

# **Design and installation for Dam Monitoring Using Multi sensors: A Case Study at Sermo Dam, Yogyakarta Province, Indonesia.**

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**Key words:** RTS, prisms, GNSS CORS, AWLR, and digital IP Camera.

## **SUMMARY**

Indonesia Island consists of several big islands such as Sumatra, Java, Kalimantan and west of Irian islands etc. This country has built more than 284 large and small dams. Some of those dams are not in good condition in terms of safety, service function, operation and maintenance, as well as quantity and quality as a source of water. One of the 284 large dams is Sermo dam which is located in Java Island and has been operated since 1996. It is suspected that Sermo dam is suffered from deformation caused by earthquake, three-dimensional position, etc so it is very urgent to monitor the dam.

A geodetic and hydrological engineering were designed to detect displacements in Sermo dam using multi sensors permanently installed. The multi sensors permanently installed are 3D Robotic Total Station (RTS) sensor, an array of permanently mounted prisms, two units of GNSS CORS sensors, Automatic Water Level Recording (AWLR) sensor, and Pan, Tilt, and Zoom digital IP Camera. GNSS CORS sensors have been installed using two towers. The first tower is for a base station (SRM1) and the second tower at upstream area of Sermo dam is for a back sight station (SRM2) which one unit of prism has also been installed. At the first tower, the RTS and GNSS CORS have been installed which the GNSS antenna was installed about 2.30 meters above RTS and. Distance between the first and the second towers is about 2500 m. Mean while 19 prisms as targets of RTS which consist of 6 prisms at the downstream slope, and 13 prisms at the crest of center dam. Automatic Water Level Recording sensor and Pan, Tilt, Zoom digital IP Camera (CCTV) are installed at Intake Sermo Dam

## 1. INTRODUCTION

Indonesia, as an archipelago, located partly on the Eurasian plate, which is subduction by the three major plates: the Indo-Australian plate in the south and in the west; the Pacific plate in the East and the Philippine Sea plate in the north (Bock et al, 2003). These subduction zones around Indonesia create a ring of volcanoes, which is called “the Ring of Fire”. Purbawinata et al., (1997) state that the subduction zone is marked by a chain of active and dormant volcanoes which spreads along Sumatra, Java, Bali, Lombok, Sulawesi to the eastern part of Indonesian.

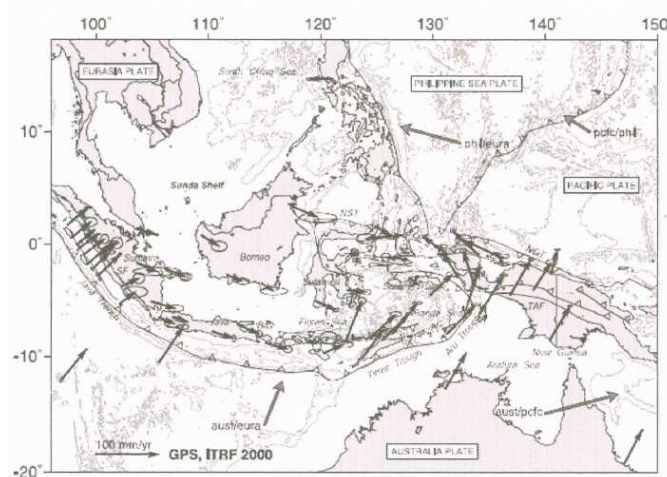


Fig.1. Indonesia Tectonic map with respect to ITRF 2000.0. Arraws are indicating horizontal displacements vector using GPS data in 1991 to 2001 (Bock et al, 2003).

Indonesia has built more than 284 large and small dams. Some of those dams are not in good condition in terms of safety, service function, operation and maintenance, as well as quantity and quality as a source of water. Expected life age of dam is generally determined by the characteristics of dam structure stability, path dynamical factors such as endogen, exogenous, tectonic earthquake, and dam management system. Dams are generally deformed by static and dynamic movements. The deformation is possibly caused by the reduction or settlement embankment, earthquake, sliding, three-dimensional position, cracks, shifting, high-low water level, seepage or leakage. Table 1 below is shown the risk of damage to dams that occurred in Indonesia. Magnitude is then classified into low level, moderate, high, and extreme ranges where the low valuation of 0 to 15, moderate rating ranged between 16 to 45, high appraisal values ranged between 46 to 75, and assessment of extreme values ranging between 76 to 90.

