The Datum Design Study of High Precision GPS Height Monitoring Network----with the Example of Monitoring Land Subsidence & Ground Fissure in Xi'an City

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Abstract

There are still some key problems having to be solved in theory and technique applications when GPS is used to monitor the vertical deformation of ground with high precision. Utilizing the GPS technology to monitor the deformation of the land subsidence and ground fissure in Xi'an, this paper puts forward advice that the datum frame of GPS network has significant influence on the precision and accuracy of the vertical deformation results by some research. The co-authors make some theoretical study of the datum error and practice by establishing the datum error models, especially the influence of scale and azimuth datum errors on GPS monitoring network. Then the datum frame design methods and arithmetic of GPS monitoring network are presented and have taken a good effect.

Keywords: datum design, datum model, GPS height monitoring network, land subsidence, ground fissure

1. Introduction

With the rapid development of GPS technology, it has become one major means of deformation monitoring. Relative to the high precision of plane position ($\pm 1 \sim 3mm$, or $10^{-9}\,ppm$) in deformation monitoring, the height precision is usually lower two or three times than the plane precision, even much lower on account of the most errors of GPS positioning mainly affect the GPS height. Therefore, there are some key problems having to be solved in theory and technique applications when GPS is used to monitor the vertical deformation of ground with high precision, such as the eliminating of troposphere refraction errors, satellite ephemeris errors, clock offset, multipath errors and the choice of deformation monitoring datum, etc. Through utilizing the GPS technology to monitor the deformation of the land subsidence and ground fissure in Xi'an, this paper puts forward advice that the datum frame of GPS network has significant influence on the height precision and accuracy by some research. The co-authors make some theoretical study of the datum error and practice by establishing the datum error models, especially the influence of azimuth datum errors on GPS monitoring network. Then the datum frame design methods and arithmetic of GPS monitoring network are presented. The practice application indicates that those methods and arithmetic have taken a good effect.

2. The adjustment model and the datum model of GPS monitoring network

2.1 The adjustment model of GPS monitoring network

The baseline vector (Δx_{ij} , Δy_{ij} , Δz_{ij}) of GPS monitoring observation is the vector with scale and azimuth datum. Because of the influence of troposphere refraction errors, satellite ephemeris errors and other errors in GPS surveying, the GPS deformation monitoring value of disparate periods may have systemic differences in scale and azimuth. Whereas the deformation analysis must be based on the same and stabile datum, so the adjustment model of GPS baseline vectors must include one scale datum parameter(u) and three azimuth datum parameters(ε_X , ε_Y , ε_Z). Thus the systemic differences of GPS observations can be eliminated in disparate periods.

For the observations of m period, there are the observation equations:

$$\begin{bmatrix} \Delta\hat{X}_{ij}(m) \\ \Delta\hat{Y}_{ij}(m) \\ \Delta\hat{Z}_{ij}(m) \end{bmatrix} = \begin{bmatrix} \Delta X_{ij}(m) \\ \Delta Y_{ij}(m) \\ \Delta Z_{ij}(m) \end{bmatrix} + \begin{bmatrix} V_{\Delta x_{ij}}(m) \\ V_{\Delta y_{ij}}(m) \\ V_{\Delta z_{ij}}(m) \end{bmatrix} + u(m) R_x R_y R_z \begin{bmatrix} \Delta X_{ij} \\ \Delta Y_{ij} \\ \Delta Z_{ij} \end{bmatrix} \quad (1)$$

In this equations, $\left(\Delta\hat{X}_{ij}(m) \quad \Delta\hat{Y}_{ij}(m) \quad \Delta\hat{Z}_{ij}(m)\right)^T$ denote the adjustment value of GPS observations, $\left(\Delta X_{ij}(m) \quad \Delta Y_{ij}(m) \quad \Delta Z_{ij}(m)\right)^T$ denote GPS observations, and $\left(V_{\Delta x_{ij}}(m) \quad V_{\Delta y_{ij}}(m) \quad V_{\Delta z_{ij}}(m)\right)^T$ denote corrections of GPS observations.

