Conservation of the 10th-Century Temple of Phnom Bakheng
Angkor, Cambodia

Progress Report, October 31, 2011

ID Number: S-CB600-08-CA-046-A001
Reporting Period: August 2011 – October 2011

This report provides information about the second phase of the Phnom Bakheng conservation project, focusing on structural stabilization and waterproofing of the East Elevation and portions of the walls to the north and the south. World Monument Fund works in close collaboration with APSARA National Authority and reports regularly to Cambodian officials on the project and presents twice a year at ICC meetings organized by UNESCO.

The Phnom Bakheng conservation project addresses the most serious decay patterns at the site. Deterioration of the live rock substrate, displacement of the applied sandstone façade due to uncontrolled water runoff, and water infiltration are issues of greatest concern. Although damage is found throughout the site, it is most visible at the corners. The stabilization program includes disassembly of wall sections that are structurally unsound, conservation of stone blocks, and reassembly of selected areas of the five levels of the East façade and its terraces. Essential to the successful conservation of the walls and terraces is the repair of the bedrock, which forms the foundation of the temple. Decayed or missing sections of bedrock are replaced with new laterite or sandstone depending on what a particular section of the temple supports. Threaded stainless steel rock bolts have been installed to reconnect detached portions of the live rock. Stone blocks of

unsound wall sections that require conservation or repair are consolidated and then reset when the section of wall is reconstructed. The gap between bedrock and sandstone facade wall is filled with new laterite blocks shaped to fit perfectly into the opening and to improve bonding. The terrace pavers are reset close to each other to minimize water penetration and the necessary pitch is established to insure proper water runoff. A PVC waterproofing membrane has been installed under the terrace pavers to act as a secondary line of defense to prevent water infiltration. The installation of this inert membrane is reversible and concealed from view.

APSARA and UNESCO's ICC for Angkor approved the use of stone units found at the site or the creation of new sandstone units to replace original stone blocks that are missing or decayed beyond repair. These replacement units are only utilized when there is no alternative and they are necessary for the proper stabilization and protection of the monument. The conservation and stabilization methods were designed by WMF with input from architectural conservators, structural engineers, and waterproofing experts in close collaboration with APSARA and the UNESCO Ad Hoc experts of the ICC. Methods and materials have been reviewed and are adapted to accommodate the specific needs of the project, meaning that a set of criteria guide the work, but as unforeseen conditions are found, responses are designed to correct these issues. As an example, severe fissures found in the bedrock required the insertion of steel bolts. While this condition was not known at the outset, the overall approach to materials and conservation methods provided a rationale for the selection of steel bolts.

During the present reporting period from July 2011 through October 2011, work at the Northern half of the East Elevation at Phnom Bakheng has continued. Reassembly of the lowest level (terrace F) has been completed and the next level up (terrace E) is underway where the waterproofing membrane and pavers are currently installed. Unsound areas of the wall and pavers at the third and fourth levels up (terrace D and C) have been dismantled including the

