Investigation of earthquake-rainfall triggered landslide in Tandikat, West Sumatra, Indonesia

a preliminary report

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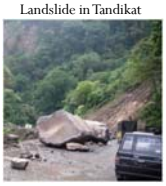
Introduction

- The M 7.6 earthquake in West Sumatera Province on September 30, 2009 caused 1,195 deaths and severe damage to 140,000 houses and 4000 other buildings.
- The earthquake was located at a depth of about 80 km within the oceanic slab of the Indo-Australian plate and its epicenter located offshore about 60 km WNW of Padang (EERI, 2009).

Introduction

Landslide in Tandikat

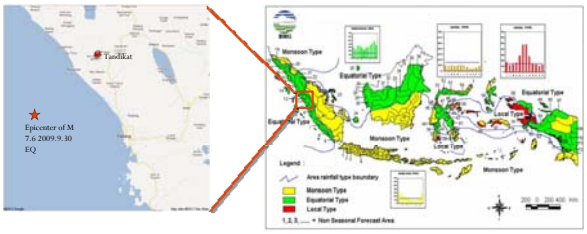


Rockfalls in roadway

- This earthquake excited a large number of landslides in the mountainous areas of Tandikat that destroyed villages and took many lives.
- The landslides accidentally happened during rainfall at afternoon (5:16 pm, local time).
- About more than 60% of death casualty is caused by landslides which are triggered by earthquake in mountain areas (EERI, 2009).

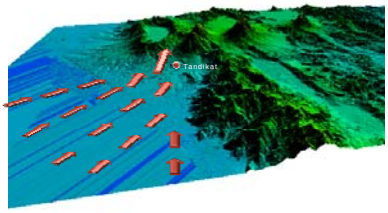
Source: Japan Association of Civil Engineering Report (2009)

Meteorology and Seismology



- Generally, west coast of Sumatra has equatorial type of rain which has no dry season and has high intensity of precipitation.

Meteorology and Seismology

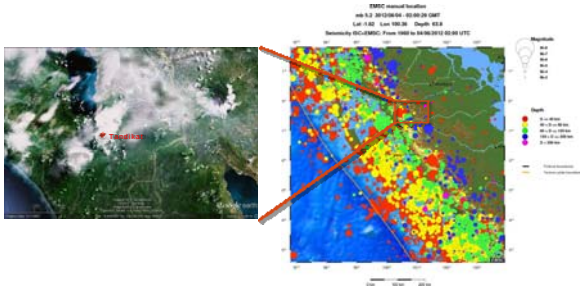


- Locally, this area has typical orographic rainfall that frequently happen in high intensity due to moist warm air movement into concave shape region formed by unique topographical terrain .

Meteorology and Seismology

- The moist warm water then moves upward due to mountain barrier and then condense and become rainfall because of the decreasing temperature.

Meteorology and Seismology



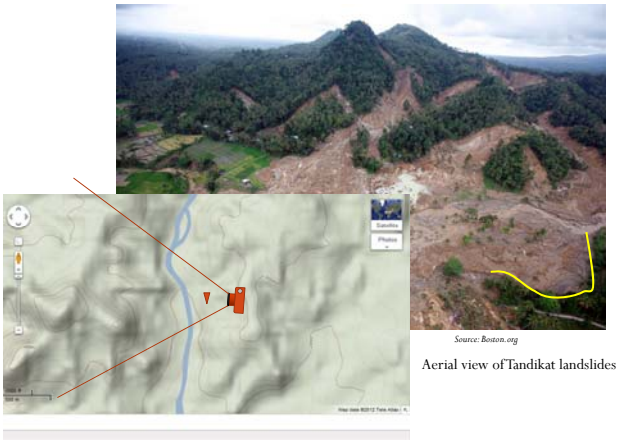
- In the other hand, west coast of Sumatra island has also high earthquake intensity .
- The sum of these facts is Tandikat area has great potential of landslide hazard that triggered by earthquake and rainfall.

Objective of Investigation

- To gain more information about the geotechnical properties, geological feature in the site.
- As the preliminary study about mechanism of causative effect between rainfall and earthquake.

Field Investigation Location

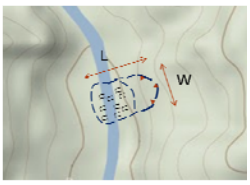
- The field investigation is located in Tandikat, Padang Pariaman Regency, West Sumatera
- The distance from the epicenter is about 60 km



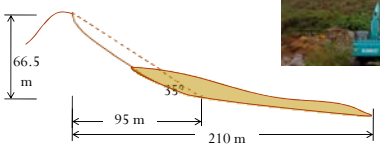
Source: Boston.org

Aerial view of Tandikat landslides

Field Investigation Location

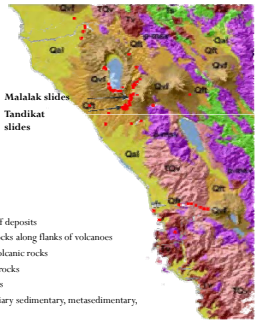


- The approximate width (W) and length (L) of the landslide are 150 m and 210 m, respectively.
- The designation of the landslide is by consideration that it has the gentlest slope among the others slide.
- Soil behavior is considered as significant contributing factor of the landslide instead of the gravity.



