RECONSTRUCTING LANDSLIDE DYNAMICS AND CHARACTERISTICS USING REMOTE SENSING DATA (PHOTOGRAMMETRY, LIDAR AND SEISMIC DATA): COMPARISON BETWEEN DIFFERENT TECHNIQUES AND COMPLEMENTARY DATA ANALYSIS

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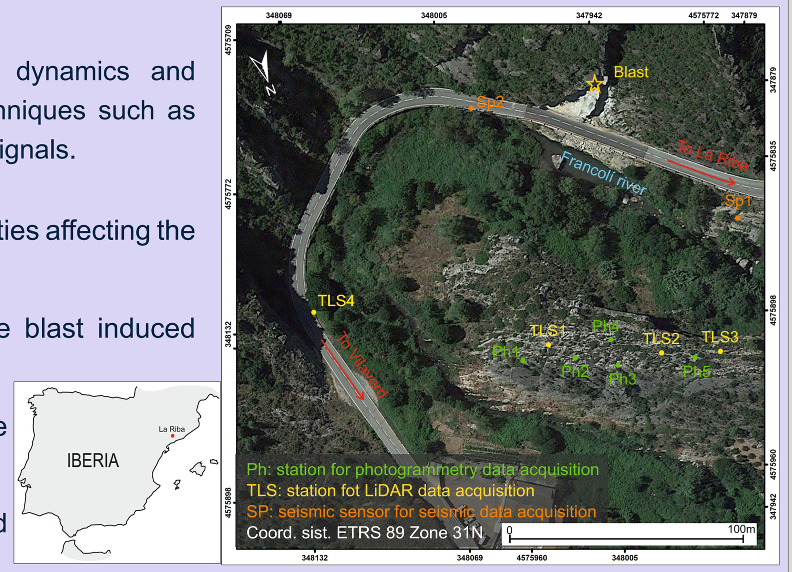
INTRODUCTION

The study was developed in a hillslope between La Riba and Vilaverd, Catalonia, Spain (road C-240z). In this area, different controlled blasts were carried out to stabilize the slope after a natural rockslide. Back-analysis and characterization of blast induced rockfalls using photogrammetry, terrestrial LiDAR data and seismic data allows us to better understand their behaviour.