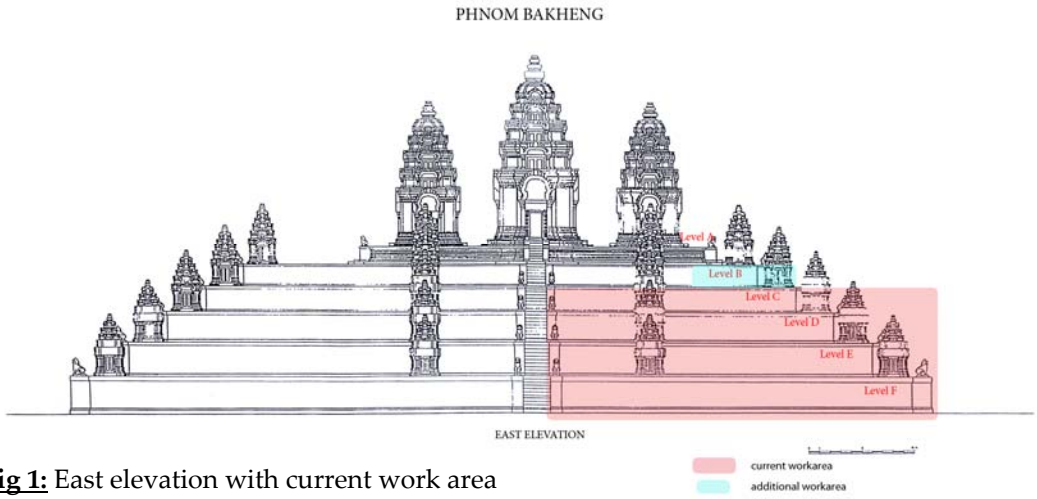


Fig 1: East elevation with current work area

sandstone shrine at the corner of level D. Bedrock repair is underway at each of these levels. During dismantling of level C a concrete foundation repair was revealed at the corner. This cement slab was installed by École Française d'extrème-orient during the beginning of the 20th century. Decayed concrete has been removed and will be replaced with laterite or sandstone. The required removal and replacement at level C affects the stability of the sandstone corner shrine

on the next terrace up (level B), which is outside of the scope of work defined for this phase of the project.. Stabilization of the corner shrine and adjacent wall sections at level B is required to complete repair at level C and to obtain an acceptable level for waterproofing the lower terraces. Thus the work will be undertaken to complete this repair. APSARA's archaeological team, working in collaboration with WMF at the site, continues to process data generated from the archeological field work completed in August 2010. Phnom Bakheng has provided a large amount of historic information with great potential for additional archaeological research and these details are also helpful for future site interpretation and public presentation of the monument. The final report by archaeologists working with WMF on this project is expected to be completed by the end of 2011.

In June 2010, WMF organized a workshop on brick shrines at the site, which provided an important opportunity to review the conservation needs of the shrines, which are an important visual feature of the monument. WMF has previously reported on the Brick Shrine Workshop. However, the results of the workshop led to conservation activities on the site this year as recommendations were followed and some experts invited back to the site to assist with these efforts. A follow up workshop was held in February 2011 to implement potential options discussed at the June 2010 workshop. With the assistance of international engineers and masonry conservators, methods to stabilize the foundations were tested and treatment options for brick consolidation were reviewed. The second phase of the workshop served to begin stabilization and consolidation of the deteriorated foundation and associated brickwork at Phnom Bakheng at brick shrine G10. The goal of this work is to formulate a comprehensive conservation and stabilization plan for brick structures at Phnom Bakheng, which may be useful for other brick shrines within the Angkor Archaeological Park, as many other temples have brick shrines in proximity to the main stone temples.

In May 2011, WMF hosted a one-week site management workshop in New York City, providing an opportunity to analyze challenges at the site and determine coordinated short, medium, and long term actions to be taken to improve management strategies and visitor enjoyment of Phnom Bakheng. The rationale for holding the workshop in New York, rather than on site, was that it was important to have the leadership of APSARA participate in these dicussions and not only those reponsible for coordinating work at Phnom Bakheng. Moving the meeting to New York assured the full participation of the most senior representatives of APSARA, a Deputy Director of the National Tourism Authority, a representative from UNESCO's Phnom Penh office, and a member of the Ad Hoc Expert Committee. The workshop dicussions were appropriately elevated behind only technical decisions and we were able to have a conversation about an overall philosophy for the long-term stewardship of the site and the need to balance conservation needs and visitor enjoyment. WMF sees this workshop as the beginning of a series of sessions that will be undertaken as the conservation work progresses and will now receive greater attention as leadership at the national level and at APSARA have been engaged in the formation of these plans. Importantly, the workshop allowed preliminary plans to be mobilized for improvement of security at the site, the creation of viewing platforms to allow visitors to see sunset of Angkor Wat without needing to be on the highest levels of the temple, and to creating systems for limiting visitor access and during certain hours both for the protection of visitors and the monument. WMF was asked to work on a visitor circulation plan, which has been submitted to APSARA.

WMF and APSARA have begun an effort to address overall management of the site and to this end, WMF brought a hydrologist to Phnom Bakheng to analyze current conditions and develolp a plan for improved control of water runoff, monitoring of soil erosion, and improved of landscape features to assist in controling water run off.

