Segmentation of Sumatran Fault Zone in Tanggamus District, Lampung based on GPS Displacement and SRTM Data

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Abstract. One of sources of earthquakes in Lampung Province is southern segment of Sumatran fault. The fault is used as consideration in generating hazard map which source comes from stress accumulation of crust which can be obtained by measurement of points in surface. Determining fault location is important for sustainable development in Lampung Province. Southern segment of Sumatran fault stretched on Kota Agung – capital of Tanggamus District, one of the cities with the oldest civilization in Lampung Province. The sedimentation of Kota Agung causes the delineation of Sumatran Fault Zone by using Digital Terrain Model conducted on previous research had flaw. GPS Displacement Data, Shuttle Radar Topography Mission (SRTM) Data and seismic activity are used as tools to determine the location of fault. SRTM Data has 30 meter resolution and measured in 2018. Seismic activity used in this research is obtained from USGS from last 100 years and is used as support data to determine whether the fault delineated with SRTM and GPS displacement is active. GPS displacement is derived from GPS coordinates measured periodically from 2006 to 2019. Displacement used in this research is horizontal displacement since Sumatran Fault is known as strike-slip fault that move on horizontal plane. The result resembles previous research. Location that has the highest possibility of Sumatran Fault Zone segmentation is identified as Sumatran Fault Zone segmentation on previous research named as West Semangko Fault, and East Semangko Fault, respectively. The only fault earthquakes occurred on location which is not identified Sumatran Fault Zone segmentation on previous research.

1. Introduction
Sumatran Fault, which locates in western Indonesia is considered as tectonically active region with many earthquake occurrences due to the presence of subduction zone in the western side of Sumatra [1], is one of hazards located in Sumatra Island. Southern segment of Sumatran fault is one of sources of earthquakes in Lampung Province. Hazard map is used as consideration in developing region. The source of hazard comes from stress accumulation of crust which can be derived from movement of points in surface. The source of hazard is southern segment of Sumatran fault which stretched on Tanggamus, Lampung in south end of Sumatra Island [2]. Because of tectonics process associated to the subduction zone and Sumatran Fault Zone, identifying more detail of Sumatran Fault Zone segmentation especially in southern region become mandatory to understand hazard in the southern Sumatera. The study of hazard identification derived from determining fault location is important for sustainable development in Lampung Province.

The most recent study of southern segments of Sumatran Fault Zone is conducted by Natawidjaja [3] as shown in Figure 1. From Suoh located in West Lampung District toward south, Sumatran Fault Zone branches into two major strands, namely the west Semangko and the east Semangko fault.
segments. The east Semangko segment is previously unmapped in Sieh and Natwidjaja [2]. Segmentation is one of the fault parameters need to be understood beside slip rate and locking depth [4]. Southern segments of Sumatran Fault Zone has geological slip rate about 8 to 12 mm/year [5] which is lower than northern segments [6].

![Figure 1. Southern segment of Sumatran Fault Zone [3]](image)

Tanggamus District, located in southern Sumatra, has capital in Kota Agung, one of the cities with the oldest civilization in Lampung Province so that its natural landscape had sedimented as urban areas are likely to be sedimentated [7]. It causes the delineation of Sumatran Fault Zone by using Digital Terrain Model conducted on previous research had flaw. This study uses GPS Displacement Data as a tool to determine the segmentation of Sumatran Fault Zone beside Shuttle Radar Topography Mission (SRTM) Data and seismic activity.

2. Method

Data used in this research are GPS measurement data, SRTM data [8], and seismic activity data [9]. GPS measurement data is proven to be an indispensable tool to be used in the analysis of crustal deformation related to fault [10,11,12]. GPS data used in this research are measured on GPS sites owned by Geospatial Information Agency of Indonesia (BIG). In total, there are 6 periodic GPS sites used in this research measured periodically from 2006 to 2019. The GPS sites are shown on Table 1 and Figure 2. Most of GPS sites are located in Tanggamus District close to southern segment of Sumatran Fault Zone.

