A new geodetic methodology for the accurate Documentation and Monitoring of inaccessible surfaces.

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Abstract: This paper deals with a new geodetic methodology for fast and accurate Surveying, Mapping and Monitoring of inaccessible ground surfaces as cliffs, dams, mine walls and rocky declivities.
The existing geodetic surveying method and its combination by the use of modern reflector less total stations allow the fast and accurate positioning of inaccessible points up to 800m, in a local 3D reference frame.
The methodology is mainly based on the capability of the total station to automatically sweep the surface by means of the scanning mode, which takes automatic measurements at defined interval within a predetermined by the user window. The advantage is that the coordinates x, y, z, of an adequate number of points can be quickly determined.
The result of the methodology is the creation of 3d Digital Terrestrial Model (DTM) of the surface by an accuracy of about ±2cm. The DTM allows the drawing of horizontal and vertical sections at any position. Additionally, the accurate determination of the main characteristics of the surface as planes inclinations, borders of big rocks, peaks and crevices, empty space among the rocks, is feasible. It is also easy to achieve the monitoring of the surface position.
The accurate DTM offers easy access to other geoscientists that have to carry out any kind of work on the site.
The method was applied for:

- the Surveying and Mapping of a high (about 50m) and long (about 400m) rocky ground surface, where there is a need for supporting works in order to prevent the fall of rocks.
- The Monitoring of the deformation of a dangerous cliff, which crumbles on the national road.

1. Introduction

Today, it is feasible to realize the detailed surveying of hazardous locations such as cliffs, dams, rock faces, ice surfaces, mine walls or inaccessible ground surface as declivities.
The monitoring of the kinematical behavior of the above type of surfaces constitutes a very important research topic for engineers for conservation of the existing natural and human structures. This study also is very useful to other scientists (geotechnical engineers, geologists), who have to deal with the study of the stability of these surfaces in order to propose the procedure that should be followed for its prevention. Surveyors can provide the geometric documentation or the monitoring of these inaccessible surfaces with adequate accuracy by spending little time and labour.

The reflectorless distance measurement solution, which offers significant productivity and safety advantages is now available anywhere. Using the modern reflectorless total station, all the above mentioned inaccessible areas can be easily measured. The ability to make this kind of non-contact measurements without having to send a person into the dangerous area, offers safety. Also, many applications use this ideal technology in underground tunneling surveying and high accurate monitoring.
The range of these instruments today (2006), is extended up to1500m. The advantage of their use is that neither rectifications nor corrections are needed. The direct measurements of the horizontal angles, the vertical angles and the distances are used for the calculation of the coordinates x, y, z of each point. These coordinates are later used for the creation of the 3d digital model of the surface. Moreover, the ordinary use of these total stations in many other surveying works, their low price, weight and the directly derived results, make them very attractive, in comparison to a laser scanner.
The following special documentations of dangerous and inaccessible areas were carried out by means of the scanning mode of a reflector less total station, as no other methodology would be effective or would be able to be performed.

- The Survey of a rocky ground surface, where there is need for supporting works in order to prevent the fall of the rocks. In this occasion, the creation of the 3d terrestrial model of the entire surface provides the significant opportunity to draw any vertical - longitudinal or horizontal section of the surface, which facilitates the total documentation.
- The determination and the monitoring of the deformations or the displacements of a dangerous cliff, which crumbles on the national road. In this occasion, the comparison of the created 3d terrestrial models of independent scanning campaigns in arranged time intervals illustrates the displacements of the area.

The data processing of the above applications were executed quickly and easily in an ordinary pc without the use of special programming.
The details and the results of these works will be analyzed in the following paragraphs.

2. Instrumentation

The total station Trimble 5605DR+ was used (phot.1) in both applications. It measures distances up to 600 m without the use of a reflector. Its angular precision is ± 5″, while its distance precision varies from ±3mm to ±5mm in the reflector less mode for distances shorter or longer of 200m [4].

