliff's condition was in danger of slumping the construction onto a narrow beach. To prevent the collapse a part of war fortifications, built during "Cold War" (50's, XX century), had to be demolished and dumped from the top of the cliff. Considering a huge weight of a building, its localization and concern about safety of construction company team, the massive structure made of steel-reinforced concrete had to be demolished using other methods than traditional ones. Despite of knocking the bunker down under supervision of construction company team, taking into consideration the weight and size of the structure, it was obvious that not only degradation of the cliff could exist but also disarrangement of its structure. Due to the above-mentioned reasons, it was assumed that survey of cliff's geometry before and after bunker demolition is indispensable.

Object registration, accomplished by ground-based laser scanner, were carried out in close vicinity of the shoreline on the toe of cliff. Two series of measurement works were performed with the co-operation of Geodetic Circle Hevelius (Gdansk University of Technology) and companies (including producer of laser scanner). Within the article, comparison of two registration series were presented. It was also assumed that there is possibility of further repetition of surveys.

As a result of work in software Leica Cyclone, MeshLab, Bentley Points and the authorial one, charts of the cliff were prepared. On the basis of received data, ground movements were specified. The localization of potential landslide was ascertained and the quick method of identification areas prone to erosion was indicated.

Keywords: slope stability, sea cliff stability, terrestrial laser scanning, measurement of ground movements

INTRODUCTION

The problem of cliffs' stability analysis is widely studied in the literature [1-4], particularly with regard to the safety and protection of coastal areas. In the instance which is mentioned in this paper, the terrestrial laser scanning connected with GNSS surveys (Global Navigation Satellite System, in particular GPS-NAVSTAR: Global Positioning System - NAVigation Signal Timing And Ranging) was selected. The method's choice was made due to its advantages: quick data collection, accurate representation of the physical terrain situation, simplicity and availability of the method. In order to simplify the measurements and method optimization, the following decisions have been taken. The results of laser scanning from two observation epochs were used but the georeference between them were limited to the binding of point clouds instead of reference to the GPS positioning of stations of scanner and field points. Exclusion of satellite measurements was also intended to provide method that can be successfully implemented in a confined space, at the field exhibition with limited accession to the GNSS signal, due to a satellite constellation or urban development [5-7].

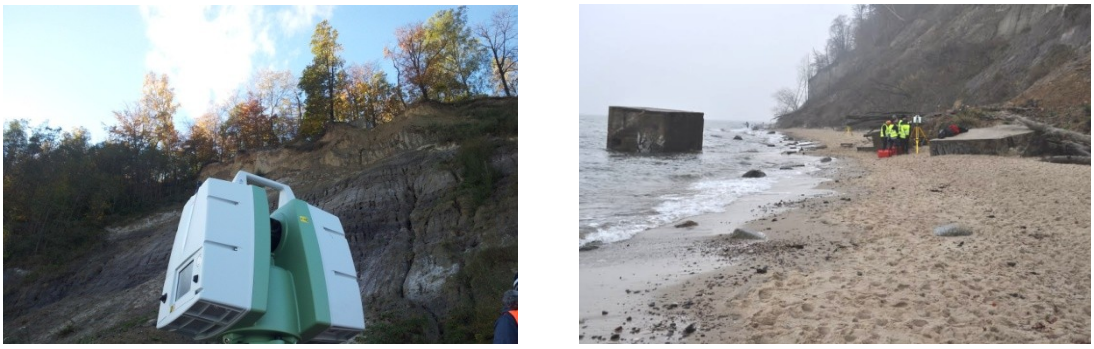
The aim of the work was to evaluate the stability of the cliff and the calculation of the displaced soil mass quantity. In the article, the method of analysis data was indicated. The conception was based on evaluation of cross-sections, which were collected from vertical sectors of the explored slope. The method was presented in comparison to differential tactics, referred to slope surfaces. As an examination object, the appropriate slope was chosen, i.e. the one where major, well known (Scanning and GNSS) changes had appeared.

As a part of an analytical process, in order to prepare data, some scan-cleaning techniques were used to eliminate noises and unwanted elements (e.g. vegetation). However, that problem is not a subject of this article.

