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InSAR, seismic noise, and geotechnical data to assess landslide activity and geometry: the Villa de Independencia (Cochabamba, Bolivia) case study

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Interferometric Synthetic Aperture Radar (InSAR) enables detailed investigation of surface landslide movements but lacks information about subsurface recognition/identification. It can be obtained by means of direct measurements (e.g., geotechnical data) and geophysical techniques. InSAR observations, seismic noise measurements, and geotechnical data were integrated to assess the deformation on the ground surface and to determine the depth of the failure surface of the Villa de Independencia landslide, Cochabamba (Bolivia) affecting the village. It is a compound slow-moving landslide (total area approximatively $3.8 \cdot 10^6$ m^2) composed by three sub-blocks slide exhibiting diverse geometries, multiple failure surfaces, and magnitudes.

For investigating the spatiotemporal characteristics of the landslide motion, Sentinel-1 time series from October 2014 to December 2019 were analysed. A new geometric inversion method was also proposed to determine the best-fit sliding direction and inclination of the landslide. Results of the Sentinel-1 time series show two substantial accelerations in early 2018 and 2019, coinciding with an increment of precipitations in the late rainy season. It allows supposing the rainy as the most likely triggers of the identified accelerations.

The seismic noise measurements (more than one hundred spreaded over the whole landslide), analysed according to the Vertical to Horizontal Spectral Ratio technique (H/V), were calibrated and validated by means of the geotechnical data derived by three boreholes and 13 between rock and soil samples. H/V data allowed identifying the different dynamic characteristics of the three sub-blocks: movements are possibly due to the different properties of shallow and deep slip surfaces. The landslides caused damage on the edifices, probably mainly caused by the shallow slip interface (located at a mean depth of 5 m) since the foundation depth of the buildings is at most 2 m. In the town centre a deeper failure surfaces, approximatively with depth between 15 and 75 m, can be identified which may be responsible for its different direction and acceleration magnitude of sliding (inferred by InSAR) compared to the other parts of the landslides. Finally, the determination of the slip surface depths allowed to estimate the overall landslide volume assessed

approximatively $9.18 \cdot 10^7$ m^3.

The study shows the great potential for landslide motion characterization and mechanism investigation by combing InSAR, seismic noise and geotechnical measurements.