Photo1: The total station
Trimble 5605 DR+

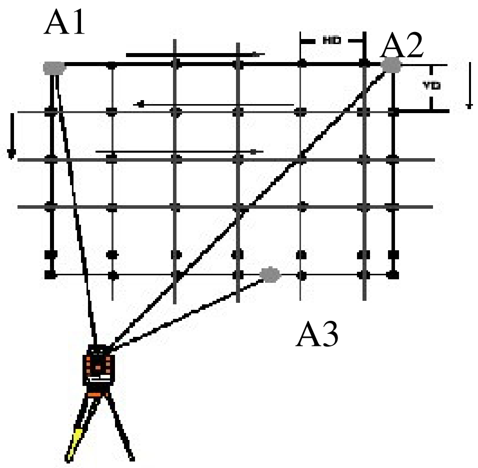

Figure 1: The definition of the surface to be swept.

The software "surface" has been established in the total station configuration as a field application [5]. When the "surface" application is run by the instrument, it works in a similar way to a laser scanner. It has the possibility to automatically sweep a predetermined surface window defined by three points A1, A2, A3, as illustrated in Figure 1. The user should define the desired horizontal and vertical interval step in meters according to which the surface will be swept. The definition of the sweeping step depends on parameters as the magnitude of the swept area, the texture and the irregularities of the surface, the desired details that will be presented in the plans and the available time. Before the instrument starts each sweeping program, it calculates the total number of points that will be measured as well as the time needed for the measurements. The user has the possibility to agree with the total procedure or to change it according to his preference.
By this procedure, the adequate number of points can be measured in an absolute geodetic manner. Additionally, one can set the desired minimum and maximum range for the instrument distance measurements. Due to this ability the instrument avoids measuring points which are situated in front of or behind the sweeping surface. The data are free from "unwanted" points.
Before using the instrument on the site measurements, the "surface" application as well as the instrument itself were tested in the laboratory for their proper function and the achieved accuracy [3]. The results show that the use of the Trimble 5605 DR$^+$ and the ″Surface″ software guarantee the accurate documentation of any surface.

3. The documentation of a rocky ground declivity

The Monemvasia fortress is situated at the south – eastern end of Peloponneseus (Greece). It was constructed at the side of a unique natural beauty rocky declivity. At the foot of the declivity a little village had been developed (phot.2). Due to the corrosion of the declivity some rocks started falling.

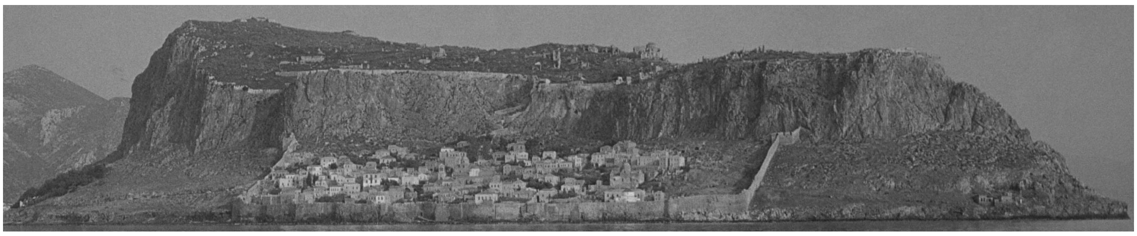

Photo 2: The rocky ground declivity

In order to prevent the village structures and the inhabitants, a geological and geotechnical study is needed in order to propose the consolidation procedure for the rocks [2]. The detailed surveying of the inaccessible declivity was requested. The declivity had a length of about 400 m and height of about 50 m. The long range reflector less total station Trimble 5600DR$^+$ was used due to the accessibility difficulties of the environment. A geodetic network was established at the surrounding area, which was measured and calculated in an arbitrary local reference system. The total station was set up at 7 station points of the network and indispensable measurement sets were carried out in order to cover the entire declivity surface. The measured distances between the declivity surface and the network stations vary from 80 m to 250 m.
About 2500 points were measured in 4 hours time. The sweeping step was set 5 m horizontally and vertically in all the scanning parts. By using the TGO software [6], the 3d digital model was produced via the x, y, z coordinates of each measured point. The model provides full geometric information for all the elements as the foot of the rock, its peak and crevices that compose the relief. Moreover the model gives us the opportunity to extract

