THE MONITORING PROCESS OF VOLCANIC DEFORMATION

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***Abstract**: The aim of the paper is to describe the monitoring process used when we aim to realize the monitoring process for a volcanic deformation considering several approaches. The described process is complex because it combines the unpredictable nature of the volcano, infinitely higher than of a land or structures, with the process of tracking the deformations which is mainly based on measurements performed in the study area and right next to it in many stages. The process is more difficult to be realized because in the volcanoes case it is impossible to be done without appropriate equipment.*

***Keywords:** deformation, volcano, monitoring*

1. Introduction

Deformation monitoring is used to prevent the occurrence of degradation of the structure regardless of the cause of their occurrence (when the object of deformation monitoring is represented by one or more structures), and also of phenomena that can cause major damage and even loss of life (when the deformation monitoring process is performed on land).

Land deformations of the underground have been demonstrated as being some of the most common signs of active volcanoes and appear because of the movement of magma that creates a high pressure on rocks in the immediate proximity, making them to be pushed in the vertical and/or horizontal, which determines to result the phenomenon of the deformations.

The deformation monitoring process for volcanoes it is more complex than the monitoring of any other kind of object because are necessary more special equipment to realise the tracking and involve more difficult conditions to be obtained, and even more dangerous. Also, when it is realised the monitoring of the behaviour of a volcano and the deformations which appear, must be took into consideration three aspects which are specific for the natural process of volcanoes: the land deformation, seismic activity and gas emissions.

Precision requirements when the previously stated phenomenon is being done, are large, but when this process aims volcanoes deformations, precision requirements are becoming even higher.

2. Approaches

2.1 The classic method for deformations monitoring of volcanoes

The oldest method it is considered to be the one in which the deformations of volcano are determined by electronic distances and some instruments used for measuring the slope of the ground, used especially in volcanology and seismology.

The distances are measured between the points of the tracking network, which involves limiting the analysis only for the area where they are located.

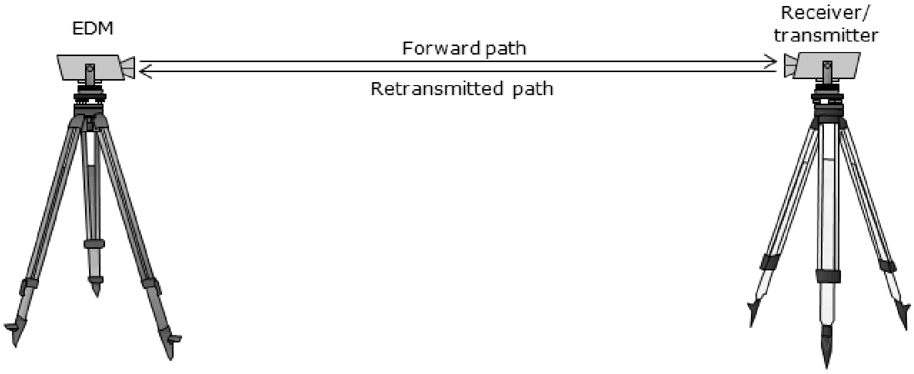

Fig. 1 EDM[1] Instrument [8]

Using only the results obtained by the electronic distances cannot obtain conclusive results regarding the deformation analysis, therefore this tracking results are related with the results obtained using the previously mentioned instrument (tiltmeter), which offers results with very high accuracy and which have been used for the prediction of a volcanic eruption since 1980.