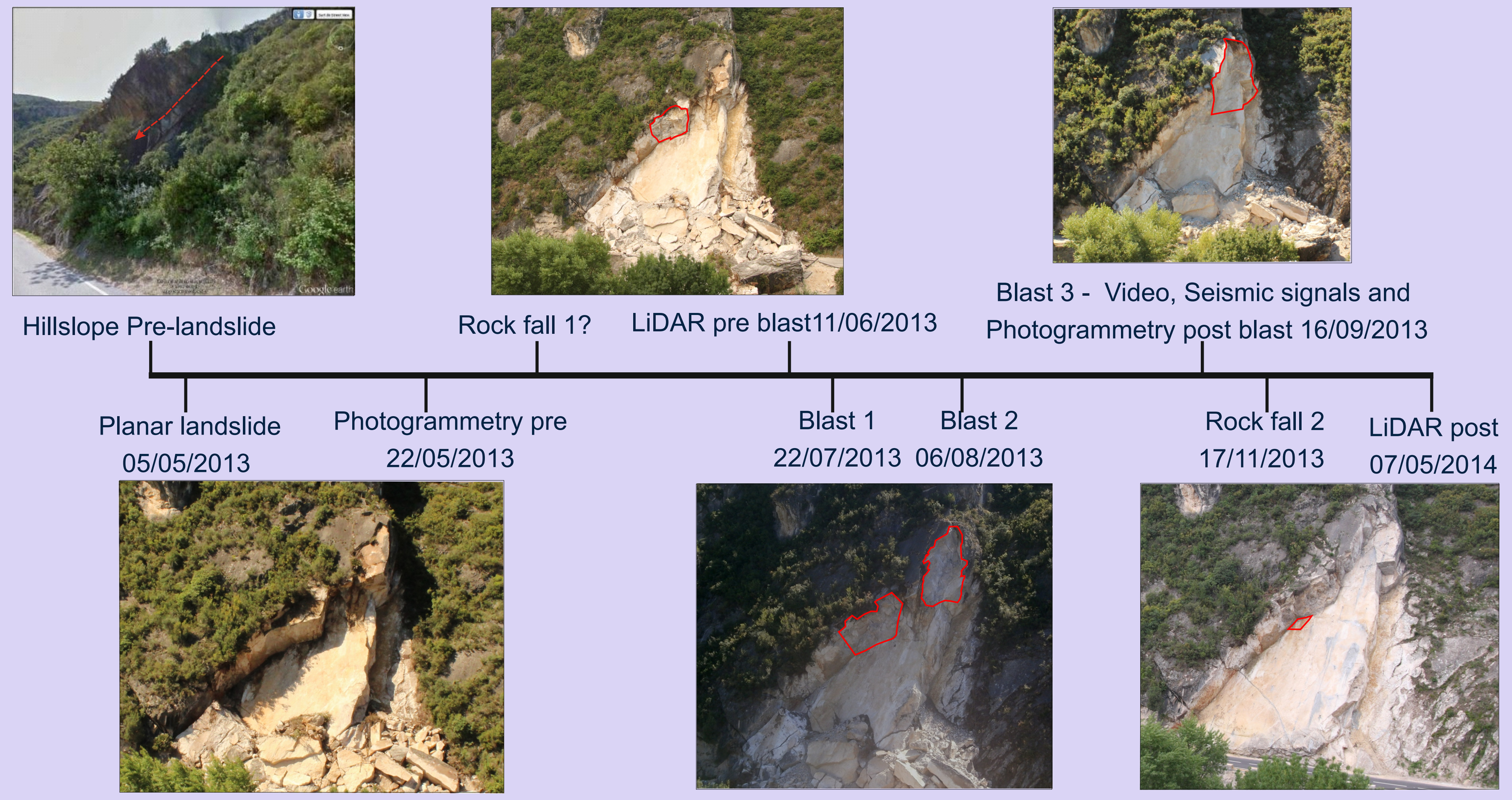
Materials affected by the rockslide are Upper Muschelkalk dolomites with pronounced bedding and different discontinuity sets.

Objectives

- Reconstruction of the blast induced rockfall dynamics and characteristics using different remote sensing techniques such as photogrammetry, LiDAR, video images and seismic signals.
- Detection and characterization of the discontinuities affecting the rock slope stability.
- Characterization of the volume involved in the blast induced rockfall.
- Seismic characterization from the analysis of the generated seismic waves.
- Determination of the advantages, limitations and complementarity of the different techniques.



DATA ACQUISITION



LIDAR:

Equipment: Terrestrial Laser Scan (Ilris 3D, Optech Inc.), GPS TopCon - with GB-1000 controller and PG-A1 antenna. Calibrated digital camera (CANON 40D).

Pre-blast data: 3 scans from 2 stations.

Post-blast data: 5 scans from 4 stations.

Photogrammetry:

Equipment: Digital Camera - CANON EOS 600D. GPS TopCon - with GB-1000 controller and PG-A1 antena.

Data: Photographs pre- and post-blast taken at 5 stations.

