Research on Transferring the National Height System to the Island

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Abstract

It is quite difficult to transfer the National Height System 1985 to the island in China. In the study, one feasible and alternative way, which measures synchronally the tide variation at the island and the coast , is firstly introduced. Then, a new method is proposed. This new method combines GPS technique and Quasi-Geoid Determination technique (GQGD). It needs gravity data, GPS data, leveling data and DEM data, together with complex calculation method and the Earth gravity model. After describing the mathematical model and presenting the calculational steps, one experiment has been shown that this method is valid and can achieve accuracy up to 5 cm for the normal height, compared with the results both from the tidal observation and height approximation. Some suggestion is also given in the end.

Keywords: GPS-leveling; Tidal Observation; Quasi-Geoid; Normal Height

1. Introduction

The National Vertical Datum 1985 is the legal height system in China. It belongs to the normal height system. The reference surface, which is called the Quasi-geoid, is the mean sea level averaging 27-year tidal measurements recorded at Qingdao tidal station from 1952-1979. The national height system 1985 includes nearly a million height control points over all the China. It was widely used in the past fifty years in China.

In ocean mapping, it always uses the normal depth datum as the reference surface. The normal depth datum is not a unique reference surface around the coast from the south to the north in China. It varies with the location. The maximum difference reaches up to 70cm between the normal depth datum in the Chinese southern sea and that in the Bo Sea. Therefore, the national vertical datum 1985 is often used as the common height reference surface to unify the different height applications in ocean mapping.

The leveling is the principal way to transfer the height datum 1985 in the main land. But the leveling can not be used to transfer the height datum 1985 to one island. In this study, one feasible way, which is tidal observation, is firstly introduced. Then, the GPS combined Quasi-Geoid Determination (GQGD) is proposed and presented here. Based on the results analysis and comparison, the proposal method is shown that its ability is up to 5 cm to transfer the height datum 1985 to the island.

2. Tidal Observation

The quasi-geoid is almost the same as the geoid in the ocean. The geoid is the equipotential gravity, and it is the superposition to the static mean sea level. It means that the heights are identical over the mean sea level. Tidal measurement is now used to determine the mean sea level. According to the performance, determining the mean sea level can be used to transfer the height datum 1985 to the island. This way can be called as Tidal observation. The detail steps can be given as following.

(1) Establish the tidal stations in the island and the seashore, respectively.

(2) Synchronally record the tidal variations at two stations.

(3) Calculate the mean sea level and mark the position of mean sea level.

(4) Survey the height difference between the known 1985 height control point and the mark of mean sea level through the leveling.

(5) Survey the height difference between the unknown height point at the island and the mark of mean sea level the leveling.

(6) Calculate the 1985 height combining the above height difference.

In this way, it requires a long span of tidal measurements, such as a few days, even a few months. If there are only a few hour records, both ports should have the same spring-tide and ebb-tide time.

3. GPS combined Quasi-Geoid Determination

The relationship between the ellipsoidal height and the normal height can be described as

$$H=h+\xi \quad (1)$$

Where H means the ellipsoidal height above the ellipsoid, and h is the normal height above the quasi-geoid. ξ denotes the height anomaly from the ellipsoid and to the quasi-geoid. If the ellipsoidal height and the height anomaly are known, the normal height can be easily obtained through the above formula. This is the basic idea to transfer the national height system using the GPS technique combined the Quasi-Geoid Determination (GQGD).

The height accuracy from the GQGD depends on both of GPS positioning and the height anomaly. With the development of the past 10 years, the accuracy of GPS positioning can reach up to a few millimeters, and the technique of determining the quasi-geoid, which includes dense GPS-leveling data and gravity measurements, can also provide the quasi-geoid with few centimeters in a city or few decimeter over the entire world. That makes the possibility of transferring the normal height through the GQGD. Of course, this way also gives the idea to transfer the normal height from the main land to the island.

It is difficult to determine the quasi-geoid over the offing due to lock of dense GPS-leveling data and imprecision data of satellite altimetry. But there are a lot of marine gravity data over the offing. In this study, the inshore and offshore gravity data, together with GPS-leveling and Digital Elevation Model (DEM) data, have been involved in the determination of the quasi-geoid over the offing.

4. Method of determining the quasi-geoid over the offing

4.1 Gravity reduction

The gravity measurements are not evenly distributed over the inshore and offshore area. Based on the discrete gravity measurements, together with the 30"×30" DEM data, the Bouguer corrections on 2.5'×2.5' grid points can be calculated using dynamic approximation. Then, the free-air anomaly on 2.5'×2.5' grid points can be got using the Move-Restore technique, after considering the mean height over the 2.5'×2.5' grid.

4.2Free-air anomaly and quasi-geoid from the gravity model

Taking the 360-order EGM96 or WDM94 as the reference earth gravity model, it is easy to calculate the free-air anomaly and the height anomaly on the 2.5'×2.5' grid point.

4.3 Residual gravity anomaly

The residual of free-air anomaly is easily obtained on the 2.5'× 2.5' grid point after differencing the free-air anomaly calculated from gravity measurements in section 4.1 and that from model in section 4.2. Then, the residual of Faye anomaly can be obtained through adding the topographic correction. The residual of Faye anomaly will be used to determine the quasi-geoid.

4.4 Height anomaly and its residual

Based on the residual of Faye anomaly on the above grid points, the Molodensky formula, which combines the FFT technique, can be used to calculate the residual of height anomaly.

