Disaster Report

Landslides in Padang, West Sumatra, triggered by the September 2009 offshore earthquake

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On 30 September 2009, numerous landslides occurred in a mountain-ringed region of West Sumatra, Indonesia, triggered by an earthquake off the coast of Padang. The landslides blocked roads in the region, hindering efforts to determine the extent of the damage. Analyses of satellite images (coverage area 1,500 km²) of the most severely damaged districts, Padang Pariaman and Agam, revealed that 253 landslides had occurred. Severe landslides, involving more than 1 million m³ of collapsed sediment, were observed at 10 sites within the study area.

Key words: landslide, mudflow, earthquake, satellite image, Padang

1. INTRODUCTION

On 30 September 2009, a magnitude 7.6 earthquake occurred in the Indian Ocean off the coast of Padang in the province of West Sumatra, Indonesia, at 5:16 p.m. (Western Indonesia Time). According to the US Geological Survey, the earthquake's center was located at 0.725°S, 99.856°E with a hypocenter depth of 81 km (**Fig. 1**). The earthquake caused 907 deaths and another 210 people are still missing.

Enormous damage occurred in areas close to the earthquake's origin, especially in the cities of Padang and Pariaman and the nearby district, where

many residences and other buildings collapsed. Numerous slope collapses also occurred in nearby mountainous regions. It took time to assess the extent of the damage because roads were blocked by landslides, and water and electricity services were severed in many places.

We conducted field investigations between 3 and 5 October 2009. Here, we report our field findings as well as the results of our analysis of satellite images of approximately 1,500 km² of the most damaged areas.

Fig. 1 Epicenter of the earthquake off the coast of Padang, West Sumatra, Indonesia

2. FIELD INVESTIGATION

We investigated the earthquake damage in the city of Padang on 3 October and conducted field investigations in the surrounding Padang Pariaman district on 4 and 5 October 2009. Many landslides and collapses occurred in this.

2.1 Conditions in Padang

Most areas in the city of Padang were still accessible by car. Some residences and other buildings had collapsed and the electricity was off. We observed some cracks and breakage in slope and bank protection structures, but while some new flank collapses had occurred on hillside slopes near Padang, none of these were massive landslides.

2.2 Conditions in Padang Pariaman

2.2.1 Overview

Many landslides and collapses had occurred in the mountain-ringed district of Padang Pariaman, located north of the cities of Padang and Pariaman. Roads through the district were blocked by landslides, delaying efforts to assess the extent of the damage. In this mountain-ringed region, more than 50% of buildings (including private homes) had collapsed; this is much higher than the collapse rates in the cities of Padang and Pariaman.

2.2.2 Landslide disasters

As part of our field investigation, we visited a landslide site in the upper area of the Naras river (0.485°S , 100.227°E) (Figs. 2, 3). Three landslides occurred in this area, becoming mudflows that joined and flowed downstream (Figs. 4, 5, 6). Large volumes of unstable sediment from these landslides also accumulated on slopes and along the mountain stream.

According to a geologic map of Padang [Kastowo et al., 1996], this area consists of volcanic rocks, mostly pumice and volcanic lapill, with diameters of 2–10 cm. The site is deeply weathered.

Fig. 2 Landslide occurrence sites

Fig. 3 Landslide occurrence sites and photograph points

Fig.4 A landslide disaster (P1)

Fig.5 A mudflow landslide (P2)

Fig.6 Landslide points on a hillside (P3)

Fig.7 Region covered by the analyzed satellite imagery

3. SATELLITE IMAGE ANALYSIS

Because landslides occurred over a wide area and many roads in the region were blocked, it was difficult to determine the comprehensive damage at the time of our field investigations. To estimate the landslide sites and disaster conditions across the

region, we used satellite images of the most severely damaged districts, Padang Pariaman and Agam.

3.1 Satellite images

We used images obtained by the German satellite TerraSAR-X. The X-band synthetic aperture radar (SAR) observations collected by this satellite are not influenced by clouds and have a spatial resolution of 3.3 to 3.5 m. We compiled imagery within the following four Universal Transverse Mercator coordinate points: A -0.273, 99.987; B -0.761, 100.080; C -0.701, 100.379; and D -0.214, 100.284. The rectangle bounded by these points measured about 1,500 km² (30 km × 50 km). We compared two satellite images: a pre-earthquake image taken on 28 February 2009 and a post-earthquake image taken on 8 October 2009 (**Fig. 7**).

