MULTIDISCIPLINARY STUDIES OF THE PUIGCERCÓS HISTORICAL LANDSLIDE IN THE CATALAN PYRENEES

GIORGİ KHAZARADZE¹, MARTA GUINAU¹, XABIER BLANCH¹, ANTONIO ABELLÁN²³, MAR TAPIA¹, GLÒRIA FURDAĐA¹, EMMA SURIÑACH¹⁴

¹ Grup RISKNAT, Institut Geomodels, University of Barcelona, Faculty of Earth Sciences, Department of Earth and Ocean Dynamics, Barcelona, Spain
² Institute of Applied Geosciences, School of Earth and Environment, University of Leeds, Leeds, UK
³ Centre de recherche sur l’environnement alpin (CREALP), Sion, Switzerland
⁴ Laboratori d’Estudis Geofísics Eduard Fontserè, Institut d’Estudis Catalans, Barcelona, Spain

* Corresponding author: gkhazar@ub.edu
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Session: NH3.8
Landslide investigation using Remote Sensing and Geophysics
Co-organized by ESSI1/GI6/GM4
Convener: Antonio Abellan
Co-conveners: Janusz Wasowski, Masahiro Chigira, Oriol Monserrat, Jan Burjanek

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ABSTRACT

More than a century ago, the Puigcercós village located in the region of Pallars Jussà (Catalonia, Spain), suffered a large-scale landslide that occurred on January 13th, 1881. More than 5 million m$^3$ of sediments and rocks were displaced and a 200 m long and 25 m high rock scarp was formed. Luckily, during the main event, the nearby village was not affected, and due to a prompt evacuation and relocation of the entire village, no casualties were reported. Nevertheless, consequent retreat of the main scarp did destroy the big part of the old village, which confirmed not only the necessity for its relocation, but also gave one of the first clearly described and confirmed examples of a successful geologic risk prevention.

During the last decade, the members of the RISKNAT-UB group have chosen this site to conduct pilot studies of rockfalls and landslides using a multidisciplinary approach. The utilized observational techniques include Terrestrial Laser Scanner (TLS), photogrammetry, GPS, seismic monitoring and geophysical prospecting techniques. The work presented here is an overview of these activities, including the main milestones of the ongoing research. Special emphasis will be given to the use of geodetic techniques for investigating changes on the depositional area of the landslide and around the crown cracks at the upper level of the main scarp. As a result of the GPS observations, for the first time, 130 years after the occurrence of the event, it was possible to observe a continuing geomorphological activity of the depositional zone of this historical landslide.

Currently, the RISKNAT-UB group operates cost-effective, high-resolution and low-cost photogrammetric instruments and seismic continuous records at the site, in order to monitor the evolution of the Puigcercós rock scarp. The correlation of the seismic and the photogrammetric data and intermittently obtained LiDAR images enables us to monitor and characterize frequent rockfalls and premonitory deformations occurring at the site. These observations have allowed quantifying the rate of retreat of the rock scarp at a rate of 10 to 11 cm/yr and a slow motion of the depositional zone up to 6 mm/yr. Since the geologic risk at the study area is not significant, due to the absence of population and/or infrastructures, this site is an ideal natural laboratory for developing new observational techniques, which can be used to develop early warning systems for rockfalls and landslides.
GEOGRAPHIC LOCATION

Puigcercós

Catalonia

Spain
REGIONAL GEOLOGIC CONTEXT

Figure from: Gómez-Gras et al. Cretaceous Research v. 57 (2016)

LOCAL GEOLOGIC CONTEXT

- Punts GPS
- Punts TS i GPS
- Punts estaques
- Peu de lòbul
- Talús d’esbaldregalls
- Dipòsit de moviment de massa
- Dipòsits col·luvials
- Acumulacions
- Fractures
- Escarpament fluvial
- Escarpament principal
- Escarpament secundari
- Badlands
- Reompliment lacustre
- Actual llit del riu
- Camps de cultiu
- **Eocè**
  - Calcàries amb alveolines
  - Margues del Ilerdà
- **Paleocè**
  - **Fàcies Garumnià**
  - Sediments de coloració groguenca
  - Sediments de coloració vermellosa
  - Guix secundari
Figure from: Royán et al., Landslides, V. 11-4, 2014.
A BIT OF HISTORY

941 - First reference to the castro Poga Circuso
1012 - Donation of the castle by Ramon Berenguer IV
1365 - Scripture that seems to indicate a different location of the town at this time.
1373 - Earthquake of the Ribagorza
1848 - Emergence of cracks in the SW slope
1857 - First collapse in a period of severe drought
1881 - Second sinking, during a day of great rainfall
1889 - Third movement, during an episode of precipitations
1881 LANDSLIDE

Figure from: Corsini, 1881.
CURRENT STUDIES BY THE UB GROUP

Investigations are led by the RISKNAT (http://www.ub.edu/risknat) group of the UB, currently under the framework of the PROMONTEC project (CGL2017-84720-R) led by E. Suriñach and G. Furdada.