DESCRIPTION OF THE EXPERIMENT

The survey was performed in the immediate vicinity of the Gdansk Bay shore, on the Orlowo Headland (southern coast of the Baltic Sea). Previous researches into the Orlowo Cliff have shown intensive abrasion of this part of the cliff (Redlowska Clump). In the result of rapid regression (1 meter per year) [8] the bunker on the top of the cliff started to be in danger of slumping onto a narrow beach. To prevent the collapse, a part of war fortifications, which were built during "Cold War" (50's, XX century), had to be demolished and dumped into the gulf. It could be interesting to observe how demolished structure, left at the cost, will improve cliff's protection as an element of a breakwater and will affect on land recession reduction bay. Considering a huge weight of a building (c. about 50 tons), its localization (c. 40m above sea level) and concern about safety of construction company team, the massive structure made of steel-reinforced concrete had to be demolished using other methods than traditional ones. Simultaneously, it could be interesting to observe if demolished structure, left at the cost, will improve cliff's protection as an element of a breakwater and will affect on land recession reduction.

Construction works consisted in undermining the bunker and poling the body of building (along with the foundation) with hydraulic cylinders. While rolling down, bunker had a forceful contact with the slope, so it was most likely that the stability of the cliff's top layer can be breached. There was also no assurance that the load of the upper part of the cliff (edge) during demolition work did not disturb the local stability of the soil.



A B

Fig. 1. View onto the cliff before slumping bunker (A); view of bunker at the coast of Gdansk Bay (B)

Recording was carried out during two sessions of measurement (28-10-2012 and 27-11-2012) with the use of Leica Geosystems terrestrial scanner - C10. Therefore, because of the public safety, it was necessary to process data and to analyze the slopes geometry immediately. After completion of measurements, the procedure of modelling was performed in Leica Cyclone. Using standard technique, connection point clouds (scanning) with the use of coordinates of targets (GNSS), the primary assessment of the cliff was performed. The preliminary evaluation had shown cliff's stability, so threat to public safety was eliminated. Within the frames of method development and proposal to limit the work exclusively to the scanning measurements. It was decided to abandon GNSS references and calculate data in the local coordinate system. Combining datasets from terrestrial scanning was made using the “cloud to cloud” technique. Filtration and noise reduction methods were carried out on the raw dataset. Office works were performed in 2013 and 2014.

On account of the military monuments located in Redlowska Clump and the pace of the land regression on this segment of the Gdansk Bay coastline, further monitoring measurements are indicated.

ANALYSIS AND NUMERIC VERIFICATION

Basically, the analytical problem boils down to the application of filtration and data segmentation methods that will allow finding this part of the measurement (in the dense point cloud) which relates directly to the coordinates identified on the ground. Measurement accuracy is dependent on the angle of incidence of the laser beam on the surface and the scanning resolution. Accuracy significantly decreases with the increasing of the scanned surface’s complexities. These restrictions were taken into account and allowed to obtain recording with the superfluous coverage.

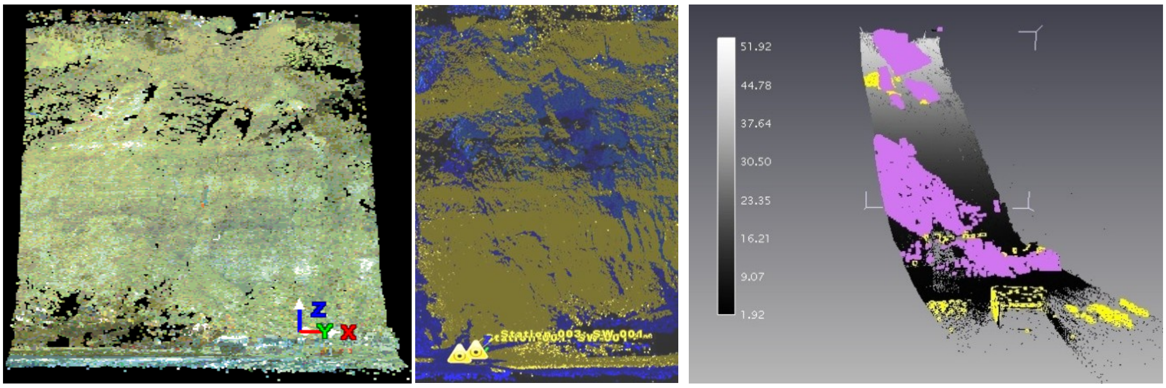
The problem was also the accuracy of combining point clouds from measurements which were realized in two different epochs. The obtained results showed that the links are sufficiently accurate and can be used to analyze the stability of the cliff. The results are summarized in Tab. 1. Notation of values of RMS, AVG, MIN, MAX is congruous with data that were generated in the Cyclone software report. However, it should not be considered, that the number of decimal digits shows the achievable accuracy. Nevertheless, it was decided to provide the notation according to the scheme presented in the software.

