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Future and Prospect for Monitoring Deep-Seated Landslide Activity over Extensive Area

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Outline

1. Challenges of Typhoon Morakot
2. Comprehensive Plan of Large-scale Landslide Hazard Mitigation
   - Risk Assessment of Potential Landslides
   - Multi-scale Monitoring Techniques
3. Future Development and Conclusions
Taiwan is subject to typhoon disasters.
Challenges of Typhoon Morakot, 2009

- Max. accumulated rainfall: 3059.5mm.
- Coverage area of total rainfall $\geq 2000$mm: $320,000$km$^2$.
- Total new landslides: 39,492 ha.
- Casualty and missing: 699 people.
- Total damage: 6.7 billion USD (1.6% GDP)

Long duration
Large amount
Broad coverage
Debris Flow Warning and Evacuation

During typhoon Morakot, the SWCB issued 21 debris flow warnings to local governments for evacuation activities based on real-time weather information.

<table>
<thead>
<tr>
<th>Debris flow warning</th>
<th>Warning ravines</th>
<th>County (City)</th>
<th>Town</th>
<th>Village</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Red alarm</strong></td>
<td>519</td>
<td>12</td>
<td>61</td>
<td>230</td>
</tr>
<tr>
<td><strong>Yellow alarm</strong></td>
<td>338</td>
<td>14</td>
<td>58</td>
<td>163</td>
</tr>
</tbody>
</table>

9,100 people were evacuated by local governments according to the warning. Among them, 1,046 people escaped from the possible casualties.
Deep-Seated Landslide in Hsiaolin Village

Landslide occurred at am 6:16, Aug 9, with $R=1676.5$ mm
Average slope: 22 degrees; Landslide area: 202 ha;
Depth: 82 meters; Volume: 25 million m$^3$
Dead and missing: 457 casualties
2. Comprehensive Plan of Large-scale (Deep-Seated) Landslide Hazard Mitigation

Risk Assessment of Potential Landslides

Multi-scale Monitoring Techniques
Comprehensive Plan of Large-scale Landslide Hazard Mitigation under Climate Change Impact
(2017-2020, Budget: 110 million USD)

Definition: Area 10 ha; Depth 10 meters; Volume 100,000 m³
Framework of Large-scale Landslide Hazard Mitigation

Where?
- Large-scale landslide potential areas
- Risk assessment
- Delineation of influence areas

How big?
- Adaptation
- Engineering
- Land use restrictions
- Residential Relocation
- Evacuation

Hardware
- 1. Prevent vulnerability factors
- 2. Drainage system
- 3. Diversion
- 4. Suppression works
- 5. Restrain works

Software
- Delimitation Announcement Restriction
- Location Coordination Relocation
- Planning Drill Promotion

Weights of evidence
- Multi-scale monitoring TCP-InSAR
- Surface displacement
- On-site detailed observation

Mechanism & event analysis
- Early warning system

When?
- Warning
  - Evacuation
  - Disaster Info.
Precursory Topographic Features of Rotational Landslide

Modified from Varnes, 1978
LiDAR: Light Detection And Ranging

Only ground points are selected to construct high resolution DEM

Frequency of laser pulse
50,000~200,000Hz
Soil and Water Conservation Bureau (SWCB)

1 m airborne Lidar DEM

Large-scale landslide potential area 45 ha
On-site Investigation of Landslide Features
Identification of Large-scale Landslide Potential Areas

- 153 large-scale landslides are selected from 3,763 sites surveyed by CGS, Forestry Bureau, and SWBC.

<table>
<thead>
<tr>
<th>Large Scale Landslide</th>
<th>Central Geological Survey</th>
<th>Forestry Bureau</th>
<th>SWCB</th>
<th>SUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysis Frame</td>
<td>571</td>
<td>763</td>
<td>251</td>
<td>1,482</td>
</tr>
<tr>
<td>Sites</td>
<td>1,125</td>
<td>2,523</td>
<td>125</td>
<td>3,763</td>
</tr>
<tr>
<td>Potential areas (km²)</td>
<td>413.86</td>
<td>789.30</td>
<td>49.62</td>
<td>1,178.01</td>
</tr>
</tbody>
</table>
Risk Assessment of 153 Large-scale Potential Landslide

Risk = Hazard × Vulnerability

Risk degree = Occurrence degree × Protected targets

**Occurrence Degree (Weights of evidence)**

- **8 Factors**: Aspect, Slope, Vegetation (NDVI), Rock mass strength, Dip, slope degree, Elevation, Distance of river, Distance of geological structure

**Protected Targets**

- Buildings
- Transportation facilities
- Important infrastructures
- Water storage range of reservoir

<table>
<thead>
<tr>
<th>Protected Targets</th>
<th>Risk Degree (153 sites)</th>
<th>Occurrence degree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>Mid</td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Mid</td>
<td>Low</td>
<td>Mid</td>
</tr>
<tr>
<td>High</td>
<td>Mid</td>
<td>High</td>
</tr>
</tbody>
</table>
Multi-scale Monitoring of Large-scale Potential Landslide Areas