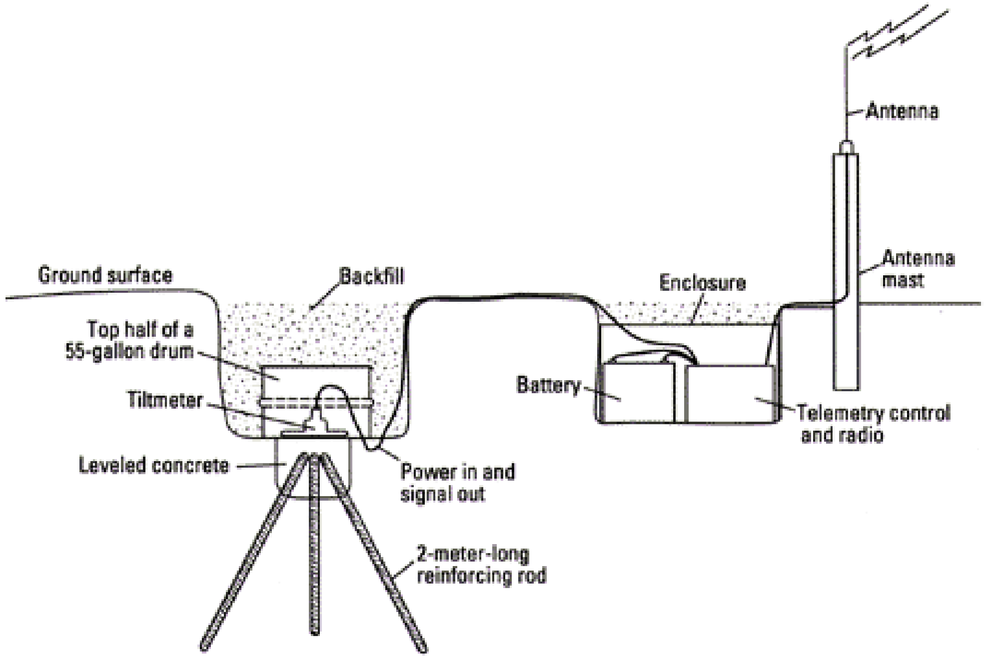

Fig. 2 Tiltmeter [9]

2.2 Monitoring volcanoes deformation using satellite measurements

This method quickly replaced the traditional method because it came to support efficient workflow, assuming a reduced time and reduced costs and offering even more precise results. Another major advantage of this method, which made the classic method to be replaced with this one, is that it provides results in real time, providing also a positioning both

[1] Electronic Distance Measurement

horizontally and vertically, without requiring visibility between the tracking network points which were presiously projected.

A disadvantage for this method can consist on the fact that for realising the tracking process it is necessary to be developed on a open area wich is free of vegetation or any other element that can obstruct the signal received from the satellites.

Also in the sphere of satellite measurements, in addition to GPS (GNSS)[2] can be remembered and taked into consideration InSAR[3], a technique for mapping land deformations of the ground surface using radar images collected from satellites that are situated above it. This method was already used to determine deformation occurring due to earthquakes and volcanoes around the early 1990s.

The advantage of this method is that it offers a very large spatial coverage and the fact that exist many software solutions for processing the taken imagines.

The disadvantages of the method are many, among them recalling: the very high costs, the poor accuracy regarding the altitude, a very important element when we are monitoring the deformations, inconsistent data, orbital errors and redundant data.

2.3 In situ deformation monitoring

To be realised the monitoring process using this method, sensors are placed on the surface which will represent the desired area to be studied, sensors which can further transmit data in real time. In situ reaction monitoring involves of an object involves also the achievement of a special monitoring project including the maintenance and rehabilitation where appropriate. In case of monitoring the volcano behaviour there can be no question achieving these milestones of maintenance and/or rehabilitation, but obtaining measurement results achieved with special sensors in real time and continuously is a very important first step in its monitoring and prediction of activity.

Advantages of such a method are represented, as noted above, of: obtaining results in real time and continuously in a large number of records, reduce the need for measurements with classic instruments and permits supplementation measuring steps with any number however great it is considered necessary and justified.

The disadvantage with this method may be that each sensor responds to the immediate proximity, which could represent the appearance or not of movements that lead to appearance of deformation. Most times, if we pay attention to a group of sensors and are taken into account parameters of the area where they are located, isolating the effects of natural surface where they are, this drawback can be overcome.