Tab. 1. Assessment of the geometry recording accuracy in first, second and combined measurement epochs

1st measurement epoch [epoka_1]	2nd measurement epoch [epoka_2]	Combined measurement epochs [epoka_1] + [epoka_2]
Mean Absolute Error:	Mean Absolute Error:	Mean Absolute Error:
for Enabled Constraints	for Enabled Constraints	for Enabled Constraints
= 0.002 m	= 0.000 m	= 0.001 m
ScanWorlds	ScanWorlds	ScanWorlds
Station-001: SW-001 (Leveled)	Station-003: SW-001 (Leveled)	ScanWorld [epoka_2] (Leveled)
Station-002: SW-001 (Leveled)	Station-004: SW-001 (Leveled)	ScanWorld [epoka_1] (Leveled)
Objective Function Value:	Objective Function Value:	Objective Function Value:
9.46962e-005 m^2	1.03827e-004 m^2	3.05678e-004 m^2
Iterations: 69	Iterations: 46	Iterations: 23
Overlap Point Count: 222533	Overlap Point Count: 92766	Overlap Point Count: 409166
Overlap Error Statistics	Overlap Error Statistics	Overlap Error Statistics
RMS: 0.0149198 m	RMS: 0.0150779 m	RMS: 0.0255162 m
AVG: 0.00930677 m	AVG: 0.00915895 m	AVG: 0.0171919 m
MIN: 2.70381e-006 m	MIN: 3.44078e-006 m	MIN: 3.84031e-007 m
MAX: 0.0961762 m	MAX: 0.093282 m	MAX: 0.0993905 m

The area exposed to damage (Fig. 2) and the surrounding, an intact area (used to link the measurement periods) were objects of the scanning. The aim of choosing of non-georeferencing method was checking the possibility of its application during an emergency situation (e.g. sudden threat of ground stability loss), when there is no possibility to use GPS technology for direct measurements or establishment of a network.

There are some practical and numerical flaws while using classical analysis to surfaces comparison, mostly performed on TIN (triangulated irregular network) or GRID models. From the practical point of view, geological cliff or slope analysis are needed to indicate damaging or destabilizing mechanisms. Difficulties arise, during comparison of slopes which are exposed to water erosion or covered with vegetation layer (Fig. 3). In the case of periodic variation of erosion grooves, the changes can be received from the comparative analysis performed on the TIN or GRID models. However, sometimes-especially in unstable or liquefied slopes, information about changing position of the furrows is not as important as the general characteristics of the slope in a narrow, indicated by specialists strip, where accumulation or landslides occurred. Local changes may reduce legibility of information: actual slope instability may be unnoticed or unreal instability can be demonstrated. Other cause of possible misinterpretation can be a layer of vegetation, which should be removed by a filtration process [9-13]. Computational geometry problems, especially performed on DTM (Digital Terrain Model) based on TIN model, which was created directly from a point cloud, are more difficult issue. With increasing scan's density numerical problems concerning the implementation of the basic assumptions algorithms (e.g. restrictions on the Delaney's triangulation execution) appear. It should be noticed that there are always some local density variations related to direction of recorded surface's exposure. Finding proper solution is difficult due to the numerical errors related with scanning specification: close or duplicate points, scanning errors bigger than the distance between points in the mesh grid, etc. In addition, we must remember that scanning directs calculations and analysis on the "big datasets", which require specific software and powerful computers.