Since 2007 we use the site as natural laboratory to develop and test new methodologies for studying landslides and rock-falls.

The techniques that we use include:

• Terrestrial Lidar
• Time-lapse photography
• Seismic monitoring
• Geodetic monitoring
GEODETIC MONITORING: METHODOLOGY

- **GPS** to monitor the stability
- **Total Station** to monitor the cracks and stability
- **Tape meter measurements** to monitor cracks
CROWN CRACK MONITORING

- Punts TS i GPS
- Punts estaques
- Fractures
- Escarpament principal
- Talús d’esbaldregalls

Calcàries amb alveolines
Margues del Llerdià

Multidisciplinary studies of the Puigcerdà historical landslide in the Catalan Pyrenees
Giorgi Khazaradze, Marta Guinou, Xabier Blanch, Antonio Abellán, Mar Tapia, Gloria Furdada, and Emilia Suriñach
CROWN CRACK MONITORING

Steel bar points
TS & GPS points
Cracks
Main scarp
RTK points
CROWN CRACK MONITORING: GROUP 1

Extension of 2.7 to 2.1 mm/yr

2.7 +/- 0.2 mm/yr

0.2 +/- 0.1 mm/yr

2.1 +/- 0.1 mm/yr
CROWN CRACK MONITORING: GROUP 2

Extension of 4.7 to 2.5 mm/yr
CROWN CRACK MONITORING: GROUP 3

Extension of 4.7 to 5.4 mm/yr
Extension of 4.4 to 3.8 mm/yr (inner crack) and Compression of -3.0 to -2.8 mm/yr (outer crack)
CROWN CRACK MONITORING: GROUP 5

Compression of -3.2 to -3.5 mm/yr
In July 2015, a network of 11 geodetic points were established: 9 points in the part of the depositional area (PGC1-9) and 2 points on the interior side of the top (PGB-1-2).
6 of these points (PGC4 to PGC9) are 5/8 inch nuts cemented into the rock.

3 points are nails anchored in the rock.

GPS MONITORING
DEPOSITIONAL AREA (PGC1-9)
GPS DATA ANALYSIS

Software: GAMIT/GLOBK from MIT

Strategy: Network mode

CGPS Stations Analyzed: AVEL BELL
CSOS ESCO GRAU LLIV SONA
SORG TLSE YEBE

Reference Frame: ITRF2014 and later fixed station PGC1
<table>
<thead>
<tr>
<th>#</th>
<th>Name</th>
<th>Longitude</th>
<th>Latitude</th>
<th># Obs. Days</th>
<th>Duration years</th>
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<tbody>
<tr>
<td>1</td>
<td>AVEL</td>
<td>0.7505</td>
<td>41.8816</td>
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<tr>
<td>2</td>
<td>BELL</td>
<td>1.4011</td>
<td>41.5996</td>
<td>2183</td>
<td>6.0</td>
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<tr>
<td>3</td>
<td>CSOS</td>
<td>0.4856</td>
<td>42.5119</td>
<td>2142</td>
<td>6.0</td>
</tr>
<tr>
<td>4</td>
<td>ESCO</td>
<td>0.9757</td>
<td>42.6936</td>
<td>2097</td>
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<tr>
<td>5</td>
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<td>0.3407</td>
<td>42.1915</td>
<td>2019</td>
<td>6.0</td>
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<tr>
<td>6</td>
<td>LLIV</td>
<td>1.9731</td>
<td>42.4781</td>
<td>2182</td>
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<tr>
<td>7</td>
<td>SONA</td>
<td>1.5168</td>
<td>41.9922</td>
<td>2167</td>
<td>6.0</td>
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<tr>
<td>8</td>
<td>SORG</td>
<td>1.1328</td>
<td>42.3745</td>
<td>2178</td>
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<td>9</td>
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<td>1.4809</td>
<td>43.5607</td>
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<td>40.5249</td>
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<tr>
<td>1</td>
<td>PGB1</td>
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<td>42.1301</td>
<td>8</td>
<td>4.0</td>
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<tr>
<td>2</td>
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<td>42.1299</td>
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<td>4.0</td>
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<tr>
<td>3</td>
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<td>42.1312</td>
<td>16</td>
<td>4.6</td>
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<tr>
<td>4</td>
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<tr>
<td>8</td>
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<td>0.8817</td>
<td>42.1300</td>
<td>8</td>
<td>2.9</td>
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GPS TIME-SERIES

