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RESEARCH ARTICLE

The Effect of Baseline Component Correlation on the Design of GNSS Network Configuration for Sermo Reservoir Deformation Monitoring

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Abstract The condition of the geological structure in the surrounding Sermo reservoir shows that there is a fault crossing the reservoir. Deformation monitoring of that fault has been carried out by conducting GNSS campaigns at 15 monitoring stations simultaneously. However, those campaigns were not well designed. With such a design, it took many instruments and spent much money. For the next GNSS campaign, it should be designed so that the optimal network configuration is obtained and the cost can be reduced. In the design of deformation monitoring network, sensitivity criteria become very important for detecting the deformations. In GNSS relative positioning, the baseline components are correlated, but this correlation is often ignored. This research examined the effect of baseline component correlations on the design results of the GNSS configuration of the Sermo Fault network based on sensitivity criterion. In this case, the western side of the fault was taken as a reference, while the other side as an object moving relatively against the western side. This study found that the baseline component correlation affects the results of GNSS network configuration. Considering the correlation could result a sensitive network configuration with a fewer baseline; therefore, the cost and time of field surveys can be reduced. It can be said that the baseline component correlation needs to be taken into account in the configuration design of deformation monitoring network.

1. Introduction

Sermo reservoir is located in the western part of Yogyakarta, Indonesia. It was built by damming Ngrancah river and officially operated in 1997. It can hold 25 million cubic meters of water and serves a vital role as a water reservoir from which water is then distributed by the Water Utilities (PDAM) serving the needs for clean water, irrigation, and flood prevention.

The condition of the geological structure in the Sermo reservoir and surrounding have an interesting phenomenon. Overlaying geological map and Landsat imagery show that there are reverse and thrust faults which cross the reservoir (Figure 1). This condition is confirmed by (Widagdo, Pramumijoyo, Harijoko, & Setiawan, 2016) in their research about the geological structure of rock distribution in the area of Kulonprogo. They found that the secondary structure which controls the rock distribution in Kulonprogo mountain is in the form of Northwest-Southeast normal fault, Southwest-Northeast reverse fault, and North-Northwest lateral fault. The similar description is also found in the main report of Sermo Reservoir Project Details Design (Departemen Pekerjaan Umum, 1985).

The fault, henceforth referred to as the Sermo fault, potentially affects the Sermo Dam deformation. In the last three years, deformation monitoring has been carried out by conducting GNSS campaigns. However, those campaigns were not well designed. Observations were carried out simultaneously at 15 monitoring stations distributed around the fault. With such a design, it took many instruments and spent much money. For the next GNSS campaign, it should be designed so that the optimal network configuration is obtained and the cost can be reduced.

In general, network optimization design can be classified into several orders, namely zero, first, second, and third orders (Halicioglu & Ozener, 2008; Kuang, 1996; Mehrabi & Voosoghi, 2014). A geodetic network needs to be designed to meet the criteria of accuracy, reliability, and low cost. However, a deformation monitoring network must meet one more criterion, that is, sensitivity to the occurring deformation (Benzao & Shaorong, 1995; Even-Tzur, 2002). Several study has been done to design the optimum geodetic and deformation monitoring network, wherein accuracy and reliability have been the most used criteria. Mehrabi and Voosoghi (2014) used the precision criteria with analytical methods and a quadratic programming algorithm to obtain the optimal GNSS baseline weight. By using this method, the number of baselines observed could be decreased by 36% so that the cost of measurement can be reduced. The use of three criteria simultaneously were studied by Alizadeh-Khameneh et al. (2015). Those three criteria were precision, reliability, and cost. The optimization design was performed through analytical methods using the single-objective, bi-objective, and multi-objective optimization models. Even-Tzur (2002) used the sensitivity criterion in developing a GPS network optimization design for deformation monitoring. Sensitivity analysis was carried out by including deformation data and geological parameters, such as deformation velocity and models. Benzao and Shaorong (1995) included the direction of the deformation movement as one of the parameters in optimization design. However, in such studies, it is quite common to optimize a network without considering correlations between baselines. Although the effect of ignoring this correlation was not significant, it should be considered for deformation monitoring purpose that requires a high level of accuracy. Furthermore, several studies have taken into account the correlation in the design of GNSS network optimization. Alizadeh-Khameneh et al. (2017) found that by considering it, a more efficient and precise network can be obtained. Craymer and Beck (1992) recommended GNSS processing method based on measurement sessions because through such, the correlations between baselines can be taken into account.

