GNSS Processing Data Result with Sequential Adjustment Method to Estimate the Monitoring Control Point Coordinate at Sermo Dam

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Abstract. Monitoring a structure building like a dam needs to detect any movement. The movement can be measured by adding control point to measure it. Geodynamic movement, expansion of area monitoring, and detection of ground cracks require by adding the new of control points. The addition of control points in a measurement requires specific data processing strategy. Therefore, it used the sequential adjustment method. This research aims to identify 3D coordinate values and the difference precision of the control points from the sequential adjustment method. The first step of sequential adjustment used five control points with one point considered fixed. The second step was added with five control points. The difference of coordinate precision analysis using sequential adjustment method indicates that there are increased precision in five control points which are processed in the first step. The addition of the coordinate precision ranges from 0,193 to 5,450 cm. Based on the comparative of two variants sample test shows that the precision of coordinates resulted for the first step is significant different from the second step. The results of the comparison between two variants test indicate that the precision of the result in first step does significantly different to the second step.

1. Introduction
Sermo Dam is a structure building that functions as a reservoir for clean water, irrigation, and flooding prevention in Kulon Progo Regency. Remember of the vital function of the Sermo Dam for the people of Kulon Progo Regency, supervision and maintenance are needed to avoid any damage of the dam. One form of this effort is to monitor the deformation dam. Previous research used terrestrial methods for monitoring deformation control points. In this study GNSS survey method was used. The advantage of using the GNSS method is the monitoring control points do not need to be seen with each other and point coordinates are specified in a particular reference frame [1].

Based on the research of [2], there is an active fault of Parangtritis-Kulon Progo which passes through the Sermo Dam. The existence of these faults is possible cause the geodynamic movements which result in the resistance of the dam structure building. Therefore, in this research a measurement control point was added to detect movements that occur due to the presence of the fault. In addition to the presence
of geodynamic movements, the expansion of the monitoring area and crack detection can also cause an addition in the number of monitoring control points.

The addition of control points in a measurement requires a special data processing strategy to determine the difference in precision generated. Therefore, it used sequential adjustment method [3]. Processing with the sequential adjustment method cannot use existing GNSS data processing software. Therefore GAMIT software was used to process GNSS data from RINEX raw data into baseline data and its precision. Baseline data and its precision were used as inputs in sequential adjustment so that the coordinates and its precision are generated. Addition of monitoring control point was done by adding five new control points so that the overall control points are 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). The results of the processing were tested by comparing two sample variants to determine whether the significantly differences in the results of the coordinates and its precision with sequential adjustment.

2. Methods

The data were used in this research are:

1. 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.
2. 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.
3. Data on five old control points (BMS1, BMS2, BMS5, BMB1, and BMB2) doy 250 in 2014.
4. Six point control data (MAK1, MAK2, MAK3, MAK4, MAK5 and BMS1) doy 129 in 2015.
5. Supporting data for processing GAMIT/GLOBK.

The software were used in this research are GAMIT/GLOBK and Mathlab. 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. Local binding was intended to get the position and its precision of the observation points relative to the local tie point [4]. In this research, the object of this research is a structure building that falls into a small scale category so that local processing was used for processing data. The steps for estimating the baseline with local binding are:

1. 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 t used as an apriori file for local binding.
2. 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 [5]. 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 [5] such as equations 1 and 2:

\[ V_1 = A_1 X + L_1 \]  
\[ V_2 = A_2 X + L_2 \]

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.

\[ X_2 = X_1 + \Delta X \]

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

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

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

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.

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

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

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

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 apostoeri.

