SPIRIT LEVELING AND GEODETIC NETWORKS TO MONITOR GROUND SUBSIDENCE IN BOGOTÁ-COLOMBIA

NIVELACIÓN GEODÉSICA GEOMÉTRICA Y REDES GEODÉSICAS PARA EL MONITOREO DE LA SUBSIDENCIA EN BOGOTÁ-COLOMBIA

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Abstract

Bogotá's Vertical Reference Network has been developed using first order methods of leveling (Spirit Leveling) on its main roads, in around 150 kilometers, with more than 80 benchmarks distributed in whole city. Data Processing, to data acquired between July and august of 2007, shows a systematic variation in heights in some zones of the city about acquired data in 2003 and 2005. In addition, permanent and detailed monitoring of Bogotá's GNSS-network supports constant ground subsidence in almost whole City.

Key words: Leveling, GNSS networks, ground subsidence.

Resumen

La Red Vertical de Referencia de Bogotá ha sido desarrollada utilizando métodos de nivelación geodésica geométrica sobre las principales vías de la ciudad, en una extensión de cerca de 150 km y con más de 80 puntos de nivelación de precisión. El procesamiento de la información adquirida entre julio y agosto de 2007 muestra una variación sistemática en las alturas niveladas en algunas zonas de la ciudad, con respecto a los datos tomados en las campañas de 2003 y 2005.

Palabras claves: nivelación, redes GNSS, subsidencia.

1. Introduction

Bogotá is the capital city of Colombia, with a population of about 7 million people[1] inhabiting an area of 310 Km^2; and it is located near the geographic center of Colombia (Latitude 4º 35' 46,3215" N, Longitude 74º 04' 39,0285" W), on the east of the Savannah of Bogotá, 2600 meters above sea level [Figure 1].

The Savannah is bordered to the east by the Eastern Cordillera of the Andes mountain range and surrounding hills run from south to north, parallel to Monserrate and Guadalupe mountains. The western city limit is the Bogotá River and the Sumapaz moorland borders the south and to the north of the city.

The city is settled on the middle of a sismotectonic environment of recognized historical activity; where the Pacific Subduction Zone and a complex system of faults, are the sismogenic sour-

1 Source: Censo 2005. Departamento Administrativo Nacional de Estadística

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ces that have greater potential effect on the entire region.

2. Data Description and Data Processing

Land subsidence in Bogotá has been measured using assorted techniques, like Spirit Leveling, Global Navigation Satellite Systems (GNSS) survey and DinSar techniques. Several works were done presenting a description of the geological structures; however, none of them have been conclusively to determine its behavior.

For this purpose, the Instituto Geográfico Agustín Codazzi (IGAC) conducted the establishment of Bogotá's Geodetic Network (Red Geodésica de Bogotá) since 2003 to provide an alternative way to monitor the ground subsidence and likewise to fulfill its missionary work.

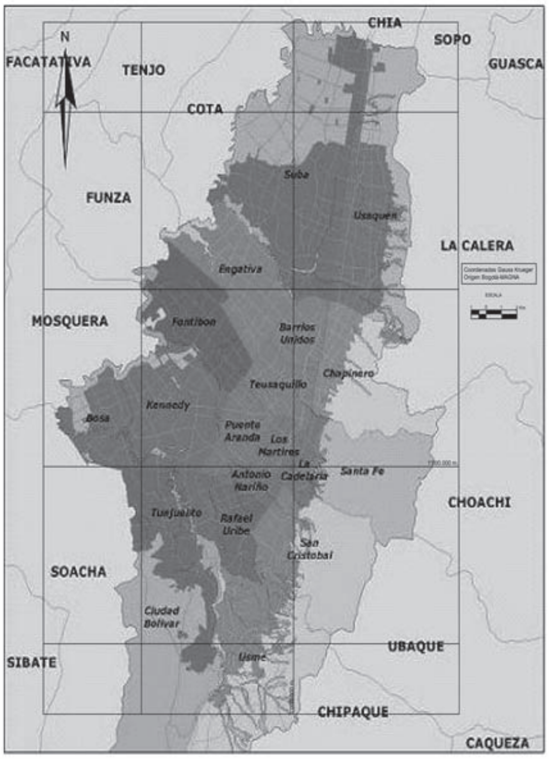

Figure 1. The City of Bogotá

2.1 Spirit Leveling

The establishment of a vertical network in Bogotá was started in 1986 by using optical leveling measurements with more than 600 points spread in entire city. Unfortunately most of these points have been destroyed due to the works of expansion and remodeling of the city grid road and now the information that we have from them is almost useless.