Generally, GNSS requires more than two receivers at one measurement session. The receivers record data simultaniously. The GNSS satellite constellation that is seen by observer stations varies periodically; therefore, there are deviations in satellite orbit modeling. This factor, coupled with the GNSS signal propagation effect factor, produces several cross-correlations between coordinate components “north” (N), “east” (E), and “up” (U) (Bos et al., 2013). Amiri-Simkooei (2013) also showed that a correlation existed between the coordinate components of GNSS even though the value was small, that is, a constant value of 0.1. In addition, the results of GNSS data processing using the scientific software GAMIT/GLOBK also showed a correlation between the components of the coordinates N, E, and U. This was explicitly stated in the report of GAMIT/GLOBK processing on files with the extension *.org. Accordingly, the baseline components were also correlated. Hence, in the double-difference GNSS observation, there is not only a correlation between baselines but the baseline components are also correlated (cross-correlation). Thus far, these correlations have often been ignored in deformation monitoring network design. In spite of the insignificant effect of these correlations in the estimation of station coordinates, for deformation monitoring purposes, where a very high level of accuracy is required, it should be considered. The former correlation effect on deformation monitoring network design had been studied by Alizadeh-Khameneh et al. (2017). This research examined the effect of the correlation between coordinate or baseline components, especially on the Sermo GNSS network configuration design based on sensitivity criterion. Network sensitivity analysis was conducted using methods developed by Even-Tzur (2002).

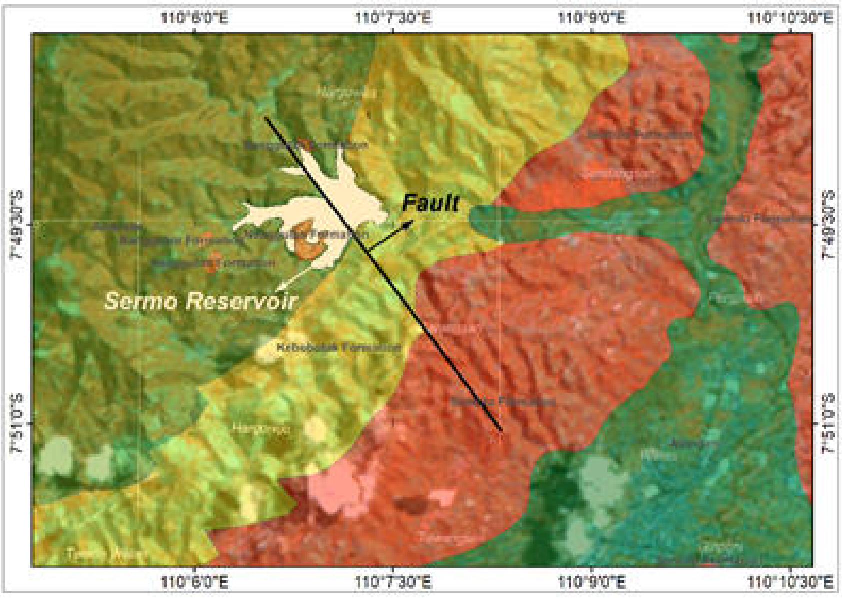

Figure 1. The fault across the Sermo Reservoir from overlaying geological map and Landsat imagery

2. The Methods

Baseline Component Correlation

The output of GNSS data processing using scientific software GAMIT/GLOBK comprises the coordinates in the Cartesian (X, Y, Z) and Topocentric (N, E, U) systems along with standard deviations and correlations between components. The example of the output can be found in (Herring, Floyd, King, & Mc Clusky, 2015).

