Landslide mapping, monitoring and early warning based on multi-source data

Case study of the Qingpo landslide (Wenchuan, China)

Weihua Zhao\textsuperscript{1*}, Mingli Xie\textsuperscript{1}, Nengpan Ju\textsuperscript{1}, Chaoyang He\textsuperscript{1}, Hongdong Huang\textsuperscript{2}, Qinghong Cui\textsuperscript{2}

\textsuperscript{1} State Key Laboratory of Geohazard Prevention and Geoenvironment Protection, Chengdu University of Technology, Chengdu, Sichuan 610059, China

\textsuperscript{2} Sichuan Western Sunny Electric Power Development CO. LTD
Discovery of the landslide

◆ On November 28 and December 4, 2018, deformation and tension cracks were discovered in the ground. The settlement of two pylon legs (A and B) was obvious, while the other two appeared stationary.

◆ Then the company reinforced the surface with concrete.

◆ After the treatment, the deformation did not stop completely, and the deformation was still developing until July 2019. Concrete and retaining walls also cracked with large cracks.
Discovery of the landslide

In July 2019, after commissioning a field investigation, it was found that:

- the pylon was deformed because it was located at the boundary of an active landslide (two legs inside the landslide and two legs outside).
- The active landslide is located within an old landslide.
1.2 Problems need to be answered

◆ What were the development characteristics and formation mechanism of the landslide, and what deformation stage was it in?

◆ During the rainy season (also the construction period of the new pylon), would the landslide experience large deformation or even failure?
1.3 Data and technical methods

**Historical data**
- Topographic map
- Geological map
- Rainfall data
- Previous research reports

**Field survey and monitoring data**
- Satellite optical imagery
- Satellite radar imagery
- In-situ investigation
- UAV aerial photography
- In-situ monitoring

**Geological background settings**
- Landform
- Lithology, attitude and geological structure
- Rainfall time, intensity
- Historical earthquake
- History of landslide

**Deformation history analysis**
- Visual interpretation of historical deformation
- Detect deformation by InSAR

**Present deformation situation analysis**
- Present deformation phenomena
- 3D view
- Real-time deformation

**A comprehensive analysis of the mechanism and evolution of the landslide**

Previous research reports
2 Geological background setting of the landslide

F1: Qingchuan–Wenmao Fault
2.2 In-situ and UAV investigation

A panoramic view of the landslide taken by UAV on July 20, 2019.
The main scarp and the left flank (facing the sliding direction) cracks have formed.

a) Cracks in the main scarp and left flank have formed but are not fully formed at the right flank boundary.
b) The landslide is characterized by two scarps, the upper scarp and the lower scarp.
c) The main scarp is approximately 2 m high at the small road (point α).
d) Tensile cracks at point β. I–I’ is the location of profile.
Deformation near the pylon: the pylon (with four legs A, B, C, and D) is located at the right flank boundary of the new landslide. The crack passes through the drainage channel (a), retaining wall, (b) and concrete floor. There is obvious deformation at the leading edge of the concrete (c and d).
2.2 In-situ and UAV investigation

◆ The landslide material is mainly silty soil containing crushed, among which the crushed stone is mainly composed of crushed.
◆ The slope often collapses, and the retaining wall is also destroyed.
◆ Frequent collapses often blocks traffic, threatening traffic and lives.

The national road G213 is located on the leading edge of the landslide, and is the only fast passage from Wenchuan to Maoxian.
3 Deformation history and real-time monitoring

The sketch map of landslide distribution along Minjiang river between Maowen and Wenchuan (Yan et al. 1998)

◆ There were 17 landslides along the Minjiang river. However, the site of the landslide is not mentioned in this paper, which means the landslide shows no obvious signs of deformation.

◆ A large number of small-scale collapses occurred in the vicinity of the study area, and only small collapses occurred in the landslide area studied, but the study slope still did not deform as a whole.

The remote sensing image of the study area on April 4, 2010 (two years after the Wenchuan earthquake, no clear remote sensing image was found in 2008-2009)
3.2 InSAR long-term deformation history

(1) InSAR result based on ALOS PALSAR data (2007-2011)

There’s no obvious change of interference fringe, that is, no obvious deformation in the landslide area from 2007 to 2011.