A B C

Fig. 2. Visualization of the cliff from the Gdansk Bay side. A: natural colours, B: differences in the cliff's geometry with areas comparison C: differences in the cliff's geometry greater than 0.10m

Fig. 3. Erosional structures produced by water and vegetation layer on the cliff in Gdynia Redlowo

Therefore, the authors' proposal is to apply analysis using the cross-sections. Cross-sections used in the method are not restricted to the intersection of cliff plane with the secant planes. The procedure is based on the analysis of the indicated and separated slope's surface and bringing it into a two-dimensional graph. It should be noted that two-dimensional graph gives human perception better opportunity to assess changes. Moreover, obtained numerical can be computed with simpler algorithms and used in geotechnical analyses.

In the analyses of changes in the slope's geometry, the authorial software was used.

From point cloud, the cliff surface (from the part of interest) was obtained.

In order to perform computing, the strip width of 2.5m was selected. The area included the whole slope, from the toe to the top of the cliff and was extracted from 2 epochs. The strip where taken along the biggest descent of the slope (according to the water and landslides gravity flows). Analyzed example consisted dataset with c.17 millions of points from each observation epoch. This required an algorithm dedicated to calculations on huge dataset (data mining).

Analysis of the cliff's geometry from datasets, obtained from terrestrial scanning, aggregates data occurring in vertical exploration window (blocks). The location of the window is perpendicular to the cross- section direction and the parameters are width and depth. Moving from the toe of slope, towards X-axis (cross-section direction), with specified increment (e.g. 1 cm), the characteristics of height (H), for every point in the profile, are calculated. Computing of the characteristic is performed as arithmetic mean of height from all point in defined window.

The selection of the step size and the search window's width and depth (w-width and d-depth in Fig. 4) depend on the shape and slope's cant. Proper selection of those parameters helps reduce the density of the resulting graph and the amount of the final data. The results of such analyses, for the 2.5m sector at combined observation periods and depth increments 0.1m, 2.5m and 1.3m., are shown in Fig. 5.

The Fig. 6 shows the result of a curve approximation by polynomial (1) of 16 degree (n=16) for the dataset obtained from the slopes analyses (slope width 2.5m and 0.1m)

$$H(x) = p_1 x^n + p_2 x^{n-1} + \ldots + p_n x + p_{n+1} \qquad (1)$$

In the event that polynomial of high degree is used, majority of coefficients of the highest indexes of power are close to zero. Rejection mentioned coefficients and acceptance of lower rank polynomial cannot be established, because of the deterioration of fitting a polynomial. When the polynomial of 16 degree was used, the fitting error did not exceed 0.04m.