Based on the correlation and standard deviation, the variance-covariance matrix for one station can be expressed by Equation (1):

$$\Sigma_{xyz} = \begin{bmatrix} \sigma_x^2 & \sigma_{xy} & \sigma_{xz} \\ \sigma_{xy} & \sigma_y^2 & \sigma_{yz} \\ \sigma_{xz} & \sigma_{yz} & \sigma_z^2 \end{bmatrix} \quad (1)$$

$\sigma_x^2, \sigma_y^2, \sigma_z^2$: variance of X, Y, Z

$\sigma_{xy}, \sigma_{xz}, \sigma_{yz}$: covariance of X and Y, X and Z, and Y and Z

Covariance between coordinate components is a function of correlation and can be expressed by the Equations (2), (3), and (4):

$$\sigma_{xy} = r_{xy}\,\sigma_x\,\sigma_y \quad (2)$$

$$\sigma_{xz} = r_{xz}\,\sigma_x\sigma_z \quad (3)$$

$$\sigma_{yz} = r_{yz}\,\sigma_y\sigma_z \quad (4)$$

The baselines between stations i and j (d_{ij}) are the difference between the coordinate components of the two stations. If X_i and X_j are the coordinates vector of stations i and j, the baseline can be expressed by the Equation (5):

$$dx_{ij} = X_j - X_i$$
$$dy_{ij} = Y_j - Y_i \quad (5)$$
$$dz_{ij} = Z_j - Z_i$$

$$d_{ij} = \begin{bmatrix} dx_{ij} \\ dy_{ij} \\ dz_{ij} \\ \vdots \end{bmatrix} \quad X_i = \begin{bmatrix} X_i \\ Y_i \\ Z_i \\ \vdots \end{bmatrix} \quad X_j = \begin{bmatrix} X_j \\ Y_j \\ Z_j \\ \vdots \end{bmatrix} \quad (6)$$

The variance-covariance matrix of (Σ_{dij}) can be obtained using the random error propagation law with general equations as Equation (7) (Ghilani, 2010; Mikhail & Gracie, 1981):

$$\Sigma_{dij} = A\ \Sigma_{xyz}\ A^T \quad (7)$$

$$\Sigma_{dij} = \begin{bmatrix} \sigma_{dx}^2 & \sigma_{dxdy} & \sigma_{dxdz} \\ \sigma_{dxdy} & \sigma_{dy}^2 & \sigma_{dydz} \\ \sigma_{dxdz} & \sigma_{dydz} & \sigma_{dz}^2 \end{bmatrix} \quad (8)$$

$$A = \begin{bmatrix} \frac{\partial dx}{\partial x_i} & \frac{\partial dx}{\partial y_i} & \frac{\partial dx}{\partial z_i} & \frac{\partial dx}{\partial x_j} & \frac{\partial dx}{\partial y_j} & \frac{\partial dx}{\partial z_j} \\ \frac{\partial dy}{\partial x_i} & \frac{\partial dy}{\partial y_i} & \frac{\partial dy}{\partial z_i} & \frac{\partial dy}{\partial x_j} & \frac{\partial dy}{\partial y_j} & \frac{\partial dy}{\partial z_j} \\ \frac{\partial dz}{\partial x_i} & \frac{\partial dz}{\partial y_i} & \frac{\partial dz}{\partial z_i} & \frac{\partial dz}{\partial x_j} & \frac{\partial dz}{\partial y_j} & \frac{\partial dz}{\partial z_j} \end{bmatrix}$$

$$= \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} & a_{16} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} & a_{26} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} & a_{36} \end{bmatrix} \quad (9)$$

Assuming that there is no correlation between the coordinates of a station and another, substituting Equations (1), (8), and (9) into Equation (7) gives the following Equation (10):

$$\Sigma_{dij} = \begin{bmatrix} {\sigma_{x_i}}^2 + {\sigma_{x_j}}^2 & \sigma_{x_iy_i} + \sigma_{x_jy_j} & \sigma_{x_iz_i} + \sigma_{x_jz_j} \\ \sigma_{x_iy_i} + \sigma_{x_jy_j} & {\sigma_{y_i}}^2 + {\sigma_{y_j}}^2 & \sigma_{y_iz_i} + \sigma_{x_jz_j} \\ \sigma_{x_iz_i} + \sigma_{x_jz_j} & \sigma_{y_iz_i} + \sigma_{y_jz_j} & {\sigma_{z_i}}^2 + {\sigma_{z_j}}^2 \end{bmatrix} \quad (10)$$