Table.1. Risk Assessment of Dams in Indonesia (Adzan dan Samekto, 2008)



One of the 284 large dams is Sermo dam which is located in Java Island and has been operated since 1996. It is located in the village area of Hargowilis, Kokap district, Kulon Progo, Yogyakarta province, Indonesia precisely. This dam is vulnerable to earthquake hazards, approximately 7 km west of town Wates or 36 km west of Yogyakarta city Indonesia.

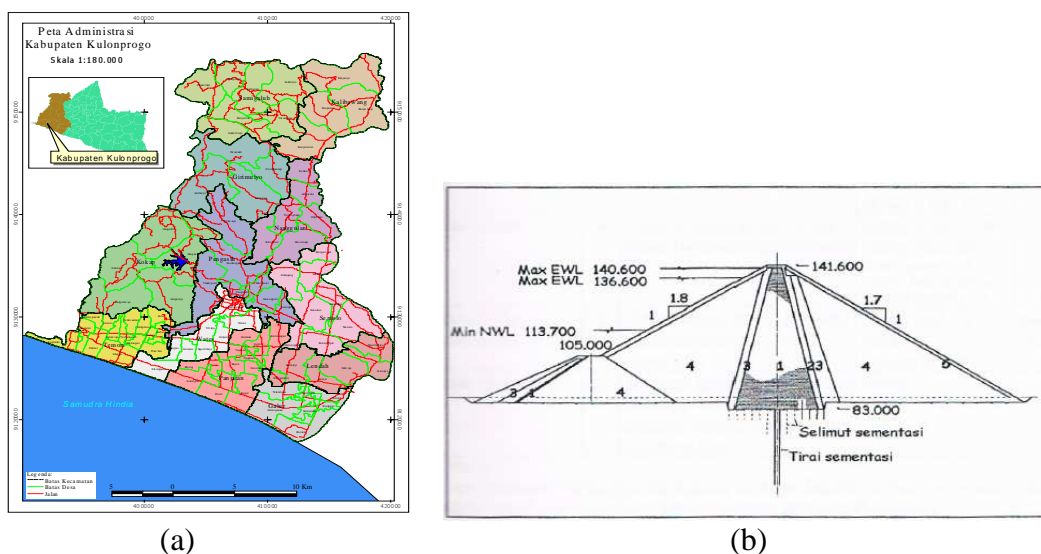


Fig.2. (a) Map of Sermo dam with dark blue color and (b) is cross section of Sermo dam.

Location of Sermo dam covers Progo river region Opak Serang Kulon Progo regency. Coverage area of Sermo dam is at  $110^{\circ} 1'$  up to  $110^{\circ} 16'$  east longitude and  $7^{\circ} 38'$  up to  $7^{\circ} 59'$  South (see Fig. 2(a)). The cross section of Sermo dam (see Fig. 2 (b)). The view of Sermo dam (upstream and downstream) can be seen at Fig. 3 (a) and (b).



Fig.3. Sermo dam area where (a) is upstream and (b) is downstream area.

It is suspected that Sermo dam is suffered from deformation caused by earthquake, three-dimensional position, etc. Sermo dam is one of critical dams in Indonesia (Azdan dan Samekto, 2008), so it is very urgent to monitor the dam properly.

## 2. SERMO DAM MONITORING SYSTEM COMPONENTS

Safety is the primary and most important reason for monitoring the deformations of dams. A secondary reason is the need for improving our knowledge of the mechanical behavior of dam embankments (Gikas and Sakellariou, 2008). Monitoring deformation pattern is often one of the most effective ways to be informed the safety status of such structures. The safety of large man-made structures, the environmental protection and the development of associated mitigating measures in the case of natural disasters, require a good understanding of the causes and the mechanism of the structural deformation process (Gikas and Sakellariou, 2008).

