



Earthquake Archaeological Effects (EAEs) in Machupicchu. Preliminary results

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Abstract: The National Archaeological Park of Machupicchu (Cusco, Peru) is one of the most important archaeological sites in the world. The relevance of this site makes the necessity of the prevention against natural hazards. Peru is affected by earthquakes from the Pacific Trench, but there are important active faults in the Andean Range that could generate destructive earthquakes. In this study we show the preliminary result of the analysis of Earthquake Archaeological Effects (EAEs) and their differentiation from the effects generated by slope movement (creep) in the archaeological site. This type of studies may be useful in the future for the prevention of earthquake effects in the archaeological site.

Key words: Machupicchu, Earthquake Archaeological Effects (EAEs), ancient earthquakes, creep slope movement.

INTRODUCTION

The archaeological site of Machupicchu, located in the Oriental Cordillera in the Andes (Fig. 1), is affected by several geological hazards, mainly landslides and erosional process, controlled and monitored by the National Archaeological Park. Some of these process are present in the archaeological site by deformational structures in the Inca buildings, like displacements in masonry blocks.

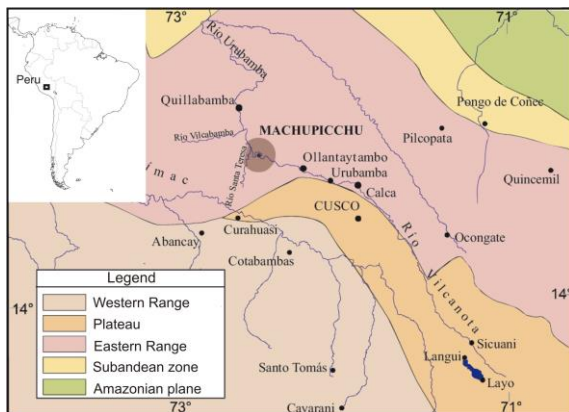


Figure 1: Physiographic setting of the National Archaeological Park of Machupicchu (Cusco, Peru) (modified from Carlotto et al., 2007).

The most important earthquakes in Peru are generated by subduction zone in the Pacific Coast, but there are active faults in the Andes Cordillera that could produce big earthquakes (Macharé et al., 2009; Benavente et al., 2013). This kind of studies could contribute to identify ancient earthquakes not recorded and generated by the seismic activity of the subduction zone. In that case, these evidences should be complemented with studies of geomorphology and paleoseismology, to identify the active faults that generated the earthquakes that affected Machupicchu in the past. These earthquakes can be used

in the future as a model to prevent future seismic effects in the archaeological site.

Applying new techniques in Archeoseismology, it is possible to discriminate the seismic origin of these deformations. The most confinable EAEs generated in masonry walls, in order to obtain the seismic direction of medium ground movement, are: dipping broken corners and displacement of masonry blocks. We selected the Temple of Sun and the sector of the Temples to study these EAEs. The Temple of Sun is a good building for the study of EAEs, because it is a semi-circular structure and the anisotropy of the orientation of the walls is reduced (Fig.2).



Figure 2: Temple of the Sun. Machupicchu (Cusco, Peru).

DEFORMATION STRUCTURES IN THE INCA BUILDINGS

Several authors described slope movements affecting to the archaeological site (Bouchard et al., 1992; Carlotto et al., 2007; Kauffmann, 2014). One of the most important phenomena affecting the Inca buildings is the creep movement slope down. One example is the Principal Temple, affected by creep (Carlotto et al., 2007) (Fig. 3).



Figure 3: Displaced masonry blocks associated to creep movement in the Principal Temple.

The earthquakes can generate different deformation structures affecting archaeological sites. In consequence we have collected the data concerning the EAEs proposed by Rodríguez-Pascua et al. (2011) and the geological structural analysis proposed by Giner et al., (2011). This classification was created for use in archaeological sites and historic buildings to distinguish seismic effects from other causes. The geological tool used for this purpose was the analysis of seismic strain structures. All of these deformational structures have been classified and studied according to the tenets of geological structural analysis to estimate the orientation of the maximum horizontal movement of the ground. The initial hypothesis requires that most of the seismic damage must be oriented in relation to the seismic ground movement, and this allows us to compare oriented seismic data with unoriented non-seismic damage. We used the Hiran Bimgham photography's (1912) took during the discovering of Machupicchu in order to observe de EAEs and discriminate posterior effects that could produce the deformations.