Based on Equation (10), it can be seen that Σ_{dij} is the sum of Σ_{xyz} for stations i and j. Because the components of the coordinates obtained from GNSS are correlated (Amiri-Simkooei, 2013; Bos et al., 2013), the baseline components are also correlated. As can be seen in Equation (10), the off-diagonal elements are not null that indicates the existing correlations between baseline components. These correlations are often ignored.

The Criteria of Network Sensitivity

Geodetic control network must be well designed to meet the criteria of accuracy, reliability, and low cost. Especially for deformation monitoring network, one more criterion is to be met, the sensitivity criterion. The network should be sensitive to the occurred displacement. Even-Tzur (2002) developed a GNSS network design for deformation monitoring based on this criteria. The GNSS network design was carried out by involving previously known deformation and geological parameters such as deformation velocity and models. In the design, Even-Tzur (2002) used a correlation of 0.7 without further explanation. In fact, the components of coordinates and baselines are correlated, but it is often ignored. Therefore, this research is focused on the effect of considering the correlations on the results of GNSS network sensitivity analysis. In this research, the sensitivity analysis was performed using a method developed by Even-Tzur (2002).

The displacement can be interpreted as the change of the station coordinates in two different epochs. If the coordinate estimation of station i at epochs 1 and 2 are $\hat{x}_i^1$ and $\hat{x}_i^2$, respectively, and the related cofactor

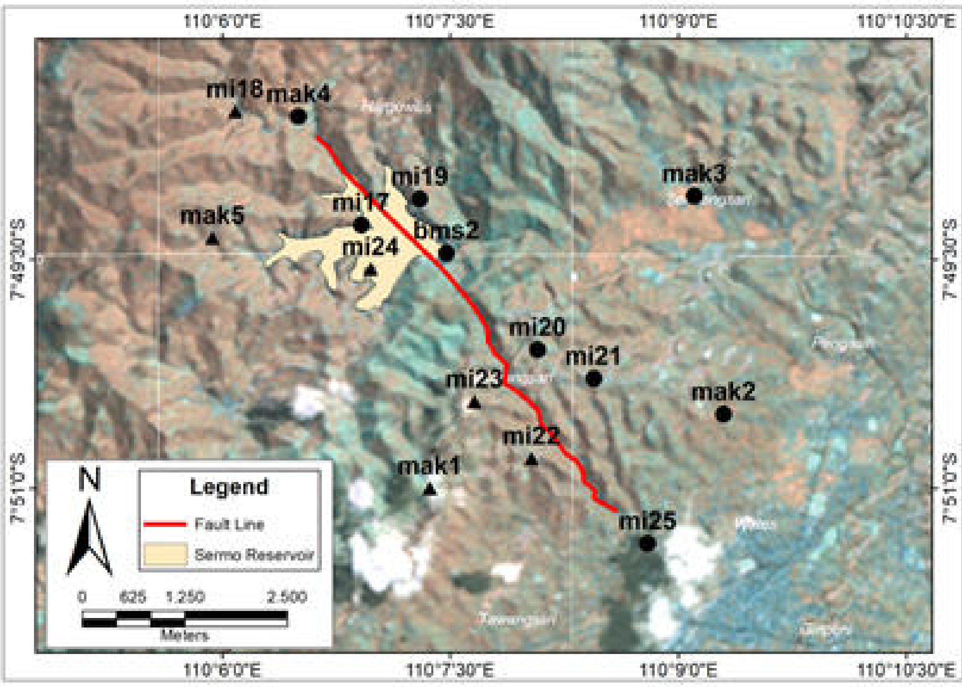

Figure 2. Monitoring network of Sermo Fault deformation

matrices are $Q_{\hat{x}}^1$ and $Q_{\hat{x}}^2$ then velocity vector Vx can be obtained by the Equation (11):