Geological Features

- The geology of the site is controlled by the surrounding volcanic mountain. The nearest mountain is Mt. Tandikat (2,374 m).
- According to the Geology Map of Padang (Kastowo et al. 1996), the surficial deposits consists of silt, sand, and gravel and may locally include remnants of pumice-tuff.



Qal	Quatenary alluvium
Qft	Quatenary fan and tuff deposits
Qvf	Quatenary volcanic rocks along flanks of volcanoes
TQv	Quatenary-Tertiary volcanic rocks
Ts	Tertiary sedimentary rocks
Tv	Tertiary volcanic rocks
P-msv	Plutonic and pre-Tertiary sedimentary, metasedimentary, and volcanic rocks

Field Investigation

- The field investigation was fulfilled during rainy season.
- The investigation consists of soil sampling, in-situ density and permeability test.

The appearance of lenticularis clouds near the location

Weather Condition

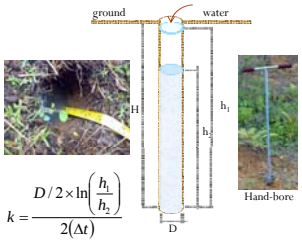
- There was some high rainfall during investigation.
- The rainfall intensity was approximately 120 mm/hour within 2 hours duration.
- According the nearest city meteorological station, the average rainfall intensity in rainy season is 30 mm/day.

Rough measurement of rainfall intensity

120 mm/hour within 2 hour

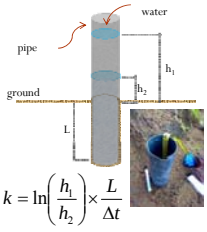
Average rainfall 30 mm/day

In-situ Permeability Test



$$k = \frac{D/2 \times \ln\left(\frac{h_1}{h_2}\right)}{2(\Delta t)}$$

Hand-bore

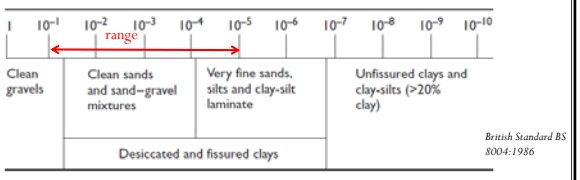


$$k = \ln\left(\frac{h_1}{h_2}\right) \times \frac{L}{\Delta t}$$

- The field permeability test consisted of two kind of test: borehole test and pipe test
- Each test have different corresponding formula
- In each test, the falling of water is measured each minutes (Δt) between h_1 and h_2
- The borehole test is performed by making about 10 cm diameter and 80 cm deep hole using hand-bore
- The pipe test is performed by penetrate 8.5 cm pipe into the soil in about 20 cm deep.

Field Permeability test results

Type	Depth	Average Permeability	Remarks
Pipe	0.00 – 0.50 m	1.43×10^{-5} m/s	Silty sand
Borehole	0.50 – 1.00 m	0.157 m/s	Sand-gravel mixtures
Pipe	3.00 – 3.20 m	8.4×10^{-4} m/s	Sand-gravel mixtures
Borehole	3.00 – 3.20 m	-	Not applicable



British Standard BS 8004:1986

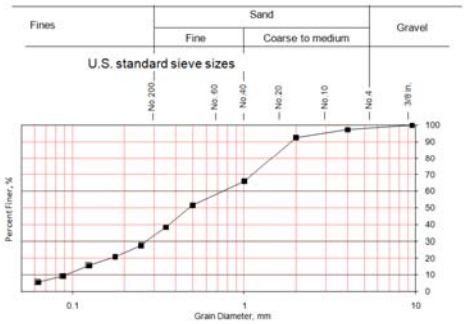
Laboratory Test

- The laboratory test consist of:
  - Water content determination test
    - To determine water content of the pumice samples
  - Specific gravity test
    - To determine the specific gravity of the solids of pumice samples
  - Grain-size distribution test
    - To examine the distribution of pumice solids and soil criteria
  - Static Triaxial Test
    - To examine the soil strength and behavior by Consolidated-Undrained trixial test

Results of index properties test

Sample Properties	Values
Average water content	69%
Specific Gravity	2.66
Bulk Density	1.50 gram/cm^3
Dry Density	0.89 gram/cm^3
Void ratio, e	2.00
Porosity, n	67%
Degree of saturation	92%

