Leveling Techniques Applied to the Southern Part of the Nicoya Peninsula in Northern Costa Rica

Enrique Hernández R.
Observatorio Vulcanológico y Sismológico de Costa Rica
Universidad Nacional (OVSICORI-UNA), Apartado 2346-3000, Heredia, Costa Rica
Faculty Sponsor: Dr. Jorge Marino Protti, Universidad Nacional, Costa Rica

INTRODUCTION

Seismic activity along the Pacific coast of Costa Rica results from the subduction of the Cocos plate under the Caribbean plate. The zone of instability product of this collision represents a region of constant crustal deformation and therefore requires extensive geodetic studies. The construction of a geodetic network with permanent benchmarks will allow the recording and quantification of vertical and horizontal movement in the region due to future large earthquakes associated with this process.

The region between the coastal town of Montezuma and Cóbano, in the southern part of the Nicoya peninsula in Costa Rica constitutes the area where we started, during our Keck project, the first stage of monumentation and leveling. Our work focused on a set of sites along two lines parallel and perpendicular to the subduction direction. This work was part of a larger project that pretends to build and level a baseline across the peninsula with the goal of documenting crustal deformation in the region associated to the earthquake cycle.

We built 6 new monuments, conducted 600 m of geometrical leveling, almost 8.5 km of trigonometric leveling, and occupied 4 monuments with global positioning systems (GPS). This way we initiated a component of a project that will collect geodetic and geophysical information all over the Nicoya peninsula.

As part of this project we compare the resolution and precision obtained by three different geodetic techniques in order to define which one will be the most appropriated to be apply to the rest of the peninsula.

METHODS

Before we started the fieldwork, we collected all available geodetic information from the region. This information included topographic sheets, an inventory of previously occupied monuments and their descriptions, and gathered the precise elevation of measured benchmarks. We obtained all this information from the Costa Rica National Geographic Institute (IGN).

After all data was collected we conducted a field check of reported benchmarks but, out of nearly 20 sites, we were able to find only two. These two monuments were labeled by IGN as G-64, located near the school in Cóbano, and G-66 located 2.4 km SW from G-64. Since we only found the concrete pier but not its brass plate, we had to rebuild G-64 installing a stainless steel pin. The monuments of the G series were built and geometrically leveled in 1955.

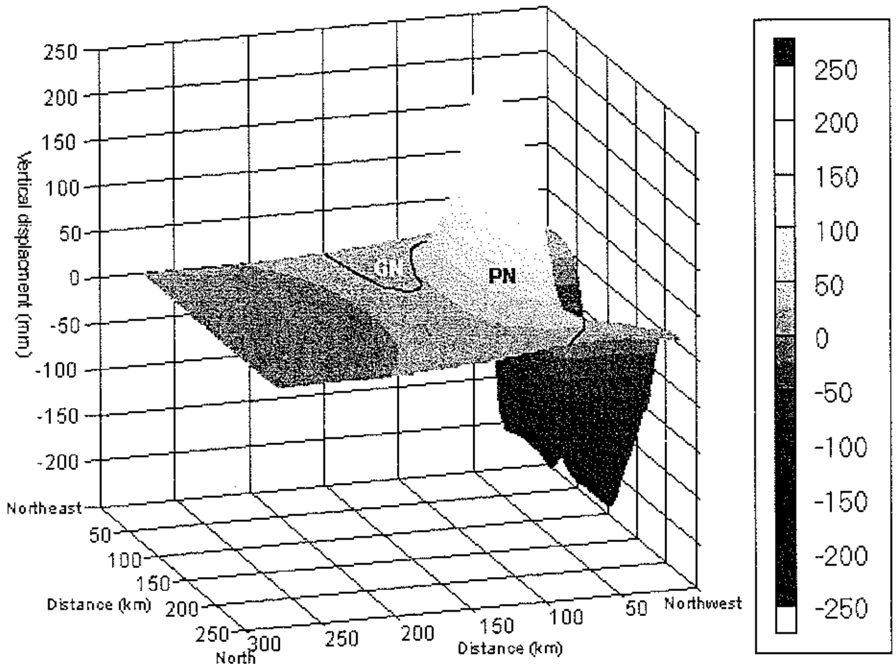
When you are interested in measuring elevation of benchmarks you have to first decide what king of exactness you require, then you choose what technique to apply (De Obaldia.et al.,1991). This led us to apply three different techniques and conduct and analysis and comparison of them:

Geometric leveling. Depending on the application, this technique receives three different names: leveling by heights, geodesic leveling and precision leveling (Jordan ,1996). Sights on a horizontal plane characterize this technique. The instrument is selected based on the application and required exactness. In our fieldwork we used a Nak2 Wild level, with a GpM3 micrometric parallel plate, which transforms the level into a first order level. This is an automatic level, which does not require centering the bubble each time you take a reading. We also used stuffs with invar tapes that are not susceptible to thermal contraction or expansion. Geodesic leveling is used at two different scales. Large-scale regional networks are occupied, in the case of Costa Rica, by IGN or the National Cadastre and are called official networks. Small or local scale networks are constructed and occupied for specific projects by institutions like OVSICORI-UNA with the goal of documenting crustal deformation.

Trigonometric leveling. In this leveling technique, sights are taken along inclined lines and therefore requires the use of instruments capable of measuring vertical angles and distances, values needed to compute the elevation difference between two points. Although this technique is not as precise as geometric leveling, it can reach the exactness of 5 to 10 mm per leveled kilometer (De Obaldia.et al.,1991). We used a Wild 2000 electronic theodolite, which gives vertical angles to half a second, and a WILD 3000 electronic distancemeter which can reach up to 14 km and have an mean error +-(5mm+1ppm).

Global positioning system (GPS). GPS gives tridimentional position of points in a geometrical and very precise way (Hollmann and Welsch.,1995).Conventionally all positions are given in global geocentric coordinates under the WGS84 reference frame. For our GPS occupations we utilized dual-frequency (L1 and L2) 4000 SI Trimble receivers and ground plate antennas. We monumented four sites (LOCA, KECK, COBA and

Figure 3. PN=Península de Nicoya, GN=Golfo de Nicoya. Three dimensional dislocation model of the uplfited forearc (Península de Nicoya) and subsided forearc basin (Golfo de Nicoya). View direction is south, shown by arrow on map below, with subduction of the Cocos plate to the northeast beneath the Carribean plate.



CONCLUSIONS

The main objective of completing a base-line survey is a success since a total of 8.5 km of trigonometric leveling is completed and ready to be reoccupied following a large seismic event. Future surveys can easily tie into this survey given the addition of six permanent monuments, three of which have absolute elevation as determined by GPS.

A comparison of survey techniques shows geometric leveling provides the greatest accuracy, but is too slow given the topography and vegetation. Trigonometric surveys are the fastest, but don't provide enough precision. On the other hand, GPS is both time effective and provides enough precision for geodetic point surveying to determine small amounts of deformation. When time and accuracy are important, a static style GPS campaign can cover a significant amount of terrain and provide enough resolution to determine small amounts of uplift.

Both the 1955 and 1998 surveys are snapshots in time, and when compared show the interseismic strain accumulation, manifested as uplift, within a single earthquake cycle. Because the surveys are contained within a single earthquake cycle, uplift rates spanning thousands of years cannot be determined. Relative elevation differences between the two surveys suggests arcward tilting of the peninsula at an angular rotation rate of 0.09°/k.y. The observed angular rotation of the peninsula towards the arc supports conclusions made by Marshall and Anderson (1995). This style of deformation is correlative with forward modeling predictions of an uplifted forearc high, subsided forearc basin, and resumed uplift at the foot of the arc. The plate geometry for the theoretical deformation indicates the Cocos plate is dipping 8° between the trench and the coast of the peninsula, where it steepens to 25°. Mechanisms for forearc deformation include interseismic accumulation of strain, coseismic release of strain, and/or underthrusting of buoyant oceanic seamounts from the Cocos Ridge.