$$V_x = \frac{(\hat{x}_i^2 - \hat{x}_i^1)}{\Delta t} \tag{11}$$

In this case, Δt is the time interval between two epochs of observation. The cofactor matrix of the velocity vector is obtained using the following Equation (12):

$$\mathbf{Q}_{\mathbf{V_x}} = \frac{(Q_{\hat{x}}^1 + Q_{\hat{x}}^2)}{(\Delta t)^2} \tag{12}$$

Assuming that the measurements for the two epochs are identical, then Equation (12) becomes

$$\mathbf{Q}_{\mathbf{V_x}} = \frac{2Q_{\hat{x}}}{(\Delta t)^2} \tag{13}$$

Assuming that all stations are unstable, and the a priori variance $\boldsymbol{\sigma_0^2 = 1}$, then

$$\mathbf{Q}_{\hat{\mathbf{x}}} = \mathbf{N}^+ = (\mathbf{A}^\mathbf{T}\mathbf{P}\mathbf{A})^+ \tag{14}$$

In this case, P is the weight matrix, and A is the design matrix.

$$\boldsymbol{P} = \sigma_0^2 \Sigma_{dij}^{-1} \tag{15}$$

Pseudoinverse $\mathbf{Q}_{\mathbf{V_x}}$ is given as Equation (16)

$$\mathbf{Q}_{\mathbf{vx}}{}^+ = \left(\frac{2(N)^+}{(\Delta t)^2}\right)^+ = \frac{\Delta t^2}{2}\mathbf{N} = \frac{\Delta t^2}{2}(\mathbf{A}^\mathbf{T}\mathbf{P}\mathbf{A}) \tag{16}$$

Furthermore, to find out the sensitivity of the GPS network, Even-Tzur (2002) used a non-central F distribution with a non-centrality parameter λ that is formulated as Equation (17):

$$\lambda = \frac{\mathbf{v_x^T}\, Q_{Vx}{}^+\, \mathbf{v_x}}{\sigma_0^2} \tag{17}$$

The substitution of Equation (16) into Equation (17) gives the following Equation (18):

$$\lambda = \frac{\mathbf{v_x^T}\, \frac{\Delta t^2}{2}\, (\mathbf{A^T P A})\, \mathbf{v_x}}{\sigma_0^2} \tag{18}$$

In this research, the sensitivity analysis was conducted in a horizontal (2D) deformation monitoring network of Sermo Fault, consisting of five macro control stations (mak1, mak2, mak3, mak4, and mak5) distributed far from the location of Sermo Fault and reservoir and 10 micro control stations (mi17-mi25 and bms2) distributed along the fault, as shown in Figure 2. From these 15 control stations, 105 baselines were formed. Based on the data of GNSS campaigns conducted in 2016 and 2017, the network shows southeastward displacement. For the next campaign, it was necessary to design a network configuration based on sensitivity criterion. By giving a certain deformation velocity (Vx) from geological information or previous data in Equation (18), the value of of λ was compared with the limit value λo. This limit value λo was obtained from the table using the variables of 1−β, the level of significance α, and the degree of freedom r (Baarda, 1968). If λ>λo, the network is sensitive to the occurring deformation. Conversely, if λ<λo, the network is less sensitive, and thus, it is necessary to add another baseline to increase the value of λ. Increased sensitivity will be more effective if the added baseline is that with the most significant contribution to the increase in value λ. Therefore, it is necessary to find the contribution of each baseline to the increase in λ. The baseline with the most significant contribution needs to be added. If λ remains less than λo, another baseline needs to be added. Baseline addition is repeated until $\sum\lambda_i > \lambda o$.

