The effect of weights observation to estimate the monitoring control point coordinate at sermo dam

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Abstract. The use of weights observation was effected on the estimation of coordinates and its precision. This research aims to identify 3D coordinates and its precision using weights observation from the result of GAMIT processing and the law of error propagation in sequential adjustment method. This research uses GNSS observation data from 10 deformation monitoring control points around Sermo Dam that was measured on doy 250 in 2014 and doy 129 in 2015. Data processing was performed by GAMIT software to get a baseline length and its precision. Baseline length and its precision were used as input in the sequential adjustment method. The values of weight observation were calculated using the result of GAMIT processing and the law of error propagation. The result of this research are 3D coordinates control point and its precision. The coordinate results using weight observation from GAMIT result does not significantly different from the law of random error propagation result, whereas the precision result is different significantly. The differences of precision reached 2 centimetres.

1. Introduction

Adjustment is a method commonly used in geodetic calculations. These cases can be found in geodetic calculations to estimated parameter with simple to high-level technology, included in the Global Navigation Satellite System (GNSS) technology. GNSS method has been used to monitor the deformation in structure building and the other [1]. Therefore, this research used the GNSS method. The monitoring aim to maintain the building [2]. The research location is Sermo Dam. This dam was located in Kulon Progo Regency, Special Region of Yogyakarta.

The addition of monitoring control points was due to the detection of active faults that split the Sermo Dam [3]. It can cause any geodynamic activities, so it requires continuous geodynamic monitoring [4,5]. This case required a special data processing strategy, so that the coordinates and precision of the old and new control points can be generated. Therefore, sequential adjustment method was used [6]. Processing with the sequential adjustment method cannot used the existing GNSS data processing software. Therefore, GAMIT software was used to process GNSS data from RINEX data into baselines and its precision [6]. Baselines data and its precision were used as inputs in sequential adjustment so that the
coordinates and its precision can be estimated. Additions were made by add five new control points, so the overall control points were 10 points. GNSS observation was carried out on the 2014 in day of year (doy) 250 on five old control points (BMS1, BMS2, BMS5, BMB1, and BMB2) and doy 129 in 2015 on five new points (MAK1, MAK2, MAK3, MAK4, and MAK5).

In the calculation of sequential adjustment, the weights observation affects the results of parameter estimates. In this research, two methods of calculating weights observation were used by inputting the value of GAMIT processing results in the weight matrix and by using the law of random error propagation. The purpose of this research was to identify the effect of weights observation using GAMIT processing results and the law of random error propagation.

2. Methods
The data were used in this research are:

- Data on 10 IGS points (CNMR, COCO, DARW, DGAR, KARR, PARK, PBR2, PIMO, TOW2, and XMIS) for the 2014 250 year and doy 129 in 2015 for global binding.
- Data on six CORS BIG stations (CBTL, CMGL, CPBL, CPWD, CSEM, and CSLO) doy 250 in 2014 and doy 129 in 2015 for local binding.
- Data on five old control points (BMS1, BMS2, BMS5, BMB1, and BMB2) doy 250 in 2014.
- Six-point control data (MAK1, MAK2, MAK3, MAK4, MAK5 and BMS1) doy 129 in 2015.
- Supporting data for processing GAMIT/GLOBK.

The software used in this research are GAMIT/GLOBK and MATLAB. Before estimation using the sequential adjustment method, GNSS data was processed using GAMIT software first so that the baseline length between the monitoring control points and their precision is generated.

2.1. Baseline length estimation with GAMIT
The baseline length estimation of the monitoring control point was carried out using a local binding reference. The steps for estimating the baseline with local binding are:

- Data from six CORS stations on the 250-year 2014 doy 129 and 2015 processed with GAMIT/GLOBK was bound to 10 IGS stations (global binding) so that the coordinate file and the precision of the points processed are obtained. The file was used as an apriori file for local binding.
- The 2014 doy 250 GNSS observation data and 2015 doy 129 processed with GAMIT was bound to six CORS BIG stations using apriori file as a result of step 1 (local binding) so that the baseline length and its precision was generated.

The BMS1 point which is an old point and has been included in the processing of GAMIT doy 250 in 2014 was included again in the processing of GAMIT doy 129 in 2015. This is because in the GNSS measurements, the coordinates are estimated using the GNSS net method. The formation of GNSS nets on GAMIT software was carried out by observation day (by doy) so that with a single point observed in two doys, the baseline can be generated from the combining of two adjustment. The result of GAMIT software is q-file which contains of the baseline length and standard deviation. Baseline length and standard deviation are used as inputs in sequential adjustment processing.