The height anomaly can be calculated from a reference earth gravity model, together with FFT technique. The true height anomaly equals to the sum of height anomaly from model and the above residual of height anomaly. All height anomalies on the grid points produce the quasi-geoid. Because this quasi-geoid is just calculated from the gravity measurement and DEM data, it is called as the gravimetric quasi-geoid.

4.5 Geometric quasi-geoid

The height anomaly, which can form the quasi-geoid, is also able to be calculated through the GPS height minus the leveling height. This kind of quasi-geoid is called as the Geometric quasi-geoid. Duo to the difference of gravity datum, the geometric quasi-geoid is not identical to the gravimetric quasi-geoid. There is a systematic bias. Therefore, the height anomaly from GPS-leveling is not equal to the height anomaly interpolated from the gravity quasi-geoid at the same point.

Based on the serial of difference from two kinds of height anomaly, it is easy to build the transformation relationship between geometric quasi-geoid and the gravimetric quasi-geoid, using the least-square method. Therefore, the height anomaly on the grid point of the gravimetric quasi-geoid can be transferred to that on the geometric quasi-geoid.

5. Experiment

In order to test the validity of the above two methods of transferring the national height system 1985 to one island, an experiment was organized in the Bo sea in China. A network was built as shown in figure 1, where LH01、LH02、LH03、LH04、LH05 and LH06 are the GPS-leveling points on the inshore area, but LH07 is a point on the island which is 16km away LH06.

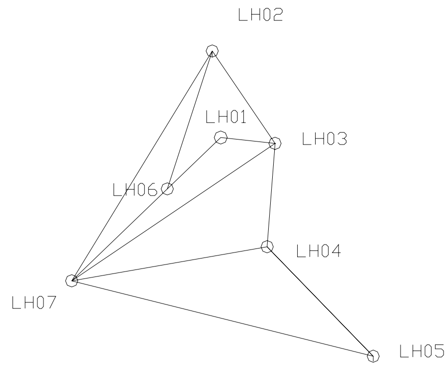

Figure 1 GPS Network

Tidal observation, GPS, leveling and quasi-geoid have been using the in the experiment. Each technique is described as:

5.1 GPS-leveling

The GPS field observations are arranged into 6 synchronous loops with TRIIMBLE 4700 GPS receiver. The observation lasts 2.5 hours at each station. The baselines are calculated through Trimble Geomatics Office (TGO) software (V1.50), and precise ephemeris from IGS is used here. All baseline solutions are passed the quality test.

In order to get the precise ellipsoidal height, three IGS stations: BJFS, SHAO and SUWN, together with LH05, are involved in the data-processing with GAMIT. After getting the geodetic height at LH05, the geodetic heights at the other points are obtained through the network adjustment, based on fixing LH05. The accuracy of these ellipsoidal heights is better than 3 cm.

The normal heights at LH01-LH06 are measured in leveling, and its accuracy is also better than 3 cm.

5.2 The quasi-geoid and normal height

According to the steps in section 3, the quasi-geoid over the offing is obtained. Then, the height anomaly at LH07 is interpolated through the quasi-geoid. Finally, the normal height can be got from the formula in section 2. It is 8.836m.

5.3 Tidal observation

The tidal observations are made at the close-by LH06 and LH07. The sampling interval is 10 minutes and the tidal observation lasts 3 hours. According to the tidal measurements at two sides, the mean sea levels are calculated during this period. Due to the same tidal characteristics at two ports, the mean of tidal measurements at two sides can be regarded as having the same height above the quasi-geoid. Then, the height differences are measured with Total Station from the mark of mean sea level to LH06 (and LH07, respectively). Finally, the normal height at LH07 can be derived from both height difference and the normal height through leveling at LH06. The result of height at LH07 is 8.887m.

6. Accuracy analysis

6.1 Additional point

In order to test the validity of the GQGD, LH01 is taken as an additional point without joining the above calculation. The difference is only 4.3cm between the normal height from the GQGD and that from leveling. This result reveals that the normal height from the GQGD is credible.

6.2 Tide measurement

Comparing the normal height at LH07 from the GQGD at section 5.2 and that from Tidal observation at section 5.3, their difference is only 5.1cm.

Additionally, one-month tide data are measured through the automatic pressure gauge. The mean sea level at situs can be obtained using the monthly mean sea level and other corrections including seasonal correction. It can be regarded that the mean sea level is nearly identical to the quasi-geoid. In that way, the height at LH07 is 8.88m above the mean sea level. It is only 4.4cm higher than that from the GQGD.

6.3 Height approximation

Based on the GPS network in figure 1, the normal height at LH07 is derived at 8.855m through the surface fitting including the topographic correction. Their difference is just 1.9cm compared to that from the GQGD.

7. Conclusion and suggestion

In the above experiment, their differences are less than 5 cm among the normal heights at LH07 from the GQGD, tide observations and height approximation. This reveals that the GQGD can give a good result better that 5cm to transfer the national vertical system from the main land to the island. It can be taken as a general method in the determining the normal height at an island.

Of course, the application of the GQGD will be limited on two factors. One is plenty of marine gravity measurements in the working area, and the other is the data of GPS-leveling at the inshore area. If the island is a few tens away the main land, the GQGD is still an expensive way in the application.

Tidal observation is a simple and low-cost way to transfer the normal height to the island. It needs a long span of tidal measurements. If the period is very short, such as a few hours, that must be certain of the same water body with the same tide characteristics at two ports. In the estuary or flood land, please be careful of using that. Moreover, the manual tidal observation also affects reading accuracy. Automatic tide-meter or tidal observation with GPS is suggested in the application.

If the island is less than 15km away the main land, and there are abundant GPS-leveling data at the inshore area, the height approximation is also able to give a satisfied result.

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