Grain-distribution result

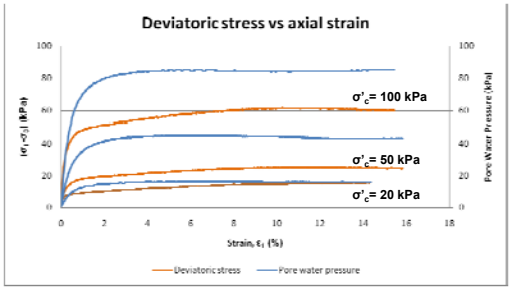


D_{10}	D_{30}	D_{60}	$C_u = D_{60}/D_{10}$	$C_c = (D_{30})^2/(D_{10} \times D_{60})$
0.091	0.268	0.746	8.19	1.06

Silt contents is 21.07 %
Gravel = 2.67 % Sand = 76.27 %

Results

- Static triaxial result



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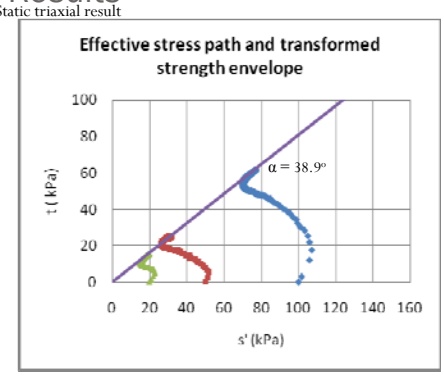

Results

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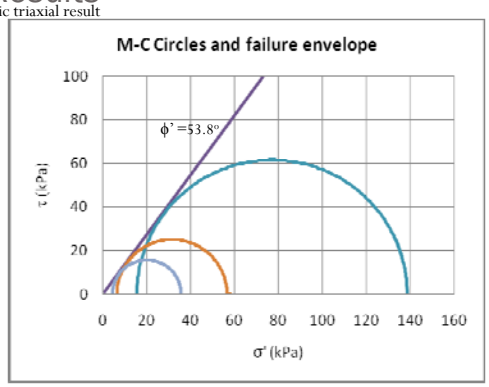
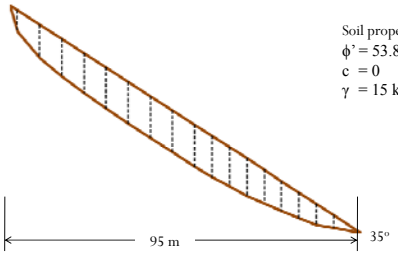


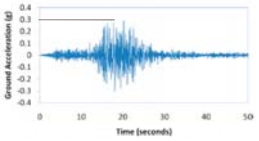
Slope Analysis



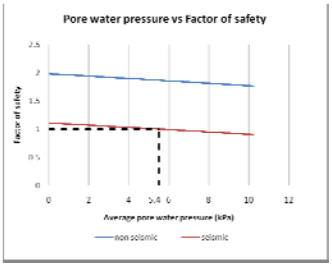
Soil properties:
$\phi' = 53.8°$
$c = 0$
$\gamma = 15$ kN/m^3

- The limit equilibrium stability analysis is carried out using Janbu's simplified theory and slice method.
- This method is considering force equilibrium to calculate factor of safety.

Stability analysis



The slope is stable without influence of earthquake even in high pore pressure condition.



The slope become unstable when earthquake force 0.3g is taken into analysis during the presence of average pore water pressure larger than 5.4 kPa.

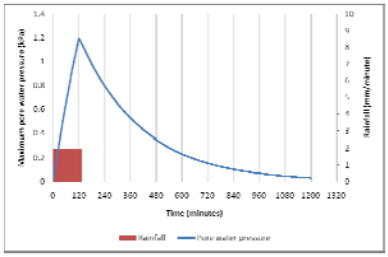
Groundwater modeling

- The groundwater model is developed using transient groundwater equation

$$k\left(\frac{\partial^2 h}{\partial x^2}+\frac{\partial^2 h}{\partial y^2}\right)-R(x,y,t)=S\frac{\partial h}{\partial t}$$

- Where:
  - K = permeability (m/s)
  - S = storage coefficient (typical value for sand 0.2 – 0.35)
  - R = recharge (m/s)

Groundwater modeling



Where:

K = 5 mm/minute
S = storage coefficient = 0.35
R = recharge of rainfall = 120 mm/hours

- The maximum pore water pressure after 2 hours rainfall is 1.2 kPa
- There was a gap of pore water pressure after rainfall and pore water pressure requested in seismic failure condition (5.4 kPa)

Conclusion

- Static triaxial test confirmed the immediate increment of pore water pressure in the pumice specimen due to contractive behavior of soil
- Slope stability analysis shows that slope is stable without influence of earthquake even in high pore pressure condition
- The excess pore water pressure due to earthquake is considered to be happened. However, further examinations are needed to get more evidence about the effect of earthquake

Thank you for your attention