Because ε_X , ε_Y , ε_Z are minute value, $R_x R_y R_z$ can be linearized to equation (2):

$$R_x R_y R_z = \begin{bmatrix} 1 & \varepsilon_Z & -\varepsilon_Y \\ -\varepsilon_Z & 1 & \varepsilon_X \\ \varepsilon_Y & -\varepsilon_X & 1 \end{bmatrix} \tag{2}$$

Substituting equation (2) into equation (1), then we have the error equations:

$$\begin{bmatrix} V_{\Delta x_{ij}(m)} \\ V_{\Delta y_{ij}(m)} \\ V_{\Delta z_{ij}(m)} \end{bmatrix} = -\begin{bmatrix} d\hat{X}_i(m) \\ d\hat{Y}_i(m) \\ d\hat{Z}_i(m) \end{bmatrix} + \begin{bmatrix} d\hat{X}_j(m) \\ d\hat{Y}_j(m) \\ d\hat{Z}_j(m) \end{bmatrix} + \begin{bmatrix} \Delta X_{ij}^0 \\ \Delta Y_{ij}^0 \\ \Delta Z_{ij}^0 \end{bmatrix} u(m) + \begin{bmatrix} 0 & -\Delta Z_{ij}^0 & \Delta Y_{ij}^0 \\ \Delta Z_{ij}^0 & 0 & -\Delta X_{ij}^0 \\ -\Delta Y_{ij}^0 & \Delta X_{ij}^0 & 0 \end{bmatrix} \begin{bmatrix} \varepsilon_x(m) \\ \varepsilon_y(m) \\ \varepsilon_z(m) \end{bmatrix} - \begin{bmatrix} L_{\Delta x_{ij}} \\ L_{\Delta y_{ij}} \\ L_{\Delta z_{ij}} \end{bmatrix} \tag{3}$$

Where,

$$\begin{bmatrix} \hat{X}_{ij}(m) \\ \hat{Y}_{ij}(m) \\ \hat{Z}_{ij}(m) \end{bmatrix} = \begin{bmatrix} X_i^0 \\ Y_i^0 \\ Z_i^0 \end{bmatrix} + \begin{bmatrix} d\hat{X}_i(m) \\ d\hat{Y}_i(m) \\ d\hat{Z}_i(m) \end{bmatrix} \tag{4}$$

$$\begin{bmatrix} L_{\Delta x_{ij}}(m) \\ L_{\Delta y_{ij}}(m) \\ L_{\Delta z_{ij}}(m) \end{bmatrix} = \begin{bmatrix} X_j^0 - X_i^0 - \Delta X_{ij} \\ Y_j^0 - Y_i^0 - \Delta Y_{ij} \\ Z_j^0 - Z_i^0 - \Delta Z_{ij} \end{bmatrix} = \begin{bmatrix} \Delta X_{ij}^0 - \Delta X_{ij} \\ \Delta Y_{ij}^0 - \Delta Y_{ij} \\ \Delta Z_{ij}^0 - \Delta Z_{ij} \end{bmatrix} \tag{5}$$

Let t points composing n baseline vectors of GPS monitoring network:

$$\underset{3t\times 1}{D}\hat{X}(k) = \left[d\hat{X}_1(m) \quad d\hat{Y}_1(m) \quad d\hat{Z}_1(m) \quad \cdots \quad \cdots \quad \cdots \quad d\hat{X}_t(m) \quad d\hat{Y}_t(m) \quad d\hat{Z}_t(m) \right]^T \tag{6}$$

$$\underset{4\times 1}{\hat{\beta}} = \left[\hat{u}(m) \quad \hat{\varepsilon}_x(m) \quad \hat{\varepsilon}_y(m) \quad \hat{\varepsilon}_z(m) \right]^T \tag{7}$$

then we have the error equation：

$$V(k) = A_x D\hat{X}(k) + A_\beta \hat{\beta} + L(k) \tag{8}$$

2.2 The adjustment datum model of GPS monitoring network

The deformation analysis must be based on the high precision and stabile datum frame. In deformation monitoring, the same monitor data even can acquire different results if the datum frame is different. Therefore, the proper and rational choice of the datum frame has significant influence on the realization of the high precision deformation monitoring.