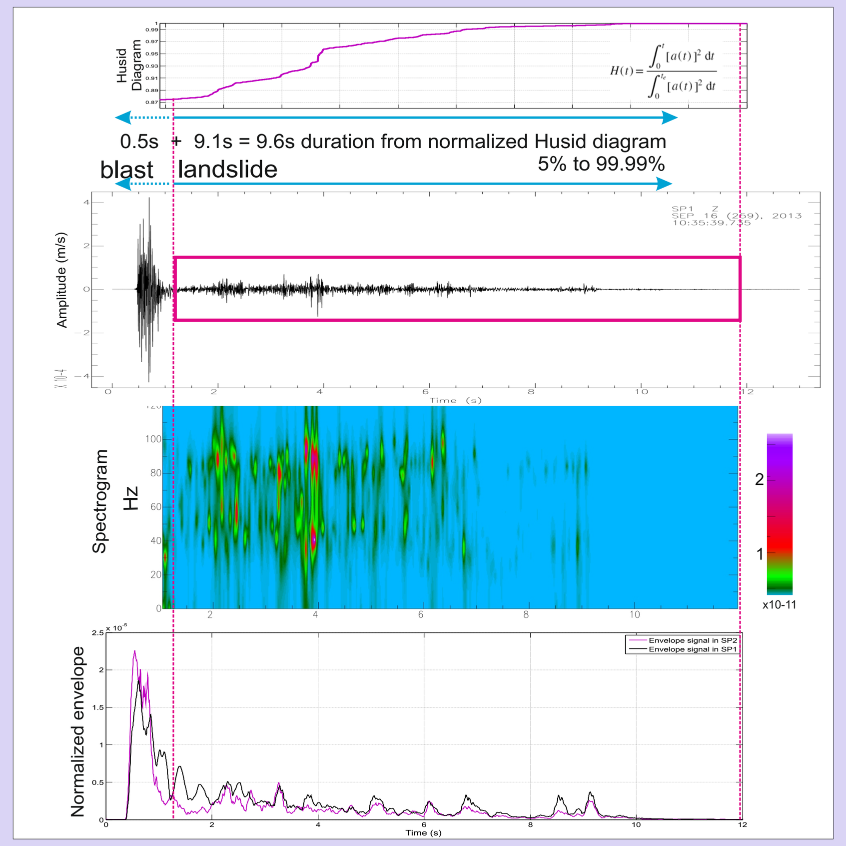
Seismic data:

Equipment: Seismic acquisition system Spidernano (Worldsensing) 24bits three channels, sampling 250 sps, continuous acquisition; GPS antenna; Seismic sensor Miniseismonitor (Geospace) 2.0 Hz tri-axial.

Video Images:

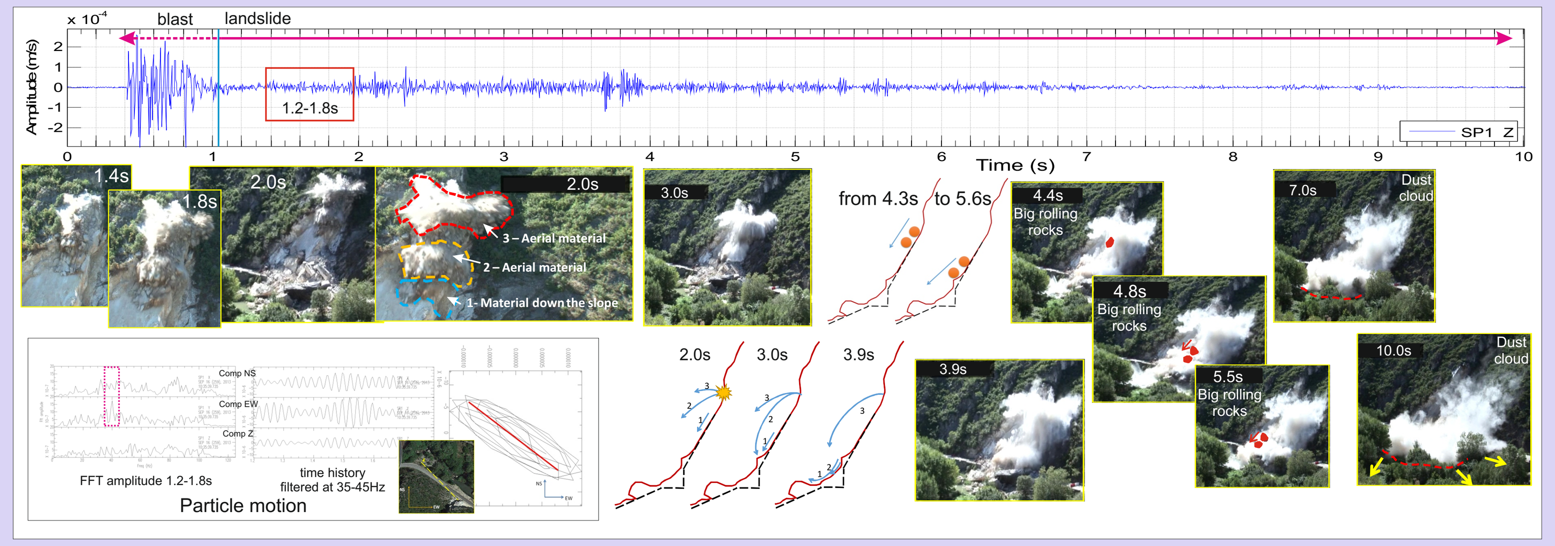
Equipment: 2 professional video cameras HD

