Geotechnical Aspects of Underground Construction in Soft Ground – Ng, Huang & Liu (eds)
© 2009 Taylor & Francis Group, London, ISBN 978-0-415-48475-6

GPS height application and gross error detection in foundation pit monitoring

H. Zhang
School of Safety and Resource Engineering, China University of Mining & Technology, Beijing, P.R. China

S.F. Xu
College of Architecture & Civil Engineering, Zhejiang University of Technology, Hangzhou, P.R. China

T.D. Lu
Department of Survey, East China University of Technology, Fuzhou, P.R. China

ABSTRACT: The author introduces a deformation monitoring model combined by traditional measuring technology and modern GPS measuring technology based on technical attribute of foundation pit deformation monitoring and author's experience of deep foundation pit construction project of underground tunnel in Lishui Road, Hangzhou city. When analyzing GPS height conversion, in order to improve GPS datum mark's reliability, one can use Dixon's test in GPS datum mark reliability test to find out height anomaly, thus provide convenience to search and delete marks with gross error. This test also improves deformation monitoring process's efficiency.

1 BACKGROUND PROJECT INTRODUCTION

Lishui Road (from Huzhou Road to Qingfang Road) project is one of Hangzhou City government's "33929" engineering project. The tunnel of the project is composed by U-tanks and box culverts. $1+568 \sim 1+638$, $1+794 \sim 1+864$ are U-tanks. Each tank is 70 m long and the width of banks is summed to 22 m. $1+638 \sim 1+794$ are box culverts. The sum of lengths of all box culverts reaches 156 m. Equally divided it into 4 parts, each box culvert is 38.25 m long and the width of all box culverts is summed to 21.4 m. Reinforced concrete piles with diameter of Φ 100 steel pipe were taken as support. They are 21 m long with concrete outside. The concrete piles with Φ60@30 were used to keep dry from water. The depth of concrete pile is 10 m. They are connected to each other side by side. The steel in the shape of $\mathcal{I}$ is used as the inside supports. The distance between two supports is 6 m wide. The depth of the foundation pit is 8 m. This foundation pit is level 2 foundation pit. The construction's ± 0.000 m level is equal to Huanghai height $+4.125$ m. The situation around site area is quiet complex, especially Jinghang Canal on the west side of site and ancient municipal heritage Gongcheng Bridge which is close to the nadir of underground lot, smallest distance is about 2 m.

2 GPS HEIGHT APPLICATION

GPS positioning technology has advantages such as no need of keeping vision between measuring stations, not restrained by weather conditions, able to measuring the target's 3D displacement and highly automated. The accuracy of short distance deformation monitoring can reach minor millimeter level[1], thus provides a new method for high-accuracy deformation monitoring of large construction and foundation pit. In Lishui Road project's case the visibility condition in foundation pit construction site is bad and most datum marks can't share vision, monitoring marks and datum marks are in different height, and also there is a across-river benchmark problem. To solve these problems above, this project take a monitoring plan using both modern and traditional measuring technology: using GPS technology to set up a 3D datum mark network, and using traditional measuring methods to monitor after the network is established[2].

After adjusting GPS measuring results, the outcome height is geodetic height H_{GPS} relevant to WGS-84 ellipsoid. Since the benchmark height (normal height) is using in foundation pit engineering application, the geodetic height H_{GPS} should be transferred into normal height H_0 in this project. The difference between normal and geodetic height is called height anomaly[3]:

$$\xi = H_{GPS} - H_0 \tag{1}$$

In solving GPS height anomaly, known marks height anomaly value's reliability is crucial to solving result accuracy. Because of restraint from site condition, it is impossible to have enough GPS marks meet benchmarks or taking benchmark co-measuring. So every single mark's height anomaly value will make considerable affect to calculating result accuracy, a mark with gross error height anomaly value could even lead to a totally useless result and complete failure. Thus the initial data should take a gross error test. During the test, the data is normally checked by geometric conditional closure, like triangle closure in triangle network or pole condition closure, which monitoring value must meet or by residual from adjustment error. Since gross error is hard to distinguish from limited error, this method is hard to discover small gross error. Also it is hard to find applicable geometric condition closure during GPS height transferring. To solve this problem, one can pick up some trustful geometric benchmark spot height and geodetic height in the GPS network to fit other benchmark height, or pick some spot separately to processing repetitive trail calculation, then obtain other measured geometric benchmarks' trail height with mathematic model from fit and using the equation below to obtain fit residual:

$$V_i = H_i' - H_i = \zeta_i - \zeta_i' \tag{2}$$

H_i', ζ_i' is trail height and trail height anomaly, H_i, ζ_i is measured benchmark height and measured height anomaly. Then, one can use residual to process relevant spots' measured benchmark height gross error test, after carefully analysis of measured value with gross error, select enough reliable measured value to run fit again.