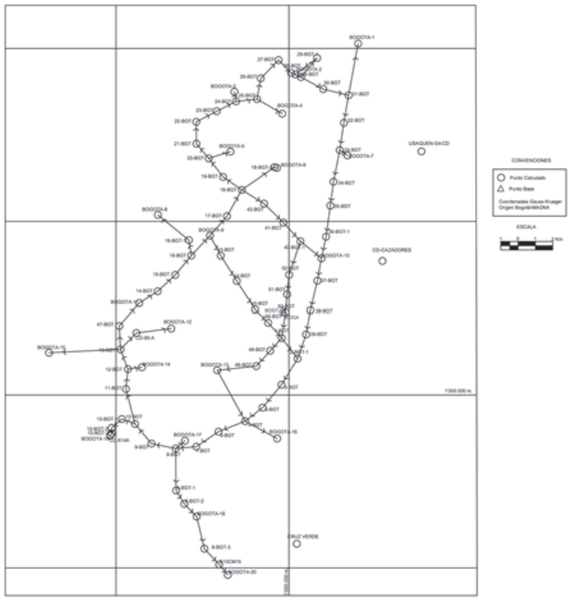

Figure 2. Bogotá's Leveling Network

In 2007, the office of Geodesy, at IGAC, conducted measurements of releveling in a series of benchmarks placed on the main roads of Bogotá in 2003 [Figure 2]. The surveys were done using Leica NA03 and Leica DNA03 precise levels. Each leveling line was measured forward and backward, and the tolerance for the difference between the forward and backward measurements was $4mm\sqrt{K}$, where K is the length of leveling line in km; this features offer a first order leveling.

These leveling campaigns were carried out between June and August, which corresponds to the season with lower rainfall in the city and with an average temperature of 14.5 C. In addition, the eastern mountains act as a natural barrier restricting the flow of moisture; therefore values were achieved relative humidity up to 80 %.

Data processing was carried out using the software Leica Geo Office version 1.1 and data obtained from processing were adjusted using the technique of placing by least squares based on the distance. Some of the basic parameters used in this process are described in Table 1.

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Table 1. Leveling Parameters

Method of adjustment	By distance
Level error per station	0,0005 m
Distance balance	10 m
Review of double observation	0,0002 m
Station difference	0,0003 m
Maximum distance Visual	80 m
Minimum height above ground	0,2 m
Corrections of level	NO

2.2 GNSS Network

In addition to the leveling network, Bogotá has 20 points to complement the Fundamental Geodetic Network [Figure 3]. These points were distributed throughout the length and breadth of the city and its location was determined taking into account geological and geotechnical parameters and above all so that they were fit to be occupied with Global Navigation Satellite Systems (GNSS).

Furthermore, there are two Continuously Operating Reference Stations (CORS) located one on the roof of the building of the Institute (BOGA) and the other one sites of the National University (BOGT) [Figure 2], which are continually recording information and realize of changing this area of the city. These stations are part of a larger reference network (SIRGAS-CON) and they are processed weekly by the Associated Regional Centre for Analysis Network in IGAC.

For this campaign of occupation, carried out between the months of June and August 2007, measurements were made on each point during three sessions of 8 hours, each station in a different day, with double-frequency GNSS antennas. The devices used were LEIAT502, LEIAT504 and TPSHIPER GD.

To data processing was used the strategy *Differences Double Phase*, in Bernese software, version 5.0. The mask elevation and sampling interval were 3º and 30 s, respectively. Absolute values of the International GNSS Service were used (IGS) for the correction of phase centers. Satellite orbits corrections, satellite's watches correction and earth orientation parameters were calculated on the solutions weekly IGS; the precise ephemerides referring to ITRF2000 (campaigns 2003 and 2004) were converted to ITRF2005.

Ambiguities phase for L1 and L2 were resolved using the strategy quasi ionosphere free (QIF). A priori ionospheric models were used to correspond with the models generated by the analysis centre CODE. The periodic movements caused by ocean load were reduced in accordance with the model of ocean tides FES2004.

Figure 3. Benchmark on Fundamental Geodetic Network

The absolute values corrections for the delay caused by atmospheric refraction at stations BOGA and BOGT were taken from IGS-RNAAC-SIR weekly solutions for the weeks corresponding. It is assumed that these absolute values are equal for all stations (maximum length of 35 km network) and only the relative values were calculated from observations GNSS (along with the coordinates of the points) for intervals of 4 hours. A campaign session was set for 24 hours and each session was processed by introducing a sigma a priori for coordinates of 1 m.

The normal equations were combined as conditions for introducing the definition of datum calls *no net rotation* and *no net translation* regarding stations BOGA and BOGT. The coordinates of the stations in question were taken from the IGS-RNAAC-SIR weekly solutions.

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3. Results

Since their installation, the stations of BOGA (2000) and BOGT (1996) have presented an unusual vertical displacement with respect to ITRF05. Figure 4 shows the behavior for these stations between 2003 and 2007. The estimated vertical displacement velocity is 54.90 ± 0.1 mm/year for BOGA and 47.80 ± 0.1 mm/year for BOGT.

Despite that the two stations are located just 200 meters away there was a slight difference in the magnitude of the subsidence of each station, which is explained by the location of the same: the station BOGA is located in the terrace of a building while the station BOGT is anchored to the floor. However, both show a similar trend.