CGPS: GRAU located in Graus, Aragon (http://gnss.aragon.es)

\[ \nu_n = 0.09 \pm 0.01 \text{ mm/yr} \]
\[ \text{WRMS} = 0.9 \text{ mm}; \text{NRMS} = 0.47 \]

CGPS: YEBE located in Yebe, Guadalajara, Castilla La Mancha (http://ign.es)

\[ \nu_n = -0.30 \pm 0.01 \text{ mm/yr} \]
\[ \text{WRMS} = 0.5 \text{ mm}; \text{NRMS} = 0.38 \]

SGPS: depositional area

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Multidisciplinary studies of the Pulgarcós landslide in the Catalan Pyrenees
Giorgi Khazaradze, Marta Guinau, Xavier Barcín, Antonio Abellan, Mar Tejeda, Gloria Furdada, and Emma Suriñach
Pulgarcós landslide, Catalonia, Spain
GPS VELOCITIES:
CONTINUOUS GPS (CGPS)
REFERENCE SITES
GPS VELOCITIES

Eurasia fixed reference frame
DISCUSSION: CRACKS AT THE CROWN

<p>| | | |</p>
<table>
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<tr>
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<th></th>
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<tbody>
<tr>
<td>PG41-43</td>
<td>-2.5+/- 0.4 mm/yr</td>
<td></td>
</tr>
<tr>
<td>PG43-42</td>
<td>-2.8+/- 0.3 mm/yr</td>
<td></td>
</tr>
<tr>
<td>PG41-42</td>
<td>0.5+/- 0.2 mm/yr</td>
<td></td>
</tr>
<tr>
<td>PG41-44</td>
<td>3.6+/- 0.3 mm/yr</td>
<td></td>
</tr>
<tr>
<td>PG42-44</td>
<td>4.3+/- 0.3 mm/yr</td>
<td></td>
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</tbody>
</table>
DISCUSSION: CRACKS AT THE CROWN

Schematic deformation of the Group 4 at the crown of the landslide
DISCUSSION: CRACKS AT THE CROWN

Schematic deformation of the Group 4 at the crown of the landslide
DISCUSSION: CRACKS AT THE CROWN

Simplified model of the behaviour of the crown cracks. Nail symbols indicate a stable (or fixed) points.

A) Map view; B) Cross-section.
DISCUSSION: DEPOSITIONAL ZONE
Detection and spatial prediction of rockfalls by means of terrestrial laser scanner monitoring

Antonio Abellán 1,2,*, Jaume Calvet 1,2, Joan Manuel Vilaplana 1,2, Julien Blanchard 1,2

1 INFORM Group, Departament de Geodèsia i Cartografia, Facultat de Llengua Catalana, Universitat de Barcelona, C/Gran Via de les Corts Catalanes, 585, 08007 Barcelona, Spain
2 CHUAS (CREA e Ingeniería de construcciones y Arquitectura, IRIT, Université de Toulouse, 31031 Toulouse, France)

*Corresponding author. Email: abellanz@ub.edu

Detection of rockfalls and spatial prediction of rockslides using terrestrial laser scanner monitoring...
TERRESTRIAL LIDAR

Original Paper

Manuel Jesús Royán · Antonio Abellán · Michel Jaboyedoff · Joan Manuel Vilaplana · Jaume Calvet

Spatio-temporal analysis of rockfall pre-failure deformation using Terrestrial LiDAR

Jugercos landslide, Catalonia, Spain
TIME-LAPSE PHOTOGRAMMETRY
RasPI and HRCam Photogrammetry Systems

Puigcercós landslide, Catalonia, Spain
RasPi System: Hardware

- Non-commercial solution
- Based on Raspberry system
- Camera Module V2
- WittyPi RTC shield
- Low-cost configuration
- Sufficient image quality

