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The restoration of San Pedro Cliff at La Alhambra
La restauration de la falaise de San Pedro à La Alhambra

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ABSTRACT
San Pedro cliff is a dihedral 65.5 m high (Fig. 1) that has progressed to place itself at 23.8 m from the *Alhambra* wall-palace that was granted a World Heritage award in 1984. Active normal faults, like the right hand side of the dihedral, have created an extension tectonic regime that loosens the ground and activates the ground falls. . The preservation solution proposed is a post-tensioned high elastic limit wire mesh and autochthonous vegetation

Fig. 1. View of San Pedro cliff below the Alhambra walls.

DISCUSSION

1. Authenticity and singularity of San Pedro cliff

Although the origin of San Pedro cliff is not exactly known, solutions to hinder the advance of the cliff have been suggested from 1520. Only for this reason San Pedro cliff must be considered an authentic relic of a singular geological phenomenon.

The inclination of the Tower of Pisa has attracted millions of visitors, and despite the danger for the integrity of the tower, at no moment the Pisa town hall has suggested to straighten it, but rather to hinder more leaning. Notwithstanding its danger for the Alhambra wall, San Pedro cliff has become a positive element of the urban landscape at the spot, owing to its singularity. The solutions should not try to refill the dihedral and to hide it, or to divert River Darro, but to conserve the singular view of this spot. Both elements are fundamentals components in a place as beautiful as the *Carrera del Darro* street.

2. Characteristics of Alhambra and its preservation

La Alhambra is a unique example of the Nasrid architecture and was built between 1273 and 1391. The preservation of the palace is not bad, although some towers have been damaged by earthquakes. As indicated in the paper a landslide corresponding to the 1,000 years return period might damage one tower seriously at the site of the cliff.

3. Safeguard from geological hazards

Active normal faults, like the right hand side of the dihedral (Fig. 1), have created an extension tectonic regime that loosens the ground and activates the ground falls. The fractures produced by the distending tectonic regime have favoured the attack of the slope of the Alhambra hill by River Darro during floods. Erosion and seepage coming from Alhambra palace have contributed also to the advance of the cliff.

3.1 Dynamic calculation

In a Poisson's process, the probability of having at least one event of acceleration larger than the design acceleration during time t is:

$$P(x\geq 1,\, t) = 1\text{-}\exp(-t/T_r) \qquad (1)$$

where T_r is the return period.

The Spanish standard recommends calculating constructions of special importance including monuments for a return period of 1,000 years. According to equation 1 the probability of exceeding the design acceleration during a life time of 100 years is 9.5%.

Although the western face of the dihedral is an active fault, the 7 m throw has been accumulated during thousands of years, and the displacement during a single earthquake will be small.

4. Solution

The solution adopted is a high yield stress (>1770 MPa) rhomboidal wire mesh, 3 mm thick, with an opening of 65 mm. A pressure of 20 kPa is applied, by post-tensioned anchorages (up to 18 m long), on the slope, acting on the mesh through double 20 mm reinforcement cables. The mesh (with post-tensioned anchorages) applies a pressure on the slope that will mitigate the effect of a displacement in the fault.

Stability of slopes calculations were carried out with different mesh pressures applied on the slope. Under the 1000 years return period earthquake the factor of safety was only 0.73 when no pressure was applied on the slope. This safety factor increased up to 1 when a pressure of 20 kPa was applied on it.