With the news of augmentation of the existing grant by $450,000 from the US Department of State and WMF's contribution of $150,000 to bring the total to the required $600,000, WMF can now move forward with additional stabilization at the main temple. The new funds will be dedicated to completing the east elevation and portions of the wall sections to the north and the south, by continuing work at the north and south elevations to the west towards the beginning of both the north and south stairs. This will enable WMF to terminate the waterproofing and repairs of the terraces at the north and south stairs in such a way that it will function adequately even if work on the western section of Phnom Bakheng is not completed immediately. At the conclusion of this phase of work the most vulnerable areas will be stabilized and waterproofed.

WMF has started the extension of the existing work area, and site mobilization for work at the South Elevation and the Southeast corner. Activities so far have included the set up of a fence to close the additional work area, to clear the site and organize scattered stones, to review documentation and to complete a unit by unit condition survey of the South Elevation. To prepare the site for the arrival of a second tower crane, excavations are underway to expose the bedrock. It is anticipated that the second crane will be erected on-site in December 2011 and restoration work at the Southeast corner will start in January 2012.

For Level F, the reassembly of the Northeast corner at the lowest terrace has been completed. This work included the removal of loose and deteriorated bedrock material, the structural reinforcement of detached sections of bedrock by threaded stainless steel rock bolts, the insertion of new laterite blocks to fill in larger cracks and depressions, and the re-installation of restored sandstone wall units and pavers. As the lowest level of the Northeast corner was one of the most damaged, the repair required the preparation of a large amount of new sandstone wall units and pavers. The new replacement sandstone quarry is very close to the ancient Angkor quarry thus is very similar in its physical and chemical properties. In total about 150 new sandstone wall blocks and 630 new pavers where prepared and installed together with original stone blocks and pavers that were structurally repaired and conserved. To better blend in the new units with the surrounding original stone, WMF is currently preparing samples of surface finishes to imitate the surface texture and condition of the original stone.

To reduce the amount of new stones required, WMF requested permission to use original stone that is found around the site and frequently has no detailed carving and no indication for its original location. At the 20th Technical Session of the ICC and the Ad Hoc Experts site visit in June 2011 WMF was granted approval to re-use original stone blocks that are scattered around the site for the repair of the terrace walls even though they are not may not be returning to their original locations. The WMF documentation team in collaboration with APSARA conducted an expanded survey and inventory of all stone blocks at the site. So far enough replacement units have been found to complete the repair at the Northeast corner without fabrication of any new sandstone blocks.

Fig 2: Northeast corner before repair

Fig 3: Northeast corner work in progress October 2011

Fig 4: Preparation of surface finishes samples at level F

Fig 5: New pavement at the northeast corner at level F

Prior to final installation of the pavers the waterproofing membrane was installed with proper connection detail to the next upper terrace wall and the corner stone at the outer edge of the terrace.

Fig 6: Waterproofing membrane at level F

Fig 7: Membrane installation training at level F

The work at the lowest level has continued at the East façade moving to the south. To repair unsound areas in this wall section a sandstone shrine that was bearing on the unstable terrace wall had to be dismantled. After proper documentation, damaged surfaces were pre-consolidated, and blocks have been dismantled to be transferred to storage or to the workshop for conservation. The bedrock has been repaired in this area and reassembly of the wall is nearing completion. Due to the architectural configuration of the temple sandstone shrine F12 will only be reassembled after the repair at level E has been completed.

Fig 8: Dismantling of sandstone shrine F12 at level F

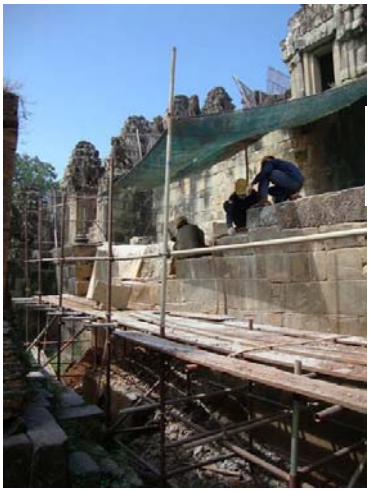


Fig 9: Reassembly at level F at the east Elevation

Work at the second terrace (level E) has progressed and reassembly of walls at the corner has been completed and the bedrock has been structurally repaired. Detached areas of the bedrock were reconnected by insertion of long rock bolts. The waterproofing membrane has been laid out and pavers are being reinstalled. Following the recommendation at the last ICC meeting to reuse stones from the site, only limited new sandstone was used for the preparation of replacement units at this terrace.