Deformation monitoring systems are designed to measure the deflection or distortion of a structure under normal and extreme conditions. Dams, bridges, large and tall buildings are examples of structures that are routinely surveyed and monitored (Choudhury and Rizos, 2011). Many man-made and natural structures such as buildings, bridges, dams, and slopes undergo various forms of deformations. Precise monitoring of the progressive deformations of these structures can often provide vital information on the stability and safety status. Deformation monitoring can be carried out by manual deformation monitoring and an automatic deformation monitoring system. Gikas et al, (2005) in their research concluded that geodetic monitoring of Mornos dam since 1977 confirms that changes in its appearance have been gradual. In their research, recent crest surveys based on GPS and precise leveling data have consistently provided evidence that the deformation pattern established years ago has developed or matured only slightly.

With high-precision geodetic GPS receivers as well as strict surveying procedures and data processing methods, the continuous or campaign GPS surveying can be used to detect ground deformation with an horizontal accuracy of 0.1 cm/ year and a vertical accuracy of 0.3 cm/ year (Cai et al., 2008). Tasci (2010) in his research concluded that maximum horizontal movements caused by water load effect could occur in the middle of the dam's crest in arch

dams was approved by applied GPS measurements and deformation analysis methods. It may offer advantages over traditional surveying techniques that measure relative geometric quantities between selected points, and also over techniques that employ geo-technical instrumentation (Ali et al., 2005). Surface displacements are an important indicator of structural stability and surface monuments are often included in the overall monitoring regime. In the long-term, dams can be subject to alternating cycles of fast filling and rapid drawdown. Therefore, instrumentation that can provide measures of horizontal and vertical movement is desirable (Hanna 1973).

Global Navigation Satellites Systems (GNSS) are a very popular technology for monitoring of both “fast” and “slow” structural deformation (Choudhury and Rizos, 2011). GNSS technology is being extensively used for monitoring the movement of engineering structures such as bridges, tall buildings, dams, breakwaters, etc. Large structures increasingly have one or more GNSS receivers installed on them, and this trend is expected to continue unabated (Rizos et al., 2010).

GNSS Continuously Operating Reference Station (CORS) not only provides navigation services based on pseudorange observations, but also offers carrier phase observations to develop realtime and quasi-realtime deformation monitoring techniques (Jiang-xiang and Hong, 2009). The development of prediction methods, which allow a determination of deformations and stress distribution and comparison of predicted values with observed, constitutes very valid tools to control safety (Chrzanowski et al., 2008). Several other trends of GNSS CORS are also emerging (Rizos et al., 2010): integrated deformation monitoring systems, real-time kinematic (RTK) being almost exclusively the GNSS technique that is used, the use of low cost L1-only GNSS sensors on the deforming structure, system control platforms that link to and manage the data logging and control of many sensors (including GNSS), increased use of sophisticated time series analysis to characterize the movement of structures, and use of installed permanent GNSS reference station infrastructure.

The dynamics of the structure typically defines the nature of the coordinate analysis (Rizos et al., 2010). Three dimensional monitoring using manual or Robotic Total Stations and reflective targets is a useful and practical method to determine whether structures are undergoing any deformation as a result of external influences. Continuous geodetic deformation monitoring applications typically rely on positioning or coordinate solutions (provided by GNSS, Total Station or other manual or automatic survey technology) and a subsequent (or near-real-time) statistical analysis procedure to unambiguously identify movement of the target or monitoring instrument that is interpreted as structural deformation (Choudhury and Rizos, 2011). The analysis led to a conclusion that the optimal monitoring scheme should be based mainly on the use of permanently installed Robotic Total Stations with the automatic target recognition and permanently installed object prisms on the crests and downstream faces of the dams in combination with a few continuously operating GNSS monitoring stations on the dam crests and the aforementioned geotechnical instrumentation. Monitoring the integrity of engineered structures demands very high precision displacement measurements from a robust system, as close as possible to real-time (Chrzanowski et al., 1986). Motorized total stations (TPS) with automatic reflector recognition are now widely accepted as ideal sensors for any monitoring projects. High accuracy GPS receivers have also gained acceptance to be deployed in such application (Cranenbroeck et al., 2004).