horizontal, longitudinal or vertical cross sections of the declivity at any desired position. These sections are indispensable for the supporting study. The produced southern façade of the declivity via the 3d model is illustrated in figure 2.

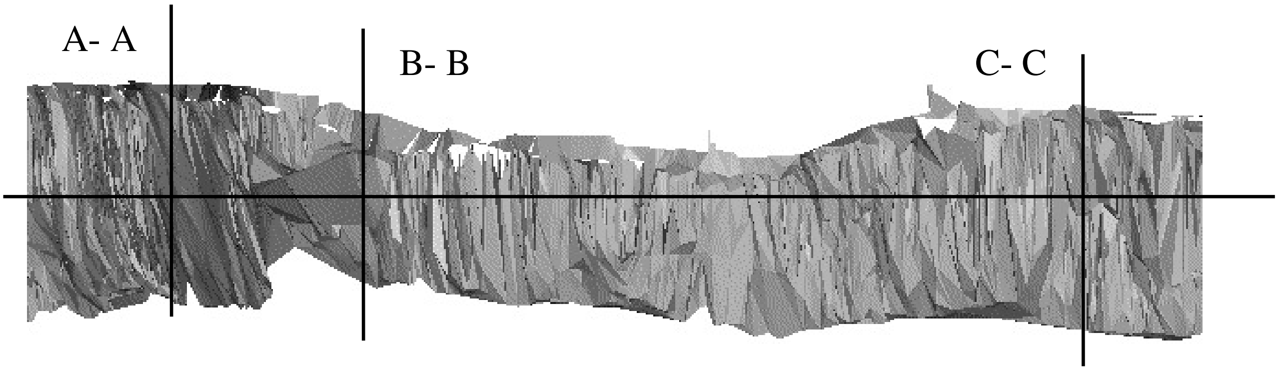

Figure 2: The southern façade of the declivity via the 3d model

Figure 3 shows three of the extracted vertical sections A – A, B – B, C – C via the model. The positions of these vertical sections on the declivity are marked in figure 2. In order to check the results, the same vertical cross sections were directly measured at the site, as they had been set at characteristic and marked positions. The comparison of the section plans proved that the differences fluctuate from 0cm to 30cm. These differences are really insignificant for this work, as the declivity rocks have strong irregularities. Also, the direct measured vertical sections at the site are not strongly followed the definition line for each one. Figure 3 presents the differences between the direct (bold line) and indirect by the model (white line) drawing of the vertical cross sections. Consequently, the model presents by an adequate detail and accuracy level the feature of the declivity.