SEISMIC SIGNALS



Two stations were installed near the blast. Station Sp1 was installed in bedrock, **81 m** from the landslide and station Sp2 in the road at a distance of **53 m**. The normalized envelope shows consistency between the observations at the two stations, once a lag time of 0.02 s was corrected. Lag time and amplitude amplification in Sp2 are observed owing to the difference in the distance landslide-seismic stations (28 m) and the different geological basement. Husid diagram shows a landslide time duration about **9.1s**. **[Left box].**

The video recordings together with the seismic signals allow us to identify different instants in the landslide and provide information about their dynamics. Note the different amplitude and frequency content of each part of the landslide. Different parts of the landslide could be identified: 1) small materials falling down the slope, 2) some individual rock impacts and 3) large rocks rolling down the slope. Signals are filtered according to the frequency content of each phenomenon. Particle motions are consistent with the directionality of the different parts of the landslide. **[Bottom box]**

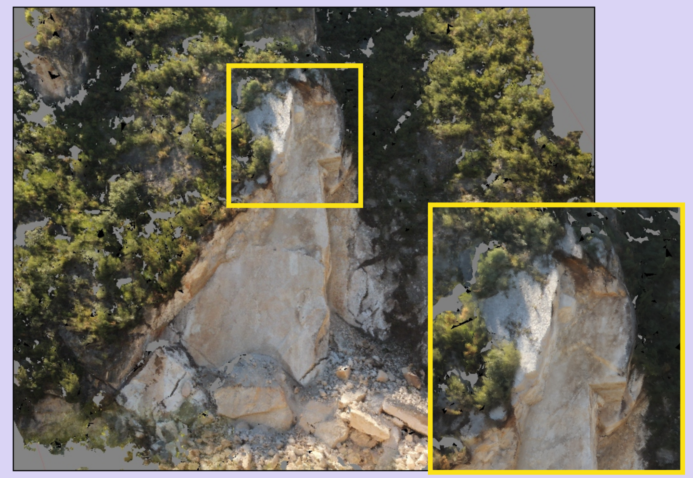


PRE AND POST BLAST MODELS

Photogrammetry models - Agisoft Photoscan (www.agisoft.com)

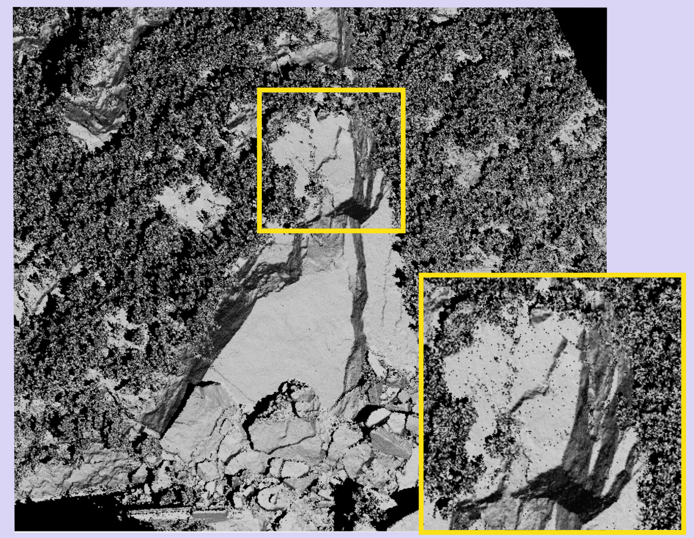
Pre-blast model
5 photos; 250.000 points and 1 point each 7

Post-blast model
5 photos; 260.000 points and 1 point each 7 cm.