3 HEIGHT ANOMALY GROSS ERROR TEST METHOD

According to Dixon Test [4], assume there're a set of residual $V_1, V_2, \cdots V_n$, sort them from low to high, and get a sequence like below:

$$V_{(1)} \le V_{(2)} \le \cdots \le V_{(n)}$$

Then we have:

$$\begin{aligned}
r_{10} &= \frac{V_{(n)} - V_{(n-1)}}{V_{(n)} - V_{(1)}} & r_{10}' &= \frac{V_{(1)} - V_{(2)}}{V_{(1)} - V_{(n)}} \\
r_{11} &= \frac{V_{(n)} - V_{(n-1)}}{V_{(n)} - V_{(2)}} & r_{11}' &= \frac{V_{(1)} - V_{(2)}}{V_{(1)} - V_{(n-1)}} \\
r_{21} &= \frac{V_{(n)} - V_{(n-2)}}{V_{(n)} - V_{(2)}} & r_{21}' &= \frac{V_{(1)} - V_{(3)}}{V_{(1)} - V_{(n-1)}} \\
r_{22} &= \frac{V_{(n)} - V_{(n-2)}}{V_{(n)} - V_{(3)}} & r_{22}' &= \frac{V_{(1)} - V_{(3)}}{V_{(1)} - V_{(n-2)}}
\end{aligned} \tag{3}$$

If one from $r_{10}, r_{11}, r_{21}, r_{22}$ and $r_{10}', r_{11}', r_{21}', r_{22}'$ is larger than critical value, then we can consider $V_{(n)}$ or $V_{(1)}$ as anomaly value. After analyzes the sensitivity of anomaly in r statistics test, Dixon claimed that when $3 \le n \le 7$, it is better to use r_{10} or r_{10}'; when $8 \le n \le 10$, use r_{11} or r_{11}'; when $11 \le n \le 13$, use r_{21} or r_{21}'; when $14 \le n \le 25$, use r_{22} or r_{22}'.

It is natural to use different statistics depending on different n. When n is small, range estimation has a better efficiency, but while n become larger, range estimation's efficiency decrease accordingly. So when n is relevant large, use range $V_{(n)} - V_2$ or $V_{(n)} - V_{(3)}$ to estimate. Statistics r_{ij} or r_{ij}''s critical value is given in $r(n, \alpha)$ in reference[4]. α is Type 1 probability, also called significance. Its value usually is 0.05 or 0.01.

When running the test, one can calculate and discriminate from both ends of residual sequence separately, until there is no gross error suspicion in both ends of the test.

4 GROSS ERROR TEST EXAMPLE

In Lishui Road underground tunnel foundation pit construction project, the datum marks are the deformation monitoring datum control system. So they are usually built in the area outside and far from the construction site to maintain their stability. They should not be too far though for the consideration of having better monitoring accuracy and also for our convenience of work. Our monitoring network is divided into two levels. The first level of monitoring network is composed by the datum marks and working spots, measured once a week to maintain its stability. The second level of the network is set up by working spots and monitoring spots, using stable datum marks to verify working spots. Six datum marks were set up: four are at the east bank and other two are at west bank of the ancient Jinghang Canal. Using GPS to introduce the two datum marks at west bank of the canal to the canal's east in favor of monitoring network. The datum network is surveyed four times; following the official construction standards entitled "Global Positioning System for Urban Survey Technique standards" CJJ73-97. Three

Trimble 4600LS GPS single-frequency receivers were set up to receive the signal at the same time. The observation time lasted more than 90 min. Information from 5–10 satellites were efficiently received. The elevation angle of satellites is ≥ 15 degree and a break of 20 sec was set for every two observations. 12 base lines were observed and four of them are the repeat ones. Specific software provided by America supplier was employed to process the data and to carry out the effective solutions. The maximum of error is about ± 5 mm while the minimum is ± 2 mm. The observation results were further checked by time synchronized and unsynchronized circle. Datum height network monitoring data is fit from 4 spots and 16 sets of data of GPS benchmarks' geometric benchmark height residual.

Running Dixon test, first discriminate the largest residual $V_{(16)}$, since $n = 16$, so take r_{22} and r'_{22} as statistics.

$$r_{22} = \frac{V_{(16)} - V_{(14)}}{V_{(16)} - V_{(3)}} = \frac{0.018 - 0.011}{0.018 + 0.010} = 0.250$$

Using $n = 16$, $\alpha = 0.05$ as argument, according to table[4], $r_0(16, 0.05) = 0.507$, since $r_{22} < r_0(16, 0.05)$, the conclusion is the geometric benchmark height which $V_{(16)}$ refers to doesn't have gross error. Discrimination of smallest residual $V_{(1)}$:

$$r'_{22} = \frac{V_{(1)} - V_{(3)}}{V_{(1)} - V_{(14)}} = \frac{-0.039 + 0.010}{-0.039 - 0.011} = 0.580$$

As $r'_{22} > r_0(16, 0.05)$, the conclusion is the geometric benchmark height which $V_{(1)}$ refers to has gross error, should be eliminated.

