Identification of Capable Fault Location around Mount Betung Area Based on GPS Strain Data

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Abstract. Sumatran Island is located in a very active tectonic zone due to subduction of Indian-Australian plate beneath Eurasian plate. This causes an increase in stress in the subduction zone thereby increasing the pressure and strain. Mount Betung, which is situated in Sumatra Island, is located in the province of Lampung with a developing economy in recent years. Therefore, understanding the strain related to earthquake hazard is important to be conducted. The strain is a tool to help in identifying capable fault location in the geodetic aspect. The purpose of this study is to identify capable fault location to ensure the safety of development and construction around Mount Betung. GPS velocity data from 2006 to 2019 on seven sites are used as tool to calculate the strain which is used to identify the capable fault. GPS strain is calculated on the every triangles and polygons possible formed by the combination of three sites or more. There are two cases for identification, and triangles or polygons within each case do not intersect each other. The capable fault is identified in the area with the strain value of more than the threshold which is determined in the area of Sumatran Fault Zone. The threshold value resulted from the studies is 0.47 microstrain/year. The velocities of sites are ranging from -2.48 to -0.02 cm/year. The area with capable fault is identified around the Sumatran Fault Zone or the extension of the fault. The area close to the capital of Lampung Province, Bandar Lampung is relatively safe since there is no identified capable fault.

Keywords : Tectonic Zone, Strain, GPS, Fault, Mount Betung

1. Introduction

One of the hazards in Indonesia is located in Sumatra Island, the very active tectonic zone resulted from subduction process of Indian-Australian plate beneath Eurasian plate [1]. The hazard in those subduction zones related to stress accumulation resulting in earthquake. Moreover, the process of subduction formed Sumatran Fault Zone and its slip is also contribute to stress accumulation [2]. The stress accumulation can be derived from strain which is calculated from the movement of points in surface. Global Positioning System (GPS) is proven to be an indispensable tool to monitor the movement of points in surface related to fault or tectonics discussion [3,4,5]. Identification of capable fault can be conducted by using either geodetic tool (GPS), geological tool [6], or seismological tool while active fault can only be identified by using those methods. The utilization of GPS to identify capable fault has been conducted before such as in India [7] and California [8]. The active fault in the study area which is Lampung Province located in the southeast of Sumatra Island is Semangko Fault and Kumering Fault with slip rate ~12 mm/yr [9].
Mount Betung is located ~70 km from Semangko Fault and ~20 km from Bandar Lampung, the capital of Lampung Province (Figure 1). Lampung Province is developed in recent years [10] especially after the opening of Trans Sumatra toll gates [11,12]. Moreover, Mount Betung is good location for tourism [13] and research such as astronomical research [14]. Therefore, understanding the capable location around Mount Betung is important to be conducted for safe construction and development. The purpose of this study is to identify capable fault location to ensure the safety of development and construction around Mount Betung.

Figure 1. Study area of this research. Black beach ball shows the earthquake occurred in last 20 years. Black thick lines show Sumatran Fault Zone. Red triangle shows Mount Betung. Blue circle shows Bandar Lampung. The terrain model is obtained from SRTM data with 1 arc second spatial resolution [15].

2. GPS Data Processing

Data used in this research are GPS data measured in 8 sites. The GPS data are owned by Geospatial Information Agency of Indonesia (BIG) and Sumatran GPS Array (SuGAr) [16]. There are one BIG GPS continuous site (CLGI), five BIG periodic sites (BPJG, KTJW, KRPN, SMK6, SMK7), and two SuGAr GPS continuous sites (TJKG, PTBN) which are shown on Table 1 and Figure 2. The data are measured varies from 2006 to 2019. The movement of the westest three sites are used as reference in capable fault analysis since there is Semangko Fault inside the triangle formed by those sites. All sites except KTJW are used to identify capable fault and the distance from Mount Betung to the site varies from 19 km to 55 km. The distance from Mount Betung to the closest known fault – East Semangko Fault – is ~45 km.