2.2. Estimation of sequential adjustment
The sequential adjustment estimation which used in this research is the parameter method. The sequential parameter adjustment method was used to calculate the parameter solutions of a project that has been completed, and then it was added with new data [6]. The estimation with sequential parameter adjustment, the data was grouped into the first and second data. The residual function in the equation can be written in a matrix [6] such as equations 1 and 2:

\[ V_i = A_i X + L_i \]  

(1)
\[ V_2 = A_2 X + L_2 \]  

In this case, \( V_1, V_2 \) are the residual matrix for the first and second data groups, \( A_1, A_2 \) are the design matrix for the first and second data groups, \( X \) is the parameter matrix, and \( L_1, L_2 \) was the remaining matrix. The parameter values are estimated by equation 3.

\[ X_2 = X_1 + \Delta X \]  

\[ X_1 = -(A_1^T P_1 A_1)^{-1} A_1^T P_1 L_1 \]  

\[ \Delta X = -(A_1^T P_1 A_1)^{-1} A_1^T T (A_2 X_1 + L_2) \]  

\[ T = (P_2^{-1} + A_2 (A_1^T P_1 A_1)^{-1} A_1^T)^{-1} \]  

In this case, \( X_2 \) is the parameter (coordinate) of the results of the second stage of adjustment, \( \Delta X \) is the contribution of new measurements to the adjustment parameters of the first step, and \( X_1 \) is the parameter (coordinates) of the first step result. The value of parameter precision can be estimated from the parameter cofactor matrix. The second step cofactor matrix \( (Q_{x_2}) \) can be searched using equation 7.

\[ Q_{x_2} = Q_{x_1} + \Delta Q \]  

\[ Q_{x_1} = (A_1^T P_1 A_1)^{-1} \]  

\[ \Delta Q = (A_1^T P_1 A_1)^{-1} A_1^T T A_2 (A_1^T P_1 A_1)^{-1} \]  

In this case, \( Q_{x_2} \) is the second step parameter cofactor matrix, \( \Delta Q \) is the contribution of a new measurement to the parameter cofactor, and \( Q_{x_1} \) is the first step parameter cofactor matrix. The precision value of each corresponding parameter was obtained from the root of the matrix \( Q_{x_2} \) diagonal element then multiplied by the variant aposteriori.

Weights observation was a number which obtained from a comparison of a measure of observation to another. Weights observation can be obtained from the inverse comparison of observation variants [8]. Variant observation is the square of the standard deviation of observation. In a set of measurements obtained varying precision. This can be occurred because of the differences distance between the points and the differences of the observational data quality, so the weights observation was needed.

The input matrix \( P_1 \) in the first step of sequential adjustment method was obtained from the results of RINEX raw data processing with GAMIT software. The results were the standard deviation values of components \( X, Y, Z \) and their correlation \( (R) \). Therefore, the other value than the main diagonal in the \( P_1 \) matrix was not worth 0 because the measurement was correlated. That values were the covariant value between the components, so the form of the \( P_1 \) matrix becomes like equation 10:

\[
P_1 = \sigma_0^2 \begin{bmatrix} 1 & \sigma_{12} & \sigma_{13} \\ \sigma_{12} & 1 & \sigma_{23} \\ \sigma_{13} & \sigma_{23} & 1 \end{bmatrix}
\]

In this case, \( \sigma_0^2 \) is value and priors, \( \sigma_0^2 \) is \( n \) variant observation, \( \sigma_{12} \) is covariant of components 1 and 2, \( \sigma_{13} \) is covariant of components 1 and 3 and \( \sigma_{23} \) is covariant of components 2 and 3.

