Various Models of Slope Stability due to Earthquake Activity in Gunung Tigo, Padang Pariaman, West Sumatera, Indonesia

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Abstract

Indonesia is placed on the subduction zone. It makes Indonesia becomes prone of earthquake activity. Earthquake can trigger another geo-hazard such as landslide. This kind of landslide was happened in Gn. Tigo, Padang Pariaman, West Sumatra in last September 2009. The aims of this study are to make sesismic slope stability models and to analyze the differences of slope failures which have various strength of earthquake (PGA). This research used three methods, i.e.: (1) field method: engineering geological mapping; (2) laboratory method: sample analysis; (3) studio method: model analysis. The research area has three soil layers, they are pumiceous tuff on top, mixed layer, and at the bottom is paleosol. Based on Probabilistic Seismic Hazard Analysis (PSHA) data, the model of slope LB 1 had the Fs results, i.e.: 1.083; 0.920; 0.790; 0.683; 0.594; 0.519. Furthermore the model of slope LB 9 had the Fs results, i.e.: 1.566; 1.27; 1.064; 0.902; 0.775; 0.674. The results show that earthquake activity have correlation with landslide occurrence. It shows that the higher of PGA the lower value of Fs.

Keywords: Earthquake, landslide, slope stability, soil, peak ground acceleration (PGA), West Sumatera, Indonesia

1. Introduction

At September 30th 2009, tectonic earthquake occurred in West Sumatera with magnitude 7.6 SR. It also occurred in Gunung Tigo Region, Padang Pariaman. The earthquake triggered several slopes in Gunung Tigo to fail. They harmed three districts in that area. The landslides killed about 289 people and destroyed a lot of houses and public facilities (Saidi, 2011).

Bromhead (1992) said that one of the causes of the landslides is the earthquake. When the earthquake is happened, the materials on the earth will be moved back and forth irregularly. This movement can be interpreted as the changed of wave velocity which spread through the materials. When the acceleration passing through the materials, it produces either horizontal or vertical forces. It is also connected with ground acceleration.

The Peak Ground Acceleration (PGA) is a maximum acceleration which is felt by the materials during the earthquake. PGA induces the change of gravity acceleration, so the unit PGA is the percent of gravity (Anonymous, 2007).

To find out the relationship between the earthquake and slope stability, it is needed to make seismic slope stability model and to analyze the correlation of them.

2. Methods

This research consisted of three methods. They were field methods, laboratory methods, and studio methods. Field methods consisted of lithology and landslide area distribution mapping. It also measured the failed slopes geometry and took undisturbed soil samples.

Laboratory methods consisted of samples analysis. It was conducted to know the physical properties and mechanical properties. Direct shear test had been done to get cohesion and angle of friction value. Density test was also conducted to generate the unit weight value of soil samples.

The last method was studio analysis. This analysis consisted of seismic slope stability simulations. It generated the value factor of safety

(Fs) when the earthquake occurred on different PGA.

This simulations were run by Geostudio software using Slope W/Analysis by adding seismic load parameter. The seismic load parameter was generated from PGA data. These simulations used pseudo-static analysis with horizontal PGA. The vertical PGA was not used, due to its insignificant effect to Fs value (Jibson, 2011 and Kim, 2012). Therefore, the formula in this analysis is:

$$k_h = ah / g \quad (1)$$

k_h = horizontal pseudo-static coefficient (g),
a_h = horizontal acceleration (m/s^2), and
g = gravitational acceleration (m/s^2).
So that the formula for Fs become:

$$Fs = \frac{c.L + \tan\varphi\,(W\cos\alpha - khW\sin\alpha)}{(W\sin\alpha + khW\cos\alpha)} \quad (2)$$

c = cohesion (kN/m^2),
φ = angle of internal friction (Mohr-Coulomb strength parameter) (^{0}),
W = wide multiple by density (kN/m^3),
α = slope angle (^{0}), and
kh = pseudo-static coefficient (g).

3. Results and Discussion

3.1 Materials

Based on engineering geological map, which was generated by field mapping (Fig. 6), research area consists of three materials.