3.2 Method of interpretation

We overlaid the two satellite photographs and determined the points that had changed as a result of landslides. We then estimated the volume of collapsed sediment at landslide sites using the following procedure:

- 1) Measure the width of the slope collapse identified in the satellite photograph
- 2) Multiply the width by 1.5 to estimate the length of the slope collapse
- 3) Multiply the width by 0.1 to estimate the depth of the slope collapse
- 4) Width x length x depth x 0.5 = the estimated amount of collapsed sediment

3.3 Analysis results

Using the satellite images, we identified 253 landslides (**Table 1**), amounting to an estimated total of 70,000,000 m³ of collapsed sediment. Of these landslides, 10 were classified as severe, each with more than 1 million m³ of collapsed sediment (**Fig. 8**). The collective volume of these 10 severe landslides, about 40,000,000 m³, represents about 60% of the total collapsed sediment volume in the study area (**Table 2**). These calculations excluded some mudflow areas; consideration of mudflow would make the estimates even higher.

Table 1 Landslide sites and number and scale of landslides

District	Subdistrict	Landslide	Large
			Scale*
Padang Pariaman	Lubuk Alung	12	1
	Sintuk Toboh Gadang	5	
	Nan Sabaris	2	
	Enam Lingkung	9	1
	Tujuh Koto Sungai Sarik	1	
	Dua Sepuluh Sebelas Enam Lingkung	9	
	Patamuan	1	
	Sungai Limau	8	
	Lima Koto Timur	51	6
	Lima Koto Kampung Dalam	27	2
	Batang Gasan	1	
	Sungai Geringging	10	
	Empat Koto Aur Malintang	5	
	Sub Total	141	10
Agam	Empat Koto	37	
	Tanjung Raya	34	
	Lubuk Basung	39	
	Empat Nagari	2	
	Sub Total	112	0
Total		253	10

Large Scale: estimated volume >1,000,000 m³

Fig.8 Distribution of landslides

Table 2 Large-scale landslide sites (sediment volume >1,000,000 m³)

No,	Subdistrict	Width (m)	Length (m)	Depth (m)	Volume (m ³)
1	Lubuk Alung	331	497	33	2,719,852
2	Enam Lingkung	378	567	38	4,050,761
3	Lima Koto Timur	284	426	28	1,717,973
4		345	518	35	3,079,772
5		534	801	53	11,420,498
6		340	510	34	2,947,800
7		457	686	46	7,158,299
8		270	405	27	1,476,225
9	Lma Koto Kampung Dalam	296	444	30	1,945,075
10		245	368	25	1,102,959
				Total	37,619,215

3.4 Relationship between topography and geology

To refine the distribution of slope collapses, we analyzed the relationship between topography and geology at landslide sites. Most landslides occurred at sites with the following topographic or geologic features (**Fig. 9**) [Kastowo et al., 1996]:

- 1) Lineament, caldera, or caldera rim
- 2) Andesite of Lake Maninjau caldera
- 3) Hornblende hypersthene pumiceous tuff
- 4) Elevation similar to the lake surface of Lake Maninjau (~500 m above sea level)

From these features, we inferred that many landslides occurred as a result of seismic movement and water supplied from Lake Maninjau, combined with a geographic predisposition to landslides.

Many slope collapses were concentrated in the Naras and Mangau river basins, which were near the earthquake's center (**Fig. 10**). A caldera rim surrounds Lake Maninjau, and the steepness of the caldera slopes contributed to landslides in this area [Fratini et al., 2004; Hürlimann et al., 2001; Zanchetta et al., 2004].

Fig.9 Landslide distribution and geology

Fig.10 Landslide distribution in the Naras and Mangau river basins

4. CONCLUSIONS

Our field investigation and analyses of satellite images yielded the following conclusions regarding slope collapses during the Padang offshore earthquake.

- 1) Many slope collapses occurred in the upstream basins of the Naras and Mangau rivers.
- 2) Landslide occurrence was closely related to topography and geology, with landslides tending to occur on steep slopes of volcanic rock.
- 3) Some landslides became mudflows and flowed downstream. In these cases, large volumes of unstable sediment were deposited on slopes and in mountain streams. Water supplied by Lake Maninjau also contributed to mudflow occurrence.

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