Fig 10: Repair of bedrock at level E

Fig 11: Installation of rock bolts at level E

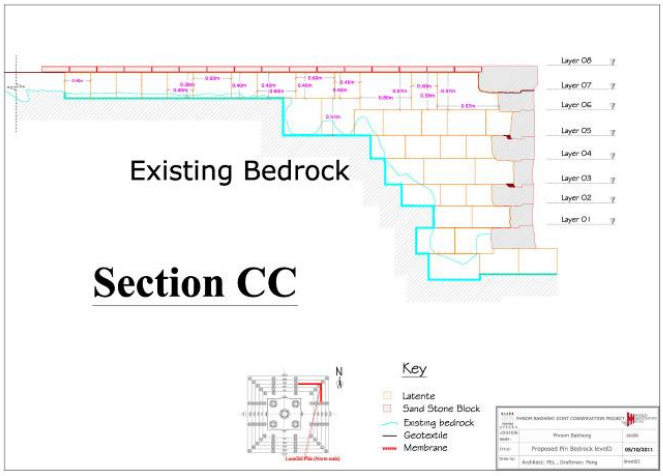
Fig 12: Reassembly at level E

Fig 13: New pavement with waterproofing membrane and bedrock repair at level E

Fig 14: Exposed bedrock after cleaning at level D

Fig 15: Deteriorated laterite at level D

Fig 16: Graphic representation of structure



Scattered stones resulting from earlier collapse and the remains of a corner sandstone shrine on the third level (level D) have been numbered and removed to storage. The original pavement has been cleaned, numbered and dismantled. The interventions are accompanied by ongoing documentation of activities, including photographs of existing conditions of all sections of the wall and pavement, graphic documentation and condition surveys, stone numbering, survey for fallen stone blocks that can be returned to their original locations, and the design of replacement units where required. Only a few laterite blocks in combination with compacted soil were used to fill in the missing portions of bedrock. The soil was removed and the bedrock was cleaned. The team has begun the repair of the bedrock which is expected to be completed within the next 3 months.

Prior to the removal of the deteriorated laterite at level D it was necessary to dismantle the corner sandstone shrine, pavers and unsound wall sections at the fourth level (level C). During dismantling the walls of level C a concrete slab installed by the EFEO in an earlier repair campaign was revealed and found to be in poor condition. WMF has removed the concrete slab and will replace it with new laterite and sandstone. WMF is currently surveying the condition of terrace B to identify the extent of the concrete repair and to explore potential solutions for the stabilization of the corner sandstone shrine at this level.

Fig 17: Dismantling sandstone shrine C 11

Fig 18: Dismantling of original pavers on level C

Fig 19: Condition at level C after dismantling with temporarily supported concrete slab

Fig 20: Level C after removal of concrete slab and critical connection to level B corner stone shrine foundation and wall

As a result of the Brick Shrine Stabilization and Conservation Workshop held in June 2010 and the subsequent on-site workshop in February 2011, WMF and APSARA are implementing a pilot project at brick shrine G10. The repair thus far has focused on the eastern side of the shrine where the southeast and northeast corners of the foundation required stabilization. In addition, brick consolidation work has been completed at the northwest corner and is continuing at the northeast corner. A hydraulic jack system introduced to WMF by Giorgio Croci, UNESCO Ad Hoc Expert to the ICC, during the February 2011 workshop was used to recover the deformation of the architecture and to enable the replacement of decayed laterite foundation blocks with new material to stabilize the structure. A series of sequenced hydraulic jacks were placed in strategic locations under the plinth sandstone blocks of the shrine to lift up the structure to take off the load allowing disintegrated laterite foundation units to be replaced. After lifting the structure, the jacks were removed and wooden props and wedges were installed. The deteriorated foundation of the shrine could then be removed until sound material was reached and new laterite blocks were added and wood blocks removed to reinstate structural stability to the tower. In addition, the northeast corner which was tilting past the degree of structural stability was pushed back into a structurally sound position using the hydraulic jack system. The intervention succeeded so that the east wall was straightened by several degrees and the opening was closed by several centimeters.