Currently, total station and electronic theodolite are the most commonly used

instrument in surveying. Recent technology with 'robotic' function provides total station and electronic theodolite with servo drive mechanism. This mechanism enables instruments to aim automatically to the points to be measured (Setan and Idris, 2008). The total stations will be remotely operated and will automatically collect three dimensional data on a set time schedule. These total stations will also be linked to GNSS CORS which will be programmed to turn on the RTS whenever a preset tolerance level of deformation is exceeded due to, for instance, an earthquake or abrupt settlement.

The foundation of shelter has been designed according to the geology of each location to provide as stable a structure as possible. A holder for GNSS antenna will be permanently mounted to a structural support on the roof of the shelter, directly above the center of the instrument so that, whenever needed, the stability of the foundation/pillar can be monitored by the GNSS control surveys connected to the on-site geodetic control network. Three Dimensional monitoring using Robotic Total Stations (RTS) and reflective targets is a useful and practical method to determine whether structures are undergoing any deformation as a result of external influences. Measurements can be taken automatically, depending on the required frequency, accessibility and accuracy. Results from this technique provide three-dimensional deformation of the structure and allow for post survey analysis to quantify the degree of deformation.

Component for Sermo dam monitoring system consists of remote area (in Sermo dam area) and computer center system. In the remote area, the components of the monitoring scheme consist of two main systems, there are :

- a) Dam Deformation Monitoring System (DDMS) which includes a number of monitored object points on the dams and a network of local reference stations with respect to which displacements of the object points are to be determined.
- b) On-site GNSS CORS System is the system for monitoring the stability of the area surrounding the reservoir (ridge lines) and for checking and updating positions of DDMS reference stations.

The computer center system consists of server and communication system from the remote area to computer center.

### **3. DESIGN AND INSTALLATION SERMO DAM MONITORING.**

Automatic deformation monitoring systems provide a critical function for the customer. Sermo Dam monitoring using multi sensor will be operated to be an automatic deformation monitoring system. The multi sensors of this research permanently installed are 3D of RTS sensor, an array of permanently mounted prisms, two units of GNSS CORS sensors, Automatic Water Level Recording (AWLR) sensor, and Pan, Tilt, and Zoom digital IP Camera. The design of dam monitoring system at Sermo consists of base station, back sight station, monitoring points, and communication system. Base station has been used as reference station. At the base station, this place has been selected where dam deformation will not affect with respect to it and it has been build a tower as a first tower for installation of GNSS CORS receiver and Robotic Total Station (RTS). The base station is usually selected at downstream or upstream depends on the situation which is able to monitor dam body. After several site visits to Sermo dam, the design of dam monitoring system at Sermo was carried

out. The first priority to the design is look for place as base and back sight station. Then the base station was designed at downstream area and for back sight station was designed at upstream area. The next design is to look for place as monitoring points at Sermo dam body. The design for monitoring points is to look for place about 20 points to be distributed at Sermo dam body and its surrounding of Sermo dam area. The distribution of monitoring points : about 19 prisms and 1 point as targets of RTS. The 19 prisms consists of 13 points are selected at crest of Sermo dam, 6 points are at the slope of downstream Sermo dam and 1 points is at back sight station. Automatic Water Level Recording sensor and Pan, Tilt, Zoom digital IP Camera are have been designed at Intake Sermo Dam.

To install the base and back sight station, construction of two towers are very important. The first tower has been installed GNSS CORS for a base station (SRM1). At the first tower, the RTS and GNSS CORS have been installed which the GNSS antenna was installed about 2.30 meters above RTS. The second tower has been installed GNSS CORS as back sight station (SRM2) at upstream area of Sermo dam, in this tower has also been installed one unit of prism. Distance between the first and the second towers is about 2500 m.