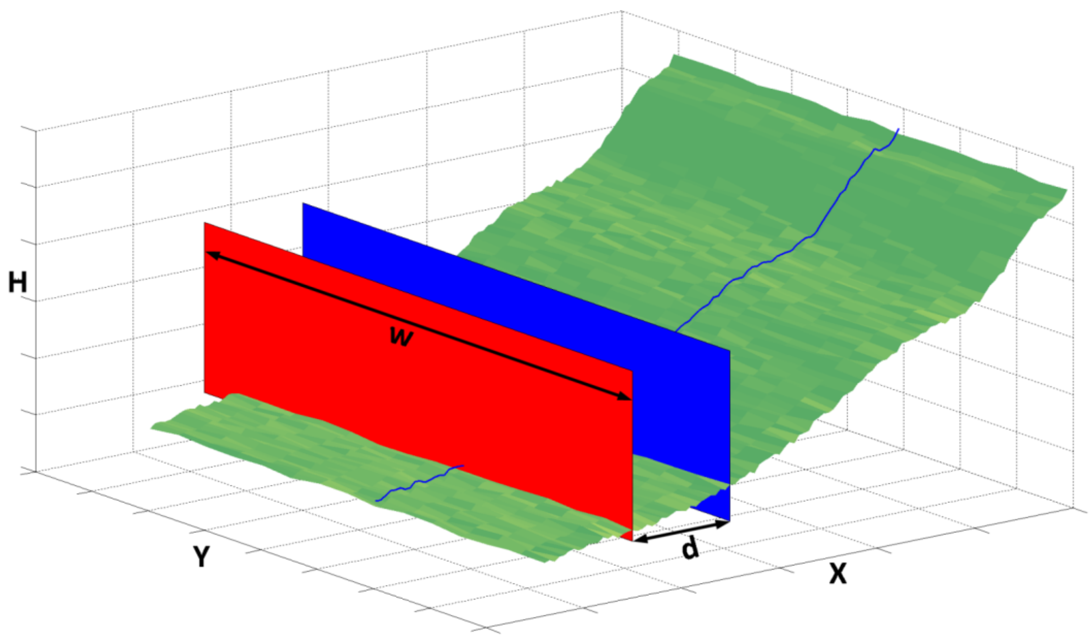


Fig. 4. The exploration window - principle of operation

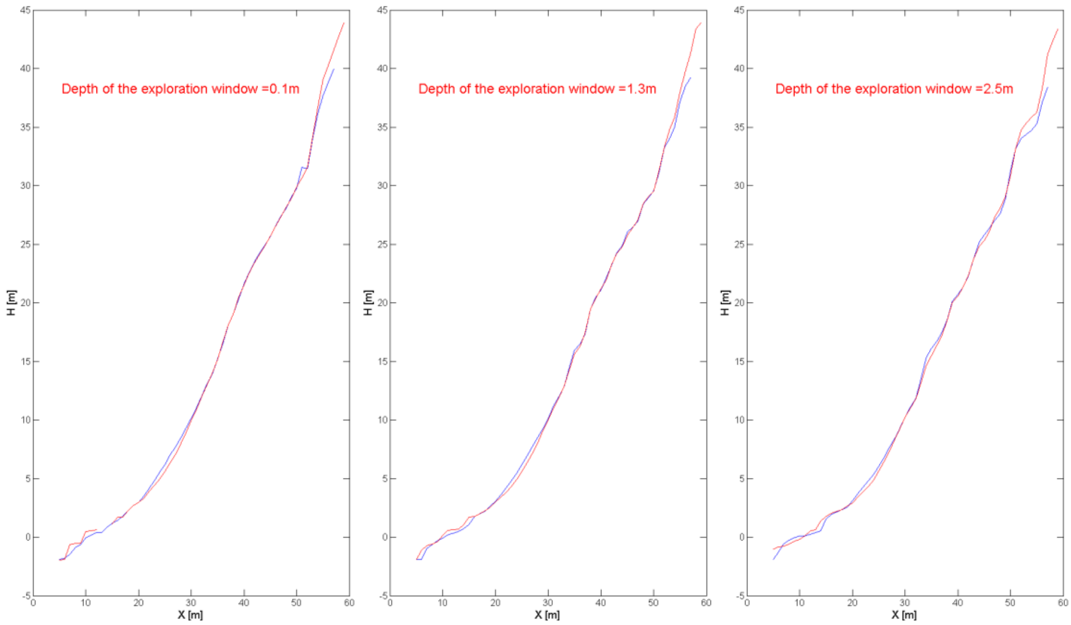


Fig. 5. Charts of the comparison of slopes geometry at 1st and 2nd epoch

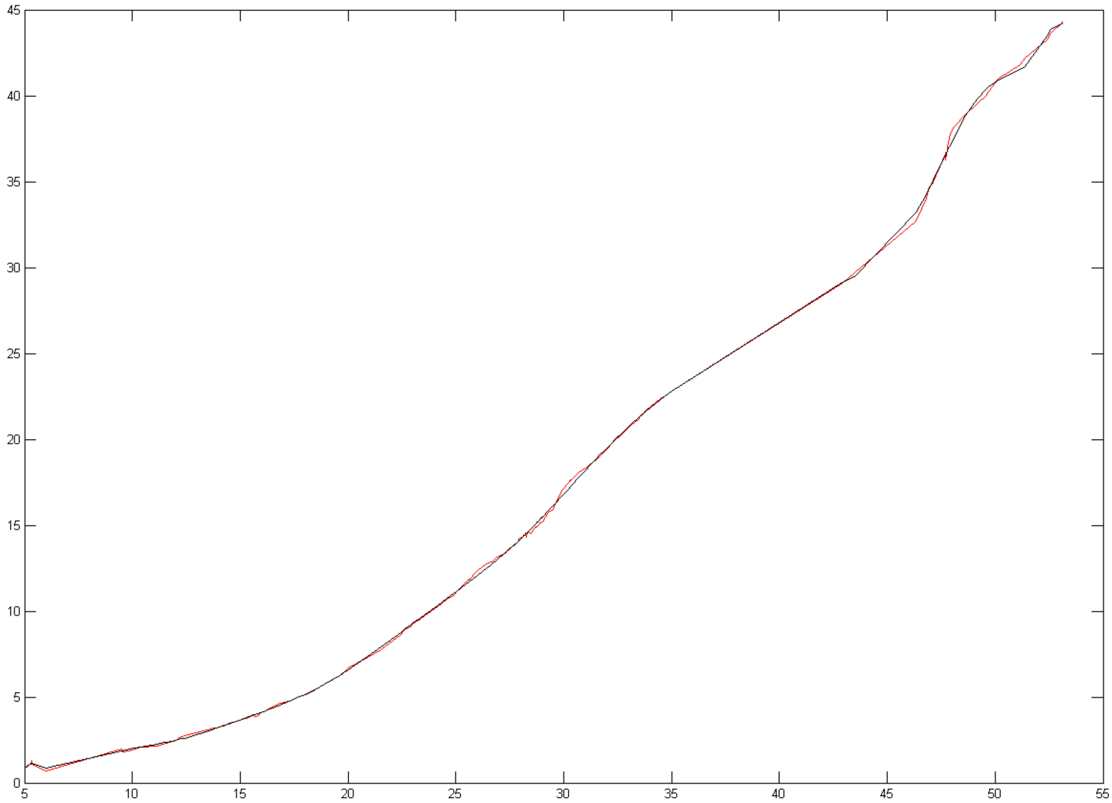


Fig. 6. Approximation by polynomial of a high degree (n^{16})

CONCLUSIONS

The largest deformation of cliff surface and displacement of ground masses was observed in the area of immediate impact of the object which was rolling down the surface. Thanks to the comparison of scans from two measurement epochs and their combining in the common coordinates system, it was possible to assess changes on the cliff and to indicate areas menaced with landslide. In the content, in Fig. 2 it is shown an example of a comparative analyses. It should be noted that the use of tools (such as e.g.) Leica Cyclone, Bentley Point and MeshLab allow performing analyses of the volume of soil mass and the analysis of surface changeability.

As a part of numerical analyses, usefulness of method that assume abjuration of the direct slope surface comparison, was pointed. The numerical method of analysis of point cloud and its further processing into two-dimensional data, was indicated. It is particularly significant due to huge amount of data connected with scanning surveys.

As a result of the experiment it has been confirmed that terrestrial laser scanning method is currently one of the most effective methods to study the stability of cliffs, slopes and mountainsides. Similar results are obtained using photogrammetric techniques [14] in conjunction with a synchronous photographs [15]. When measuring the slopes it is required to pay attention to the possibility of implementing a non-invasive measurement method and the measurement points should be selected in an objective manner (i.e. not partial). The method of laser scanning provides these features. The disadvantage of scanning is the recording of the vegetation layer. The use of filtration method seems at this point to be the best solution, despite the actual depletion of the number of points that characterize the slope. The degree of slope overgrow with vegetation has the extraordinary importance and in case of surfaces covered with a layer of vegetation that completely restricts access to land, the method of laser scanning cannot be considered as acceptable. Its usage for cliffs, especially subjected to abrasion process that discovers solid rock or soil is an effective solution.

