Analysis Deformation Monitoring Techniques Using GNSS Survey and Terrestrial Survey (Case Studi: Diponegoro University Dam, Semarang, Indonesia)

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Abstract: Global Navigation Satellite Systems (GNSS) are recently used in deformation monitoring applications, e.g., estimating infrastructure and motion of crustal plate. The new improvement of GNSS instruments which allow high-precision with 24 hours availability data processing. Deformation measurement techniques were considered and mostly used by geodesy specialist will be reviewed. The need of doing the deformation measurements periodically in engineering structures will be emphasised. In this research, monitoring displacement on a dam structure were conducted using GNSS survey and terestrial survey base on Total Station and Waterpass. Analyses will be carried out with the focus of assessing the position precision that can be acquired using GNSS and terestrial survey. This paper also emphasize the role of GNSS and terestrial application in deformation especially for dam monitoring.

Keywords: GNSS, Deformation, Precision

1. INTRODUCTION

There are some factors which could cause damage of embakment dams like erosion, stability problems due to high pore pressures [1]. To preserved the safety of dams it should be monitor dam behavior before and after construction process [2]. Dams are affected and deformed by internal and external loads. The loads are not constant and can change over time [3]. The hydrostatic pressure of a reservoir can also cause a permanent horizontal deformation that is perpendicular to centreline of the dam [3]. There are several techniques for measuring the deformations. These can be grouped mainly into two as geodetic and non-geodetic techniques [4].

There are several advantages of Dam building. It has an important for human life. The main purpose of Diponegoro Dam is to supply raw water for necessity laboratory and campus, beside the Diponegoro Dam is also being used for education research. Dam are susceptible to deformation due to factors change in the ground water level, tidal, geotechnical processes. It have to be investigated and reported due to maintain the structure of Dam.

The purpose of this research is to monitor and analyze the deformations at crest of the Pendidikan Diponegoro dam. A secondary goal was to determine whether GPS observations could meet the accuracy requirements for dam deformation. Deformation analyses were conclude using both an GNSS survey dan terrestrial survey. Then, the results of the two methods have been compared and discussed. Deformation Pendidikan Diponegoro Dam has been research using GNSS [5], Close Range Photogrammetry [6].

Dams and their surrounding areas can be monitored with a variety of techniques to find out if horizontal and/or vertical deformations will arise in time. Because these data focus on particular areas of the dam that have moved, inspectors are alerted to look for potential problems during the visual
inspection. Movement can cause damage or structural distress in concrete dams, and cracking and sliding in embankment ones.

In this method, some points are placed at selected locations, periodically determined coordinates carefully by using GPS survey method. By studying the coordinate change from these points from one survey to the next, then along with other supporting data the dam deformation characteristics will be seen and studied.

2. Pendidikan Diponegoro Dam Monitoring System.

2.1 Study Area.
In this study, the deformations of the Pendidikan Diponegoro Dam were investigated using GPS and precise levelling data. Diponegoro Pendidikan Dam was located in Diponegoro University. The monitoring system consist of 9 Bench in the body of Dam. (see Figure 1).

![Figure 1 (Diponegoro Dam)](image)

The network has 9 reference points, set around the viaduct and 24 deformation points, set on the building of the viaduct and they are established especially on the piers where expected to be most stable places on the structures. The deformation measurements of Diponegoro Dam involved two measurement campaigns. The first campaign was carried out in April 2017, the second in April 2018. The two campaigns include GPS surveys, Total Station and Precise leveling measurements. It should be well designed local geodetic network points.

2.2 Terrestrial measurements using Total Station and Precise Levelling.
Total stations have been used to measure the movement of structures and natural processes with good results [7][8] quote accuracies of better than 1mm for their bridge and tunnel surveys. They use a remote system that logs measurements 6 times daily via a modem, with measurements still possible at peak times. [8] use a reflectorless total station to monitor the long term deformation of bridges. Measurements are taken of the whole bridge every six years and statistical tests are used to confirm if the points have moved. [7] use a total station and other sensors to measure the deformation of the land in a landslide region.