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RINE) which also constituted anchor points in our geometric and trigonometric leveling lines. The first three sites were occupied with the GPS receiver for 4 to 5 consecutive days and the last one for only a day. The GPS campaign was carried out while conducting the leveling and the data was later processed at the Jet Propulsion Laboratory in Pasadena using the GIPSY software.

DISCUSSION

We call geodesic leveling to every line leveled twice by different surveyors each time, which has a final error equal or less than 1.5 mm times the square root of the total length (in km) of the line surveyed, and to which has been applied the required gravimetric corrections (we ignored this last condition given the short length of our line) (Valbuena and Dolores,1996).We conducted geodesic leveling between LOCA and KECK with an error of 0.07 mm in a 600 m line. Applying the above condition (1.5 mm * sqr(0.6 km) = 1.16 mm) we have that 0.07 mm is less than 1.16 mm and therefore our leveling line is considered a first order geodesic line.

For trigonometric leveling the tolerance is 2.5 mm times the square root of the total length (in km) of the line surveyed. We also conducted trigonometric leveling between LOCA and KECK and obtained a final error of 36 mm in a 402.13 m of surveyed line, which is way too large for the accepted tolerance (2.5 mm * sqr(0.4 km) =1.58 mm).

From the 1955 leveling the elevation difference between G-64 and G-66 was 14.878 m. Our trigonometric leveling between these same two sites gives an elevation difference of 14.9627 m, and therefore results in an elevation rate of 1.9 mm/year for G-66 with respect to G-64.

For the KECK-COBA baseline the computed elevation differences using GPS give a difference of 1.6 cm with respect to that obained with trigonometric leveling (table 1).

Table 1.Comparison between elevation differences obtained with the different techniques

Method	LOCA-KECK			KECK-COBA			RINE-G66		
Operator	Todd	Enrique	Difference	Todd	Enrique	Difference	Todd	Enrique	Difference
Geometric	23,217	23,2177	-0,0369				-1,2897	-1,2897	0
Trigonometric	23,2458	23,2539	-0,0081	6,0011	5,883552	0,117548	-1,2861	-1,2872	0,0011
GPS				5,896	5,896				

Table 1. Elevation differences between monuments ,data from Todd and Enrique,the geometric leveling have difference in millimeters,while trigonometric leveling has centimeters.

CONCLUSIONS

Each technique applied in our surveys has different precision and tolerances. The technique and instrumentation will determine the final precision obtained, and therefore have to be selected based on the required resolution and amount of expected deformation.

For geometric leveling the sources of error are the instrument and stuff hights, errors in hitting the target and refraction effects. Errors in trigonometric leveling are proportional to the segment length.

In our trigonometric leveling we recorded 30 measurements of angles and distances, but a post survey analysis of the mean quadratic errors indicated that 10 distance measurements and 10 angle readings (5 in position I and 5 in position II) are enough to obtain an acceptable mean quadratic error. Therefore, for the continuation of the leveling line, we recommend to save time at each locality by taking only 10 readings and thus have a larger coverage per day.

Based on the experience gained in theses survey I recommend the extensive use of GPS. The resolution and computational analysis of global positioning system data is becoming more precise every day.

Although geometric leveling gives the best resolution, the distances covered per day depend mainly on topographic conditions (very rough all over the Nicoya peninsula) and is very time consuming making it more expensive. If the expected amount of deformation is large (in the order of cm) trigonometric leveling constitutes a faster and cheaper technique with good enough resolution for the task required. Careful fieldwork, not too long shots and real-time computation in the field could help improve the resolution to the sub-centimeter level.

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