3. Results and Discussion

The main focus of this research is to identify the effect of considering the correlation of the baseline components on the sensitivity analysis of deformation monitoring network. Therefore, in the sensitivity analysis, the weight matrix P in Equation (18) was composed using correlation coefficient c that varied from 0 to 0.6 with an interval of 0.2. The c = 0 means no correlation, c = 0.2 represents a low correlation, c = 0.4 represents a moderate correlation, and c = 0.6 represents a strong correlation (Gunawan, 2017). The weight matrix P was computed using standart deviation of coordinates obtained from GNSS campaign in 2016. The data were processed using GAMIT/GLOBK software. Based on the standard deviation and correlation coefficient c, a variance-covariance matrix of station coordinates in the deformation monitoring network can be obtained. Then, using the error propagation principle, a variance-covariance matrix of baseline component can be calculated as shown in Equation (10). For the displacement model, we assumed that one part of the fault moved relative to another. In this case, the western part of the fault represented by the stations mi22, mi23, mi24, mi18, mak1, and mak5 was taken as a reference, while the eastern part was an object moving relatively toward the western part. The displacement velocity was assumed to be 5 mm/year southeastward, in line with the results of previous studies (Febrina, 2016; Yulaikhah & Andaru, 2014). The displacement velocity matrix becomes

$$V_x = [3.5 \quad -3.5 \quad 3.5 \quad -3.5 \quad \ldots]^T \tag{19}$$

Furthermore, the contribution of each baseline to be calculated using Equation (18). The baselines that contributed greatly to the sensitivity of the network were the baselines that significantly increased the value of ∑λ. The results indicated 54 baselines gave a value of λ>0, aand the remaining 51 baselines showed a value of λ = 0. Regardless of the correlation coefficient given, the results were similar. The 54 baselines with a value of λ > 0 were the baselines that connected the reference stations and the monitored object stations, as shown in Figure 3. It can be said that these baselines contributed to the network sensitivity, and high-precision baselines had a greater contribution (Yulaikhah & Santosa, 2018). The baselines with the value λ = 0 were the baselines that connected two reference stations or two object stations. The baselines that connected two reference stations did not contribute to network sensitivity. This was very logical because the baselines were stable and not related to the monitored object station. These baselines did not affect the coordinates of the object monitoring stations, and observing them was a waste of time and cost. The baseline between two object stations also did not contribute to the network sensitivity because of the assumption that the displacements had the same magnitude and direction for all object stations as if they moved together in one block with the same magnitude and direction. Complete initial information, such as displacement velocity prediction of each station, is important to provide a more realistic analysis results.

Typically, GNSS surveys are carried out using more than two receivers so that in one observation session, two types of baselines, independent baseline (non-trivial) and trivial baseline, can be obtained at the same time. A trivial baseline is a baseline that can be derived from other baselines in one session (Seeber, 2003). In general, if the survey uses n receivers in each session (n > 2), then overall, there are n (n-1)/2 possible baselines. There are a number of (n-1) independent baselines between these baselines. The rest are trivial baselines. For example, if the GNSS survey uses four unit receivers, there are six baselines in total, consisting of three trivial baselines and three independent baselines (Sickle, 2015). The use of trivial baselines in the adjustment process do not show a significant effect on the obtained coordinates and their accuracy (Fotiou, Pikridas, Rossikopoulos, & Chatzinikos, 2009).

Based on the contribution of each baseline to network sensitivity as shown in Table 1 and Figure 3, the baselines that had no contribution to the network sensitivity could be removed from the observation plan, as well as trivial baselines. Therefore, the cost and time of the field survey can be reduced.

Table 1 shows the first 20 baselines that had the largest λ values. We used the correlation coefficient of 0, 0.2, 0.4, and 0.6. It can be seen that the greater the correlation between the baseline components, the greater the contribution of each baseline to the sensitivity of the network (λ). However, this did not significantly change the baseline sequence.