2.4 Deformation monitoring based on the reference model of the elevation

This method requires as a key reference elevation model considered above sea level, at which corrections are measured using deep pressure.

Initially, a major disadvantage of this method was that it did not provide the possibility of including those effects due to an irregular topographic profile. However this fact was carefully researched and the method has been improved initially adding corrections due to low slopes of the topographic profile, determined by simulating the source of pressure as

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2 Global Positioning System (Global Navigation Satellite System)

3 Interferometric Syntetic Apeture Radar

lines of movement, subsequently advanced to determine the effects of irregular topography. It faded to the possibility of eliminating the restriction of flat surfaces considered in developing the method and obtain an algorithm to determine the depth of the pressure source varies according the actual land model.

However this method provides good results with a good accuracy for displacements that occur vertically, but the results do not meet the requirements for accuracy horizontally. To resolve this impediment was again proposed an alternative method which will use a reference altitude which to apply weightings according to the characteristic slope of the points in which the measurements are taken. Thus the method has been improved enough to provide results of high accuracy even in areas with a high slope.

2.5 Using 3D models created using FEM[4] for deformation monitoring

We can talk about a comprehensive analysis of volcano deformation using a correlation of elements determined by surveying methods with different parameters describing the shape of the land.

This was possible in the late 1980s when new methods were developed using 3D models generated using the finite element method in several volcanic areas in the world. The results thus obtained were compared with the results obtained using the improved conventional methods. To realise the study were selected three such areas, with different parametric history and to demonstrate the effectiveness and applicability of the method in multiple situations (Rabaul – Papua New Guinea, Tenerife Island – Spain, El Hierro Island - Spain).

For each of the three cases they were considered different parameters and different properties of the 3D model. These elements can be found in the table below.

Table 1 The main parameters used in the analysis [7]

	Rabaul model	Tenerife model	El Hierro model
FEM domain coordinates (m)	(UTM zone 56S)	(UTM zone 28N)	(UTM zone 28N)
	x_{min} = 360,290	x_{min} = 288,901	x_{min} = 153,272
	x_{max} = 460,290	x_{max} = 398,901	x_{max} = 253,272
	y_{min} = 9,480,000	y_{min} = 3,078,450	y_{min} = 3,034,950
	y_{max} = 9,580,000	y_{max} = 3,178,550	y_{max} = 3,121,050
Pressure centre (m)	C_x = 410,290	C_x = 339,030	C_x = 203,272
	C_y = 9,530,100	C_y = 3,128,400	C_y = 3,071,000
	C_z = −2965.5	C_z = −542.8	C_z = −1640.8
Level of reference flat free surface (m)	34.5 b.s.l	3542.8 a.s.l	1359.2 a.s.l
Number of mesh elements	1.452×10^6	0.954×10^6	1.049×10^6
RDD (–)	Min = −0.05	Min = −0.29	Min = −0.27
	Max = 0.09	Max = -0.12×10^{-3}	Max = 0.02
*SLOPE*max (°)	Min = 0.01	Min = 0.04	Min = 0.09
	Max = 36.87	Max = 52.18	Max = 60.81
EXPOSURE (–)	Min = −0.34	Min = −0.45	Min = −0.35
	Max = 0.99	Max = 0.99	Max = 0.99
Plan curvature *Kc* (radians $(100\ m)^{-1}$)	Min = −0.493	Min = −1.075	Min = −0.755
	Max = 0.392	Max = 0.723	Max = 1.418
Profile curvature *Kp* (radians $(100\ m)^{-1}$)	Min = −0.037	Min = −0.140	Min = −0.307
	Max = 0.054	Max = 0.134	Max = 0.421

4 Finite Element Method

For all three models were considered the same depth (20km) and the same radius from the source of pressure (1,5km).

Following the analysis were found a few differences from the results obtained using classical methods, particularly those describing deformations occurring volcanoes located in the islands of Spain, but after some adjustments to the model studied by both methods were indicated deformations of similar values.