RasPI: setup

Puigcerdà landslide, Catalonia, Spain
RasPi System: Setup scheme
RasPi System: Methodology – 3 STEPS

- **Increase** 3D model quality – Image **redundancy** – Iterative process with **different** approximate solutions

15 simultaneous photos from each camera

15 Points Clouds (Agisoft Metashape)

1 Dense Point Cloud
RasPi System: examples

- 5 Photogrammetric modules
  Raspberry Pi 3B
  Camera RasPi v2 (8mpx)
  WittyPi 2

- 60/80 meters (RasPi – Cliff)
RasPi System: results

- **Rockfall monitoring** and magnitude - frequency analysis

- **Prefailure deformation** analysis (study of the accelerations)

**Cost-effective system**

- **High temporal rate**

- **Real-time**: data transfer and remote processing

Time-lapse photogrammetry: HRCam

Quintero-Montaño, E. M. (2019). Análisis de límites de detección y cálculo de volumen de desprendimientos en escarpes rocosos mediante datos LiDAR y fotogramétricos
Especialidad: Riesgos Geológicos. Universitat de Barcelona.

TFM dirigido por Blanch, X., & Guinau, M. (UB)
HRCam System: examples

- 3 Photogrammetric modules
  Sony A7r II – FF: 42 Mpx
  Lens: 35mm - f7.1

- 2 Photogrammetric modules
  Canon EOS 77D - APSC: 24Mpx
  Lens: 24mm (38 eq) - f7.1

- 100/120 meters (HRCam – Cliff)
## HRCam photogrammetry: Methodology

<table>
<thead>
<tr>
<th>Instrumento</th>
<th>Año: 2018</th>
<th>Año: 2019</th>
<th>Ventana temporal</th>
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<tr>
<td></td>
<td>Fecha</td>
<td>Datos</td>
<td>Fecha</td>
</tr>
<tr>
<td>LiDAR</td>
<td>17 de Mayo</td>
<td>2 escaneos</td>
<td>05 de Febrero</td>
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<tr>
<td>Nikon</td>
<td>05 de Marzo</td>
<td>7 fotografías</td>
<td>05 de Febrero</td>
</tr>
<tr>
<td>Sony</td>
<td>26 de Octubre</td>
<td>7 fotografías</td>
<td>05 de Febrero</td>
</tr>
</tbody>
</table>

Posiciones de los instrumentos de adquisición de datos.
SEISMIC MONITORING

Puigcerdà landslide, Catalonia, Spain
Main objective:

To identify and characterize rock falls:

- FIRST PHASE HELPED BY PHOTOGRAPHS
- SECOND PHASE FOR INDEPENDENT MONITORING
SEISMIC MONITORING

Estació sísmica
Caseta càmera

42.1296, 0.8825

Image © 2015 Institut Cartogràfic de Catalunya

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SEISMIC MONITORING

1) Rock-fall identification using photographs. Time intervals. (Time resolution: some hours)

2) Rock-fall identification in the seismic signal. (Time resolution: exact time)

3) Rock-fall seismic characterization

Rock 1
Aug 30, 2017 17:28
Aug 31, 2017 09:28

Rock 2

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CONCLUSIONS 1

• The Puigcercós landslide continues to be **active**
• Apart from the frequent rockfalls at the scarp, the **cracks** at the crown of the scarp are **deforming**, showing an interesting pattern of simultaneous compression and extension, reaching half a cm/year.
• The body of the century old landslide is also **active**, although its deformation rates are slow. We hypothesize that the westerly motion of the lower group of the GPS sites are due to shallow creep, driven by gravitational forces.
The correlation of the seismic and the photogrammetric data and intermittently obtained LiDAR images enables us to monitor and characterize frequent rockfalls and premonitory deformations occurring at the site.

These observations have allowed quantifying the rate of retreat of the rock scarp (10 to 11 cm/yr) and a slow motion of the depositional zone up to 5 mm/yr.

Since the geologic risk at the study area is not significant, due to the absence of population and/or infrastructures, this site is an ideal natural laboratory for developing new observational techniques, which can be used to develop early warning systems for rockfalls and landslides.
ACKNOWLEDGMENTS

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We are also thankful to UNESCO Global Geopark Conca de Tremp-Montsec for their support.
THANKS TO ALL