Conference Paper

Deformation Measurement in the Penggaron Tol Bridge Area Using GNSS Technology

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Abstract

The Penggaron Bridge is one of the longest bridges on the Semarang-Solo Toll Road Section I Km.20. This bridge is in an area with less stable soil conditions. So, the deformation monitoring must be carried out to determine the deformation conditions in the area around the toll bridge. Measurement of deformation in the bridge area of Penggaron was conducted in 2015 and 2016 using the technology of the Global Navigation Satellite System (GNSS). This research was conducted by observing GNSS at eight observation points in the Penggaron Toll Bridge area. Measurements were taken three times over three months in 2018. The velocity rate of horizontal component of observation station of the Penggaron Toll Bridge area deformation after elimination the effect of Sunda Block Rotation become ranged for 1.5 mm/year to 12.1 mm/year. The statistical test results that all observation stations have no movement or no deformation. Four new stations measured and installed in 2018 require another measurement the following year to get a good velocity rate.

Keywords: penggaron toll bridge, deformation, GNSS survey

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1. Introduction

The Government of the Republic of Indonesia is increasing the construction of extensive infrastructures such as toll roads, bridges, and dams. A bridge is a building structure that connects one place to another. The two places can be separated by waterways, rivers, cliffs to the sea or even cross over other roads. The bridge parts consist of the upper structure, which is the part that receives the load directly, the lower structure as a whole load bearer, and the foundation part that performs to carry the loads above it, toward the subgrade. Bridges can be damaged due to the burden it upholds, construction structure, or the soil conditions that support the bridge's foundation. One of the soil conditions that can cause bridge damage is ground movement. Movement in ground may cause deformation of the bridge structure.

The Penggaron Bridge, with a length of approximately 400 meters, is one of the bridges located on the Semarang-Solo toll road section Km.20. The bridge is above the

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unstable land and is influenced by a fault in Semarang Regency/City [1]. The geological structure is in the form of a normal west-east trending fault that intersects the Kaligetas Formation and the Kerek Formation. Some north-directed alignment patterns are a potentially weak area to control ground motion. This condition can induce a significant change of position in the area around the bridge. The Penggaron Bridge is located on a toll road linking two major cities in Central Java, so it has a significant role in regional economic development. Therefore, it is vital to observe deformation in the bridge area as an early warning system.

Deformation monitoring or structural monitoring is generally a work procedure to ensure the safety of building structures and also to validate the design of building structures. Structural monitoring is essential in bridge construction. Bridge structures can change in shape, even shift, due to several factors such as environmental stresses, structural loads, and tectonic movements.

Measurement of deformation in the bridge area of Penggaron was conducted in 2015 and 2016 using the technology of the Global Navigation Satellite System (GNSS). Measurements were made at four observation points. The results of the two measurements have not taken into account as a deformation effect due to the rotation movement of the Sunda Block [2 & 3]. This study measured deformation at four old observation stations and four new observation stations. Then calculate how much the deformation value of the Penggaron area from 2015 to 2018.

2. Monitoring of Deformation Bridges

A bridge is one of the most important constructions in the field of infrastructure management. Regular inspection and monitoring of bridge structures are needed to ensure bridge stability and reliability. Conventional deformation surveys (terrestrial) and GNSS satellites can be used to monitor bridge deformation. The terrestrial survey method with precise leveling is a remarkably efficient, reliable, and accurate method for short-term monitoring. GNSS technology is an effective method for monitoring deformation in the long run [4].

Another method that can be applied for monitoring deformation is Close Range Photogrammetry (CRP). This method can be used for monitoring deformation in a multitemporal bridge. This method has been applied to monitoring the Suramadu Bridge deformation. The CRP method uses a non-metric camera with automatic calibration and space resection processing in a bundle adjustment technique [5]. Structural Health Monitoring (SHM) bridge can use the combination of GNSS and accelerometer. An accelerometer is considered to be a traditional sensor in bridge monitoring. The integration of these sensors with other high-accuracy sensor technology may overcome the deficiencies in each measurement technique. However, GNSS has better accuracy in measuring bridge deformation compared to accelerometers [6].