The GPS three-dimension monitoring network adjustment model usually can be divided two datum models according to the different choice of datum frame. They are the fixed datum model and the barycenter datum model.

2.2.1 The fixed datum model

When a GPS deformation monitor network has three or more stabile and high precision known points, then those points can constitute the constrained conditions of the fixed datum. And they can give the strong datum constraint for every periods monitor data:

$$\underset{3t_0\times 3t}{B} \cdot \underset{3t\times 1}{DX} + \underset{3t_0\times 1}{W} = 0 \tag{9}$$

Where t_0 denotes the numbers of known points.

In $3t_0$ datum equations, there are three kinds datum conditions:

① Position datum conditions:

$$\begin{cases} DX_i = 0 \\ DY_i = 0 \\ DZ_i = 0 \end{cases} \tag{10}$$

② Scale datum conditions:

$$\left((X_j - X_i)^2 + (Y_j - Y_i)^2 + (Z_j - Z_i)^2 \right)^{1/2} - S_{ij} = 0 \tag{11}$$

③ Azimuth datum conditions:

$$arctg \frac{(Z_k - Z_i)}{\left((X_k - X_i)^2 - (Y_k - Y_i)^2 \right)^{1/2}} - \alpha_{ik} = 0 \tag{12}$$

Taking equation (9) as the constrained conditions and combining it with equation (8), then we can solve the two equations by the least squares method:

$$\begin{bmatrix} D\hat{X} \\ \hat{\beta} \end{bmatrix} = N^{-1} \left(\begin{bmatrix} A_X^T \\ A_\beta^T \end{bmatrix} P_X L - B_X^T K \right) \tag{13}$$

Where,

$$N = \begin{bmatrix} A_X^T \\ A_\beta^T \end{bmatrix} P_X \begin{bmatrix} A_X & A_\beta \end{bmatrix} = \begin{bmatrix} A_X^T P A_X & A_X^T P A_\beta \\ A_\beta^T P A_X & A_\beta^T P A_\beta \end{bmatrix} \tag{14}$$

$$K = B N^{-1} B^T \left[W - B N^{-1} \begin{bmatrix} A_X^T P_X L \\ A_\beta^T P_X L \end{bmatrix} \right] \tag{15}$$

If the continuous GPS tracking stations are adopted as the datum points, the datum conditions must consider the velocity of those points because those points not only have the high precision coordinates but also have the velocity brought by the plate motion. In addition, if the tracking stations' precision is considered, we can adopt the loose constraint to this datum conditions, i.e. the weak datum constraints, by adding the root mean square errors of every point's coordinate components.

2.2.2 The barycenter datum model

When the stabile points are less than three in deformation monitoring network, this deformation monitoring network is a rank defect network. Then the barycenter datum constraint conditions can be adopted.

$$G_X^T DX + G_\beta^T \hat{\beta} = 0 \tag{16}$$

Where,

$$G_X^T = \begin{bmatrix} 1 & 0 & 0 & 1 & 0 & 0 & \cdots & \cdots & \cdots \\ 0 & 1 & 0 & 0 & 1 & 0 & \cdots & \cdots & \cdots \\ 0 & 0 & 1 & 0 & 0 & 1 & \cdots & \cdots & \cdots \\ -X_1^0 & -Y_1^0 & -Z_1^0 & -X_2^0 & -Y_2^0 & -Z_2^0 & \cdots & \cdots & \cdots \\ 0 & -Z_1^0 & Y_1^0 & 0 & -Z_2^0 & Y_2^0 & \cdots & \cdots & \cdots \\ Z_1^0 & 0 & -X_1^0 & Z_2^0 & 0 & -X_2^0 & \cdots & \cdots & \cdots \\ -Y_1^0 & X_1^0 & 0 & -Y_2^0 & X_2^0 & 0 & \cdots & \cdots & \cdots \end{bmatrix} \tag{17}$$

$$G_\beta^T = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{18}$$

According to the circumstances of the known stabile points in GPS deformation monitoring network, the barycenter datum model can be divided several forms as follows:

① If there has no known stabile points in deformation monitoring network, we can choose equation (16) as the barycenter datum conditions. In this circumstance, the barycenter position, the barycenter scale and the barycenter azimuth of the network's approximate coordinates are selected as the deformation monitoring network datum.