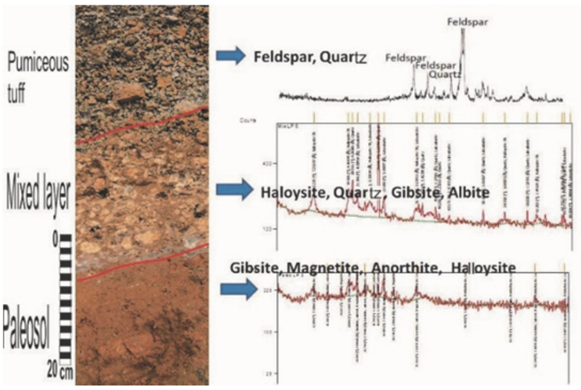

Fig. 1 Soil profile in research area.

3.1.1 Pumiceous tuff

This material was placed on the top of the soil layer. This materials came from the tephra of Tandikat or Singgalang Mountain. When that volcanoes erupted, the tephra felt down then covered the surface. It becomes recent topography.

The characteristics of pumiceous tuff are: fresh color greyish-white, weathered color brownish-yellow, size is fine-gravel (gravel dominated), the thickness approximately 3-5m, grain size is fine sand to rough gravel, and it also dominated by fine gravel.

This layer was the collapsed layer. The physical properties and mechanical properties of this material are: γ: 14.86 kN/m^3; c: 7.84 kPa; and φ: 37.28^0. Based on USCS, this material is classified as SP.

3.1.2 Mixed layer

This layer is the second layer which placed between pumiceous tuff and paleosol. This layer existed due to the mixed of pumiceous tuff and paleosol underneath. This layer has characteristics: greyish white for fresh color, greyish brown for the weathered one, grain size is clay to pebble which dominated by silt. The thickness of this layer approximately 10-40 cm.

This unique layer was the sliding surface of the landslides. It occurred because this layer is dominated by silt and halloysite. In natural condition this layer has more water than others. It was proofed by saturated degree more than 80%. Mechanical properties of this layer are: γ: 15.575 kN/m^3; c: 18.326 kPa; and φ: 29 11^0. Based on USCS, this material classified as ML.

3.1.2 Paleosol

This layer is the third layer or the bottom of soil profile in research area. This layer had been buried by pumiceous tuff, and became paleosol. It is a deposit of debris flow which became a part of topography before it was covered by pumiceous tuff (paleotopography). This material has characteristics: fresh color reddish brown, weathered color yellowish light brown, grain size is clay to pebble which dominated by medium sand to silt.

This layer was interpreted as debris flow deposition which did not fail. The mechanical properties of this layer are: γ: 13.073 kN/m^3; c: 4.998 kPa; and φ: 30.185^0. Based on USCS, this material classified as SM.

3.2 Geomorphology

Based on field observation, geomorphological unit in research area is classified as rough hills. This research area is dominated by hills with slopes value 15-70%. It is dominated by V shape valley. It represents that research area is a young valley and lied on hard rock formation. It also indicates that research area has high value of angle of friction, rough materials such as tuff, and low grade of erosions.

Photo. 1 Rough hills geomorphological unit.

3.3 Peak Ground Acceleration (PGA) of Research Area

The PGA was derived from Probabilistic seismic hazard analysis (PSHA). It was based on PGA Probabilistic Zonation Map period of 50 years (Ministry of Public Works, 2010). The research area had PGA from 0.1 – 0.5 g. Meanwhile, the PGA of September 30th 2009 earthquake could be estimated by deterministic seismic hazard analysis (DSHA). Furthermore the PGA at that moment were 0.24 g at slope LB 1 and 0.25 g at slope LB 9 (Darana, 2015).