Continuous bridge deformation monitoring can be done using the GNSS real-time kinematic method. The high sampling rate of GNSS (currently up to 100Hz) can provide flexibility to measure real-time positions with high accuracy from static and dynamic monitoring points. RTK GNSS monitoring system can monitor deformation within a bridge, using high accuracy, in the expense of high cost. Therefore, when it a method of network-based real-time kinematic (NRTK) GNSS was developed to precisely point positioning of GNSS for monitoring use, with a lower cost [7]

3. Monitoring Toll Penggaron Bridge Deformation Monitoring

Waluyo et al. conducted deformation measurement at eight points control area of Penggaron Toll Bridge in 2015, employing GNSS survey method. Measurements were made three times in three months. Coordinate processing with GAMIT software uses eight IGS stations as reference points. The result of the calculation of point displacement is that there is no significant displacement in all observation points. In this study, the influence of point displacement due to the effect of rotation of the Sunda Block was not taken into account [2].

Nugroho et al. also carried out GNSS measurements at eight deformation observation points in the Penggaron Toll Bridge area. Measurements were taken four times at four points, over four months, and twice at four locations, for two months in 2016. Data processing of the observation point coordinates was carried out by two methods of binding to the reference point. The first method uses the CORS IGS reference point and the second method with the CORS BIG reference point. The coordinates produced in the first method have higher accuracy compared to the second method [3].

4. Research Methodology

This research was conducted by observing GNSS at eight observation points in the Penggaron Toll Bridge area. Measurements were taken three times over three months in 2018. Deformation calculations were performed using Waluyo et al 's 2015 measurement data; Nugroho measurement data in 2016; and measurement data in this study. The deformation observation point used is four the same spot with measurements in 2015 and 2016 and a new four-point mounted, as shown in Figure 1. Four new points were installed because four old points were lost. The measurement time in 2018 can be chosen at Table 1.

Figure 1: The Location of Observation Stations.

Table 1: The Day of Year (DOY) of 2018 Station Observation.

Station	Session 1	Session 2	Session 3
BMDU	088	123	174
BMSA	088	123	174
CPDU	088	123	174
CPSA	088	123	174
TK01	087	121	173
TK02	087	121	173
TK03	087	121	173
TK04	087	121	173

The coordinate data processing method uses the referencing strategy to the global reference point (IGS). Processing CORS data using global reference points (IGS) produces more precise coordinates compared to processing using regional points of interest (CORS BIG) [8]. The geocentric coordinates that result from processing in the GAMIT/GLOBK GNSS software are transformed to topocentric coordinates. The topocentric coordinates in the first observation session of each station serve as the origin of each station's topocentric coordinate system. Therefore, each station has its own topocentric coordinate system. The velocity vector of observation point is calculated by the least square method [9].

The velocity vector of the observation point at the result of the least square count is still affected by the Sunda Block rotational movement effect. Therefore, this effect must be eliminated to get the local deformation of the Penggaron Toll Bridge area.

The parameter calculation of the Sunda Block rotation effect uses the origin coordinate value and the angular velocity of the Sunda Block from Kuncoro et al. [10].

4.1. The GNSS Data Processing

This research was conducted by observing GNSS at eight observation points in the Penggaron Toll Bridge area. Measurements were taken three times over three months in 2018. Deformation calculations were performed using Waluyo et al 's 2015 measurement data; Nugroho measurement data in 2016; and measurement data in this study. The deformation observation point used is four the same spot with measurements in 2015 and 2016 and a new four-point mounted, as shown in Figure 1. Four new points were installed because four old points were lost. The measurement time in 2018 can be chosen at Table 1.

GNSS data processing uses the IGS reference station. Eight stations use the IGS stations: BAKO, COCO, DARW, DGAR, GUAM, IISC, KARR, and PIMO. The topocentric coordinates of the results obtained at GAMIT / GLOBK can be seen in Tables 2, 3, and 4.

Table 2: The Topocentric Coordinate of 2018 Station Observation Session 1.

Station	n (m)	e (m)	u (m)
TK01	-792,443.9302	12,197,112.7516	314.8157
TK02	-792,431.3565	12,197,207.5753	300.6418
TK03	-792,599.4452	12,197,229.6124	276.0811
TK04	-792,524.3068	12,197,138.9317	298.7403
BMDU	-792,933.9417	12,197,119.8551	340.7018
BMSA	-792,024.7804	12,197,196.8345	353.3241
CPDU	-792,053.6150	12,197,211.3960	352.1288
CPSA	-792,934.7085	12,197,181.4800	343.7002

Table 3: The Topocentric Coordinate of 2018 Station Observation Session 2.