The Wenchuan earthquake did not cause significant deformation of the slope.
3.2 InSAR long-term deformation history

(2) InSAR result based on Sentinel-1A data (2014-2019)

The spatial deformation evolution law of the landslide shows that it gradually develops forward from the rear, and the deformation of the left side (facing the river) is greater than that of the right side.
3.2 InSAR long-term deformation history

The **temporal deformation** of the landslide can be divided into four sections.

1) From October 2014 to May 2016, the landslide began to deform, and the deformation value was small.
2) From May 2016 to around July 2017, the deformation rate of the landslide began to accelerate, but the deformation value and acceleration were still relatively small.
3) From July 2017 to July 2018, the landslide deformed rapidly. During this period, displacement increased at a relatively fast rate.
4) From July 2018 to October 2019, the deformation value was still increasing, but the rate of increase slowed.
3.3 In-situ real-time monitoring

Monitoring began on July 22, 2019 and lasted until August 26, 2019, when the pylon was relocated.

- During the monitoring period, the landslide continued deforming, but the deformation rate was not high (the monitoring curves increased slowly).
- The deformation and dip change of the four legs are small, but are affected by the landslide deformation during August 19 and 20.
4 Discussion on landslide evolution and multi-source data

4.1 Comprehensive analysis of landslide deformation mechanism and evolution process

(1) Deformation mode of the active landslide

◆ According to the long-term InSAR deformation analysis, from October 2014 to October 2019 the landslide continued to creep over a period of 5 years.
◆ The landslide also gradually expanded from the rear edge to the front edge.
◆ Combining deformation evolution history with historical rainfall data, the landslide deformation is considered sensitive to rainfall.
(2) Temporal deformation evolution

- The long-term monitoring curve revealed that the landslide began to deform in 2014, however, the rate decreased after July 18 and remained relatively constant.
- The real-time monitoring curves from July 2019 to August 2019 also showed that the deformation at the cracks were at a constant rate.


### Table: Warning parameters

<table>
<thead>
<tr>
<th>Warning parameters</th>
<th>Rate Increment ($\Delta v$)</th>
<th>$\Delta v \approx 0$</th>
<th>$\Delta v &gt; 0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tangential angle ($\alpha$)</td>
<td>--</td>
<td>$\alpha = 45$</td>
<td>$\alpha &gt; 45$</td>
</tr>
<tr>
<td>$\alpha \geq 80$</td>
<td>$\alpha \geq 85$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Chart:

- $T - t$ curve converted from the $S - t$ curve.
- The chart shows the relationship between time ($t$) and displacement ($S$), with $\alpha$ representing the tangential angle.

Although the landslide has undergone a deformation history of up to five years, the boundary crack system of the landslide has not yet been fully formed and is still in the stage of constant deformation.
4 Discussion on landslide evolution and multi-source data

4.2 Comparison of InSAR and Real-time monitoring

- It is noted that the total deformation value of the InSAR monitoring curve is less than 200 mm from 2014 to 2019, while the real-time monitoring of the crack meters exceeded 150 mm in a month.

- One of the limitations of InSAR is that it is only capable of measuring a 3D projection of a real deformation vectors on the radar LOS; therefore, it is not possible to retrieve the full displacement vector. InSAR data are more applicable to judge the evolution trend rather than the accurate displacement of landslides.
Conclusion

The temporal and spatial evolution characteristics of the landslide were comprehensively analyzed through on-site deformation investigation, long-term deformation monitoring by InSAR, and ground-based real-time monitoring.

◆ The deformation and failure mode of the landslide is that of a creep landslide. Although the landslide has undergone a five-year deformation history, it is still in the stage of constant deformation.

◆ To realize real-time and effective early warning, ground-based real-time monitoring methods are more applicable and accurate on the premise of understanding the evolution mechanism of landslide and spatial distribution of cracks.

◆ Furthermore, it should be noted that the landslide is sensitive to rainfall. Therefore, as the landslide is still deforming it remains a great threat to the national road at its leading edge.

Continuous monitoring based on multi-source remote sensing is still under way.