The sensitivity of the deformation monitoring network is sufficient for detecting the displacement when $\sum\lambda_i > \lambda o$. The value of λo can be found at the table (Baarda, 1968) for different power of test 1−β, significance level α, and degrees of freedom r. When we use the power of test 1−β = 0.8, α = 0.05 and r = 26,

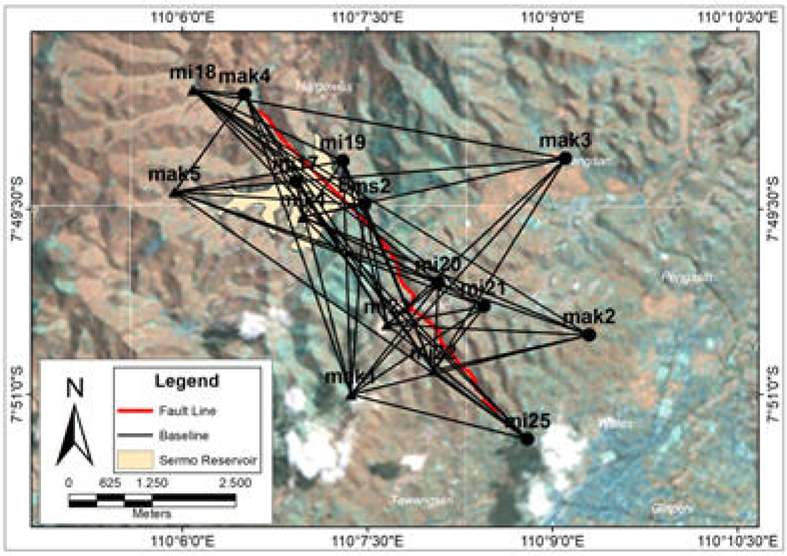

Figure 3. The baseline that contributes to the network sensitivity

Table 1. The first 20 baselines and their contributions to network sensitivity

c = 0			c = 0.2			c = 0.4			c = 0.6		
Baseline	λ_i	$\Sigma\lambda_i$	Baseline	λ_i	$\Sigma\lambda_i$	Baseline	λ_i	$\Sigma\lambda_i$	Baseline	λi	$\Sigma\lambda_i$
68	0.674	0.674	68	0.836	0.836	68	1.107	1.107	68	1.654	1.654
62	0.667	1.341	62	0.824	1.659	62	1.089	2.197	62	1.624	3.277
5	0.651	1.992	5	0.808	2.467	5	1.072	3.269	5	1.602	4.879
36	0.636	2.627	36	0.781	3.248	36	1.028	4.297	36	1.528	6.407
38	0.580	3.207	38	0.719	3.967	38	0.954	5.250	38	1.424	7.831
32	0.573	3.780	32	0.709	4.677	32	0.939	6.189	32	1.400	9.231
26	0.567	4.347	26	0.703	5.380	26	0.933	7.122	26	1.393	10.625
2	0.563	4.910	2	0.699	6.079	2	0.928	8.049	2	1.386	12.011
20	0.560	5.470	20	0.693	6.772	20	0.918	8.967	20	1.369	13.380
1	0.551	6.020	1	0.684	7.456	1	0.908	9.875	1	1.357	14.737
98	0.525	6.545	98	0.651	8.107	98	0.864	10.739	98	1.292	16.029
80	0.518	7.063	80	0.642	8.749	80	0.851	11.590	67	1.272	17.301
67	0.512	7.576	67	0.639	9.388	67	0.850	12.439	80	1.270	18.571
10	0.511	8.087	10	0.635	10.023	10	0.844	13.283	10	1.261	19.833
66	0.504	8.591	66	0.628	10.651	66	0.835	14.118	66	1.250	21.082
49	0.500	9.091	49	0.622	11.273	49	0.827	14.945	49	1.238	22.320
94	0.497	9.588	94	0.617	11.890	94	0.819	15.764	94	1.224	23.544
51	0.494	10.082	51	0.614	12.505	51	0.817	16.580	51	1.222	24.767
43	0.491	10.573	43	0.611	13.115	43	0.811	17.391	3	1.213	25.979
79	0.491	11.064	3	0.609	13.724	3	0.810	18.201	43	1.212	27.191