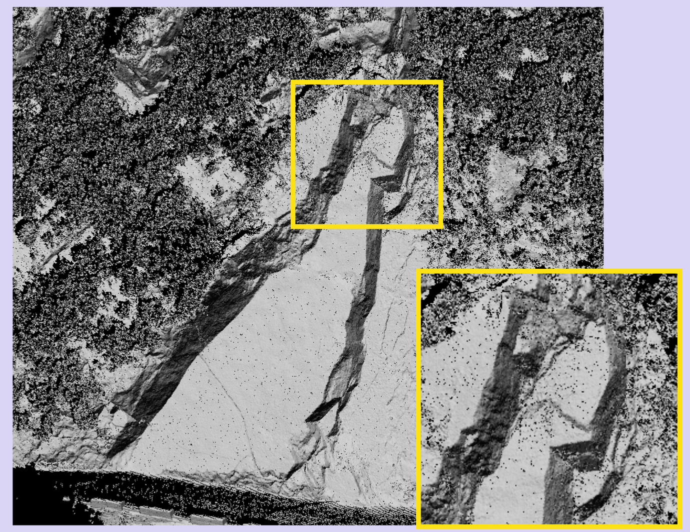


LiDAR models - Polyworks (www.innovmetric.com)

Pre-blast model
3 scans at 2 positions
435.000 points and 1 point each 5 cm.



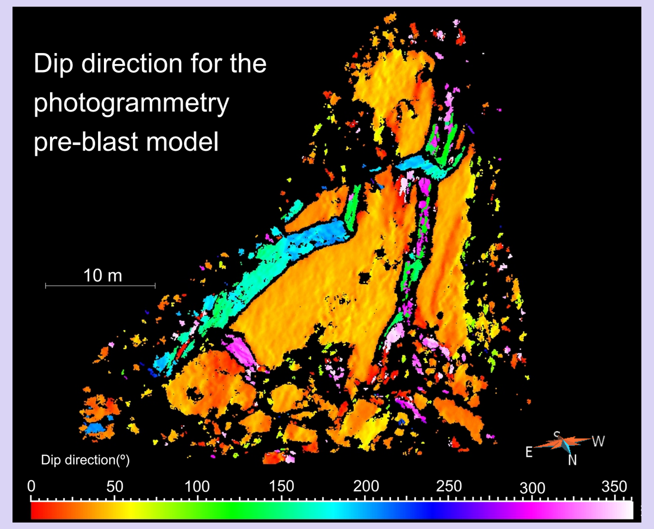
Post-blast model
5 scans at 4 positions
560.000 points and 1 point each 5 cm.

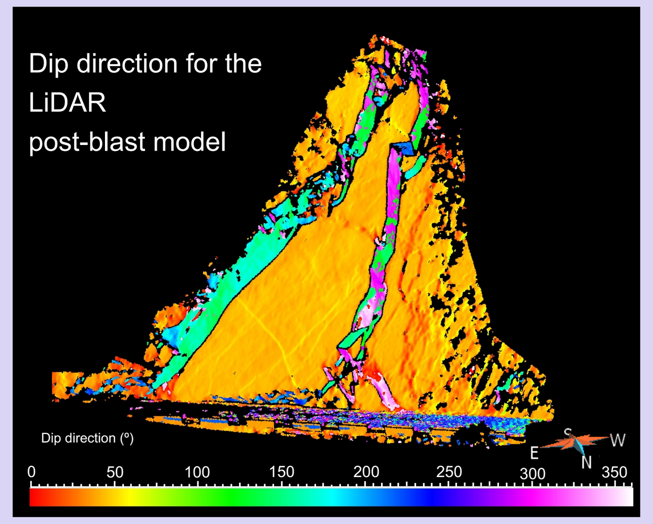


DISCONTINUITIES CHARACTERIZATION

Planar regression - SELF tool (GEOMODELS-UB software, Garcia-Sellés et al. 2011)

For each point of the point clouds obtained with LiDAR and photogrammetry, the Normal Vector of the plane containing the point was calculated by planar regression. Parameters that define the plane adjustment are M co-planarity and K co-liniarity. Values used: Search radius= 0.1-0.25 m; K > 3.25; M < 1.2