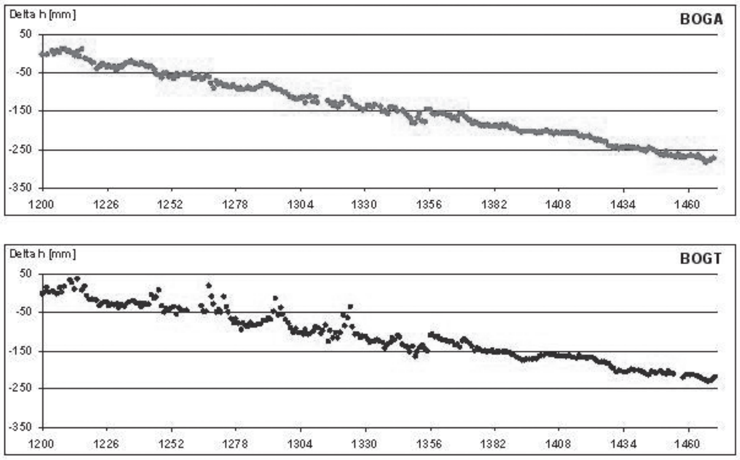

Figure 4. Time Series of BOGA (up) and BOGT (down)

On the other hand, the results of GNSS processing for the Fundamental Geodetic Network shows an homogeneous behavior in the vertical component, with a trend toward negative values in the order of 15 ±1 mm/year; however, there are some areas of the city where behavior is noticeably different reached values up to 96 mm/year [Figure 5].

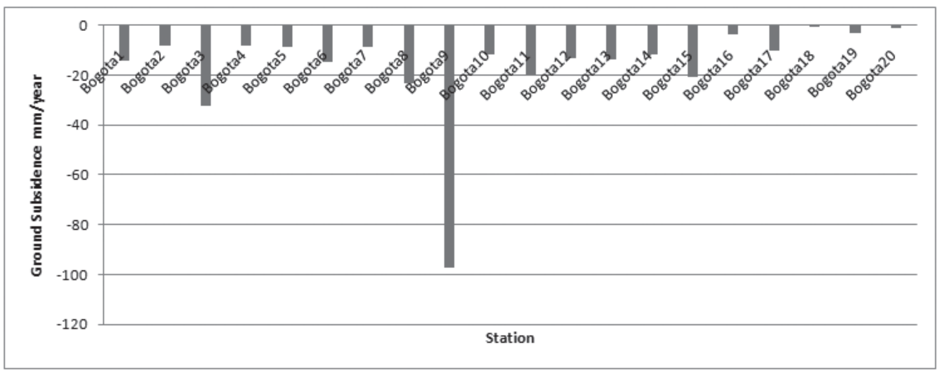

Figure 5. Subsidence from GNSS data to Fundamental Geodetic Network

Besides this, data from geodetic leveling confirm the behavior of most parts of the city, and reaffirm the strong tendency of some others. Figure 5 shows this behavior. Nevertheless, there is a notable difference between the values of subsidence occurring from satellite techniques and conventional leveling.

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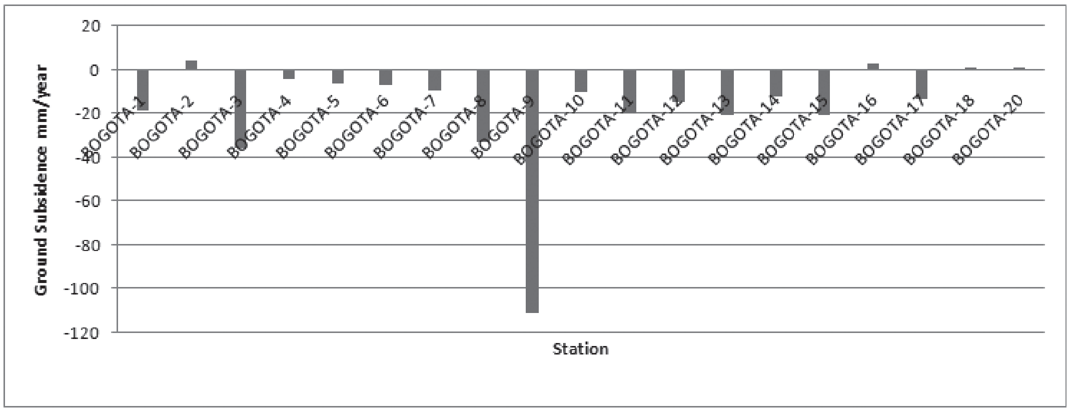

Figure 6. Subsidence from Spirit Leveling data to Fundamental Geodetic Network

However, because of the geometric distribution of the leveling and GNSS network, it is not possible to have additional data reaffirm the behavior presenting the stations BOGA and BOGT.

4. Conclusions

The results of this study confirms the need to establish priority as ongoing a detailed monitoring of the Fundamental Geodetic Network of Bogota, as well as the Leveling Network.

However, it must be said that future work should be expected to extend this network and cover areas of the city that have not yet been detailed and thus establish a more faithful behavior of the dynamics of subsidence in the city.

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