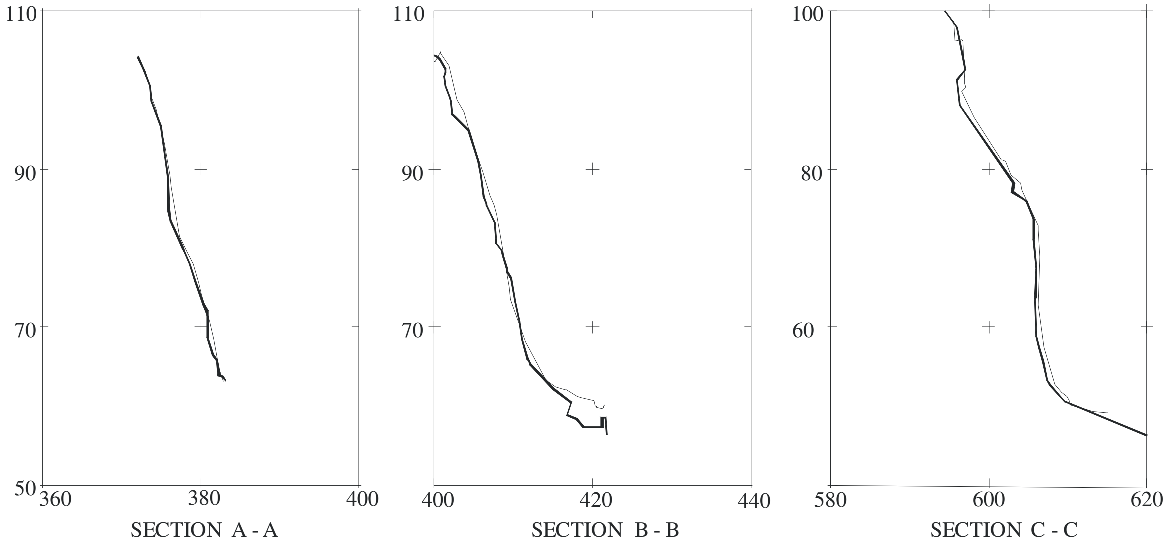

Figure 3: The vertical cross sections A-A, B-B, C-C

Moreover horizontal and longitudinal sections of the declivity were extracted via the model according to the geotechnical engineers request, to give them more detail information about the state of the rocks. Figure 4 presents a selected longitudinal section of the declivity, as figure 5 illustrates an horizontal section at the height of 80m.

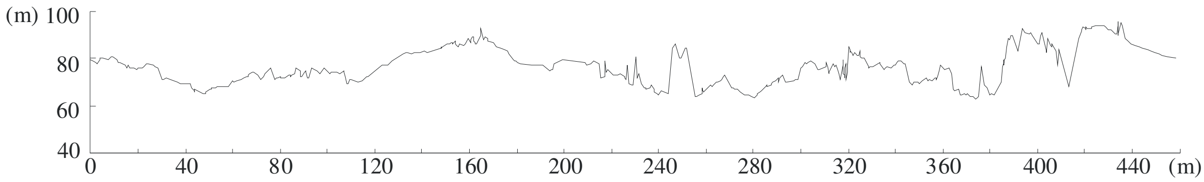

Figure 4: A longitudinal section of the declivity

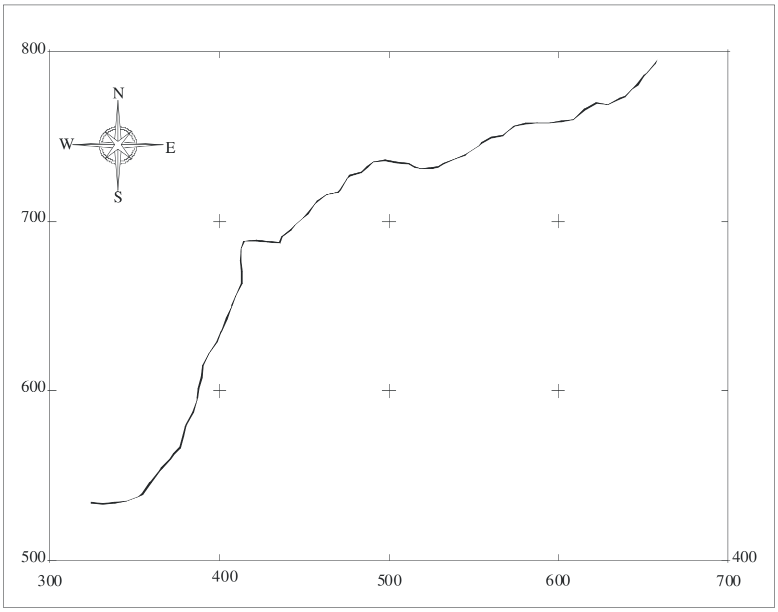

Figure 5: The horizontal section of the declivity at the height of 80m

4. The determination of the displacements of a cliff

A small cliff situated at the side of the national road (phot. 3) was suddenly crumbled carrying away a part of the road having a length of about 300 m. After that, the road had to be closed, as it became very dangerous, and a new setting out of the road must be proposed after a careful study of the situation.