After the elimination of residual $V_{(1)}$, the both ends test should be run again.

First discriminate the largest residual $V'_{(15)}$

$$r_{22} = \frac{V'_{(15)} - V'_{(13)}}{V'_{(15)} - V'_{(3)}} = \frac{0.018 - 0.010}{0.018 + 0.005} = 0.348$$

Using $n = 16$, $\alpha = 0.05$ as argument, according to table[4], $r_0(15, 0.05) = 0.525$, since $r_{22} < r_0(15, 0.05)$, the conclusion is the geometric benchmark height which $V'_{(15)}$ refers to doesn't have gross error. Then test the smallest residual $V'_{(1)}$:

$$r'_{22} = \frac{V'_{(1)} - V'_{(3)}}{V'_{(1)} - V'_{(13)}} = \frac{-0.025 + 0.005}{-0.025 - 0.010} = 0.571$$

Since $r'_{22} > r_0(15, 0.05) = 0.525$, and $r'_{22} < r_0(15, 0.01) = 0.616$ it can be concluded that the geometric benchmark height which $V'_{(1)}$ refers to doesn't have gross error.

5 CONCLUSION

With GPS technology's widely application, people can simply and efficiently obtain horizontal accuracy of certain spot on minor millimeter level, but still can't obtain the spot's height on same accuracy level. So in order to extend GPS's superior ability in surveying 3D displacement, we should put our efforts on researching how to improve GPS survey accuracy of vertical displacement, thus it can match with survey accuracy of horizontal displacement. The reason why GPS has a low survey accuracy of vertical displacement is that though GPS could provide a high accuracy geodetic height, the lack of a geodic model with relevant accuracy lead to a serious accuracy decrease during transferring from GPS geodetic height to normal height. To seek the GPS height anomaly's value, the reliability of known spots' height anomaly value is critical to result's accuracy[5], is the key to improve vertical deformation accuracy. To apply the GPS height survey in our project's foundation pit monitoring, the questions below should be considered:

1. Height anomaly is unstable, it maybe smooth in small range or flat-contour region, where height datum network of foundation pit monitoring is often established, thus is easy to seek anomaly value; but it is very variant in wide range or complex contour region, possible to occur several value with high residual. So in order to improve reliability of gross error detection, when discriminated an anomaly value, one should analyze carefully before delete it.
2. In calculation of GPS height anomaly, the source of error is various; it could be surveying error of GPS geodetic height or GPS geodetic height difference, or error from geometric benchmark surveying. This problem directly leads to a difficulty of deciding error distribution pattern for height anomaly. Since test method usually run in a certain error distribution pattern, (e.g. Dixon test, requires residual is random sample from normal distribution) the credibility of using this test to run gross error detection is decreased in real application.
3. Many factors could affect GPS height component accuracy. Various measures should be taken to guarantee the accuracy in specific projects. Minimize the multipath effect when surveying with GPS in urban area, choosing geodetic type of GPS to monitoring datum during foundation pit construction period. Experience proved that using these methods not only avoid the restrictions brought to site conditions from conventional methods, but also improve working efficiency and assure construction quality.

GPS static relative positioning survey has tremendous practical significance to precise engineering survey. With the reasonable monitoring plan according to engineering condition and purpose, its accuracy could meet almost every requirements of precise engineering survey. It also has multiple advantages such as low cost, high efficiency and a high degree of automation. The application in Lishui Road foundation pit project is a useful experience.

REFERENCES

Li, Z.H. & Huang, J.S. *GPS measurement and date process*. Wuhan: Wuhan University Press, 2005

Lu, T.D. Zhou, S.J. Guan Y.L. Height anomaly Gross Error Test and Analysis in GPS Height Conversion. *Geotechnical Investigation & Surveying*, 2004(4) 51–54

Yang, J.T. Jiang Y.X. Zhou J. Analysis on Reliability and Accuracy of Subsidence Measurement with GPS Technique. *Journal of Geodesy and Geodynamics*, 2006(1) 70–75

Zhang, H. & Gu, J.S. Deformation monitoring and data analysis of foundation in municipal engineering. *Journal of Zhejiang University of Technology*, 2003(5) 571–574

Zhang, F.G. & Zhang J.Y. *Statistical Distribution and Test of Survey Error*. Beijing: China Measurement Press, 1991