Mechanism of Fluidized Landslides due to the 2016 Kumamoto Earthquake and Risk Evaluation of Unstable Soils - A Factual Investigation by Japan-USA Joint Research –

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Dr. Nick Oettle (AECOM)
Summary of Project Activities

- Surveying of the affected areas using UAV (Unmanned aerial vehicle), LIDAR (Light Detection and Ranging) and Resistivity Imaging
- Collection of acceleration and fault data, their analysis and evaluation
- Quantitative evaluation of fluidized flow using laboratory tests
- Modeling and analysis using energy-based approach
- Construction of hazard maps
- Regular meeting of the leaders/subleaders of Japan and USA
- Organizing workshop to disseminate the information (Will be held at Kyushu University on March 6, 2017).
International Workshop on the 2016 Kumamoto Earthquake

– Japan-US Joint Workshop –

March 6, 2017
Inamori Center, Kyushu University
Fukuoka, Japan

Organized by
J-RAPID Project Team

Co-organized by
Kyushu University
National Disaster Research Council, Japan
National Disaster Information Center of Western Japan, Kyushu University
International Press-in Association (IPA)
Center for Reducing Disaster Risk, Kumamoto University

Supported by
Japan Science and Technology Agency
Japan Foundation Engineering Co., Ltd.
Major Surveyed Locations

- Aso area
- Nishihara village
- Mashiki town
- South Kumamoto
Survey Schedule

1\textsuperscript{st} Survey
5/11 (Wed)
5/12 (Thur)
5/13 (Fri)

2\textsuperscript{nd} Survey
June 25 (Sat)
June 26 (Sun)

3\textsuperscript{rd} Survey
August 22 (Mon)
August 23 (Tue)
August 24 (Wed)
Survey using Modern Equipment (1)

- **LIDAR (Light Detection and Ranging)**
Survey using Modern Equipment (2)

- UAV (Unmanned aerial vehicle):

- Resistivity Imaging
Landslides, Slope Failures and Debris Flows

(Based on photograph by Geospatial Information Authority of Japan (GIA))
Huge Surficial Failure at Takanoobane

Landslides occurred in moderately inclined slope, thickness was small in relation to the width and length.
Geological and Topographical Characteristics of the Landslide

- The landslide occurred on a moderately inclined slope (inclination: 10 to 15 °).
- Orange-colored pumice soils were found to be scattered here and there around the failed slope.
- Relatively consolidated tephra layers were found to exist beneath the orange-colored pumice layers in the slope geology, and they were found to be intact.
- Seepage flow was observed close to the pumice layers on the scarp during rainfall (heavy rain during our second field survey).
Hinotori Hot Spring Disaster (Debris Flow)

- Non plastic volcanic soil (called Hido (灰土) in Japanese) which is very porous with low specific gravity
- Water content was found to be high
- Loses strength with very little load
Geological Aspects in Aso Area

AC: Aso central cone tephra and pumice, 7.3 cal ka～up to now,
K-Ah: Kikai Akahoya ash, 7.3 cal ka (Dark brown color)
ATn: Aira Tn ash, 29 cal ka (Shiny white color (glassy))
Kpfa: Kusasenrigahama pumice, 31 cal ka (Orange color (without biotite))
Tp: Pre Takanoobane lava pumice, 51 ± 5 ka (Blackish)
# Soil Properties

<table>
<thead>
<tr>
<th>Soil Properties</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>2.24-2.38</td>
</tr>
<tr>
<td>Dry density (g/cm(^3))</td>
<td>0.51-0.58</td>
</tr>
<tr>
<td>Wet density (g/cm(^3))</td>
<td>1.23-1.30</td>
</tr>
<tr>
<td>Water content (%)</td>
<td>54.62-58.36</td>
</tr>
<tr>
<td>Liquid limit (%)</td>
<td>113.40</td>
</tr>
<tr>
<td>Plastic limit (%)</td>
<td>88.25</td>
</tr>
<tr>
<td>Plasticity index (%)</td>
<td>25.15</td>
</tr>
<tr>
<td>Sand (%)</td>
<td>35.8</td>
</tr>
<tr>
<td>Silt (%)</td>
<td>39.2</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>25</td>
</tr>
<tr>
<td>Soil classification (JGS 0051-2009)</td>
<td>Volcanic cohesive soil type II (VH(_2))</td>
</tr>
</tbody>
</table>

- **Low specific gravity** (Lower than silt and clay)
- **Properties similar to silt with high liquid limit (MH)**
- **Found near volcano area**
## Chemical and Mineral Contents (From XRF and XRD Tests)

