CONCEPT OF MONITORING OF CLIFF SHORES

Czesław Suchocki
Technical University of Koszalin
e-mail: suchocki@wbiis.tu.koszalin.pl

1. INTRODUCTION

Cliff shores are those objects which due to their dynamics should be subject to periodic measurements in order to determine their displacement. These measurements need to be cyclically performed in an established time interval according to specific criteria. In this article, the methodology developed to monitor cliff shores is presented, which defines the rules to carry out measurements and the manner of data processing aimed at building the Digital Cliff Model. A number of partial investigations, whose results were published in the studies by (Suchocki et al. 2008, Suchocki 2009a, Suchocki 2009b, Suchocki and Wasilewski 2009a, Suchocki and Wasilewski 2009b, Suchocki 2010, Suchocki and Wasilewski 2010) were performed to develop this methodology. This paper constitutes a summary of several years’ research, whose effect is an extensive methodology developed to monitor cliff shores with an application of terrestrial laser scanning technology.

2. OBJECT UNDER EXAMINATION AND ITS MEASUREMENTS

The research which aimed at drawing up a methodology to monitor cliff shores was carried out on a real object, i.e. a coastal cliff situated in the vicinity of Pleśna place. Within the framework of these investigations, testing measurements of the condition of the object monitored were performed three times in annual intervals in the years of 2006-2008. In these measurements, a GPT-8203A SCAN scanning tachometer manufactured by Topcon company was used, which was automated by means of a TPS1201 tachometer manufactured by Leica Geosystem company and a ScanStation 2 terrestrial laser scanner of Leica Geosystem company. The application of the different types of instruments was meant to indicate the disadvantages and advantages of terrestrial laser scanners and scanning tachometers in the measurements of cliff shores.
3. METHODOLOGY OF MONITORING OF CLIFF SHORES

The developed methodology to monitor cliff shores provides answers to two following fundamental questions:

- in what way are periodic observations to be performed of cliff shores with the use of scanning instruments in order to register the diversified cliff surface?
- and in what way is the measuring data to be processed in order to build the Digital Cliff Model with the expected (one-decimeter) accuracy to make spatial analyses which permit to determine the rate of those changes which occur on cliff shores?

3.1. SURVEYING NETWORK

Due to the fact that active cliff shores are geotechnical objects with significant dynamics of changes in the object itself and also its environment, the stabilization of the points of the control network (i.e. reference points) on the object itself and in its immediate neighborhood (i.e. the beach) is not justified. In view of this fact, it seems to be the most reasonable to determine the situation of the points of the surveying network before every measurement directly on a beach, or if this is possible and it does not endanger our safety, on the object monitored at the foot of the cliff or even on its top. These points could be used once only during the current control measurement of the cliff shore.

The application of satellite techniques is the best solution to determine the points of the surveying network. For this purpose, the situation of several points which are treated as reference points should be determined by means of a static method outside the object under examination in a place where there are no covers of the celestial sphere. These points will also be used as reference points which serve to determine the points of the surveying network on a beach by means of the GPS RTK method. A relatively quick determination of the situation of points within an accuracy of ca. $m_p=0.010$ m and $m_h=0.015$ m is an advantage of the GPS RTK method. Such an accuracy is completely sufficient to conduct the monitoring of a geotechnical object, i.e. a coastal cliff.
3.2. MEASUREMENTS WITH A TERRESTRIAL LASER SCANNER OR A SCANNING TACHOMETER

Monitoring of an active cliff shore should be cyclically performed in established time intervals. The frequency of the performance of observations should be made conditional on the purposes accepted. The largest damages to cliff shores occur in the autumn and winter period because at that time there occurs the largest number of storms, and due to this fact, periodic observations should be performed after this period. When there are civil structures at the back of a cliff, the frequency of observations of the cliff shore should be considerably increased; if it is necessary, such observations are to be made even after each storm.

During the measurement of a cliff shore with scanning instruments, the distance between the measuring positions should be selected in such a way so that the so-called dead spaces (i.e. those areas which are not covered with the measurement) should not occur. In this situation, special attention is to be paid to the degree of the diversification of the lie of cliff wall and to the distance of the measuring positions from the cliff slope, which is dependent from the width of the beach.

On each measuring position, the adjustment of the appropriate scanning resolution is important so that the measuring points obtained should reliably express the lie of the cliff and be free from any redundancy of data. This resolution should be mainly made dependent from the diversification of the surface of the cliff wall and from the expected accuracy of the results of the digital model of the object under examination. A resolution from ca. 10 to 30 points/m² is the suggested resultant resolution of scanning for the purpose of building the Digital Cliff Model of the GIRD type with one-decimeter accuracy. This quantity was estimated on the grounds of the research described in (Suchocki and Wasilewski 2010) for a specific object under examination and should be treated as a directional value only. For economic reasons, the scanning resolution can be also be made dependent from the type of the instrument which is used. It is suggested to select the upper range of the resolution assessed, i.e. ca. 30 points/m² because terrestrial laser scanners can perform measurements with very large speeds up to several hundred thousand points/sec. Scanning tachometers make measurements with a considerably lower speed up to ca. 30 points/sec.; for this reason, it is suggested to select the lower range of the resolution assessed above 10 points/m².