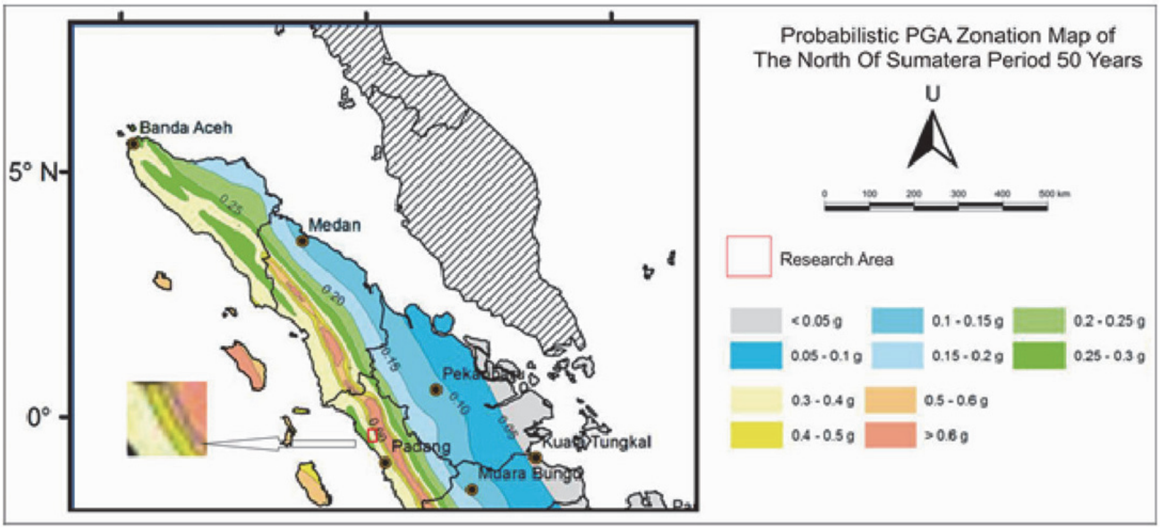

Fig. 2 PGA Probabilistic Map of research area Period 50 years (not to scale) (modified from Ministry of Publi Works).

3.4 The Effect of PGA to the Slope Stabilities (Fs)

Table 1 Slopes Geometry.

Slopes	Coordinate		Slopes Geometry					
	Latitude	Longitude	a (m)	b (m)	c (m)	α (^{0})	Crown length (m)	Landslide area (m^2)
LB 1	S 0^0 29’ 06.4”	100^0 14’ 28.3” BT	57	67.5	88.34	37	225	54.480
LB 9	S 0^0 29’ 03.3”	100^0 13’ 48.5” BT	76.5	41	86.8	30.4	413.7	42.550

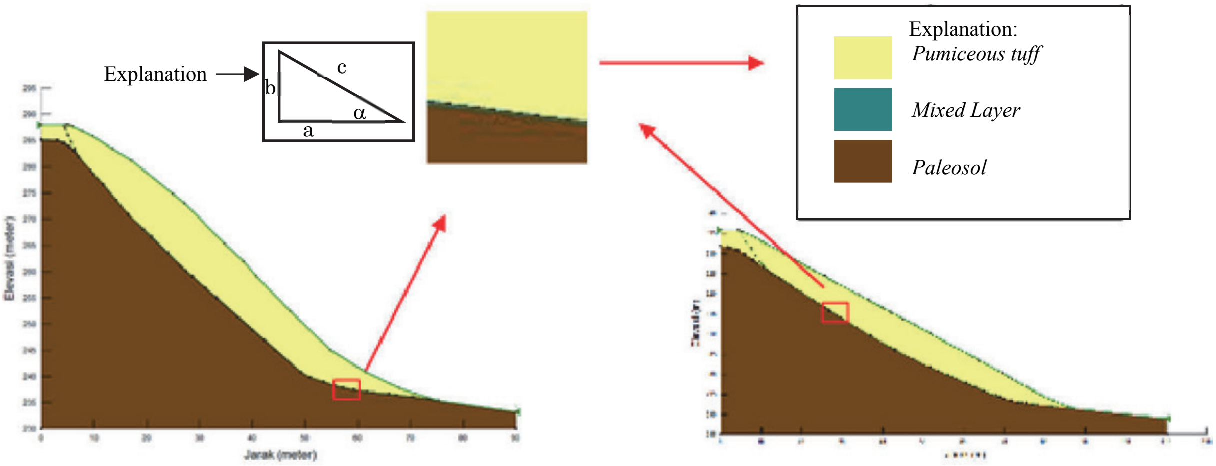

Fig. 3 Research Slope, LB1 Left and LB 9 Right by Software Geostudio (not to scale).

Two slopes from research area had been chosen as models to analyze the effect of seismic to the Fs value. They were LB 1 and LB 9 (Fig. 6). The geometry of slopes were measured in the field and shown in table1. Digital elevation model (DEM) was used to generate the topography of research area before landslide occurred. After the data had been collected, the slopes were modeled and analyzed in Geostudio Software (Fig. 4).

3.4.1 Slope LB 1

Table 2 Result of Fs Simulation in LB1.