② If there has one known stabile point in deformation monitoring network, the known point can be chose as the fixed position datum. And the scale and azimuth datum still adopt the barycenter datum. Here only the front three lines are not zero in the front three row of the matrix of $\hat{G}_X^T$.

③If there has two known stabile points in deformation monitoring network, we can choice the fixed position and scale datum and the barycenter azimuth datum, or the fixed position and azimuth datum and the barycenter scale datum as the datum. The fixed datum conditions can adopt corresponding datum equation as equation (9). And the barycenter datum conditions can be composed by the corresponding row in the matrix of $\hat{G}_X^T$

④If there has three or more known stabile points in deformation monitoring network, those stabile points' barycenter datum can be selected as the datum. Here the every row and line of $\hat{G}_X^T$ are all zero except the corresponding line of those points' three-dimension coordinates which can hold its value.

Substituting equation (16) into equation (8), then we can get equation (19) by the least squares method:

$$\begin{bmatrix} D\hat{X} \\ \hat{\beta} \end{bmatrix} = \left(N + G\left(\left(G_S^T G \right)^{-1} G_S^T \right)^{-1} \right)^{-1} U \tag{19}$$

Besides those two kinds of datum, the free network adjustment method is usually adopted in GPS data processing. In this method, one GPS point is chosen as the position datum conditions, and the weighted mean scale and azimuth information that included in GPS observations are selected as the scale and azimuth datum.

3. The choice of datum and its influence on the deformation results

The phenomenon always occurs in GPS data processing that is we obtained the different results even if we used the same software and the same observation data. Sometimes this difference may become very big. One important reason lead to this phenomenon is that the adjustment datum is used different in data processing. Then how much does the different datum influence on the deformation analysis? And how is the adjustment datum chosen rationally? The co-authors make some theoretical study and analysis aiming at this problem.

3.1 Free network adjustment

There is no problem that the disturbed results are caused by the incompatible external datum because the scale and azimuth information included in each period GPS observations are adopted as the datum in free network adjustment. But the different systemic errors are always existed in GPS baseline vectors observed in different sessions, so the deformation analysis results may be distorted due to the nonuniform datum.

For this adjustment model, we can educe the disturbed results brought by the scale and azimuth systemic errors:

$$\begin{bmatrix} \delta X \\ \delta Y \\ \delta Z \end{bmatrix} = -\left(A_\beta^T P A_\beta\right)^{-1}\left(A_x^T P A_\beta\right)\beta \tag{20}$$

Then we can educe the influences about geodetic coordinate by the relations between the space three-dimension rectangular coordinate system and the geodetic coordinate system:

$$R = \begin{bmatrix} -\dfrac{\rho \sin B_i \cos L_i}{M_i + H_i} & -\dfrac{\rho \sin B_i \sin L_i}{M_i + H_i} & \dfrac{\rho \cos B_i}{M_i + H_i} \\ -\dfrac{\rho \sin L_i}{(N_i + H_i)\cos B_i} & \dfrac{\rho \cos L_i}{(N_i + H_i)\sin B_i} & 0 \\ \cos B_i \cos L_i & \cos B_i \sin L_i & \sin B_i \end{bmatrix} \tag{21}$$

$$\begin{bmatrix} \delta B \\ \delta L \\ \delta H \end{bmatrix} = -R\left(A_\beta^T P A_\beta\right)^{-1}\left(A_x^T P A_\beta\right)\beta = R\begin{bmatrix} \delta X \\ \delta Y \\ \delta Z \end{bmatrix} \tag{22}$$

It has proved by the characteristics of GPS error source and the practice that the influences on the GPS height measurements can achieve several centimeters, even much more in some extreme circumstances that are brought by the difference of the system errors of satellite ephemeris errors, clock offset and atmosphere refraction errors in different times. So the free network adjustment model and datum cannot be adopted in the deformation monitoing by GPS, especially when the GPS height is used to monitor the vertical deformation of land subsidence & ground fissure.