### 3.1 GNSS CORS sensors at Base Station

The GNSS CORS sensors consists of Leica and Javad receiver. The Leica receiver has been installed at the first tower and the Javad receiver has been installed at the second tower.

The GNSS - CORS Receiver Main Monitoring Receiver Leica GRX1200+ and antenna CHOKE RING - GNSS Antenna with Dome, geodetic type as base station, at the first tower as SRM1 station (see Fig 4 (a)).

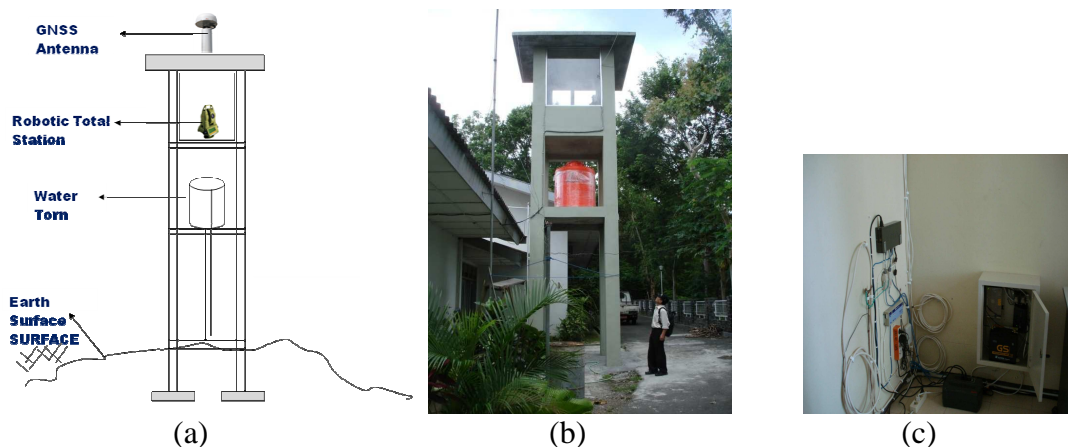


Fig.4. (a) Design and (b) the first tower for RTS and GNSS CORS at SRM1 station, (c) box for GNSS CORS receiver at SRM1 station.

Robotic Total Station and GNSS receiver has been housed in an “observation shelter”. This observation shelter is located at DMU station (Fig. 4). The window has been constructed of four large glass panels joined in a faceted arrangement, similar to a control tower window at the airport. Windows has been 6 mm thick soda lime float glass. This glass has 91% transmission of light due to low iron content. The window has been installed at a slight angle. This is to prevent the theodolite line of sight perpendicular to the glass panel.

### 3.2 Prism as Monitoring points

The survey of object points has been accomplished by taking radial shots in direct and reverse mode to all the object prisms. The RTS has been monitored horizontal and vertical directions, and slope distances. One of the reference stations as base station (presumably the most stable one) has been assigned as the main reference back sight for direction measurements as DMU area.



Fig.5. (a) Crest of Sermo dam where points monitor (prisms with yellow color) have been installed.

Prisms are mounted on each of the points to be monitored together with two stable reference points, with their observation controlled by a GEOMOS software application. The number of monitoring points depends on the need of monitoring itself and will be installed at center line dam body and slope of dam body. In this research, the number of monitoring points are 20 points which are distributed 12 points at crest of Sermo dam, 6 targets of monitoring points have been installed slope of Sermo dam at downstream area and one unit of prism monitoring point has been installed at second tower.



Fig.6. Target of monitoring with prism at slope of Sermo dam body

Leica TCA2003 total stations with the automatic target recognition and with a specially calibrated EDM component have been selected as the robotic total stations for this research. They offer standard deviation of distance measurements of  $\sqrt{(1\text{mm})^2 + (2\text{ppm})^2}$  and angle measurements (one set in average atmospheric conditions) with a standard deviation of 1.5''



or better. The targeting of the total station to each prism is typically achieved by automatic target recognition. An Automatic Target Recognition (ATR) uses a charge-coupled device (CCD) camera mounted in the telescope of the total station to measure the return from a laser. The resulting image is analyzed to identify any prism located in the field of view and to calculate the offsets between the centre of the prism and the axis of the telescope. Using ATR, the centre of the prism can be reliably found to within a few millimeters with the current specified range of monitoring total stations of 1 km (Brown et al., 2011).