Table 1. GPS sites used in this research.
GPS data are processed using GAMIT/GLOBK software package [17,18] by considering the other parameters such as International GNSS Service (IGS) final ephemeris, earth rotation parameters, ionosphere model parameters, differential code biases for satellites and receivers, and ocean tide model coefficient. IGS GPS sites (ALIC, COCO, CUSV, DARW, DGAR, IISC, KARR, KAT1, NTUS, PBRI, PIMO, TOW2, XMIS) are used as reference sites to produce daily solution refer to ITRF2014 [19].

Figure 2. GPS sites used in this research represented by orange squares. Black lines is Semangko Fault obtained from Natawidjaja [9]

3. Strain Calculation Method

Strain is calculated by using velocity of at least three sites. Velocity is calculated in two components: north-south component and east-west component by doing linear regression of coordinate time series resulted from GPS data processing. Up-down component velocity is not considered and only horizontal velocity is considered since the quality of vertical coordinates of GPS sites is not good enough. GPS strain is calculated on the every triangles and polygons possible formed by the combination of three sites or more. The calculated strain is the normal strain and shear strain of centroid of the either triangle or polygon. Those strains are used to calculate the principal strain.

There are 33 areas and two cases for capable fault identification. The area and its number is shown on Figure 3. Every GPS sites is connected by a line to define area formed by those GPS sites. The line is also used as side of...
either triangle or polygon used to calculate the strain of the first case whereas the second case is calculating the strain of one polygon formed by border line of study area. The border line is line connecting SMK6 and TJKG, TJKG and BPJG, BPJG and CLGI, CLGI and PTBN, PTBN and KRPN, KRPN and SMK6. The first case has four subcases where each subcase have more than one non-intersected triangle. The principal strain of each case of each area is used to identify capable fault in the respective area.

Strain threshold from Semangko Fault is used as threshold to identify whether the area has a capable fault. Strain threshold is calculated on the triangle formed by KTJW, KRPN, and PTBN sites since there is Sumatran Fault Zone inside the triangle. The strain threshold value is absolute which makes negative value from contractional strain is positive. The strain threshold is the extensional strain if it is higher than contractional strain and vice versa. If the principal strain of the defined area is equal to or more than the principal strain calculated from strain threshold, there is a capable fault in the respective defined area. The illustration of calculating the percentage of capable fault location in the defined are from all cases is shown on Figure 4. There are 4 GPS sites in the corner of the rectangle and 2 cases of calculation in the figure. Principal strain in the green triangle and purple triangle is calculated in the (a) case while principal strain in the yellow triangle and blue triangle is calculated in the (b) case. If there is a capable fault only on the green triangle and yellow triangle based on the principal strain calculation and strain threshold, the probability of capable fault is 100% in area A, is 50% in area B and D, and is 0% in area C. The probability value is categorized into four classes [20]: very low with the probability less than 17%, low with the probability between 17% and 33%, medium with probability between 33% and 66%, and high with the probability more than 66%.

Figure 3. The area defined for capable fault identification. Black lines connect each GPS sites.
Figure 4. Illustration of calculating the percentage of capable fault location of two cases: (a) and (b). GPS sites are located in the corner of the rectangle.

4. Results and Discussion

Most of the velocity of GPS sites have homogeneous direction which is derived from coordinate time series calculation (Figure 5). The velocities of sites are ranging from -2.48 to -0.02 cm/year. All sites move eastward due to the motion of Sundaland Plate [21]. All sites move southward except KTJW site since its location is in the west side of right-lateral Semangko Fault [22]. The magnitude of the velocity on all sites that moves eastward is more than 2 cm/year (Table 2) except KRPN and PTBN since those two sites are close to Semangko Fault and the capable fault is probably located around those two sites.

Figure 5. Coordinate time series of seven GPS sites represented by red points and its velocity trend represented by blue lines.

Table 2. The velocity of GPS sites obtained from doing linear regression on coordinate time series.