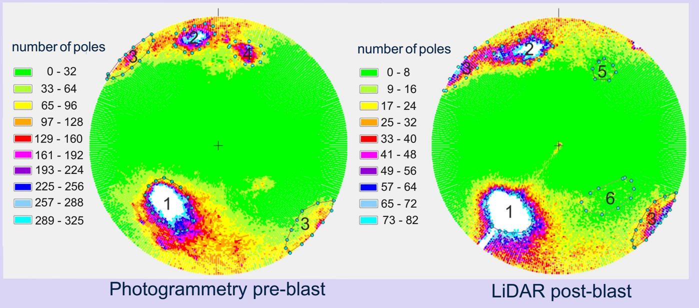


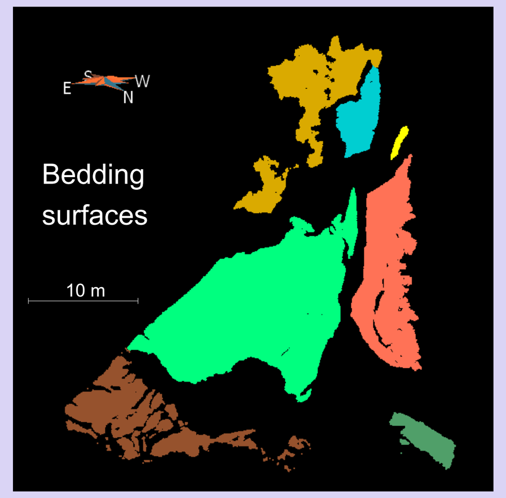
Filtering tool

Isolated points not belonging to discontinuity surfaces were eliminated.

Attributes classification tool

All the points of each model were represented in a stereographic projection according to the dip and dip direction. This representation allows establishing a user defined cut off for each discontinuity family.



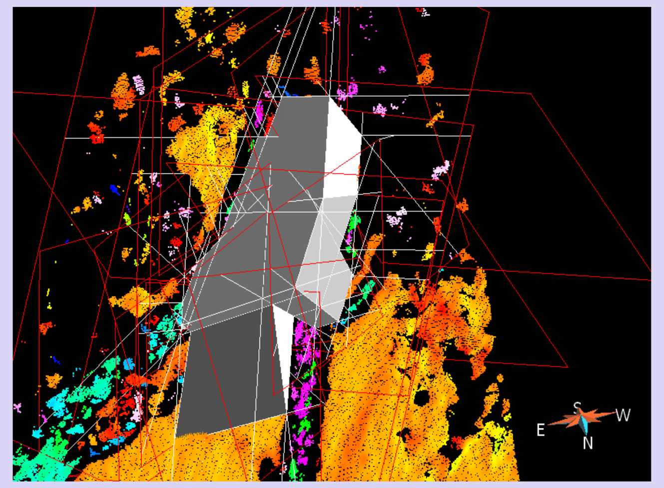


Clustering tool

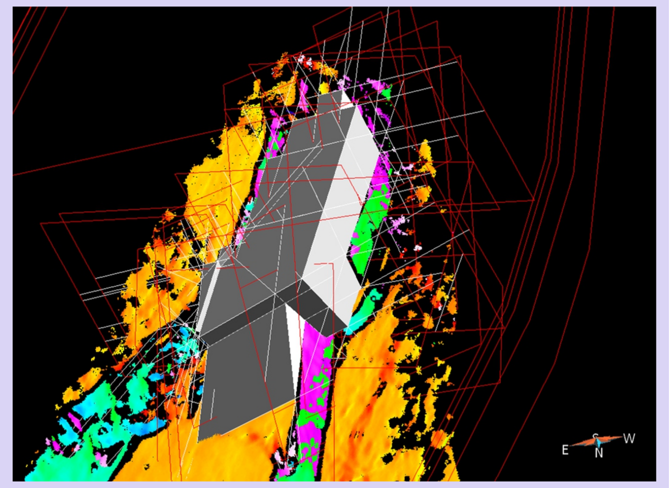
This tool individualizes sets of points belonging to the same discontinuity.

VOLUMES OBTAINED FROM SURFACES

From each cluster a simplified (flat) surface was constructed using GOCAD software (Paradigm – www.pdgm.com). The blasted volume can be delimited and calculated by combining the surfaces obtained from the pre and post models.