There are several advantages and disadvantages of measurement using a total station for deformation monitoring. High accuracy as main priority. The advantages include the high accuracy as quoted above, the automatic target pointing [7]. Technical specification of this research using Total Station Topcon GTS 235 which has angle measurement 5", distance measurement are accurate to: ± 2mm + 2ppm. The total station is a surveying instrument that combines the angle measuring capabilities of theodolite with an electronic distance measurement (EDM) to determine horizontal angle, vertical angle and slope distance to the particular point.[9]. Total Station can be manually adjusted which can
drive their telescope very accurately. Recently, Total stations can be operated remotely at various levels of automation.

For precise levelling which has specifications Waterpass digital GeoMax ZDL700 with distance accuracy reach 10 mm for D≤ 10 m Distance in m x 0.001 for D>10 m. Measuring time single measure (Electronic). Typically 3 seconds and less in normal daylight condition; needs longer measuring time in uniform dim light condition (20 lux), Magnet damped pendulum compensator with electronic range monitoring; Tilt Warning Range (Electronically): – 10’, Compensator range (Mechanically): – 10’, Setting accuracy: 0.35” max. (Standard Deviation), Magnetic field sensitivity: < 10” (Line-of-sight difference in horizontal constant magnetic field at a field strength of up 5 Gauss)

Many advantages in the use of total station and GPS obtained, but also disadvantages. Total Station observations have limitations in measurements between points that must be visible to each other. When the controls point is far from study area, while need to transfer total station to propagate control is time consuming task. Characteristic of GNSS survey is not needed of line of sight requirement. This advantage more effective for control point establishment, beside GNSS survey cannot be used with lot of obstruction. Comparison of GNSS survey and Total Station Survey shown in Table 1.

### 2.3 GNSS Survey in Diponegoro Dam Monitoring

It should be noted here that in the context of deformation study of dams by GPS survey method, there are several advantages and advantages offered, namely as described below [10].

1. GPS gives the vector value of movement in three dimensions (two components horizontal and one vertical component), so in addition to providing information on the vector of the movement of the dam in the horizontal direction, the GPS also provides information about the vector of the movement of the dam in a vertical direction.
2. GPS gives the vector value of movement in a reference coordinate system single. With it then the GPS can be used to monitor the movement of a region locally effectively and efficiently.
3. GPS can provide vector movement value with precision level in several mm, with high consistency both spatially and temporally. With this high level of precision and consistency, it is expected that even small damages will be well detected.
4. GPS can be utilized continuously regardless of time (day and daynight), in all weather conditions. With these characteristics then implementation of GPS surveys for monitoring the movement of the earth's crust in phase interseismic can be implemented effectively and flexibly.

In this study two GPS surveys have been conducted to monitor deformation Darma Dam, on 09-10 April 2017 and April 2018. GPS Survey implemented on 9 GPS points using a two-frequency geodetic GPS receiver. The location and distribution of GPS points are shown in Figure 2. The GPS Survey implemented by staff from Diponegoro and Geodesy Engineering students.
While observation of GPS satellites, each point generally observes about 4 to 6 hours. Observations were conducted with interval data of 30 seconds and a mask angle of 15°. An example of multiple GPS points in the Diponegoro Dam is shown on figure 2. GPS Station Survey was distributed over body of dam shown on Figure 3.

Figure 2. GPS Network Survey

Figure 3. Survey GNSS (GPS Survey in April 2018)

3 Result and Discussion
3.1 Evaluation of Accuracy and Precision
To evaluate the accuracy and precision of the measurement, RMS and standard deviation of the individual measurements were computed. $\text{nrms}$ (normalized root mean square) is a measure of accuracy of the individual measurement. It can be computed from the deviations between true and measured values. True value of the measured quantity is the value which was determined with significantly higher precision. $\text{nrms}$ was computed using the following formula:

$$
\text{postfit nrms} = \sqrt[4n-u]{x^2}
$$

(1)

With

$$
x^2 = \frac{\partial o^2}{\theta o^2}
$$

(2)

$\partial o^2$ = apriori variance
$\theta o^2$ = aposteriori variance
n = number observation
u = parameter

$\text{nrms}$ is a comparison between an apriori variant with aposteriori variant, standard quality of postfit alue $\text{nrms}$ 0.25, if the $\text{nrms}$ value is greater then still found cycles clip which still not missing or related with extra bias parameter, or error in modeling. Other parameters for checking for phase ambiguity are the values of WL and NL. W1 more than 90% is good, if less then there is noise on
pseudorange. NL values are good if over 80%, if less then there are errors in network configuration size, orbital, a priori coordinates or atmospheric conditions. Table 2 shows the WL values below 80% at points B700 and B800 and NL values below 80% indicate errors in orbital and network configuration, as well as atmospheric conditions.