PGA (g)	Ordinary		Bishop		Janbu		M.P	
	Moment	Force	Moment	Force	Moment	Force	Moment	Force
0	1.128	-	1.185	-	-	1.083	1.171	1.180
0.1	0.965	-	1.022	-	-	0.920	1.015	1.013
0.2	0.831	-	0.890	-	-	0.790	0.890	0.887
03	0.719	-	0.782	-	-	0.683	0.789	0.786
0.4	0.625	-	0.690	-	-	0.594	0.706	0.697
0.5	0.544	-	0.611	-	-	0.519	0.640	0.636

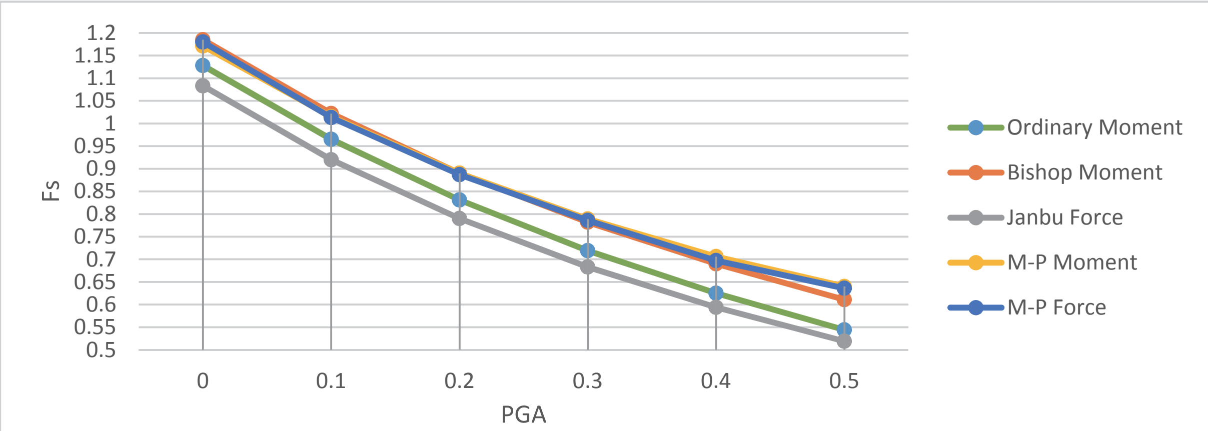

Fig. 4 Graphic of Fs Simulation in LB 1.

Photo. 2 Slope LB 1 slope that occurred landslide when earthquake happened at 30th September 2009.

The natural slope stability (PGA=0) was 1.083 calculated used Janbu Method (the smallest value around PGA=0). Based on Fs classification by Bowles (1989), the slope is in critical condition. When the earthquake occurred with PGA 0.1 g, the Fs value became 0.920. It means the slope is failed, which is based on Fs classification (Bowles, 1989). This analyzes show that the higher PGA the lower Fs value. The data of PGA and Fs value were plotted to the graphic Fs simulation (Fig. 4) then. The graphic shows the declining trend of Fs.

3.4.2 Slope LB 9

Table 3 Result of Fs Simulation in LB9.

PGA (g)	Ordinary		Bishop		Janbu		M.P	
	Moment	Force	Moment	Force	Moment	Force	Moment	Force
0	1.574	-	1.732	-	-	1.566	1.614	1.605
0.1	1.293	-	1.423	-	-	1.276	1.318	1.312
0.2	1.085	-	1.199	-	-	1.064	1.104	1.097
0.3	0.923	-	1.026	-	-	0.902	0.939	0.936
0.4	0.795	-	0.889	-	-	0.775	0.807	0.811
0.5	0.690	-	0.779	-	-	0.674	0.705	0.708

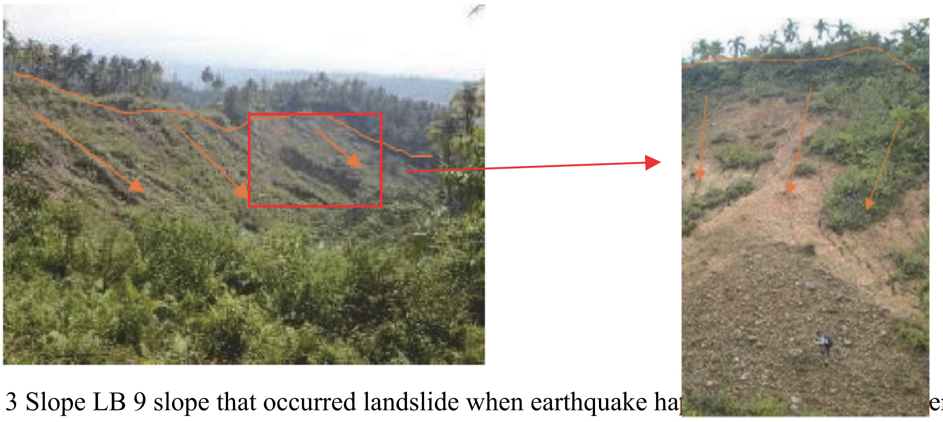

Photo. 3 Slope LB 9 slope that occurred landslide when earthquake ha[...]er 2009.