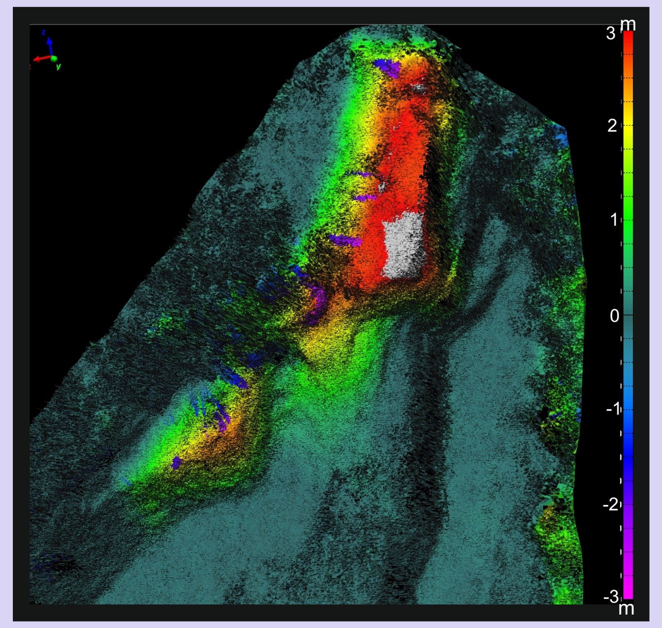
Photogrammetry



LiDAR

VOLUMES OBTAINED BY COMPARING MODELS

A TIN (Triangulated Irregular Network) was built from each model (pre and post blast) by PolyWorks software (InnovMetric – www.innovmetric.com). Moreover, a flat surface parallel to the slope (reference plane) was constructed. The volume between pre and post TIN and the reference plane were obtained using the Surface to Plane tool of PolyWorks. The volume involved in the blast was calculated from the difference between the two previous volumes.



VOLUMES OBTAINED

The difference between the data acquired (photogrammetry or LiDAR data) shows that in both cases (obtained from surfaces and by comparing models), the LiDAR models have larger volumes than those of photogrammetry (between 10 and 12%).

The difference between the methodologies used (GOCAD or PolyWorks) shows that the difference in volume 4 is less than 10% in the two sets of acquired data.

The larger difference in Volume 2 is due to the fact that it is not possible to limit simplified surfaces owing to the difference of the models pre-photogrammetry and pre-LiDAR.

Volumes

		Gocad		PolyWorks	
		Photogrammetry (m^3)	LiDAR (m^3)	Photogrammetry (m^3)	LiDAR (m^3)
Volume 1	Rock fall 1 (?)	-	-	19.62	
Volume 2	Blast 1 (22/06/2013)	16.43	18.71	27.35	30.48
Volume 3	Blast 2 (06/08/2013)	75.15	85.31	-	-
Volume 4	Blast 2 + 3 (06/08/2013 – 15/09/2013)	196.01	220.69	183.11	206.67
Volume 4 – Volume 3	Blast 3 (15/09/2013)	120.86	135.38	-	-

Comparison

		Photogrammetry vs LiDAR		Gocad vs PolyWorks	
		Gocad (%)	PolyWorks (%)	Photogrammetry (%)	LiDAR (%)
Volume 2	Blast 1 (22/06/2013)	12.19	10.27	39.93	38.62
Volume 3	Blast 2 (06/08/2013)	11.91	-	-	-
Volume 4	Blast 2 + 3 (06/08/2013 – 15/09/2013)	11.18	11.40	-7.04	-6.78
Volume 4 – Volume 3	Blast 3 (15/09/2013)	10.73	-	-	-

CONCLUSIONS

- Discontinuity characterization is faster with photogrammetric data due to the reduced number of points compared with LiDAR data.
- LiDAR data models are more accurate than photogrammetric ones: some surfaces are detected only with LiDAR data because of the presence of shaded zones in the photographs used in photogrammetry.
- Both techniques and methodologies for calculating volume yield similar results (approximately 10% difference).
- Seismic analysis allows us to determine the duration and the different stages of the phenomenon and their characteristics.
- Complementarity of the different techniques has proved to be useful.
- To use both techniques, discontinuities must have a surface expression and the area of vegetation must be limited.
- Owing to their resolution, remote techniques are an excellent tool to obtain data and to reduce the exposure of technicians in unstable or inaccessible areas.

REFERENCES AND ACKNOWLEDGEMENTS

García-Sellés, D., Falivene, O., Arbués, P., Gratacos, O., Tavani, S., & Muñoz, J. a. (2011). Supervised identification and reconstruction of near-planar geological surfaces from terrestrial laser scanning. Computers & Geosciences, 37(10), 1584–1594.

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