The covariance values of components 1 and 2 (\( \sigma_{12} \)) are calculated using equation 11.

\[
\sigma_{12} = R \sqrt{\sigma_{11}^2 \cdot \sigma_{22}^2}
\]

The \( P_2 \) matrix was obtained from inputting the measurement variant value in the main diagonal and non-diagonal covariant values. Values of variant and covariant were obtained from q-file which processed by GAMIT. The variant and covariant values that filled in the \( P_2 \) matrix were obtained from a combination of q-file processing of GAMIT day 250 in 2014 and day 129 in 2015.
2.3. Coordinate estimation with weights observation from law of random error propagation

Estimation of coordinates with sequential adjustment using equation 1-9. Weights observation with the law of random error propagation was used in the second step of adjustment. The \( P_2 \) matrix in the second step of sequential adjustment was obtained from the calculation of the covariant variant weight matrix for the old point baselines. At the new points, the weight value was taken from GAMIT processing result. The input calculation of the covariant variant matrix weight for the old point was the parameter covariant variant matrix from the first step. The first parameter covariant variant matrix was obtained from the parameter cofactor matrix which multiplied by the first step variant aposteori. The covariance variant observation matrix was calculated using random error propagation equations. It cause the content of the covariant variant parameter was the variant where covariant calculated in the first step, whereas for the calculation of \( P_2 \) observation the baseline variants of the measurement results were needed. The covariant variant observation matrix of the old point was calculated using equation 12 [8].

\[
\sum yy = G \sum xx G^T
\]  

(12)

In this case, \( \sum yy \) is covariant observation matrix variants, \( G \) is matrix which contain the first derivative of a mathematical model where parameters are a function of observation and \( \sum xx \) is covariance variant matrix parameters.

3. Result and discussion

The results of this research are the coordinates and its precision of the monitoring control points at Sermo Dam using sequential parameter adjustment where it calculated from GAMIT processing and from law of random error propagation. The coordinates obtained are the coordinates of 10 monitoring control points and five precision coordinates of old monitoring control point. Precision can be seen from the amount of standard deviation generated.

In the first step of sequential adjustment there are four coordinate control points. The BMB1 point is used as a fixed point with coordinates -2174072,399 m; 5933543,933 m; -862689,652 m. The coordinate system used is the 3D Cartesian coordinate system. The sequential adjustment of the first step by calculating the weights observation from GAMIT and with the law of random error propagation errors yields the same precision, it causes in the first step the both used the results of GAMIT processing to fill the weight matrix component. The coordinates and its precision of the sequential adjustment results from first step was presented in Table 1.

| Point | Component | Coordinate (m) | \( \sigma \) (cm) |
|-------|-----------|----------------|------------------|
| BMS1  | X         | -2173994.722   | 1,265            |
|       | Y         | 5933592.585    | 2,843            |
|       | Z         | -862625.3933   | 0,615            |
| BMS2  | X         | -2174236.963   | 0,983            |
|       | Y         | 5933501.312    | 2,055            |
|       | Z         | -862561.5899   | 0,502            |
| BMS5  | X         | -2174219.433   | 7,921            |
|       | Y         | 5933435.029    | 10,086           |
|       | Z         | -862704.217    | 2,369            |
| BMB2  | X         | -2174225.656   | 1,012            |
|       | Y         | 5933530.935    | 2,102            |
|       | Z         | -862459.54     | 0,527            |
In the second step, five new control points of deformation monitoring were added, measured in the doy of 129 in 2015. The new five points are MAK1, MAK2, MAK3, MAK4 and MAK5. However, the standard deviation result from this adjustment is the standard deviation of the monitoring control point that used in the first step. This is because in sequential adjustment only the increasing precision effect value was generated due to the addition of points in the second step. The standard deviation of the second step of sequential adjustment results from GAMIT data processing was presented in Table 2.

| Point | σX (cm) | σY (cm) | σZ (cm) |
|-------|---------|---------|---------|
| BMS1  | 0.790   | 1.811   | 0.405   |
| BMS2  | 0.682   | 1.432   | 0.351   |
| BMS5  | 5.598   | 7.124   | 1.674   |
| BMB2  | 0.702   | 1.465   | 0.369   |

The second step, P2 matrix using the law of random error propagation was obtained from inputting the observation variant value in the main diagonal and the covariant value in the others. The variant and covariant values were obtained from q-file results with GAMIT for doy 129 in 2015. Covariant variant values for 2014 doy 250 data were searched using the equation of random error propagation (equation 12). The standard deviation generated in the second step sequential adjustment using the law of propagation of random errors was presented in Table 3.

| Point | σX (cm) | σY (cm) | σZ (cm) |
|-------|---------|---------|---------|
| BMS1  | 0.678   | 1.525   | 0.345   |
| BMS2  | 0.603   | 1.264   | 0.309   |
| BMS5  | 3.578   | 4.636   | 1.089   |
| BMB2  | 0.617   | 1.287   | 0.321   |

Based on Tables 2 and 3, it can be seen that there is a difference in precision between the results of GAMIT processing and with the law of random error propagation. The difference ranged from 0.048 - 2.488 cm. The differences in precision was presented in Table 4.