3.3. DATA PROCESSING

The data acquired from various measuring periods should undergo the appropriate numerical processing. Owing to this, it will be possible to observe the changes which occurred in the object under examination in a specific period of time. This processing is to be performed in the following successive steps:
1. First, all the measuring data should be expressed in a uniform system of coordinates. When measurements are made with scanning tachometers, the data has already been expressed in the network system as a result of the orientation of the instrument onto the points of the network. However, when a measurement is made with a terrestrial laser scanner, each cloud of points is usually expressed in the internal system of coordinates in the scanner. During the measurement of a cliff, high resolution scanning of specialist plates that are positioned in the points of the surveying network, which at the time are automatically recognized, should additionally be made for the orientation of the data obtained in this way. Owing to
this, in post-processing, the so-called registrations of the individual clouds of points, which consist in a transformation of the data from the internal system of coordinates in the scanner to the network system, use the scanned and recognized targets as connective points.

2. Further, a detailed analysis of the data is to be made, which is meant to remove any possible gross errors and to perform a selection of the data consisting in an elimination of any unimportant observations, i.e. those elements obtained from the observation which are not included in the object under examination (e.g. shrubs or branches). The filtering process of the clouds of points acquired from the laser scanning of the cliff can be supported with computational modules which serve for this purpose, e.g. in Cyclone program (Suchocki 2009a).

3. In the further part of the study, the Digital Cliff Model of the GIRD type is to be built from the measuring data (Suchocki 2010). A decisive factor which has an influence on the precision and detail of the digital development the GRID type model is the accepted resolution of the network. In the paper by (Suchocki and Wasilewski 2009a), it was established that a resolution of $0.20 \times 0.20$ m is the proper resolution for the construction of the Digital Cliff Model of the GIRD type. This resolution is assessed for the specific object under examination and for this reason, it is to be treated only as a directional value for other cliff shores. Apart from the resolution of the GIRD network, the algorithm applied of the interpolation of $z$ coordinate in the nodes of the network is also significant for the accuracy of the process. In the paper by (Suchocki 2010), the usefulness of the four most popular interpolation algorithms such as the Natural Neighbor, IDW, Kriging, Spline was verified. On the grounds of these investigations, it was demonstrated that the Natural Neighbor algorithm modeled the diversified surface of the cliff wall with the highest accuracy in the relation to other algorithms. As a result of the assessment of the accuracy for the Digital Cliff Model, it was established that the value of the RMS error of the model built in this way is up to ca. three decimeters. This accuracy is sufficient only for the location of considerable landslides, which occur on cliff shores, or for the creation of a Digital Cliff Model for visual purposes. This accuracy is too low in detailed investigations concerning the retreat of cliff shores. In order to increase the accuracy of the Digital Cliff Model, the author proposes to make a transformation of the data from the network system to the defined system of the object before the construction of the Digital Cliff Model. $Ox'y'$ plane of this system should be a regressive plane, i.e. the one for which the square sum of the distances of all the measuring points from this plane will approach the minimum. Then it will be dependent from the inclination of the cliff wall. As a result of the expression of the measuring data in the newly defined system of the object and further building the Digital Cliff Model, the accuracy of the model built will improve significantly. It can be concluded from the research carried out and contained in (Suchocki 2009b) that the average error of the construction of the model in the system of the object expressed the value of the RMS error does not exceed one decimeter.
4. When having the constructed GRID models of the cliff wall from different measuring periods, their comparisons can easily be made when creating differential surfaces or generating profiles along a given line. Besides, depending from the purposes of the study, the data modeled can be displayed e.g. as a map of declines.

Fig. 3 presents a simplified diagram of the conception developed for the measurements of cliff shores with the use of terrestrial scanning instruments and processing of the data from these measurements.
4. FINAL REMARKS AND CONCLUSIONS

It can be demonstrated from the research conducted that terrestrial laser scanners and scanning tachometers prove to be good for the measurements of cliff shores. There is a
possibility for the observation of the whole surface of the wall of the cliff from a safe
distance through the application of the measurement technique of the distance without
mirrors, without interfering in the object under observation. This is of a special
importance in the case of monitoring of objects which are difficult to access and are
dangerous, where staying directly on the object or in its immediate environment may
cause a hazard to the human health and life.

It is possible to model the Digital Cliff Model of the GRID type from the data obtained
from the measurement as a result of the appropriate processing. The concentration of
the measuring points for the object under observation and also the accepted resolution
of the GRID network and the kind of the interpolation algorithm used have an influence
on the accuracy of the Digital Cliff Model. In the investigations, it was assessed that the
concentration of 10-30 points/m² of the area of the cliff wall permits to build the Digital
Cliff Model with one-decimeter accuracy. The optimal size of the GRID network was
also determined for the object under examination of 0.20 m. This quantity may
constitute the reference value for other cliffs. The Natural Neighbor algorithm was
determined as the most favorable one from the methods examined of the interpolation
of the Digital Cliff Model. With the aid of this algorithm, the surface which best
expresses the real surface of cliff, is obtained.

The methodology developed can be used in monitoring of cliff shores. Apart from it, this
methodology can be also used for monitoring of geotechnical objects with a similar
character to that of cliffs, e.g. escarpments, precipices, embankments or walls of the
evacuations of open-cut mines.

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