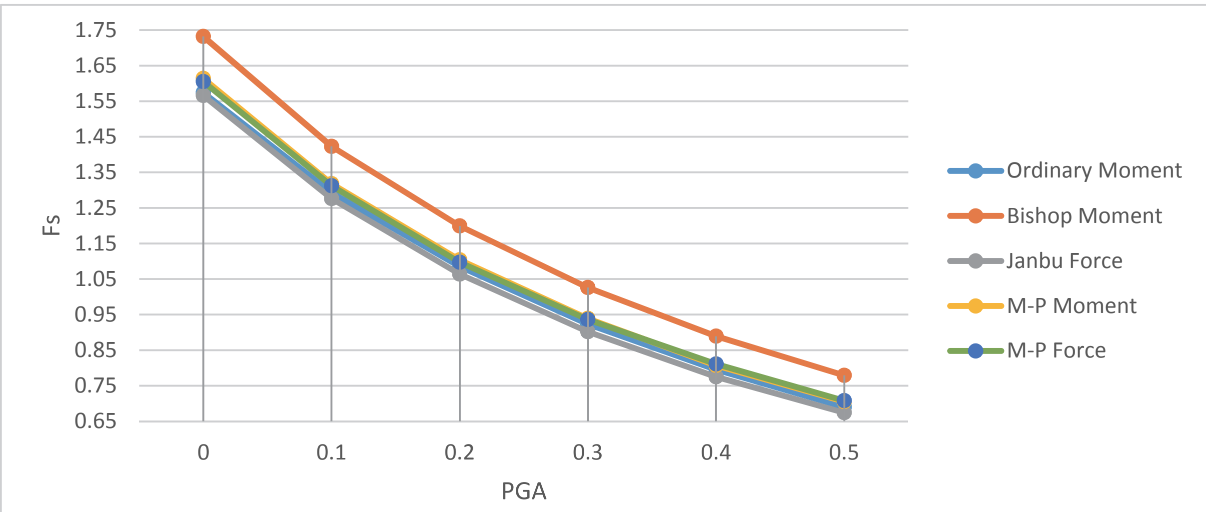

Fig. 5 Graphic of Fs Simulation in LB 9.

The natural slope stability (PGA=0) was 1.566 calculated used Janbu Method. This value means that slope is stable (Bowles, 1989). It remained stable even the PGA is 0.1 g. However, when the PGA became 0.2 g, the Fs value became 1,064 which means the slope is critical (Bowles, 1998). Moreover when the PGA became 0.3 g, the slope became unstable. It is also confirmed that the higher PGA the lower Fs Value. Likes the LB 1, this slope generated the graphic which showed the declining trend.

Those slope stability simulations show the smallest Fs value was generated from Janbu Method. It could be happened because the material of these mass movement are soil and the type of these landslides are rotational not circular (not properly circular). Janbu method is more reliable than others for this case. It because Janbu method determines the failure plane based on the weak zone that is existed in soil mass (Bromhead, 1992; Khrahn, 2004).

Slope LB 1 Generated lower Fs value than slope LB 9. It is because slope LB 1 had higher slope angle than slope LB 9. It means LB 1 steeper than slope LB 9. Therefore, in this case, the steeper slope angle the lower Fs value.

4. Conclusions

- Soil profile shows three materials: (1) pumiceous tuff (failure layer), (2) mixed layer (sliding surface), and (3) paleosol (stable layer).
- Research area has the rough hills geomorphological unit with slopes value 15-70%.
- Natural slope stability shows the Fs Value of LB1 is 1.083 which means critical and LB 9 is stable due to its Fs value is 1,566.
- Slope LB 1 and LB 9 were failure when Fs simulations was run with PGA 0.1-0.5. It shows that the higher PGA the lower Fs value.
- The Fs value of slope LB 1 were lower than slope LB 9. It is because slope LB 1 higher angle than slope LB 9. Therefore, in this case, the steeper slope the lower Fs value.