<table>
<thead>
<tr>
<th>Chemical content</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>48.832</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>35.959</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>8.910</td>
</tr>
<tr>
<td>CaO</td>
<td>3.300</td>
</tr>
<tr>
<td>TiO₂</td>
<td>1.843</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.489</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.259</td>
</tr>
<tr>
<td>MnO</td>
<td>0.172</td>
</tr>
<tr>
<td>SrO</td>
<td>0.069</td>
</tr>
<tr>
<td>ZrO₂</td>
<td>0.065</td>
</tr>
<tr>
<td>SO₃</td>
<td>0.060</td>
</tr>
<tr>
<td>Ag₂O</td>
<td>0.018</td>
</tr>
<tr>
<td>Y₂O₃</td>
<td>0.008</td>
</tr>
<tr>
<td>ZnO</td>
<td>0.008</td>
</tr>
<tr>
<td>Ga₂O₃</td>
<td>0.007</td>
</tr>
<tr>
<td>NbO</td>
<td>0.003</td>
</tr>
<tr>
<td>Mineral content</td>
<td>%</td>
</tr>
<tr>
<td>Albite</td>
<td>57</td>
</tr>
<tr>
<td>Bytownite</td>
<td>40</td>
</tr>
<tr>
<td>Sodium Hidrogensulfide</td>
<td>2.0</td>
</tr>
<tr>
<td>Calcium copper germanium oxide</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Contains 57 % Albite and 40 % Bytownite. Presence of these two minerals, known as mineral Plagioclase, contributes to brittle tenacity.
Microstructure of Soils (From SEM Test)

- Soil skeleton is formed by crystal flakes with high porosity
- By comparing two photographs (before and after cyclic loading), the amount of fine particles is found to be increased after cyclic loading

Reference: Paper to be presented by Ms. S. Ode at International Workshop on the 2016 Kumamoto Earthquake, March 6, 2017, Kyushu University, Fukuoka
Arrangement of Resistivity Sensors (West Slope of Takanoobane)
Resistivity Profiles

Kpfa is distributed in a very shallow depth and not parallel to the terrain

Reference: Paper to be presented by Dr. Y. Kochi at International Workshop on the 2016 Kumamoto Earthquake, March 6, 2017, Kyushu University, Fukuoka
Evaluation of Landslide by Energy-based Approach

Energy balance in flow-type failure of slopes

Earthquake

\[ E_{EQ} : \text{Earthquake energy contributing to slope failure} \]
\[ E_P : \text{Potential energy due to gravity} \]
\[ E_{DP} : \text{Energy dissipated in soil due to slope deformation} \]
\[ E_K : \text{Kinetic energy of sliding soil mass} \]

Performance-based Evaluation of Landslide by Energy Approach

Evaluate Input energy $E_{IP}$

$$E_{IP} = \rho V_S \int (du/dt)^2 dt$$

$\rho V_S$ : Impedance,

$du/dt$ : Velocity time history

Locations of strong motion stations (NIED), slope failures and epicenter of the 2016 Kumamoto earthquake
Simulation Results in Aso Area

Input earthquake energy $E_{IP}$ at a base layer was calculated from multiple KIK-net vertical array records (NIED).

- **Input energy $E_{IP}$ distribution map**

- **Acceleration value $\rightarrow$ small**
- **Input energy value $\rightarrow$ large**
Simple theory of spherical energy radiation
Gutenberg and Richter (1956)

\[ \log E = 1.5M + 11.8 \]

Spherical energy radiation of body wave

\[ \frac{E_{IP}/A}{E} = \frac{1}{4\pi R^2} \]

Approximate line by M=7.1 Kumamoto EQ.

Reference: Paper to be presented by Dr. T. Ishizawa at International Workshop on the 2016 Kumamoto Earthquake, March 6, 2017, Kyushu University, Fukuoka
## Landslide Predictive Factors

<table>
<thead>
<tr>
<th>No.</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Slope gradient</td>
</tr>
<tr>
<td>2</td>
<td>Aspect</td>
</tr>
<tr>
<td>3</td>
<td>Elevation</td>
</tr>
<tr>
<td>4</td>
<td>Plan curvature</td>
</tr>
<tr>
<td>5</td>
<td>Profile curvature</td>
</tr>
<tr>
<td>6</td>
<td>Terrain roughness</td>
</tr>
<tr>
<td>7</td>
<td>Lithology unit</td>
</tr>
<tr>
<td>8</td>
<td>Distance to seismic fault</td>
</tr>
<tr>
<td>9</td>
<td>SPI</td>
</tr>
<tr>
<td>10</td>
<td>TWI</td>
</tr>
<tr>
<td>11</td>
<td>Drainage density</td>
</tr>
<tr>
<td>12</td>
<td>Distance to stream</td>
</tr>
<tr>
<td>13</td>
<td>NDVI</td>
</tr>
<tr>
<td>14</td>
<td>PGA</td>
</tr>
<tr>
<td>15</td>
<td>Constant</td>
</tr>
</tbody>
</table>
High and very high vulnerable zones are located in the central parts of the study area, especially around the Aso volcano.

The area which contained volcanic ash, very high elevation and steep slopes was classified as the high and very high hazard zones.

The developed landslide hazard map showed that the probability of landslide occurrence is large in high slope and high elevation areas.

Reference: Paper to be presented by Prof. G. Chen at International Workshop on the 2016 Kumamoto Earthquake, March 6, 2017, Kyushu University, Fukuoka
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Mr. Yuta Kitano (Giken Ltd., Tokyo, Japan)
Mr. Babloo, Mr. Nishimura, Ms. Chu, Ms. Ode, Ms. Thuy, Mr. Suzuki, Mr. Manafi, Mr. Ogo (Kyushu University, Fukuoka, Japan)
Ms. Jenny and Ms. Samantha (University of Colorado, Boulder, USA)
J-RAPID Project Team of Japan
Thank you for your kind attention