GPS Data is processed using Bernese GNSS Software 5.2 by considering the other parameters such as International GNSS Service (IGS) final ephemeris, earth rotation parameters, tropospheric and ionospheric model, differential code biases for satellites and receivers, atmospheric loading, and ocean tide model coefficient. Daily solutions are produced with a consistent reference frame in the International Terrestrial Reference Frame 2014 (ITRF2014) [13].
Table 1. GPS sites used in this research

| No | Site Name | Longitude (°) | Latitude (°) | Location | Data Period        |
|----|-----------|---------------|--------------|----------|--------------------|
| 1  | KTJW      | 104.339718    | -5.600059    | Bengkunat | 2007.36-2019.51    |
| 2  | SMK3      | 104.519515    | -5.464804    | Wonosobo  | 2014.87-2019.51    |
| 3  | SMK4      | 104.641571    | -5.503299    | Kota Agung| 2014.86-2019.52    |
| 4  | SMK5      | 104.737528    | -5.417555    | Gisting   | 2014.88-2019.52    |
| 5  | KRPN      | 104.810618    | -5.59852     | Kuripan   | 2006.28-2019.53    |
| 6  | SMK6      | 104.912869    | -5.364473    | Pagelaran | 2014.89-2019.53    |

Figure 2. GPS sites used in this research shown as orange squares. Black lines is southern segment of Sumatran Fault Zone obtained from Natawidjaja [3]

In order to make the GPS displacement resulted from this research more appropriate for tectonic discussion and represent the actual displacements, GPS data reference frame is translated into Sundaland block calculated from ITRF2000, with parameters as follows: 49.0°N, −94.2°E, 0.336 / Ma [14]. Displacement used in this research is horizontal displacement since Sumatran Fault Zone is known as strike-slip fault that move on horizontal plane.

The GPS displacement refers to Sundaland block is used to understand the segmentation of Sumatran Fault Zone. The GPS displacement reference point is altered so that the nature of strike-slip Sumatran Fault Zone is appeared. Since Sumatran fault is dextral strike-slip fault [1,2,15] and the necessity of minimum of one GPS site on each side of fault to monitor strike slip fault [16], the direction of GPS sites will be used as indicator whether the fault is segmented. The GPS displacement is also used to calculate geodetic strain between every three GPS sites to determine whether the fault is segmented to presume the location of Sumatran Fault Zone segmentation.

The presumption location of Sumatran Fault Zone segmentation is then compared with Sumatran Fault Zone delineated from SRTM data and seismic activity obtained from USGS and Meteorogical, Climatological, and Geophysical Agency of Indonesia (BMKG) on last 100 years. SRTM Data which is conditional equivalent with Digital Terrain Model has 30 meter resolution and measured in 2018. The result is also compared with previous research by Natawidjaja [3].
3. Result and Discussion

The GPS displacement refers to ITRF2014 is shown on Figure 3. The average displacement of those GPS sites is around which is dominated by Sundaland block movement (eastward) around 2 cm/year. The GPS displacement refers to Sundaland block is shown on Figure 4. The displacement direction and magnitude is dominated by Sumatran Fault Zone movement since the value of GPS site displacement is close to displacement of GPS sites which is parallel to Sumatran Fault Zone.

Reference point of GPS displacement parallel to Sumatran Fault Zone is altered so that the nature of strike-slip Sumatran Fault Zone is appeared. The process is conducted to identify Sumatran Fault Zone segmentation. The reference point is presumed as Sumatran Fault Zone segmentation. The point used as reference points are GPS sites located between the westest site and eastest site (4 locations) and the zone between each sites (5 locations). Reference points alteration is repeated nine times. The nature of dextral strike-slip faults (of Sumatran Fault Zone) is the direction of points in the westward of fault and eastward of fault. Points in the westward of fault are in northwestward direction while points in the eastward of fault are in southeastward direction. The points and zones used as reference points are shown on Figure 5. The GPS displacement refers to those reference points are shown on Figure 6. The values are shown on Table 2. Negative value means the direction is northwestward.
**Figure 4.** GPS displacements resulted in this research. Red lines are displacements refer to Sundaland blocks. Blue lines is displacements parallel to Sumatran Fault Zone.