2.3. The Comparison of Two Sample Variants Test
A comparison of two sample variants test was carried out to test the variants of two different samples. The test aims to evaluate the differences in the first and second samples. A comparison of two sample variants test was carried out in sequential adjustment. The F-count distribution value was accepted if the comparison of the apostoeri variants in the interval according to equation 10 [6]:

\[ \frac{\hat{\sigma}_1^2}{\hat{\sigma}_2^2} \frac{1}{F_{f_1,f_2}} < \frac{\hat{\sigma}_1^2}{\hat{\sigma}_2^2} \frac{1}{F_{f_2,f_1}} \]

In this case, \( f_1, f_2 \) are the degree of freedom, \( \alpha \) is the degree of trust, \( \hat{\sigma}_1^2, \hat{\sigma}_2^2 \) are the first and second apostoeri variant, and \( F \) is the distribution value Fisher table.

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. 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. Differences in precision only seen in five old control points because the five points involved in the first and second step of sequential adjustment.

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 coordinates of the sequential adjustment results was presented in Table 1.

### Table 1. The coordinate from sequential adjustment

| 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            |

Based on Table 1, the BMS5 has the worst precision. This is influenced by the location of the BMS5 point located at the valley of the Sermo Dam, so that the satellite viewing space is limited. In addition, there are high plants around the point, so there are a lot of obstructions.

In the second step of the adjustment, five new control points of deformation monitoring were added, measured in the 129 doy of 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 was presented in Table 2.

### Table 2. Standard deviation of second step from GAMIT data processing

| Point | \( \sigma_X \) (cm) | \( \sigma_Y \) (cm) | \( \sigma_Z \) (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 Table 1 and 2 there is an increase precision in each component of the monitoring control point. This is because in the adjustment processing of the second step, the increases of monitoring control points cause increase the number of equations. It made the error value of a point distributed to another. Therefore, there was an increase in precision at another four monitoring control points.

### Table 3. The difference of precision in the first and second step of sequential adjustment

| No. | Point | First step | Second step | Difference |
|-----|-------|------------|-------------|------------|------------|

4
Based on Table 3, it can be seen that there is a difference of precision between first and second step. The difference ranges from 0.193 cm to 5.450 cm. The visualization of the differences in precision was presented in Figure 1.

| Point | Component | \( \sigma_X \) (cm) | \( \sigma_Y \) (cm) | \( \sigma_Z \) (cm) | \( \sigma_X \) (cm) | \( \sigma_Y \) (cm) | \( \sigma_Z \) (cm) |
|-------|-----------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| 1 BMS1 | X         | 1.265                | 2.843                | 0.615                | 0.678                | 1.525                | 0.345                | 0.578                | 1.318                | 0.270                |
| 2 BMS2 | Y         | 0.983                | 2.055                | 0.502                | 0.603                | 1.264                | 0.309                | 0.380                | 0.791                | 0.193                |
| 3 BMS5 | Z         | 7.921                | 10.086               | 2.369                | 3.578                | 4.636                | 1.089                | 4.343                | 5.450                | 1.280                |
| 4 BMB2 | X         | 1.012                | 2.102                | 0.527                | 0.617                | 1.287                | 0.321                | 0.395                | 0.815                | 0.206                |

Table 4. The comparison test results of two sample variants of standard deviation values

| Point | Component | \( \sigma_1^2 \) | \( \sigma_2^2 \) | F-count (F-table = 1.82) | Result |
|-------|-----------|------------------|------------------|--------------------------|--------|
| BMS1  | X         | 1.601            | 0.460            | 3.477                    | Rejected |
Table 4 shows that the test results comparing two sample variants are 100% rejected. This states that the coordinate variance value of the BMS1, BMS2, BMS5, and BMB2 in the first step is different from the second step. This can be happened because of the addition of monitoring control points at the Sermo Dam in the second step. The addition of control points for deformation monitoring made an increase of the measurement equations. This adds to the value of precision which obtained in the second stage of the adjustment.

4. Conclusion
The use of a sequential adjustment method is suitable to to estimate the coordinates of the monitoring control points and its precision if additional control points occur and cannot be measured together. The addition of the precision of the five old monitoring control points in Sermo Dam ranged from 0.193 cm to 5,450 cm. In this research, it is considered that there is no shift value at the point, if the old point was shifted, this method cannot be used because it must be estimated using deformation analysis.

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