Station	n (m)	e (m)	u (m)
TK01	-792,443.9318	12,197,112.7476	314.7149
TK02	-792,431.3597	12,197,207.6081	300.6804
TK03	-792,599.4505	12,197,229.6141	276.0797
TK04	-792,524.3113	12,197,138.9298	298.7288
BMDU	-792,933.9355	12,197,119.8660	340.7037
BMSA	-792,024.7943	12,197,196.8299	353.3393
CPDU	-792,053.6231	12,197,211.3968	352.1466
CPSA	-792,934.7273	12,197,181.4712	343.7172

Table 4: The Topocentric Coordinate of 2018 Station Observation Session 3.

Station	n (m)	e (m)	u (m)
TK01	-792,443.9312	12,197,112.7492	314.7808
TK02	-792,431.3710	12,197,207.6293	300.6457
TK03	-792,599.4503	12,197,229.6118	276.0793
TK04	-792,524.3067	12,197,138.9300	298.7283
BMDU	-792,933.9396	12,197,119.8690	340.6974
BMSA	-792,024.7922	12,197,196.8384	353.3577
CPDU	-792,053.6240	12,197,211.3950	352.1512
CPSA	-792,934.7206	12,197,181.4882	343.6711

4.2. The Velocity Rate of Penggaron Toll Bridge Deformation Stations

The displacement velocity of observation station was calculated exclusively for the four stations measured from 2015 to 2018. Four new stations installed and measured in 2018 need another measurement the following year to get a good velocity rate.

The velocity rate of observation stations was calculated from the topocentric coordinates time series. This calculation used the least square method.

Table 5: The Velocity Rate of The Observation Stations (m/year).

Station	Ve	Vn	Vhor
BMDU	0.0321	-0.0054	0.0325
BMSA	0.0273	-0.0067	0.0281
CPDU	0.0276	-0.0076	0.0286
CPSA	0.0358	-0.0009	0.0359

We can see in table 5, the velocity rate of four stations is around 28.1 mm/year until 35.9 mm/year. deformation activity in the measurement area is dominated by sundanese block rotation. therefore, to get the deformation value in the penggaron toll road, the rotation effect of the sunda block rotation must be eliminated.

The velocity rate of observation station due to Sunda Block rotation was calculated using a euler pole model in ITRF 2008. This model has origin of rotation at -89.4° of longitude and 46.2° of latitude and angular velocity 0.327 deg/Myr [10].

The velocity rate of the observation station after reducing the effect of rotation of the sunda block can be seen in table 6.

The velocity rate of horizontal component of observation station of the Penggaron Toll Bridge area deformation after elimination the effect of Sunda Block Rotation become ranged form 1.5 mm/year to 12.1 mm/year.

TABLE 6: The Velocity Rate of The Observation Stations (m/year) after elimination the Effect of the Sunda Block rotation.

Station	Ve	Vn	Vhor
BMDU	0.0060	0.0026	0.0066
BMSA	0.0012	0.0013	0.0018
CPDU	0.0015	0.0004	0.0015
CPSA	0.0098	0.0071	0.0121

Statistic T-tests are performed on velocity rate of observation station. The test variable is the value of velocity rate (V) of each station. We used the normal distribution table with 95% confidence interval that was obtained the value T> tdf, α/2 is 1.96 [9]. The statistical test results that all observation stations have no movement or no deformation.

5. Conclusion

The displacement velocity rate of the four stations is 28.1 mm / year to 35.9 mm/year. Deformation activity in the measurement area is mainly caused by the activity of the rotation movement of Sundanese fault. Therefore, to get the value of deformation in the Penggaron Toll Road, the rotation effect of the Sunda Fault must be eliminated.

The velocity rate of horizontal component of observation station of the Penggaron Toll Bridge area deformation after elimination the effect of Sunda Block Rotation become ranged for 1.5 mm/year to 12.1 mm/year. The statistical test results that all observation stations have no movement or no deformation.

Four new stations measured and installed in 2018 require another measurement the following year to get a good velocity rate.

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Conflict of Interest

The authors have no conflict of interest to declare.

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