4.1 Future Plans of This Study

- This landslide study only used earthquake (PGA), the mechanical and physical properties of its materials, and the geometry of the slopes as parameters. It could be more accurate if this study use another parameters such as rainfall intensity, groundwater condition, the extra load at the surface (e.g. houses), vegetation condition, etc.
- It is also suggested to analyze more slopes, so that the Fs data could be shown as spatial information. It also could be made the zonation of areas prone to this hazard. It could be useful for planning and managing the land use such as infrastructure, houses, farms, etc.

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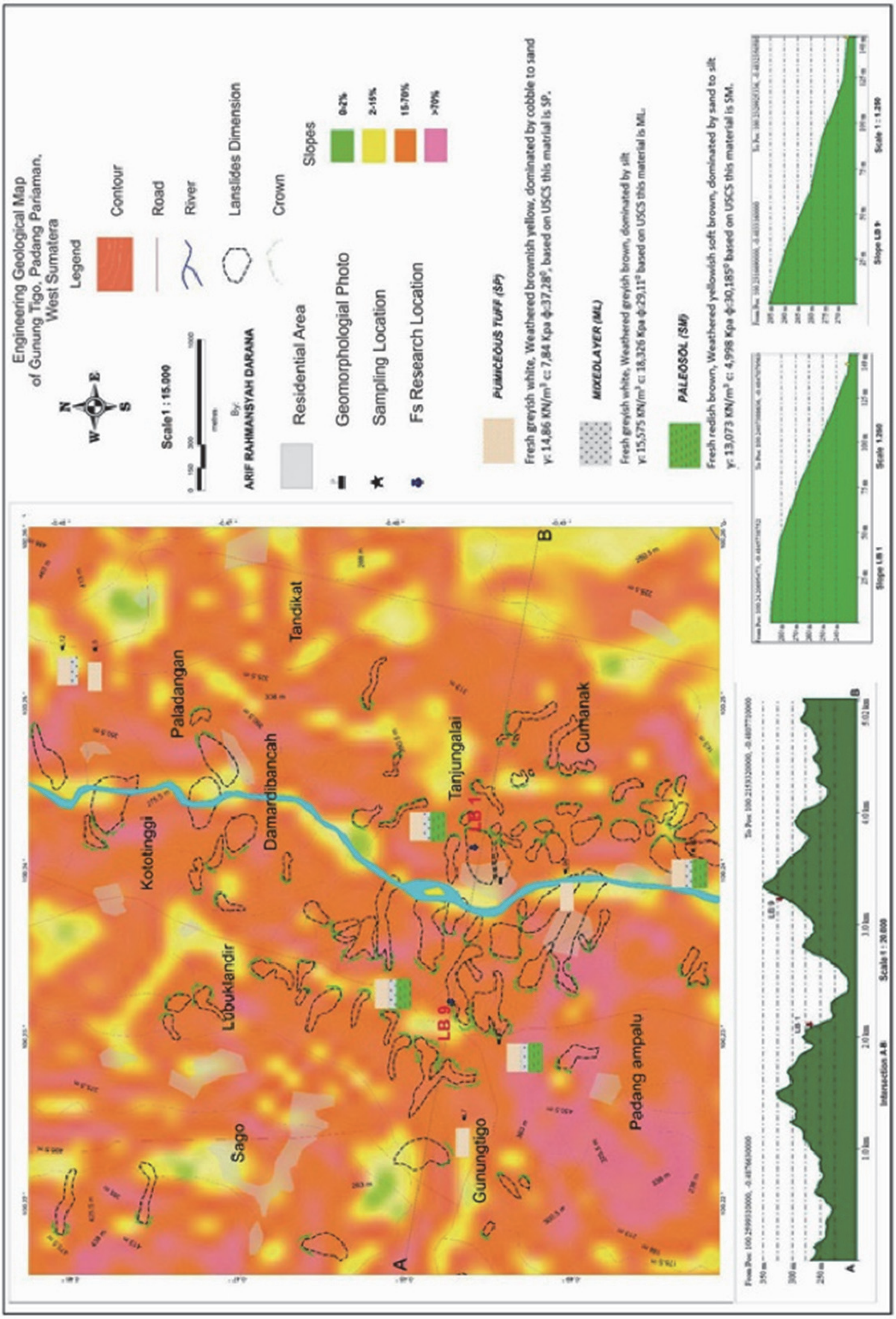

Fig. 6 Engineering Geological Map of research area.