3.2 The barycenter adjustment datum

Another optional datum is the barycenter datum in GPS deformation monitoring. This datum takes the network's barycenter scale and azimuth as its datum and one stabile point or the network's barycenter coordinates as the position datum. It keeps the unchangeable datum of the network's barycenter position, barycenter scale and azimuth after adjustment. This datum is fit for the deformation monitor network that all points have the same degree of deformation or stabilization. But it will smooth the true deformation when the deformation of each point of the network has large difference. Therefore the applicability of the barycenter adjustment datum is limited by its characteristics in deformation monitor data processing.

3.3 The fixed adjustment datum

The stabile fixed adjustment datum can be provided when the GPS deformation monitor network has three or more stabile and high precision known points. Then we can get the adjusted displacement value of sever periods by the equation (8) and (9) according to the least squares adjustment method with the constraint conditions. But in this case there are more than seven constraint condition equations of the essential datum equations of GPS three-dimension network. Thus the network will be distorted by the datum errors after adjustment when there are differences and errors between the datum points. We can obtain the influences on the adjusted coordinates brought by the strong constraint conditions through the least squares adjustment model:

$$\delta X = N^{-1}B\left(B^T N^{-1} B\right)^{-1}\Delta_W \tag{23}$$

Where Δ_W denotes the error of constraint condition equation:

$$\underset{d\times 1}{\Delta_W} = B_\Delta X + W_\Delta \tag{24}$$

And d denotes the numbers of the constraint condition equations with errors. It can be rewritten as:

$$B_\Delta X + W_\Delta - \underset{d\times 1}{\Delta_W} = 0 \tag{25}$$

The degree of the network's distortion induced by the datum error is not only related to the value of the datum errors, but also related to the network's structure and the distributing of the datum points. So sometimes the distortion of the deformation value cannot be ignored which brought by the datum error.

3.4 Quasi－stable adjustment datum

In order to overcome the distortion induced by the strong constraint datum, the quasi－stable adjustment to take the barycentre of the stabile points as its datum when there are three or more stabile points in GPS deformation monitor network is an efficacious data processing method, besides using the stabile and high precision known datum points.

4. The datum study of the land subsidence & ground fissure monitoring data of GPS in Xi'an

4.1 The monitoring scheme of the land subsidence and ground fissure in Xi'an

Xi'an is an old famous civilized capital city with a long history, and also the economic and cultural center of northwest area in China nowadays. Since the 1950s, the geological hazards of land subsidence and ground fissure have gradually occurred in Xi'an. Those hazards have done great harm to people's life and city construction, and severely affect the development of the city in the same time. Therefore, in order to hold and understand the inducement mechanisms, the changing laws and the influence ranges of those geology hazards, the GPS monitoring network of land subsidence and ground fissure is designed and established in Xi’an city. Thus, the deformation and development laws of land subsidence and ground fissure can be accurately spotted with the help of the GPS technology and other monitoring methods, and the base information can be provided for hazards control and reduction about city construction and development as well.

4.2 The general situation of the GPS monitoring network and the monitor surveying in Xi'an

The GPS monitoring network in Xi'an is composed of 24 GPS monitoring points (see the figure 1). And the three grades network is adopted to monitor the vertical deformation of the land subsidence and ground fissure in Xi'an city with high precision and accuracy. The first grade network is the datum network with 6 stabile GPS monitoring points. The length between datum points is no more than 30km. Three GPS continuous tracking stations XIAA (in Xi’an), XANY(in Xi’an) and BJFS (in Beijing) are adopted as the stabile known points in the datum network. The second grade network is the basic network with 8 GPS monitoring points. Those points are distributed in the center of subsidence funnels and mainly used to monitor the land subsidence in Xi'an. The third grade network is the ground fissure monitor network with of 8 points that are distributed the two sides of the ground fissure for monitoring the 3-dimensional deformation characteristics of the ground fissure.