the corresponding $\lambda_o = \lambda(\alpha, 1-\beta, r, \infty) = \lambda(0.05, 0.8, 4, \infty) = 23.5$ was obtained. In cases where the correlation between baseline components was ignored (c = 0), using 54 or 105 baselines resulted in $\Sigma\lambda_I = 22.98$, which is slightly lower than λ_o. This means that the network was not sensitive to detect a 5 mm southeastward displacement, even though all baselines were involved. This result seems unrealistic. Conversely, when the correlation was taken into account, $\Sigma\lambda_I > 23.5$ was obtained. This means the sensitivity of the network was sufficient for detecting the possible displacement. The resulted number of baseline for the correlation coefficient of 0, 0.2, 0.4, and 0.6 can be seen in Table 2. The data in Table 2 and the graph in Figure 4 show that the stronger the correlation, the network sensitivity will be higher. For low (c = 0.2), medium (c = 0.4), and

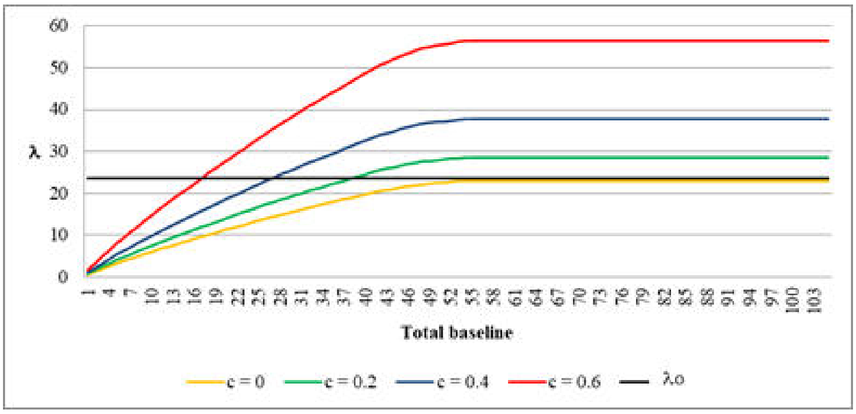

Figure 4. The effect of correlation on the network sensitivity analysis

Table 2. Results of network sensitivity analysis of deformation monitoring

Correlation (c)	c = 0	c = 0.2	c = 0.4	c = 0.6
$\sum\lambda_i$(54 baselines)	22.98	28.49	37.76	56.39
$\sum\lambda_i$(105 baselines)	22.98	28.49	37.76	56.39
Total sensitive baselines	N/A	38	28	18
Conclusion	Not Sensitive	Sensitive	Sensitive	Sensitive

strong (c = 0.6) correlations, the network becames sensitive by using 38, 28, and 18 baselines respectively. It can be said that considering the correlation has significant effect on the results of the sensitivity analysis of the Sermo Fault deformation monitoring network. It agrees with the result of study by Alizadeh-Khameneh et al. (2017). When the correlations were taken into account, the resulting GNSS network configuration consisted of fewer baselines. Hence, the cost and time of observational surveys can be reduced.

According to the results, the correlation between the baseline components needs to be taken into account in the design of the deformation monitoring network configuration. Neglecting it, leads to unrealistic results of network sensitivity analysis.

4.Conclusion

The results of the GNSS network configuration design for monitoring Sermo Fault deformation based on sensitivity criteria indicated that 54 of a total of 105 baselines contributed to the network sensitivity in detecting 5 mm southeastward displacement. They were baselines that connected reference and object station. The baseline connecting two reference or two object stations did not contribute to the network sensitivity. This was due to the assumption that object stations moved in the same magnitude and direction. Therefore, a more detailed information about the predicted movement of each object station was needed to give a more realistic analysis. Moreover, it should also be noted that the problem was associated with trivial baselines. Trivial baselines that had no contribution could be ignored from the campaign design.

The baseline component correlation affects the results of GNSS network configuration. Considering that correlation resulted in a sensitive network configuration consisted of fewer baselines, whereas ignoring it yields unrealistic results of network sensitivity analysis. It was also found that as the correlation coefficient increases, the network sensitivity also increases, and the number of involving baseline decreases. As a result, the cost and time of the campaign can be reduced. Hence, including the baseline components correlation in the design of deformation monitoring network configuration is necessary.

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