Photo 3: The cliff at the side of the national road

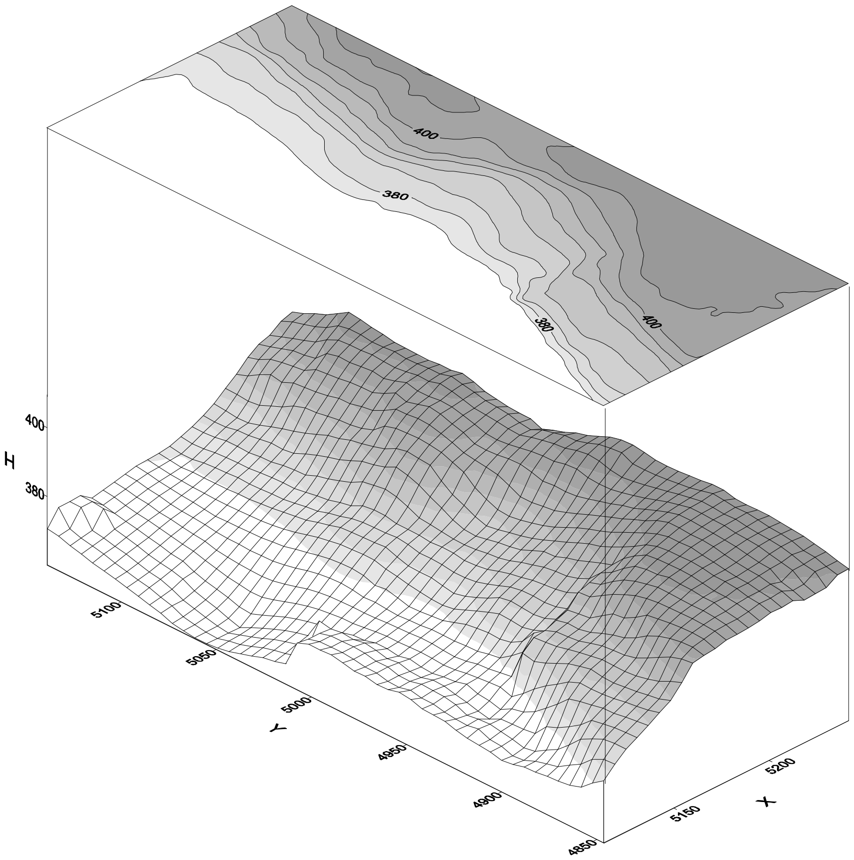

Figure 5: The 3d model created by using the measurements of the total station.