**Figure 5.** Reference points used to identify Sumatran Fault Zone segmentation based on nature of strike-slip Sumatran Fault Zone.
Figure 6. GPS displacement refer to Zone A, Zone B, Zone C, Zone D, Zone E, Point F, Point G, Point H, Point I, respectively.
Table 2. GPS displacement parallel to Sumatran Fault Zone with different location of reference points

| No | Site Name | Displacement per year (cm/yr) |
|----|-----------|------------------------------|
|    |           | A   | B   | C   | D   | E   | F   | G   | H   | I   |
| 1  | KTJW      | -2.4| -0.2| -1.2| -1.7| -1.8| -1.7| -0.4| -2.1| -1.2|
| 2  | SMK3      | 0.2 | -0.9| -1.3| -1.4| -1.3| 0.0 | -1.7| -0.9| -2.0|
| 3  | SMK4      | 1.9 | 0.9  | 0.4 | 0.3 | 0.5 | 1.7 | 0.0 | 0.9 | -0.3|
| 4  | SMK5      | 1.0 | 1.2 | 0.7 | 0.6 | 0.8 | 2.0 | 0.3 | 1.2 | 0.0 |
| 5  | KRPN      | 2.2 | 0.0 | -0.4| -0.6| -0.4| 0.9 | -0.9| 0.0 | -1.2|
| 6  | SMK6      | 0.7 | -0.4| -0.8| -0.9| -0.8| 0.5 | -1.2| -0.3| -1.5|

GPS displacement is also used to understand geodetic strain behavior around Sumatran Fault Zone as shown on Figure 7. The strain is analyzed in every location for every reference point shown on Figure 5. Delaunay triangulation [17] is created between each GPS sites so that four triangles are formed. The geodetic strain resulted in those triangles are ranging from 0.29 microstrain to 0.93 microstrain. Compared to other research which calculates strain around the fault [18], the value above 0.5 microstrain is an indicator that the fault is segmented. As consequences, location A and location B with the strain value of 0.93 and 0.75, respectively is more likely to have Sumatran Fault Zone segmentation than location C, location D, and location E.

![Figure 7](image_url)  
**Figure 7.** Geodetic strains derived from GPS displacement with red arrows indicate extension while blue arrows represent shortening. Green lines indicate Delaunay triangle for strain calculation.

The result of Sumatran Fault Zone segmentation from SRTM Data is overlaid with seismic activity obtained from USGS and BMKG from last 100 years and Sumatran Fault Zone earthquake history researched by Hurukawa [9]. The only earthquake studied by Hurukawa was occurred on June 24th, 1933 with the magnitude of 7.5 and 15 km depth. The number of seismic activity obtained from USGS are 7 earthquakes while the number of seismic activity obtained from BMKG is one earthquake occurred on May 2nd, 2016 with the magnitude of 5.9 and 132.7 km depth. But it is located far north of Tanggamus district which is not analyzed in this research. The result is also overlaid with segmentation from Natawdijaja [3]. The result is shown on Figure 8. Segmentation from SRTM data
is close to Natawidjaja result except for few differences. One of them is that there is a segmentation far west of Tanggamus district which is not analyzed in this research. The other one is branchation of East Semangko Fault in location B.

**Figure 8.** Seismic activity around Sumatran Fault Zone in Tanggamus district obtained from Hurukawa [9] large orange circle, USGS (small blue circle), and BMKG (small green circle). Black lines are Sumatran Fault Zone obtained from Natawidjaja [3] while red lines are Sumatran Fault Zone segmentation delineated from this research.

GPS displacement parallel to Sumatran Fault Zone, strain, SRTM segmentation, and seismic activity are analyzed in every location for every reference point shown on Figure 5 to identify Sumatran Fault Zone segmentation in area around Sumatran Fault Zone in Tanggamus District, Lampung. The detailed analysis is shown on Table 3.