| GPS Site | Easting Velocity (cm/year) | Northing Velocity (cm/year) | Easting Velocity Standard Deviation (cm/year) | Northing Velocity Standard Deviation (cm/year) |
|----------|----------------------------|----------------------------|-----------------------------------------------|-----------------------------------------------|
| TJKG     |                            |                            |                                               |                                               |
| PTBN     |                            |                            |                                               |                                               |
| CLGl     |                            |                            |                                               |                                               |
| SMKG     |                            |                            |                                               |                                               |
| BPJG     |                            |                            |                                               |                                               |
| KTJW     |                            |                            |                                               |                                               |
| KRPN     |                            |                            |                                               |                                               |
Principal strain threshold obtain from KTJW-PTPN-KRPN triangle is 0.47 microstrain/year. The value is higher than the threshold in the eastern Mediterranean region which is 0.1 microstrain/year [23], but lower than the threshold in Cimandiri Fault which is 3 microstrain/year [24]. The used threshold in the area is the calculated principal strain since the the fault in the triangle is the closest known fault around Mount Betung area. It is used as tools to identify whether the area has a capable fault. The example of capable fault location identification is shown on Table 3 which is the first subcase of the first case. The probability of capable fault triangle 3, 4, 5 is 100% since the the absolute value of one of its principal strain is more than principal strain threshold. Those three triangles cover 17 areas which are area the 5, 7, 8, 9, 10, 11, 12, 13, 14, 15, 25, 26, 27, 29, 30, 32, and 33. Those area have the 100% probability from the first subcase of the first case but it is still need to be combine with the probability result of the other subcases and another case to identify the capable fault.

The area around Mount Betung is dominated by very low and low probability of capable fault. It means the probability of most of the area around Mount Betung is less than 33%. There is no area with high probability of capable fault. The reason is the principal strain value of the second case which calculate the strain from all seven sites is less than the principal strain threshold and the weight of the first case is similar to the second case. The other reason is most of GPS sites have uniform direction and the value is relatively close except KRPN and PTBN. The classification result is in the same road with the velocity result (Figure 6). All of the area around KRPN site have medium probability of capable fault. In terms of number, all the areas is coincidentally equally distributed into three classes which are 11 areas in each class. In terms of area, the area with the very low probability is 1306.3 km² or 50.73% of study area, the area with the low probability is 916.7 km² or 35.60% of study area, and the area with the medium probability is only 352.0 km² or 13.67% of study area.

Table 3. Principal strain value of the first subcase of the first case to identify the capable fault.

| Number | Triangle           | ε₁ (microstrain/year) | ε₂ (microstrain/year) | θ (degree) | Capable Fault Probability (%) |
|--------|--------------------|------------------------|-----------------------|------------|------------------------------|
| 1      | SMK6-SMK7-TJKG     | 0.23                   | -0.39                 | -89.5561   | 0                            |
| 2      | BPJG-SMK7-TJKG     | 0.23                   | 0.04                  | -187.8719  | 0                            |
| 3      | KRPN-SMK6-SMK7     | 0.62                   | -0.04                 | 5.7524     | 100                          |
| 4      | CLGI-KRPN-PTBN     | 0.01                   | -0.53                 | -10.2077   | 100                          |
| 5      | BPJG-KRPN-SMK7     | 0.74                   | 0.00                  | -1.4619    | 100                          |
| 6      | BPJG-CLGI-KRPN     | 0.13                   | -0.19                 | 94.7282    | 0                            |
Figure 6. The classification result to identify capable fault location.

The area within 20 km of Mount Betung have low probability of capable fault. It includes the capital city of Lampung Province – Bandar Lampung – around BPJG site. It means that the construction and development around Mount Betung like establishing the center of ecotourism in Lampung Province in the area [25] is relatively safe from earthquake with the epicenter inside 20 km radius around Mount Betung. Nevertheless, there are other hazards to the area such as Semangko fault earthquake [26], megathrust earthquake [27], and landslide [28]. The area with medium probability of capable fault is highly suggested the extension of East Semangko Fault. The fault identification from imagery [29] shows almost different result since it showed seven normal faults within the area with low probability of capable fault. The imagery fault identification can be in line with fault identification using GPS strain used in this research if the dip of normal fault is more than 80° since the GPS strain method used in this research only consider horizontal velocities.

5. Conclusion

The highest probability of capable fault location around Mount Betung which is hazard to the area is located in area more than 20 km from Mount Betung and highly suggested the extension of East Semangko Fault. Construction and development of tourism and research around Mount Betung is relatively safe from earthquake with the epicenter inside 20 km radius around Mount Betung. The geological tool or seismological tool should be conducted to identify capable fault in the area to ensure more the safety around Mount Betung but it is highly suggested that there are no active fault around Mount Betung.

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