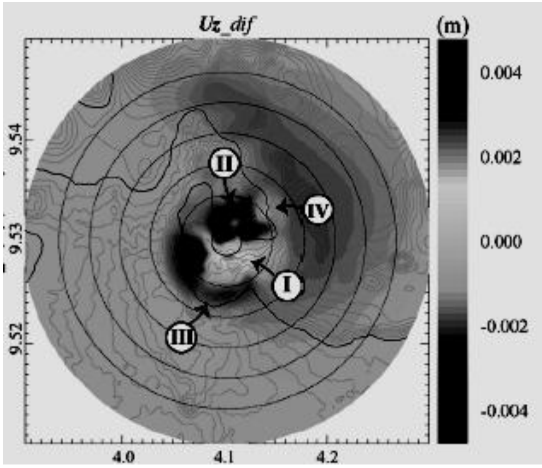

Fig. 3 The result obtained for Rabaul [7]

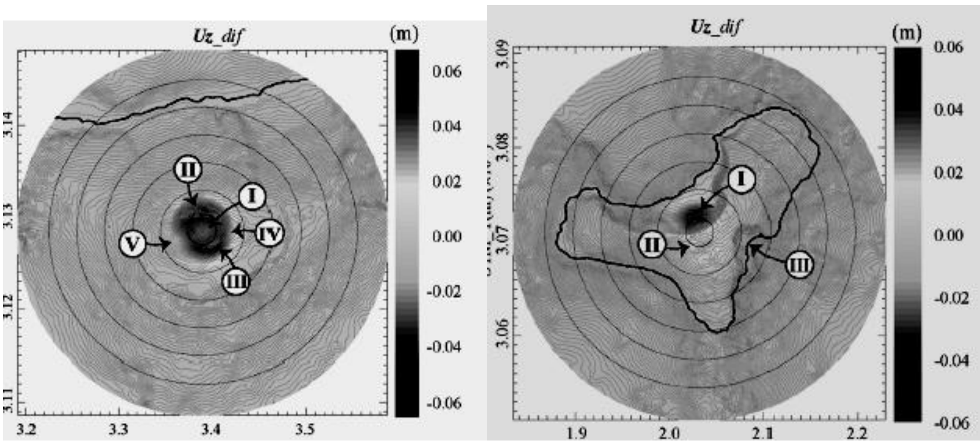

Fig. 4 The results obtained for Tenerife și El Hierroo Islands [7]

3. Conclusions

The monitoring process for studying the deformations which appears at volcanoes is very complex and for plausible results and well-founded is imperative necessary that studied phenomenon is well known to those who performed.

Each of the above methods has advantages but also disadvantages, but all can provide outcomes that are used to analyse deformation of volcanoes.

When you choose the method to be used, as in any other domain specific process topography, taking account of conditions on the ground, and the equipment available.

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With the evolution of technology, have been tried new solutions adapted to the possibilities offered by them. There have been created and are working on improving volcanoes models based on the finite element method which demonstrated the applicability and sustainability. By models developed by this method it demonstrated a link between the magma and pressure versus time deformation of the volcano. More specifically it has been shown that the inclusion of specific parameters in viscoelasticity models for the crust around the volcano, significantly reduces the pressure source and introducing a time-varying deformation resulting from the viscous response of the crust. It is intended that the models obtained from finite element method to introduce viscoelastic models to provide additional physical correction and that will lead to the determination of accurate pressurization trends.

The conclusion, however regardless of the measurement method chosen is that geodesic monitoring volcanoes allows the collection of key data on the dynamics of the eruption (the mouths of eruption and crater), information representing a dataset very important not only for deformations monitoring of volcanoes, but also for professionals who do volcanology constant research to understand how that works the plumbing system of magma from the volcano, especially during eruptive events. In addition data collected through the monitoring system provides useful and relevant information for ante and post-eruptive dynamics thereof. These data can be connected further with methods of identifying and forecasting movements landslide near the volcano studied.

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