REFERENCES

[1] Abellán A., Oppikofer T., Jaboyedoff M., Rosser N. J., Lim, M., Lato, M. J.: Terrestrial laser scanning of rock slope instabilities. Earth Surface Processes and Landforms, 39(1), 80-97 (2014)

[2] Slob, S., Hack, R.: 3D terrestrial laser scanning as a new field measurement and monitoring technique. In: Engineering Geology for Infrastructure Planning in Europe. Springer Berlin Heidelberg, p. 179-189 (2004)

[3] Rosser, N. J., Petley, D. N., Lim, M., Dunning, S. A., & Allison, R. J.: Terrestrial laser scanning for monitoring the process of hard rock coastal cliff erosion. Quarterly Journal of Engineering Geology and Hydrogeology, 38.4: 363-37 (2005)

[4] Vezočnik R., Ambrožič T., Sterle O., Bilban G., Pfeifer N., Stopar B.: Use of terrestrial laser scanning technology for long term high precision deformation monitoring. Sensors, 9(12), 9873-9895 (2009)

[5] Janowski, A., Nowak, A., Przyborski, M., Szulwic, J.: Mobile indicators in GIS and GPS positioning accuracy in cities. Proceedings of Joint Rough Set Symposium (RSEISP 2014). Granada-Madrid, Spain (2014)

[6] Specht, C., Koc, W., Nowak, A., Szulwic, J., Szmagliński, J., Skóra, M., Specht, M., Czapnik, M.: Availability of phase solutions of GPS / GLONASS during the geodesic inventory of railways – on the example of tram lines in Gdańsk, Rail Transport Technique TTS, vol. 01/2012, pp. 3441-3451 (2012)

[7] Stateczny, A., Kazimierski, W.: A comparison of the target tracking in marine navigational radars by means of GRNN filter and numerical filter. 2008 IEEE Radar Conference, vols. 1-4. Book Series: IEEE Radar Conference, pp. 1994-1997. Rome, Italy (2008)

[8] Mielczarski A.: Photogrammetric analysis of the images of ancient sea shore and its application to the study of variation Redlowski Promontory (Polish: Fotogrametryczna analiza dawnych zdjęć morskiego brzegu oraz jej zastosowanie do badań zmienności Redłowskiego Cypla). Florek W. (Ed.), Geology and geomorphology Embankment and the southern Baltic Sea. Słupsk, Poland: 145–164 (2000)

[9] Błaszczak-Bąk, W., Janowski, A., Kamiński, W., Rapiński, J.: Optimization algorithm and filtration using the adaptive TIN model at the stage of initial processing of the ALS point cloud. Canadian Journal of Remote Sensing, 37(6), 583-589 (2012)

[10] Brodu N, Lague D.: 3D terrestrial LiDAR data classification of complex natural scenes using a multi-scale dimensionality criterion: applications in geomorphology. ISPRS Journal of Photogrammetry and Remote Sensing 68: 121–134 (2012)

[11] Janowski, A., Rapinski, J.:M-Split Estimation in Laser Scanning Data Modeling. Journal of the Indian Society of Remote Sensing 41: 15-19 (2013)

[12] Ingensand H.: Metrological aspects in terrestrial laser-scanning technology. In Proceedings of the 3rd IAG/12th FIG Symposium, Baden, Austria / Lichti DD. 2007. Error modelling calibration and analysis of an AM-CW terrestrial laser scanner system. ISPRS Journal of Photogrammetry and Remote Sensing 61(5): 307–324 (2006)

[13] Voegtle T, Schwab I, Landes T.: Influences of different materials on the measurement of a Terrestrial Laser Scanner (TLS). In Proceedings of the XXI Congress, The International Society for Photogrammetry and Remote Sensing, ISPRS2008, Vol XXXVII, Commission V, 3–11 July 2008, Beijing, China; 1061–1066. (2008)

[14] Lim, M., Petley, D. N., Rosser, N. J., Allison, R. J., Long, A. J., Pybus, D.: Combined digital photogrammetry and time-of-flight laser scanning for monitoring cliff evolution. The Photogrammetric Record, 20(110), 109-129 (2005)

[15] Janowski A., Szulwic J.: Synchronic digital stereophotography and photogrammetric analyses in monitoring the flow of liquids in open channels. International Conference “Environmental Engineering” (9th ICEE), Vilnius Gediminas Technical University, Lithuania (2014)