Opak Strike Slip Fault Modeling Interpretation Using Photogrammetry Method of Drone Survey in Trimulyo, Bantul, Yogyakarta Province

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Abstract. The Opak fault was known as the Epicenter of the Yogyakarta earthquake on May 27, 2006. This earthquake claimed more than 5,000 more lives, especially in the Yogyakarta area and its surroundings. Various studies have been carried out in determining and defining Opak faults. This study focuses on describing the crush zone of the Opak fault in Trimulyo, Bantul, Yogyakarta using photogrammetry method of drone survey. The area photogrammetry of study area equal to +256.000 m² with 231.159 tie points, 29.484.107 points of dense cloud, 1.965.606 face of 3D model, 3.08 cm/pixel resolution of the tiled model, and 12.3 cm/pixel resolution of the DEM/DTM model. The interpretation showed in this area were found in the form of two (2) major strike – slip fault that are defined as Opak Fault [4]. Opak faults are the main structure controlling this study area that have direction from 0° to 35°. There are minor faults (flower structure) with a very heterogeneous direction orientation from 0° to 160° as result of compressional wrenching from major fault, defined as number 1-10 fault. According to Sanderson and Manchini (1984) [27] model, the geometry and kinematics of structures expected for this study area are controlled by a maximum compression (σ1) axis in an approximately North-South direction, as the movement of the Indo-Australia subduction to Eurasia (South East Asia) tectonic plate [28]. This flower structure character in this area defined as the destruction zone caused the devastation in the Yogyakarta earthquake in 2006.

Keyword: Opak Fault, Photogrammetry, Active Fault Structure

1. Introduction

On May 27, 2006 Yogyakarta was hit by an earthquake. It caused many casualties and physical destruction, especially in Bantul and Piyungan Area. The destruction, 5.9 Richter scale, was an inland epicenter. This Epicenter was assumed from the movement of a fault. The closest fault to the location of the Epicenter of the earthquake in Yogyakarta is the Opak Fault, which has the same place and the direction is aligned with the Opak River. The Opak fault is assumed to be old and reactivated along with the Yogyakarta earthquake in 2006 [1]. The reactivation of Opak fault caused by the compression resulted from the Indo-Australia subduction to South East Asia. [1]

The earliest report of NEIC (National Earthquake Information Center) indicates that the Epicenter of the shock was at the south coast of Yogyakarta Province, south of Opak River, with a depth of 10 km.
However, other institutions reported different locations of epicenters and focal mechanisms estimation. According to NIED (National Research Institute for Earth Science and Disaster Resilience – Japan), the Epicenter was at the northeast end of the Opak Fault. However, the Harvard-CMT's result was at about 15 km east of the NEIC's result. All focal mechanisms indicated the right-lateral strike-slip in the NW-SE direction \[2],[3].

Before the Yogyakarta earthquake on May 26, 2006, the Opak river fault was the main fault that should be anticipated \[4]. However, the seismic source study of the 2006 Yogyakarta earthquake suggested a different fault line outside the Opak river fault \[2],[5],[6]. Those studies proposed left-lateral strike-slip faulting, which parallels the Opak river fault but a little bit eastward, about 10 to 20 km.

The importance of this research is to determine the model of the Opak strike-slip fault movement in Trimulyo Bantul. The study area is one of several Opak Fault outcrops in bedrock and is easily observable. Opak fault on fresh rock is hardly observed from the surface because the alluvial layer has buried it. This model can later determine the pattern of destruction from an Opak Fault that caused more than 5,000 fatalities in the 2006 earthquake.

2. Regional Geology
Java Island is one of the archipelagic arcs products from Cretaceous Period’s convergent interaction (100-65 million years). As is well known and revealed by researchers that, plate tectonic activity in the form of convergent interactions between the Indian-Australian Ocean Plate slides down (Subducted) the Sunda Shelf, which is part of the Eurasian continent's plate forming an archipelago \[7],[8],[9].

Located in the southern part of Central Java, Yogyakarta was substantially controlled by the Indo-Australian Oceanic Plate’s Subduction towards the Eurasian Continental Plate. The subduction activity resulted in earthquakes and tsunamis and the formation of volcanoes along the south of Java Island. Merapi Volcano is one of the most active volcanoes in the world and has a significant impact on the geological–morphological condition nearby. Yogyakarta is located in an almost flat region bordered by high terrains at its east and west (Figure 1). The coast at the south of Yogyakarta valley is a gentle slope beach that is open to the Indian Ocean. The coasts at the east part of the province are mostly steep due to the Southern Mountain's hilly morphology.