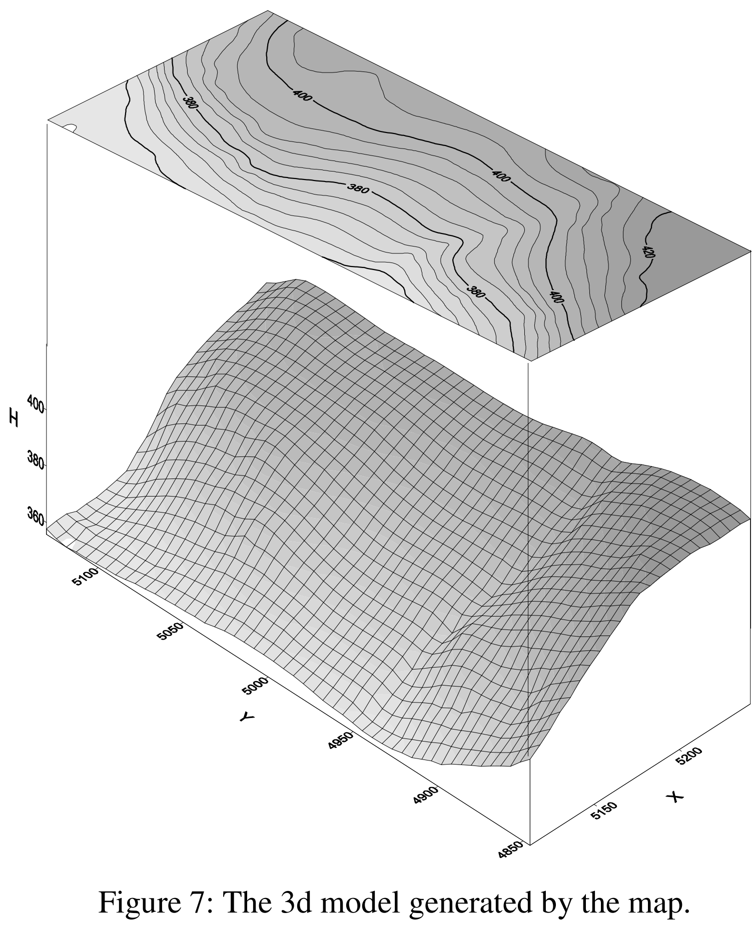

Figure 7: The 3d model generated by the map.

At first, the comparison between the façade of the last cliff and the previous status of the site was indispensable. Only non contact measurements may be performed, due to the dangerous environment. A geodetic network was established outside the problematic area in order to support the study of the ground displacements. The profile of the cliff, about 25 m in height, was measured using the reflector less total station via the ″surface″ software. The dangerous cliff declivity was scanned from two proper network stations.

The sweeping step was set 3 m horizontally and vertically and about 1100 points were measured. The distance between the declivity and the instrument stations was of the order of 100 m. The measurements lasted about 3 hours. Figure 6 illustrates the model created by using the total station measurements.

The 3d model of the cliff before the crumbling was generated by digitizing an available map, (Scale 1:5000) which has contours by 4 meters interval (fig. 7). The comparison of both models demonstrates obvious differences present the surface deformations. It was calculated that the profile of the cliff has an average change of 4 m in height and 2m in x and y direction. The monitoring is going to be continued by this methodology as the same area is going to be swept every six months in order to register the evolution of the phenomenon.

5. Conclusions

- Hazardous locations can be measured rapidly with no contact reflectorless measurements exploiting the modern total stations technology and software, without sending a person to the dangerous area.
- The opportunity of one - person - surveying - crew reduces the cost of the site work.
- The advantages of the use of a reflectorless total station are:
    - The easy operation and the quickness.
    - The achievement of high accuracy (of the order of ±2cm) in the calculated coordinates.
    - The easy data processing. There is no need for transformations, use of a powerful pc or special software.
    - The low weight and cost.
    - The long range distance measurement rejects the difficulties of the area accessibility.
    - The regular distribution of the measured points all over the swept area.
    - The measurement of "unwanted" points is avoided as limits can be set for the min and max distance in which the measurements are permitted.
    - Other parameters as humidity and overheating have no influence at the instrument.
- The above mentioned applications prove that:
    i. The 3d terrestrial models can be created in short time, using minimum staff, an ordinary PC and software. Adequate accuracy is achieved by spending minimum money, time and work.
    ii. Any vertical or horizontal cross section of the surface can be easily drawn via the created 3d model. No particular measurements at the site are needed for each one.
    iii. The comparison of the created 3d terrestrial models is an excellent tool for monitoring the displacement of a dangerous area in arranged time intervals. If three or more campaigns are carried out, the velocity and the acceleration of the displacement can be calculated in order to anticipate the phenomenon.
- Consequently, the conventional survey method by using modern reflectorless total station and the sweeping program remains still attractive and effective. It offers high productivity, is accurate and easy at the site measurements and the data processing.

References:

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