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Modern technology introduced to safeguard old monuments in Angkor

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Abstract
Some case histories of use of modern technologies and innovative materials for monument structures with damages provoked by geotechnical causes are presented.

Strengthening of Pre Rup temple's towers

Towers of the Temples of Angkor are affected by three main phenomena that can interact each other: tilting, disarticulation of the structure and crushing. They usually suffer from soil settlements, in many cases also related to the outward movement of the retaining walls of the terraces on which they lay, which severely compromise the stability of the whole structure. The intervention proposal consisted in a general structural strengthening through reconnection of the elevation walls and foundation enlargement and different local conservative measures. For the cases of major damages strengthening of foundation consisted in the creation of an inner stiff r.c. structure below the floor level, pre-stressed before the final connection with the original foundation. For the upper Towers of the Temple and for the less damaged ones a chaining was applied to the base of the Tower, by the use of FRP aramidic rods crossing the structures in small diameter holes. The pre-stressing of the rods assured a prompt effectiveness to the reinforcing measure.

Restoration of Angkor Wat temple's front steps

The Angkor Wat Temple compound is surrounded by a rectangular moat. The portion of the embankment concerning the project is located just across the causeway leading into the Angkor Wat Temple. The Angkor Wat moat embankment has suffered from landslides in the past all along its perimeter, at least three times a reconstruction of this portion of embankment was recorded along the last century. The steps last collapsed on September 27th 1997, following a torrential rain. During the site survey, in the aftermath of the landslide, it was noticed that the laterite and sandstone blocks of the stepped slope were assembled with a bedding mortar, unknown to the original Khmer technique. Such sealing probably prevented the water from flowing between the fissures of the protecting blocks, and favored the building up of a water head behind the wall, resulting in pore over pressure. The uphill water table with respect to the downhill moat level might have directly pushed outwards the steps, or might the fast rising moat waters have reached a level higher than the water table inside the embankment, thus causing a siphonage due to the water gradient through the foundation basement. Reconstruction of the moat steps and the backfill involved the strengthening of a significant volume of earth behind the moat edge, in order to prevent any further dangerous instability of the slope. Soil reinforcing was realized by deploying a specifically designed textile into the body of the embankment's filling soil. The implementation of an effective and durable drainage system, both at the interior of the embankment and at the surface level was also cared for.

Monitoring system of Angkor Wat south gallery

In the South gallery of the Temple of Angkor Wat a monitoring system was installed. The gallery is covered by a 2-span dry jointed stone blocks vault sustained by a wall and two rows of sandstone columns. A generalized strain pattern, quite evidently all along the gallery, could be recognized in the vaults, namely for the large rotations of the horizontal beams under the smaller vault, at the downhill side, testifying the tilting of the smaller lateral columns. Fig.1 shows a close correlation between the water table level and the opening of the joints, the process seems to be almost fully reversible. It suggests to exclude the presence of any subsidence phenomenon and makes few realistic a hypothesis of plastic deformation of the foundations of the columns. More reliable seems the scenario of elastic rotation pattern of the closure retaining wall caused by the increase of back water pressure due to lack of drainage, that causes the enlargement of the cracks and joints of the beams. The risk level of the structure appears undoubtedly high, due to the sensitiveness of the vault to the limit state of displacement of the columns.

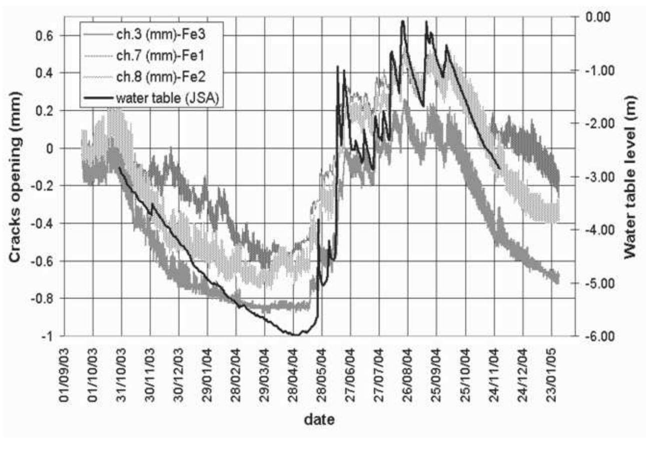

Fig.1: Correlation between cracks opening and water table level.