Figure 1. Fault configuration of Java (Clements, B. et al 2009) \[10]\n
According to Wartono et al. (1977) \[4], the geology of Yogyakarta province (Figure 1) consists of Alluvium (gravel, sand, silt, clay), Merapi volcanic deposit (tuff, ash, sand, agglomerate), Sentolo Formation (limestone, sandstone with marl), Wonosari Formation (calcarenite limestone, reef limestone),
Kepek Formation (marl, clastic, limestone), Sambipitu Formation (tuff, shale, siltstone), Semilir Formation (breccia tuff and clay tuff), Nglanggeran Formation (volcanic breccia, tuff), Kebo Butak Formation (volcanic breccia, andesite, agglomerate). This study was conducted at Semilir Formation.

Figure 2. Geological map of Yogyakarta. Red lines are structures (lineations) (Rahardjo et al., 1995[4] in Lina H, 2019[5]). Green and blue circles are epicenters of past earthquake events, for shallow and intermediate depths, respectively (source: NEIC-USGS). PR = Progo River, OF = Opak Fault.

3. Active Fault
Based on Keller and Pinter (1996) [11] active fault moved at least 10,000 years ago. The potentially active fault is a fault that moved on the time frame of 2 million years ago. While non-active fault is a fault that has not been or never moved in a period of 2 million years ago. Huzita, K, et al. (1992) [12] defines that active fault is a fault that moved in the quarter and has the potential to move back at the time to come. The fault cut the quarternary morphology and quarternary rocks. This active fault could trigger an earthquake if reactivated. Opak fault is formed due to the strain release laterally in the direction of the smallest normal strain axis and shortening on the direction of the largest normal strain axis [1]. The offset and bifurcation in the strike-slip fault caused transtension and transpression. Transtensional will produce a pull-apart basin while transpressional will produce push up mountain range [1].

4. Methodology
The photo-based 3D reconstruction method is the evolution of photogrammetry with a special technique. It has the advantage which is not requiring expensive hardware and has result of high accuracy. Fundamentally, photogrammetry works by overlapping several photos (Figure 3). The series of photographs is possible overlapped to make 3-dimensional (3D) resolution photos. Some of these photos are given coordinates as a connecting point as georeferencing. [13]
The orthophoto are very useful in the high-resolution mapping of outcrops, sediments, morphology, and structural geology. The orthophoto results can be exported in various formats such as .obj, .ply, .pdf, etc. making it easier to visualize. Distribution and accuracy are greatly influenced by control point data, measurement scale, camera position, and network geometry of overlapping images \cite{13}. Fractal analysis/stiffening is usually limited by the resolution of the image/photo.

This image data can be captured using a digital camera or a UAV (Unmanned Aerial Vehicle). Tavani et al. (2016) \cite{14} used a high-accuracy terrestrial photogrammetry method in analyzing the fault custody in the form of extensional trishear vs flexural-slip and throw distance analysis on the fault. The workflow can be seen in Figure 4. Vollgger & Cruden (2016) \cite{15} in his research aerial photogrammetry on the folds and fractures can produce statistical data of spread & fracture trends and fold trends, directions, types & axes to fold reconstruction. Studies of various scales try to identify the same stocky density values at regional scales, outcrops, or thin cuts. Various studies explain some perspective errors because they focus specifically on outcrops with flat surfaces \cite{16}.

This research required three major steps: Fieldwork, Software Processing, and Interpretation. The Fieldwork, divided into three steps: establishing control points or scales, run flight parameters and continued with collecting photographs. After obtaining the desired aerial photograph, the next is processing by software (Agisoft Metafile trial). In data processing by software, first performed a non-stationary portion of the image mask, followed by feature detection, bundle adjustment, and 3D scene reconstruction (producing a sparse point cloud) then pixel grid-based matching (producing a dense point cloud that will be processed into DEM / DTM). After generating pixels, build a mesh / interpolate surface and then do georeferencing and scale. In the final processing, texture mapping is performed which results in a photorealistic model and reprojection is performed to produce an orthomosaic. The last step is

![Figure 3. Perspective aerial view from UAV of the photographic model (in blue)](image-url)
interpretation. Interpretation required photorealistic model, orthomosaic, DEM/DTM for interpretation (lineation, structure, and cross-section) and regional geology (literature study) to make the model. The workflow can be seen in figure 4.