**Table 3.** Sumatran Fault Zone segmentation in Tanggamus district based on GPS displacement parallel to Sumatran Fault Zone, strain, SRTM segmentation, and seismic activity

| Tool                  | Presumption Method              | Weigh | Location (Zone) | Location (Point) |
|-----------------------|---------------------------------|-------|-----------------|------------------|
| GPS Displacement      | Displacement parallel to Sumatran Fault Zone | 2     | 100% 83.3% 50% 66.7% 50% 100.0% 60% 60% 80% |                  |
|                       | Geodetic Strain                 | 2     | 100% 100% 50% 0% 0% -- -- -- -- |                  |
|                       | Natawidjaja [3]                 | 5     | 100% 0% 100% 0% 0% -- -- -- -- |                  |
|                       | SRTM                            | 1     | 100% 100% 100% 0% 0% -- -- -- -- |                  |
| Seismic Activity      | Hurukawa [9]                    | 2     | 0% 0% 0% 0% 100% -- -- -- -- |                  |
|                       | USGS                             | 1     | 100% 100% 0% 0% 0% -- -- -- -- |                  |
| Presumption Overall   |                                 |       | 84.6 43.6 61.5 10.3 20.3 100.0 60.0 60.0 80.0 |                  |
| Percentage            |                                 |       | %    %    %    %  %    %  %    %  |
The segmentation location is presumed since there is no field survey conducted. It is purely based on GPS displacement analysis, SRTM, seismic activity and previous segmentation conducted by Natawidjaja [3]. The segmentation location presumption is estimated by using percentage. In other words 100% location presumption means the location is surely have Sumatran Fault Zone segmentation. The location itself is based on every reference point shown on Figure 5 that consists of 5 areas and 4 points. The point location analysis is used for only GPS Displacement parallel to Sumatran Fault Zone. The weighing for each parameter is determined by the relation between strike-slip fault behavior and the presumption method. The previous research weight is the highest since the method to understand Sumatran Fault Zone segmentation is superior than the other presumption method used in this research. SRTM data weight is low since the method used is only based on visual delineation containing human errors. USGS seismic activity is also low since the seismic activity recorded by USGS is not only strike-slip fault behavior but also subducting plate behavior.

The highest presumption Sumatran Fault Zone segmentation percentage is in location A. This location is the most likely to have Sumatran Fault Zone segmentation. This location is also already identified as West Semangko Fault by previous research. The only unsupporting parameter of this segmentation is the lack of fault earthquakes researched by Hurukawa [9]. The second highest presumption Sumatran Fault Zone segmentation percentage is in location C. The unsupported parameters are the lack of any earthquakes, average geodetic strains, and the behavior of dextral strike-slip fault detected by GPS displacement. This location is also already identified as East Semangko Fault by previous research. Location B is not identified by previous research but has a better supporting parameter on the behavior of dextral strike-slip fault detected by GPS displacement. Location F, which has the lowest chance of segmentation based on the behavior of dextral strike-slip fault and no chance of segmentation based on other factors including Natawidjaja [3] research, have the highest probability of segmentation than location D since there is record of fault earthquake on 1933 [9]. The result would be more accurate with more GPS sites built like proposed by Alif [19].

4. Conclusion
GPS displacement data, SRTM data, and seismic activity used as tools to determine the segmentation of Sumatran Fault Zone are producing the resembling result with the previous research. Location A (West of Tanggamus District) and location C (Central of Tanggamus District), that has the highest possibility of Sumatran Fault Zone segmentation, is identified as Sumatran Fault Zone segmentation on previous research named as West Semangko Fault, and East Semangko Fault, respectively. The only contradicting parameter of these segmentations is the lack of fault earthquakes. The only fault earthquakes occurred is located on location E (East of Tanggamus District) which is not identified as Sumatran Fault Zone segmentation on previous research. Longer GPS time series, the utilization of continuous GPS, and building more GPS sites to monitor Sumatran Fault Zone will produce better Sumatran Fault Zone segmentation from GPS displacement method perspective.

5. Conflict of Interest
There are no conflicts to declare.

Acknowledgments
This research was funded by Institut Teknologi Sumatera Smart Mandiri 2019 Research Grant Fund No. B/364/IT9.C1/PT.01.03/2019. Authors acknowledge assistance from students of Institut Teknologi Sumatera to help processing data for this research. Figures were drawn using GMT software [20].

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