Risk Degree

- **High Risk**
  - On-site Detailed Observation
  - Geophysical exploration
  - Geological survey
  - Geological boring
  - Ground water
  - Surface and Underground displacement

- **Middle Risk**
  - Surface Displacement Observation
  - Single frequency GPS
  - Extensometer
  - Rain gauge

- **Low Risk**
  - Long-term extensive Observation
  - TCP-InSAR Techniques
  - Extensive Observation
TCP InSAR for Large-scale Potential Landslide Monitoring

Temporarily Coherence Point (TCP) Interferometric Synthetic Aperture Radar (InSAR)

TCP InSAR technology has been proven very useful in assessing remotely ground displacements. It is a fast and economic approach to evaluate the activity of large-scale potential landslide.

**Advantages**

- **All-day, all-weather**
- **Wide range, spatial continuity**
- **High precision surface deformation without ground instruments**
Detection of Large Scale Potential Landslide in Chingjin Area, Central Taiwan
**D057 (Rotational Sliding)**

- **C**: Main scarp
- **D**: Extension crack

*Image Source: Cooper, R.G. (2007)*
Surface Displacement Monitoring System

6 single frequency GPS stations, 1 rain gauge, and 1 extensometer

Middle Risk
GPS Monitoring Example in Sulin, New Taipei City

The figures show a very good correlation between landslide displacement and heavy rainfall.

June 19 - July 19, 2016, torrential rain
Eastward: 70 mm, Downward: 40 mm

Sep. 25 - 28, 2016, typhoon Megi
Eastward: 20 mm, Downward: 15 mm
On-site Detailed Observation in Wanshan, Kaohsiung City

Geophysical exploration - Electrical Resistivity Survey
Comparing the resistivity profile with geo-drilling data for stratum cross section.
Different On-site Detailed Observation Techniques

- Geological Investigation
- Boring core
- Geological profile
## Deployment of On-site Monitoring Sensors

<table>
<thead>
<tr>
<th>Monitoring Items</th>
<th>Number Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Rainfall</td>
<td>1 point Every 5 minutes</td>
</tr>
<tr>
<td>2. Groundwater level</td>
<td>3 points Every 5 minutes</td>
</tr>
<tr>
<td>3. Surface tilt</td>
<td>3 points Every 5 minutes</td>
</tr>
<tr>
<td>4. TDR</td>
<td>1 point Every 5 minutes</td>
</tr>
<tr>
<td>5. CCD camera</td>
<td>2 points Every 1 minutes</td>
</tr>
<tr>
<td>6. Water inrush</td>
<td>1 point Every 5 minutes</td>
</tr>
<tr>
<td>7. Inclinometer</td>
<td>5 points, manual Every month</td>
</tr>
<tr>
<td>8. Surface displacement</td>
<td>10 points, manual Every month</td>
</tr>
</tbody>
</table>
3. Future Development and Conclusions
Influence Area of Large-Scale Landslide

Runout distance $L_{\text{max}}$ can be derived from equivalent friction coefficient

$$f = \log\left(\frac{H}{L_{\text{Max}}}\right) = 0.624 - 0.157 \log V$$

(Scheidegger, 1973)

$$V = 0.1025 \times A_L^{1.401}$$

(Shieh et al, 2015)

Deposit width $W_{\text{MAX}}$ is about 1.5-2 times than that of landslide width

$$W_{\text{MAX}} = 2W_L$$

(Shieh et al, 2015)
Soil and Water Conservation Bureau (SWCB)

Rainfall analysis of historic landslides events

- **New large-scale landslide**
  - Accumulated rainfall $\geq 1000$ mm
  - From accumulated rainfall FIG
    - Occurring times are near inflection point
  - From rainfall hydrograph
    - Landslides occurred after the peak

- **Enlargement or combination**
  - Accumulated rainfall $200$-$600$ mm
  - From accumulated rainfall FIG
    - Occurring times lie among the rising period
  - From rainfall hydrograph
    - Landslides occurred before or near the peak

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Application of Seismic Network on Landslide Detection

Broadband Array in Taiwan for Seismology, BATS

Ground vibrations generated by landslide can be detected by seismometer. We try to acquire the initiation time of large-scale landslide through BATS.

42 stations around Taiwan

Vibrations of Hsiaolin large-scale landslide
Conclusions

1. The prevention measures for debris flows disasters have been developed more than 15 years. The experiences could be the basis of developing a new mitigation strategy for large-scale landslide.

2. From the lessons of Hsiaolin village, the large-scale landslide has become a new challenge in the coming future of Taiwan which results in the brand new project-the comprehensive plan of large-scale landslide hazard mitigation under climate change impact. It might take another 10 years to fulfill all those tasks.

3. Different up-to-date techniques such as Lidar DEM, TCP InSAR, single frequency GPS system, traditional on-site detailed observation skills and BATS system should be integrated in order to mitigation the possible hazards of large scale landslides in the future.
Thank You for Your Attention

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