### 3.3 GNSS CORS sensors at Back sight station

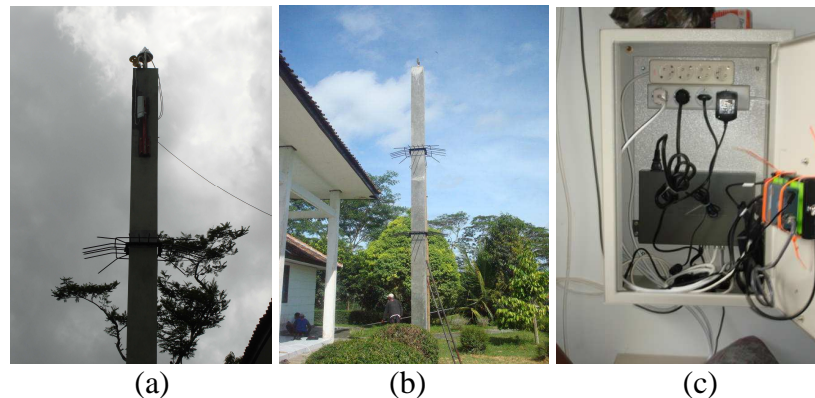


Fig.7. An antenna of the second GNSS CORS and a single of Prism as back sight (a) and (b); (c) box for GNSS CORS receiver at SRM2 station.

The second tower has been used to installed a GNSS CORS and one unit of prism as a back side monitoring as SRM2 station where the station is in upstream area of Sermo dam. At the back sight station has been install GNSS CORS Javad Delta G3T GNSS Basic (GPS+Glonass) and Javad antenna GrAntG3T with Cone which is locaited in climatology Station. The distance between the first and the second towers is about 2500 m.

### 3.4 Sensors of Tilt, Zoom digital IP Camera (CCTV)

Sensors of Tilt, Zoom digital IP Camera has been installed at Intake Sermo Dam. This sensor is ued to show video situation directly in upstream and downstream area.

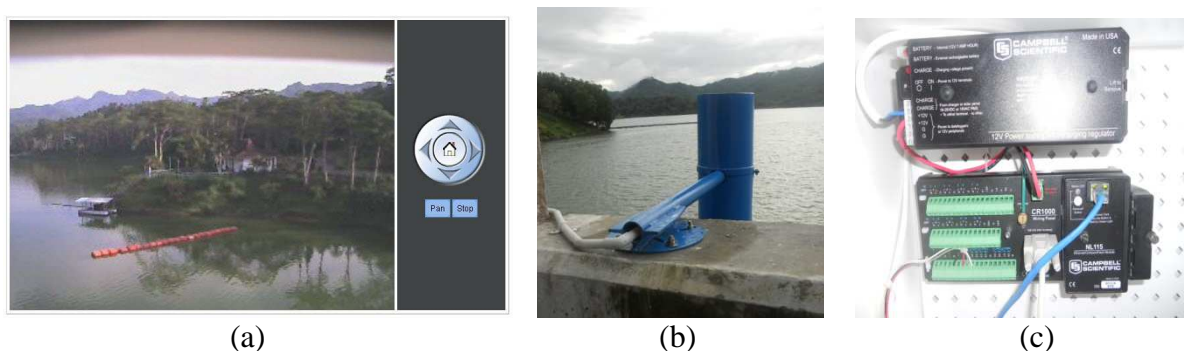


Fig. 8. (a) Is IP Camere presentation (CCTV), (b) and (c) are AWLR (Automatic Water Level Recording)

### 3.5 The sensor of Automatic Water Level Recorder (AWLR)

The sensor of Automatic Water Level Recorder (AWLR) has been installed at intake Sermo dam. This sensor has been used to record the fluctuation of water in the upstream area.