**Figure 4.** The workflow that illustrates the 3 Dimensional photo reconstruction process (Modified from Bemis et al., 2014) [13]

The equipment used is the Drone UAV using DJI Mavic Air (The specifications of the UAV camera can be seen in Table 1). Flight in the research area establishes a control point or scale (planning and measuring) using the Dronedeploy software resulting in overlapped photos. The parameters used for Dronedeploy can be seen in Table 2.
Table 1.
Hardware Specification

| Sensor | Lens |
|--------|------|
| 1/2.3 CMOS | Effective: 12 MP |
| FOV: 85° | 35 mm EQ 24 mm |
| Aperture: f/2.8 | S.R.: 0.5 to ∞ |

Table 2.
Parameters of the flight plan in Dronedeploy

| Area   | Altitude | Image    | Time Flight | Resolution | Front ovlap | Side ovlap |
|--------|----------|----------|-------------|------------|-------------|------------|
| 18 Ha  | 85 m     | 250 Images | 14.57 min   | 2.9 cm/px  | 75%         | 65%        |

5. Discussion and Result
The area photogrammetry of study equal to ±256.000 m2 with 231.159 tie points, 29.484.107 points of dense cloud, 1.965.606 face of 3D model, 3.08 cm/pixel resolution of the tiled model, and 12.3 cm/pixel resolution of the DEM/DTM model.

The results of interpretation showed that in this area were two (2) major faults that are defined as Opak Fault [4]. Opak faults are the main structure controlling this research area (Figure 5 shown by the red lines) was described as "A" & "B" faults that have direction from 0° to 35°. There are minor faults with a very heterogeneous direction orientation from 0° to 160°, defined as number 1-10 fault (shown in the blue line Figure 5). The direction of the alignment of this structure is shown in Table 3.

Table 3
The direction of the alignment

| Major Fault | Definition | Minor Fault | Definition | Direction |
|-------------|------------|-------------|------------|-----------|
|             | Direction  |             |            |           |
| A           | 0° – 35°   | 1           | 30° – 80°  | 6          |
| B           | 5° – 35°   | 2           | 0° – 45°   | 7          |
|             |            | 3           | 20° – 50°  | 8          |
|             |            | 4           | 45° – 75°  | 9          |
|             |            | 5           | 10° – 90°  | 10         |

Figure 4 shows structural heterogeneity in the research area, especially in the crushed zone bounded by faults A and B as the major fault (Opak Fault). This main fault movement produces fault blocks (bounded by minor faults), which have an up and down offset and are in the area of the fault plane’s strike (Interpreting from the bird view in Figure 5). This movement and development of Riedel shear result flower structure that have direction orientation from 0° to 160°. The interpretation of this cross-section for flower structure can be seen in Figure 6. Figure 6 shows that several blocks have increased and decreased due to compressional wrenching of the major fault. This flower structure character defined as the destruction zone caused the devastation in the Yogyakarta earthquake in 2006 in this area.
Figure 5. Morphology analysis of Opak Strike Slip Fault, Trimulyo Bantul that show lineation of Major and minor fault, Cross section line, and bird view
Flower structures are typical for wrench fault zones and have usually been considered as one of the most important features that can be used to identify strike-slip faults in regional tectonic studies. These structural features are mainly characterized by their internal fault and fold architecture and their association with straight and continuous zones of deformation. In conventional models, flower structures are classified into two types according to their internal structural architecture, so-called negative and positive structures. A negative flower structure consists of a shallow syn-form bounded by upward spreading strands of a wrench fault with mostly normal separations, while a positive flower structure consists of a shallow anti-form displaced by upward diverging strands of a wrench fault with mostly reverse separations.

These major strike slip fault (Opak Fault), along with other associated structures (flower structure) are predicted by the transtensional strain model (Fig. 7) of Sanderson and Manchini (1984). According to this model, the geometry and kinematics of structures expected for this study area are controlled by a maximum compression (σ1) axis in an approximately North-South direction, as the movement of Indo-Australia tectonic plate (28) (Fig. 8).
6. Conclusion

1. The area photogrammetry of study area equal to ±256,000 m² with 231,159 tie points, 29,484,107 points of dense cloud, 1,965,606 face of 3D model, 3.08 cm/pixel resolution of the tiled model, and 12.3 cm/pixel resolution of the DEM/DTM model.

2. The interpretation showed in this area were found in the form of two (2) major strike-slip fault that are defined as Opak Fault [4]. Opak faults are the main structure controlling this study area that have direction from 0° to 35°. There are minor faults (flower structure) with a very heterogeneous direction orientation from 0° to 160° as result of compressional wrenching from major fault, defined as number 1-10 fault. According to Sanderson and Manchini (1984) [27] model, the geometry and kinematics of structures expected for this study area are controlled by a maximum compression (σ1) axis in an approximately North-South direction, as the movement of the Indo-Australia subduction to Eurasia (South East Asia) tectonic plate [28]. This flower structure character in this area defined as the destruction zone caused the devastation in the Yogyakarta earthquake in 2006.

![Figure 8](image-url)

**Figure 8.** Plate movement and structure map of Indonesia (Modified from Darman, H. & Sidi, H. (eds.), 2000) [28]
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