Table 2. Posfit nrms and Phase Ambiguity 2017

| Point | DOY | Postfit nrms | Ambiguity |
|-------|-----|--------------|-----------|
|       |     | Constrained  | Loose     | WL % | NL % |
|       |     | Free Fix     | Free Fix  |      |      |
| A100  | 97  | 0.196 0.200  | 0.163 0.169 | 91.90% | 71.80% |
| A200  | 97  | 0.216 0.221  | 0.215 0.221 | 88.60% | 74.50% |
| A300  | 97  | 0.194 0.198  | 0.180 0.184 | 89.40% | 64.20% |
| A400  | 97  | 0.236 0.240  | 0.224 0.228 | 90.70% | 68.90% |
| A500  | 97  | 0.234 0.237  | 0.222 0.225 | 90.00% | 70.70% |
| A600  | 97  | 0.198 0.203  | 0.184 0.188 | 89.30% | 74.50% |
| B700  | 98  | 0.201 0.202  | 0.174 0.176 | 76.70% | 26.40% |
| B800  | 98  | 0.202 0.203  | 0.183 0.185 | 79.10% | 45.00% |
| B900  | 98  | 0.261 0.262  | 0.249 0.249 | 84.50% | 44.20% |

The results of Gamit 10.7 in 2018 for WL show, a value of > 90%, indicating no pseudoranges noise error, whereas for NL for point A100, A300 and A400 meet tolerances with values> 80%, while other points indicate there are orbital errors, network errors as well as atmospheric conditions. For more details are presented in Table 3. Both posfit nrms value in 2017 and 2018 is around 0.2 so that the postfit nrms value falls within the criteria for good GAMIT processing.

Table 3. Posfit nrms and Phase Ambiguity year 2018

| Point | DOY | Postfit nrms | Ambiguity |
|-------|-----|--------------|-----------|
|       |     | Constrained  | Loose     | WL % | NL % |
|       |     | Free Fix     | Free Fix  |      |      |
| A100  | 116 | 0.204 0.209  | 0.182 0.187 | 94.40% | 82.10% |
| A200  | 114 | 0.204 0.208  | 0.192 0.196 | 92.40% | 79.00% |
| A300  | 114 | 0.204 0.208  | 0.190 0.195 | 92.20% | 83.70% |
| A400  | 114 | 0.203 0.207  | 0.190 0.195 | 92.80% | 83.70% |
| A500  | 97  | 0.210 0.214  | 0.189 0.194 | 91.00% | 79.50% |
| A600  | 97  | 0.211 0.215  | 0.190 0.195 | 93.40% | 78.30% |
| B700  | 98  | 0.221 0.224  | 0.195 0.198 | 94.30% | 75.20% |
| B800  | 98  | 0.219 0.223  | 0.194 0.197 | 84.50% | 44.20% |
| B900  | 98  | 0.220 0.224  | 0.195 0.198 | 95.50% | 75.20% |

GPS Data Processing in this research using GAMIT 10.7. Result shown in Figure 4, The standard deviations of GPS-derived relative ellipsoidal from all surveys were in general not better enough in range 0-4cm. A few points have slightly larger standard deviations, due to the lack of observed data caused by the signal obstruction). The most larger standart deviation in Yaxis comparing X and Z axis.
3.2. Waterpass Time series observations.

Digital Waterpass observations give results with a standard deviation value ranging from 0.0014 m to 0.0006 m in 2017 and 0.0001 to 0.0013 m in 2018 can be seen in Table 4. In 2017 found the lowest standart deviation was located in point A2 with the standart deviation level 0.0002m. The highest standart deviation was found in A9 with standart deviation 0.0014m. The result of monitoring deformation using Digital Waterpass in 2018 shown that the lowest level of standart deviation 0.0004m in A6. The Largest standart deviation found at A8.

| Point | 2017             | 2018             |
|-------|------------------|------------------|
|       | h ( m ) STDEV ( m ) | h ( m ) STDEV ( m ) |
| A1    | 95,3122 0.0006   | 95,3031 0.0011   |
| A2    | 95,4368 0.0002   | 95,4302 0.0005   |
| A3    | 95,6031 0.0008   | 95,5977 0.0013   |
| A4    | 95,6763 0.0021   | 95,6694 0.0006   |
| A5    | 95,6501 0.0013   | 95,6435 0.0006   |
| A6    | 95,6648 0.0013   | 95,6539 0.0004   |
| A7    | 91,0826 0.0012   | 91,0809 0.0000   |
| A8    | 90,8492 0.0013   | 90,8413 0.0042   |
| A9    | 90,5592 0.0014   | 90,5539 0.0100   |

