



## **Kinematic analysis for the implementation of landslide mitigation measures**

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The present work is finalised at the implementation of a landslide risk mitigation master plan of the ancient citadel of Machu Picchu. After the warning launched in March 2001, by the scientific community on potential collapse of the citadel from a near-disastrous landslide event different studies have been promoted to reconstruct landslide activity and suggest landslide risk mitigation measures for the protection and conservation of Machu Picchu cultural heritage. A site-scale analysis has been implemented following the application and integration of geomechanical classifications, ambient noise measurements and structural and kinematical analysis. The geology of the area is characterized by granitoid bodies that had been emplaced in the axial zones of the main rift system that are now exposed at the highest altitudes, together with country rocks (Precambrian and Lower Paleozoic metamorphics) originally constituting the rift 'roots'. The bedrock of the Inca citadel of Machu Picchu is mainly composed by granite and subordinately granodiorite. This is mainly located in the lower part of the slopes. Superficially, the granite is jointed in blocks with variable dimensions, promoted by local structural setting. Single blocks vary from 10–1 to about 200 m<sup>3</sup>. Soil cover, widely outcropping in the area, is mainly composed by individual blocks and subordinately by coarse materials originated by chemical and physical weathering of minerals. Regional tectonic uplift and structural setting rule the general morphological features of the area and as a consequence, landslide type and evolution. Rock falls, rock slides, debris flows and debris slides are the main landslide typologies affecting the citadel slopes. In the last mission in May 2009, elastic and deformation rock parameters have been collected using a passive seismic innovative technique based on natural microtremor measurements and geostructural scan lines elaboration. A landslide zoning of the citadel has been developed by comparing GSI classification, geomorphological field survey and kinematical analysis. More in detail, areas potentially prone to rock fall and toppling have been discriminated with respect to those kinematically affected by planar sliding, and a map on potential landslide types has been implemented. This map has been used to develop a preliminary master plan on landslide risk mitigation works that take into account a vulnerability analysis previously undertaken for each single archaeological structure. Finally, a set of low impact structural measures have been designed as a function of rock mass quality and site landslide potential activity suggesting priorities in the light of recent development and exploitation by local authorities of new areas, potentially at risk, for tourism.