### 3.6 Installation of Communication System

The total stations will be linked to a computer system that will automatically and remotely control all functions.

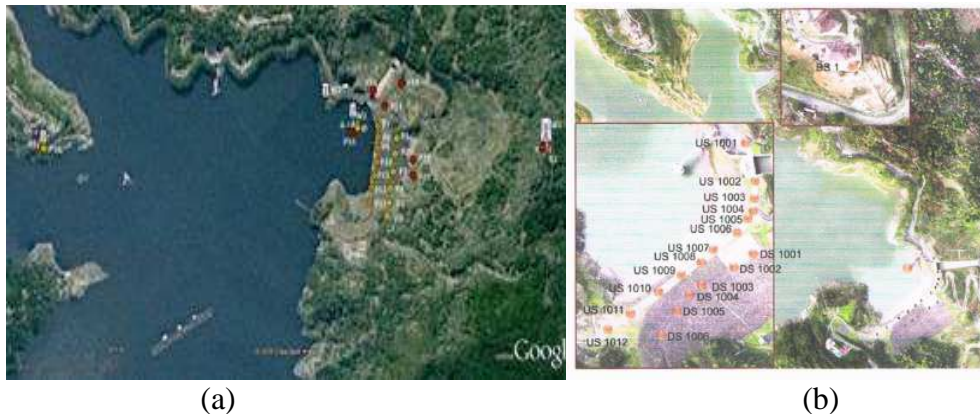


Fig. 9. Design for distribution of prism at Sermo dam where US: Upstream, DS : Down Stream

Explanation

- |  |                            |
|--|----------------------------|
| ◆ : AWLR                                       | ⊗ : Prism                  |
| ⬠ : Back sight station at SRTM2                | 📡 : Wireless communication |
| 📍 : GNSS Reference/Monitoring Station at SRTM1 | 📹 : IPcam (CCTV)           |
| ■ : Robotic Total station                      |                            |

The system has operated on a set time schedule and has automatically turn on at the correct time and start direction (horizontal and vertical) and distance measurement sets. The RTS has been programmed to collect a prescribed number of sets of angles at predetermined time intervals to achieve a preset level of accuracy. When collection of all the prescribed sets of the observation data will be completed, the data will be transmitted to the main office computer for its evaluation, processing and deformation analysis. The distribution of monitoring points surrounding Sermo dam body is plotted at Fig. 10. According to the final design, the DDM system has been installed a permanently mounted RTS at the first tower for monitoring 20 object targets (EDM prisms) mounted on a pillar type monuments. The 13 targets stations are at the crest of Sermo dam and 6 targets at the slope dam body at the downstream area and one prism at the back sight. The total station array has been installed to keep all distance measurements at 400 m or less. At least one reference back sight targets will be installed and included in the observation scheme at each robotic total station.

Data communication and remote access between the onsite PCs running the total stations and the survey office will be accomplished using a spread spectrum wireless LAN system. Differences between the independently calculated displacements of those common points will

serve as the final check on the quality of observations and stability of the reference system.

#### 4. RESULT AND DISCUSSION

The current system at Sermo dam consists of conventional sensors (reservoir water level, seepage at v-notch building, ground water level, stand pipe piezometer, vibrating wire piezometer, seismograph, settlement gauge, inclinometer, extensometer, and climatology data, etc) and computerised multi sensors. This research monitoring system has been carried using complerized multi sensors. Data will be able to be logged over time to provide information regarding the effects of aging, earthquakes, erosion, storm events, and other variables on the overall health of the dam. With an effective monitoring program, these causes can be detected early and repaired or mitigated. Due to the number of factors involved (hydrological, geotechnical, structural, and power related), a wide variety of measurements are required for dams monitoring systems. Automated monitoring systems have become an important part of many dam maintenance programs. The systems will be flexible enough to measure the wide variety of sensors used in dam monitoring applications. Their low power requirements and rugged design allow them to operate unattended in harsh environments for long periods of time. Telemetry options provide real-time data and alarms to assist remote management system.