For a first approximation to the origin of the deformational structures in Machupicchu we selected the displaced masonry blocks (Fig. 4) and the dipping broken corners (Fig. 5). Both of them are structures generated by horizontal movement of the ground and we can discard other effects like creep slope down.

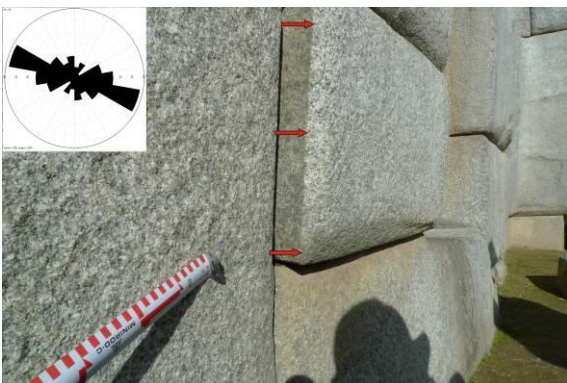


Figure 4: Displaced masonry block in the Temple of the Three Windows. The rose diagram show the medium ground movement of the structural analysis of total displaced masonry blocks data.

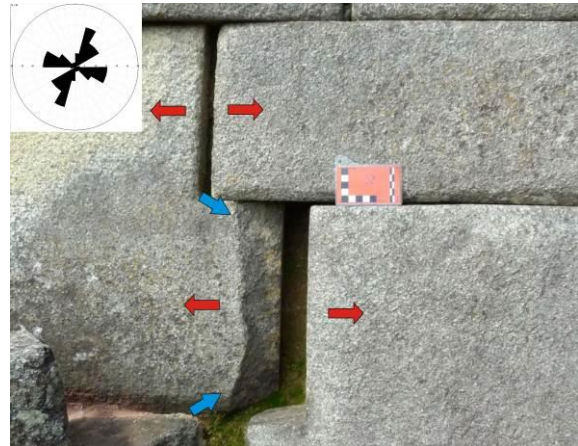


Figure 5: Displaced masonry blocks (red arrows) and dipping broken corner (blue arrows) in the Temple of the Sun (external wall). The rose diagram show the medium ground movement of the structural analysis of total dipping broken corners data.

DISCUSSION AND CONCLUSIONS

We took 142 measures of deformation structures in in both sectors. The results obtained for the medium direction of ground movement are two: N025°E and N110°E. The direction of maximum slope in these sectors is N060°E. The two directions of ground movement are incongruent with the slope movement and it is possible that could be generated by two different earthquakes. If we plotted in a histogram the accumulated displacement in masonry blocks two main direction were obtained: N060°-080°E and N100°-120°E (Fig. 6). The first one (N060°-080°E) is the maximum with an accumulated movement of 190 cm, related to slope movements (Fig. 6).

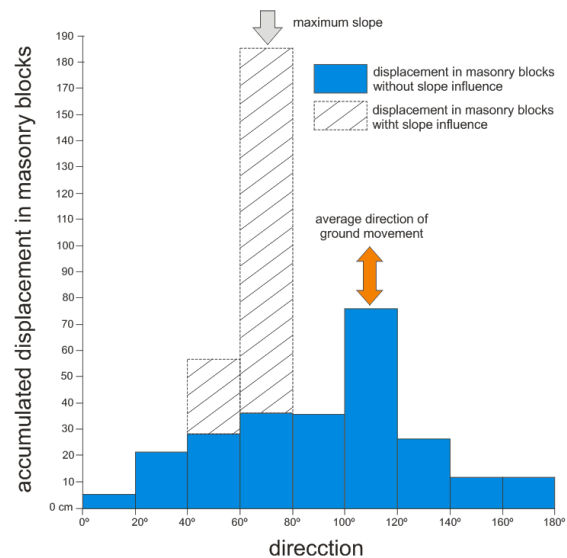


Figure 6: Histogram of the accumulated displacement in masonry blocks in the Temple of the Sun and in the Temples Sector (Principal Temple and Temple of the Three Windows).

The secondary orientation is N100°-120°E, with an accumulated movement of 76 cm (Fig. 6) and parallel to the medium ground movement direction N110°E



obtained by the EAEs analysis. The direction of N025°E has a little displacement of masonry blocks (25 cm), but it is good represented by dipping broken corners. For this reason, our hypothesis is that the directions of medium ground movements N025°E and N110°E are not related to slope movements and the seismic hypothesis is the most confinable with the present data. The direction N060°-080°E, parallel to the slope, is conditioned by gravity processes with the maximum of accumulated displacements in the archaeological site.

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