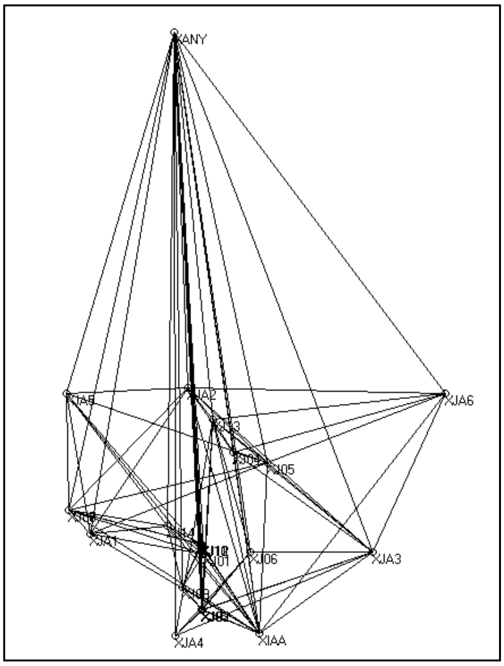

Figure 1. The distributing of the datum and monitor points.

On November 2005, the first period GPS observation started and the GPS monitor points were measured in the networks and the second period GPS observation was completed on June 2006. The GPS measuring adopted the static relative positioning technique by using the double frequency receivers with choke ring antennas. The least observation time is no less than 36 hours in the first period. In the second period, the observation time is extended to 72 hours.

4.3 The data processing and the datum study of the GPS monitor network in Xi’an

The baseline vectors were solved by the GAMIT/GLOBK software developed by MIT and Scripps when every period observation was finished. The network adjustment was done by the software developed by our research group.

Three datum points XIAA, XANY and BJFS are adopted in the data processing of the GPS monitor network in Xi’an city. They are all the continuous GPS tracking stations with high precision and accuracy. So we can use those datum points as the constraint conditions to do some studies on the choice of datum and its influence on the deformation results. The initial study schemes are as follows:

Scheme 1: Three datum points are all used as the constraint conditions to do the adjustment of the monitor network.

Scheme 2: Two datum points (BJFS and XANY, or BJFS and XIAA, or XIAA and XANY) are used as the constraint conditions for the adjustment of the monitor network.

Scheme 3: Only one datum point (BJFS, or XIAA, or XANY) is used as the constraint conditions to do the adjustment of the monitor network (Free network adjustment).

The results of those schemes are listed on table 1.

Table 1. The vertical deformation value of the GPS monitor points on different adjustment datum.

Points name	The vertical deformation value of GPS monitor points (mm)						
	Scheme 1	Scheme 2			Scheme 3		
	A	B	C	D	E	F	G
XJ01	-17.1	-15.2	-14.8	-13.8	-6.4	-13.6	-14.0
XJ02	-26.0	-27.4	-23.3	-28.9	-21.9	-29.1	-29.4
XJ03	-14.4	-15.3	-11.7	-16.4	-9.3	-16.6	-16.9
XJ04	0.0	-1.2	2.8	-2.0	5.0	-2.2	-2.5
XJ05	-21.4	-21.3	-19.0	-21.8	-14.6	-21.8	-22.2
XJ06	0.0	-2.4	3.1	-4.0	2.9	-4.3	-4.6
XJ13	19.6	17.1	23.0	16.2	23.0	15.8	15.4
XJ14	41.2	42.9	43.5	44.1	51.5	44.3	43.9
XJA1	-48.2	-47.1	-46.2	-47.1	-39.8	-46.9	-47.4
XJA2	-15.9	-15.9	-13.4	-16.0	-8.9	-16.0	-16.4
XJA3	5.3	2.7	8.6	1.5	8.3	1.1	0.7
XJA4	-0.8	-3.3	2.3	-4.9	2.0	-5.1	-5.5
XJA5	-12.3	-11.2	-10.2	-11.2	-3.9	-11.2	-11.5
XJA6	5.2	4.2	7.9	3.2	10.2	3.1	2.7

The schemes of the datum points used are as follows:

A—BJFS, XANY and XIAA B—BJFS and XANY

C—BJFS and XIAA D—XIAA and XANY

E—BJFS F—XANY G—XIAA

From the comparing with the leveling data, we know that the scheme 1 is the best adjustment datum model. So we contrast the other schemes with scheme 1 and the contrasting results are listed on table 2.