| No. | Point | From GAMIT data processing result | From law of random error propagation | Difference |
|-----|-------|-----------------------------------|--------------------------------------|------------|
|     |       | σX (cm) | σY (cm) | σZ (cm) | σX (cm) | σY (cm) | σZ (cm) | σX (cm) | σY (cm) | σZ (cm) |
| 1   | BMS1  | 0.790   | 1.811   | 0.405   | 0.678   | 1.525   | 0.345   | 0.112   | 0.286   | 0.060   |
| 2   | BMS2  | 0.682   | 1.432   | 0.351   | 0.603   | 1.264   | 0.309   | 0.079   | 0.168   | 0.042   |
| 3   | BMS5  | 5.598   | 7.124   | 1.674   | 3.578   | 4.636   | 1.089   | 2.020   | 2.488   | 0.585   |
| 4   | BMB2  | 0.702   | 1.465   | 0.369   | 0.617   | 1.287   | 0.321   | 0.085   | 0.178   | 0.048   |

Based on Table 4 there are differences in accuracy resulting from the two methods of determining size weights. The biggest difference is at the BMS5 point for X, Y, and Z components, which are 2.020 cm, 2.488 cm, and 0.585 cm respectively. The Y component becomes the highest precision difference.
component because the Y component as a vertical component. This is because the location of the Sermo Dam is around the equator and in the eastern longitude [9]. From [9,10] the vertical component of GNSS observation has 2.5 times precision lower than the horizontal component , [9], and [10].

4. Conclusion
The use of weights observation using the law of random error propagation yields more precision than using the results of processing directly from GAMIT. It can be seen in the BMS5 point which experienced a difference in accuracy reaching 2.020 cm in component X, 2.488 cm in component Y and 0.588 cm in component Z.

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References
[1] Y Yulaikah, S Pramumijoyo and N Widjajanti 2018 Correlation of GNSS Observation Data Quality Resulted from TEQC Checking and Coordinate’s Precision. *Journal of Geospatial Information Science and Engineering (JGISE)* 1(1) 8 - 13
[2] D Lestari, Y Yulaikah and R I Sari 2018 Time Variant Adjustment for The Solution of Control Point Unstability in Deformation Analysis of Borobudur Vertical Deformation Monitoring Network. *Journal of Geospatial Information Science and Engineering (JGISE)* 1(1) 43 - 50
[3] M I Taftazani and Yulaikhah 2018 Movement Detection of Sermo Dam Control Point Based on GNSS Observation Data in 2016 – 2017 (2018 4th International Conference on Science and Technology (ICST)-Yogyakarta) 1-5.
[4] N Widjajanti, S S Emalia and P Parseno 2018 GNSS Monitoring Network Optimization Case Study: Opak Fault Deformation, Yogyakarta. *Journal of Geospatial Information Science and Engineering (JGISE)* 1(1) 14 - 21
[5] A Richter, E Ivins, H Lange, L Mendoza, L Schroder, J L Hormaechea, G Cassasa, E Marderwald, M Fritzche, R Perdomo, M Horwart and R Dietrich 2016 Crustal Deformation Across the Southern Patagonian Icefield Observed by GNSS. *Earth and Planetary Science Letters* 452 2016-215.
[6] A Leick 2004 *GPS Satellite Surveying* John Wiley & Sons Inc New York
[7] M D A Sanjaya, A Sunantyo and N Widjajanti 2018 Geometric Aspects Evaluation of GNSS Control Network for Deformation Monitoring in the Jatigede Dam Region. *International Journal of Remote Sensing and Earth Sciences* 15 (2) 167-176
[8] P R Wolf and C D Ghilani 1997 *Adjustment Computations Statistics and Least Squares in Surveying and GIS* Jhon Wiley & Son Inc New York.
[9] H Ulinnuha, A Sunantyo and N Widjajanti 2018 Analysis of the July 10th 2013 Tectonic Earthquake effect on the Coordinates Changes of Mentawai Segment Monitoring Station. *Journal of Geospatial Information Science and Engineering (JGISE)* 1(2) 51 – 57
[10] R Muryamto, M I Taftazani, Y Yulaikhah, B K Cahyono and A S Prasidya 2018 Development and Definition of Prambanan Temple Deformation Monitoring Control Points. *Journal of Geospatial Information Science and Engineering (JGISE)* 1(2) 81 – 86