3.3. Total Station Time Series observations

The observed deformation point used for GPS observations are also controlled movement to the total station control point (TS01) located outside the body of the dam, every observation period observed the distance from the control point to the monitor point deformation, distance measurement is done as much as 5 times each measurement period and the average distance taken, then the results obtained distance per observation period (see Table 5).
Table 5. Time Series in Total Station Survey

| Point | 2017 D (m) | STDEV (mm) | 2018 D (m) | STDEV (mm) |
|-------|------------|------------|------------|------------|
| A100  | 180,883    | 1.70       | 180,881    | 0.29       |
| A200  | 148,493    | 0.70       | 148,502    | 0.04       |
| A300  | 122,925    | 2.91       | 122,925    | 0.04       |
| A400  | 88,335     | 0.85       | 88,330     | 0.03       |
| A500  | 59,181     | 0.05       | 59,189     | 0.05       |
| A500  | 33,758     | 0.37       | 33,770     | 0.05       |
| B700  | 43,847     | 0.37       | 43,852     | 0.05       |
| B800  | 87,802     | 1.99       | 87,798     | 0.03       |
| B900  | 134,470    | 0.43       | 134,467    | 0.28       |

4 Discussion and Conclusion

In general, deformation analysis is evaluated in three steps in a geodetic network. In the first step, the measurements, taken during the measurement periods $t_1$ and $t_2$, are adjusted separately according to the free adjustment method; outliers and systematic errors are detected and eliminated in this step. In the second step, a global testing procedure is performed and with this test it is ensured that if the network point, assumed to be stable, remains completely stable in $\Delta t$ interval time.

The highest difference height found at the point A6 reach 1.09 cm shown in Figure 5. Difference height observed waterpass were conducted using statistical tests (t-test) to find out whether significant changes occur, following results Test statistics for waterpass observations are shown Table 6.

![Figure 5. Difference Height observed using waterpass survey](image-url)
Table 6. The results tests using Waterpass

| Point | Difference Height (mm) | σ1 (mm) | σ2 (mm) | t table | t-count | Displacement |
|-------|------------------------|---------|---------|---------|---------|--------------|
| A1    | -9,10                  | 0,60    | 1,13    | 12,71   | -10,08  | No           |
| A2    | -6,60                  | 0,20    | 0,49    | 12,71   | -17,55  | Yes          |
| A3    | -5,40                  | 0,80    | 1,34    | 12,71   | -4,91   | No           |
| A4    | -6,90                  | 2,10    | 0,64    | 12,71   | -4,46   | No           |
| A5    | -6,60                  | 1,30    | 0,64    | 12,71   | -6,47   | No           |
| A6    | -10,90                 | 1,30    | 0,35    | 12,71   | -11,47  | No           |
| B7    | -1,70                  | 1,20    | 0,10    | 12,71   | -2,03   | No           |
| B8    | -7,90                  | 1,30    | 4,24    | 12,71   | -2,53   | No           |
| B9    | -5,30                  | 1,40    | 9,97    | 12,71   | -0,75   | No           |

From the statistical test data from the height using the Digital waterpass shown in Table 6 it is concluded that the elevation change occurred at point A2. As for the other point of observation point there is no elevation change. The result of analysis from observation with total station Figure 6 shows the distance difference from Base Station to point observation. The highest difference reach to 1.65 cm was located at A200 and the shortest distance difference at point B900 range to 0,04cm

![Difference Distance](image)

Figure 6. Different Distance observed using Total Station

Result of t test to change of distance of all observation point of deformation shows result of t-count value bigger than t-table value, so statistically said that significant distance change is shown in Table 7. There are two stable point. It were A100 and A300. Can be Statistically said that there are no displacement at that point.