Table 2. The contrasting results of the GPS monitor points on different calculation schemes.

Points name	The contrasting results of the different schemes （mm）						
	Scheme 1	Scheme 2			Scheme 3		
	A	B	C	D	E	F	G
XJ01	0	-1.9	-2.3	-3.3	-10.7	-3.5	-3.1
XJ02	0	1.4	-2.7	2.9	-4.1	3.1	3.4
XJ03	0	0.9	-2.7	2.0	-5.1	2.2	2.5
XJ04	0	1.2	-2.8	2.0	-5.0	2.2	2.5
XJ05	0	-0.1	-2.4	0.4	-6.8	0.4	0.8
XJ06	0	2.4	-3.1	4.0	-2.9	4.3	4.6
XJ13	0	2.5	-3.4	3.4	-3.4	3.8	4.2
XJ14	0	-1.7	-2.3	-2.9	-10.3	-3.1	-2.7
XJA1	0	-1.1	-2.0	-1.1	-8.4	-1.3	-0.8
XJA2	0	0.0	-2.5	0.1	-7.0	0.1	0.5
XJA3	0	2.6	-3.3	3.8	-3.0	4.2	4.6
XJA4	0	2.5	-3.1	4.1	-2.8	4.3	4.7
XJA5	0	-1.1	-2.1	-1.1	-8.4	-1.1	-0.8
XJA6	0	1.0	-2.7	2.0	-5.0	2.1	2.5

From table 1 and table 2 we can see that the fixed adjustment datum is the best adjustment model if there are three or more stabile known points and they are compatible. In addition, the two datum points is also the available schemes. But the distortions induced by the datum errors are not ignored. These kind distortions have reached to 4 mm(scheme D) in table 2.

On the other hand, we also can see that scheme E is inferior to others from table 2. The reasons lead to this phenomenon is the datum point of BJFS is far from Xi'an and more datum errors are brought to the adjustment models.

5 Some conclusions

Form those research we can get some conclusions as follows. In deformation monitoring, the datum plays very impotent role to get right deformation result and the deformation analysis must be based on the same datum frame with high precision.

Since the system errors of the GPS observations in different monitoring period are not the same, the system transforming parameters must be considered in adjustment model.

If there are three or more stabile known points, the fixed adjustment datum can be as the adjustment datum. But the distortions induced by the datum errors must be regard when those data are incompatible. The quasi－stable adjustment to take the barycentre of the stabile points as its datum may be more better choice.

The free network adjustment that only have position datum is not available for deformation data processing. The two stabile known points are the available schemes. If there has no known stabile points in deformation monitor network, we can choose the barycenter adjustment datum.

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Reference

1. Zhang Qin and Li Jia-quan, "The Surveying Principle and Application of GPS", *Chapter 6 of the Data Processing of GPS Surveying*, Bei Jing: Science Press, 2005, pp. 183-211.
2. Liu Da-jie and Tao Ben-zao, *The Datum of the Deformation Analyses in the GPS Monitoring Network and Its Testing*, "The Application and Data Processing of GPS Satellite Positioning", Shang Hai: Tong Ji University Press, 1994, pp. 92-102.
3. Li Yan-xing, Hu Xin-kang and Zhao Cheng-kun, "Study on Data Processing Program for GPS Monitoring Network", Acta Geodaetica et Cartographica Sinica, Vol. 28, No. 1, Feb. 1999, pp. 62-66.
4. Cheng Yong-qi, "The Data Processing of Deformation Monitoring", Bei Jing: Publishing House of Surveying and Mapping, 1988, pp. 264-280.
5. Sui Li-fen, Yang Li, Xu Yang-bin, "The Deformation Datum Research of GPS Repeat Observation Network", Bulletin of Surveying and Mapping, No.7, 2001, pp. 3-5.