The GNSS CORS raw data have been computed in a two step process using the GAMIT (GPS Analysis Package Developed at MIT) and GLOBK software to define base station and back sight station.

The coordinates results (3 D Cartisian , Geodetic and UTM system) of base station SRM1 and back sight SRM2 are shown tables as follows (Sunantyo and Basuki, 2012) :

Based on Table 2 the precision of 3 D cartesian coordinates for SRM1 and SRM2 are very high, the precision is about 5 to 2 mm. It means that the result of precision for base and back sight stations are very high and can be used as good reference. The condition of base and back sight stations are very stable and are supposed will not be affected by the displacements of Sermo dam. The installation of 20 monitoring points are supposed to be enough for monitoring of Sermo dam. The AWLR and CCTV sensors will be integrated to be one system of Sermo dam monitoring.

To carry out the future monitoring system at Sermo dam several steps will be done such as preparation, data acquisition, data processing, analysis, publication of analysis using web base.

Table. 2. Coordinates and their precision for SRM1 and SRM2 stations

Sta.	Numerical Value					
	SRM1	LAT.	-7° 46' 32,92201	LON.	110° 7' 38, 71838	h(m)
X(m)		-2.174.538,94742	Y(m)	5.933.406,28999	Z(m)	-862.922,86462
$\sigma_x$ (mm)		5,130	$\sigma_y$ (mm)	4,158	$\sigma_z$ (mm)	3,054
E (m)		403.787,192	N(m)	9.140.387,265		
SRM2	LAT.	-7° 45' 58,03710	LON.	110° 7' 00,59983	h(m)	202,71629
	X (m)	-2.173.483,16108	Y(m)	5.933.919,11690	Z(m)	-861.850,60211
	$\sigma_x$ (mm)	5,470	$\sigma_y$ (mm)	4,030	$\sigma_z$ (mm)	2,062
	E(m)	402.617,347	N(m)	9.141.456,224		

## 5. CONCLUDING REMARKS

The results presented here that first step dam monitoring using integration of two GNSS receivers and one Robotic Total Station : a case study at Sermo dam, Yogyakarta province, Indonesia has the following summary comments can be made as follows:

1. Safety and precise monitoring of Sermo dam deformations are the most important task to provide vital information on the stability and safety status.
2. GNSS technology will be extensively used for monitoring Sermo dam deformation; here two GNSS receivers have been installed at two difference towers (first and second towers). The first tower has been installed a GNSS receiver and a Robotic Total Station. The second tower has been a GNSS receiver and 1 point target monitoring.
3. The installation of 20 points which have been distributed along the center line of Sermo dam body (13 points), slope of Sermo dam body (6 points) and 1 point at the second tower are supposed to be enough for Sermo dam monitoring.
4. The installation of multi sensors (GNSS CORS, RTS, AWLR, and CCTV) to be integrated in one system will be a good automatic Sermo dam deformation monitoring system.

## 6. ACKNOWLEDGMENT

The authors would like to thank Dean of Engineering Faculty Gadjah Mada University, Indonesia, Director of Balai Besar Wilayah Sungai Opak dan Serayu Public Department Indonesia, and Head Department of Geodesy Engineering, Faculty Gadjah Mada University to support their valuable contributions to this research.

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### **Biographical Notes :**

Phd program (sandwich program): Graduated from Geodetic Departmet, Faculty of Engineering, Gadjah Mada University, Indonesia and Institute of Physical Geodesy, Technical University Darmstad, Germany.

### **Research experiences:**

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TS01F - Dam and Reservoir Engineering Surveying, 5572 13/14  
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Physical Geodesy (i.e geoid studies, vertical reference system etc) and Geometrical Geodesy ( GNSS and GPS for structural deformation studies, Indonesia geodynamic studies, Dynamic datum inIndonesia, cadastral mapping etc).

International research experience:

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2. Prof. Bill Kearslye, New South Wales University, Australia,

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