Table 7. The results tests using Total Station

| TS01 to | Difference Distance (mm) | σ1 (mm) | σ2 (mm) | n  | t table | t-count | Displacement |
|---------|--------------------------|---------|---------|----|---------|---------|--------------|
| A100    | -0,72                    | 0,54    | 0,333   | 5,00 | 2,78    | -2,64   | No           |
| A200    | 4,97                     | 0,00    | 0,316   | 5,00 | 2,78    | 34,95   | Yes          |
| A300    | 0,01                     | 2,91    | 0,422   | 5,00 | 2,78    | -0,01   | No           |
| A400    | 3,92                     | 0,41    | 0,675   | 5,00 | 2,78    | 11,03   | Yes          |
Calculation of GPS data in 2017 shows the standard deviation is large enough in the Y component, reaching 36.23 mm, while in component X reaches 19.51 mm. A considerable deviation occurs at point A100 in both X and Y components (see Table 8).

### Table 8. Coordinat GPS Survey 2017

| Site  | X (m) | Y (m) | Z (m) | Sigma X (mm) | Sigma Y (mm) | Sigma Z (mm) |
|-------|-------|-------|-------|--------------|--------------|--------------|
| A100  | -2211370.03 | 5931608.708 | -777830.312 | 15.14 | 36.23 | 9.02 |
| A200  | -2211376.14 | 5931602.38 | -777861.944 | 13.22 | 27.25 | 7.04 |
| A300  | -2211380.66 | 5931597.533 | -777887.249 | 12.41 | 27.13 | 7.41 |
| A400  | -2211386.79 | 5931590.722 | -777922.096 | 9.83 | 17.93 | 5.59 |
| A500  | -2211392.07 | 5931584.649 | -777952.973 | 11.27 | 20.02 | 5.64 |
| A600  | -2211398.07 | 5931578.165 | -777985.838 | 12.32 | 24.86 | 6.64 |
| B700  | -2211406.8 | 5931573.608 | -777958.256 | 18.15 | 25.7 | 7.3 |
| B800  | -2211399.85 | 5931581.672 | -777914.424 | 18.36 | 21.4 | 6.6 |
| B900  | -2211392.89 | 5931589.992 | -777868.589 | 19.51 | 23.17 | 6.6 |

GPS data processing year 2018 (Table 9) showed results with a fairly large standard deviation both X and Y components, the largest X and Y value at the point A10 of 16.41 mm, and 36.69 mm. The large standard deviation value at all points of observation indicates that the indication of the strength of the satellite geometry is not good, it can be caused by long GPS probe. GPS observations that lasted for 4.5 to 5 hours. This implies a considerable standard deviation value. T test analysis cannot be done further due to the considerable standard deviation value both in 2017 and 2018.

### Table 9. Coordinat GPS Survey 2018

| Site  | X (m) | Y (m) | Z (m) | Sigma X (mm) | Sigma Y (mm) | Sigma Z (mm) |
|-------|-------|-------|-------|--------------|--------------|--------------|
| A100  | -2211370.040 | 5931608.674 | -777830.331 | 16.41 | 36.69 | 10.09 |
| A200  | -2211376.173 | 5931602.384 | -777861.950 | 9.46 | 21.11 | 6.53 |
| A300  | -2211380.690 | 5931597.529 | -777887.272 | 8.94 | 20.6 | 5.74 |
| A400  | -2211386.798 | 5931590.689 | -777922.106 | 8.88 | 20.36 | 5.67 |
| A500  | -2211392.088 | 5931584.607 | -777952.978 | 8.2 | 17.7 | 5.46 |
| A600  | -2211398.071 | 5931578.069 | -777985.836 | 9.31 | 21.73 | 5.93 |
| B700  | -2211406.824 | 5931573.518 | -777958.266 | 11.64 | 27.45 | 7.2 |
| B800  | -2211399.892 | 5931581.666 | -777914.429 | 11.22 | 26.46 | 7.02 |
| B900  | -2211392.942 | 5931590.017 | -777868.606 | 10.99 | 25.8 | 6.87 |
The results of the study conclude:

1. The results of processing point deformation from waterpass survey shown there are no deformation all of point observation except A200.

2. Statistical test for Total Station data shown there are horizontal displacement except A100 dan A300.

3. Result of GPS Data Processing both in 2017 and 2018 has large standard deviation in order to 36,23 mm in y absis and 19,51 mm in x absis. It cannot be continue to analysis because of lack of data gps observation.

4. The displacement in observation of GNSS occurs due to reference to the global coordinate, so it needs to be taken into calculate the effect of the block deformation of the Sunda block.

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