Since February 2011 WMF has inserted 90 new laterite blocks and 8 new sandstone blocks to stabilize the southeast and northeast corner of G10. The stabilization of remaining foundation at the western half of the temple is underway. The final presentation and details of improved water management of this repair is currently being designed and options will be presented to the Ad Hoc Experts of the ICC in December 2011. One of the questions to be discussed will be how to incorporate the repair aesthetically and how to protect the repaired foundation from deterioration from water infiltration. WMF is working on the design of a water collection and drainage system as well as options for the final presentation of the foundation repair.

Fig 21: Southeast corner of Brick shrine G10 in 2007

Fig 22: Southeast corner of Brick shrine G10 with stabilized foundation in October 2011

With the assistance of a special brick unit at APSARA, WMF reviewed and tested various repair methods and materials during the workshop in February 2011, including preparation of samples of potential pointing mortars, grouts and organic binders as there was indication that bonding of brick was originally achieved with the utilization of a resin from a Southeast Asian tree lacquer. The program also entailed laboratory testing of some of the conservation materials.

Preliminary results indicate that a pure lime mortar with pozzolanic additives will serve best. The repair system that was found to be most applicable has been applied at the northwest corner of the brick shrine G10. The program entails documentation, cleaning, application of biocides and herbicides to prevent vegetation from growing back and termites from re-infesting, and the partial dismantling of detached areas to enable stabilization. To follow the original building methods cracks are primarily filled with new bricks that are worked in a way to fit almost without joints and the use of mortar is kept to a minimum. An integrated system of grouting and cross pinning using Helifix stainless steel threaded rods was tested at the northwest corner to stitch together detached masonry segments as part of an in-situ consolidation program. Thus far the conservation of the brick work at the northwest corner has been completed and work is continuing at the northeast corner. The various methods and materials tested at G10 since February 2011 will be reviewed and resulting information will be combined in a conservation plan for the consolidation and stabilization of the brick shrines at Phnom Bakheng.

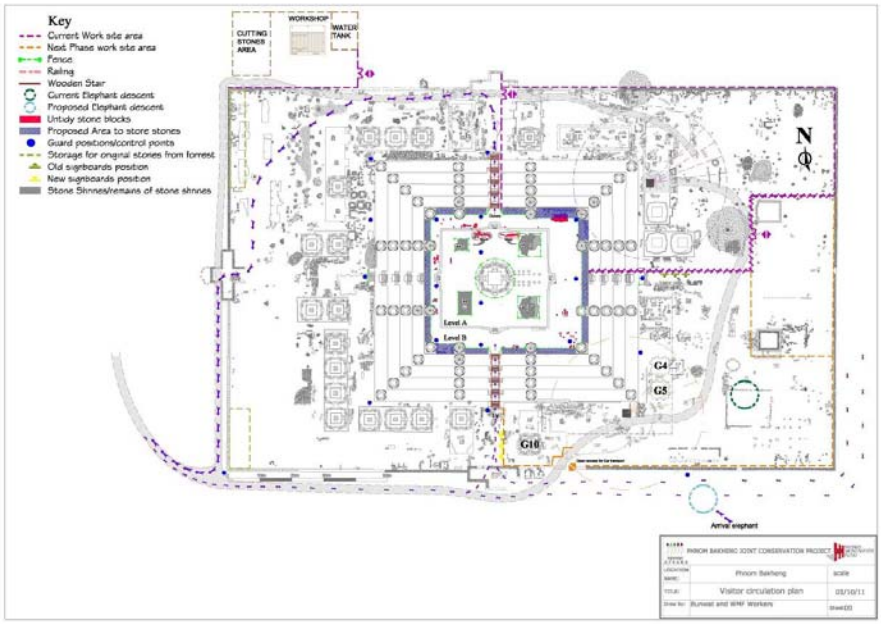
Fig 25: Northwest corner of brick shrine G10 before consolidation

Fig 26: Northwest corner of brick shrine G10 during consolidation

Fig 27: Northeast corner of brick shrine G10 after consolidation

Fig 28: Northeast corner of brick shrine G10 after consolidation at the top

Fig 29: Organization of stone blocks at level A and B

Fig 30: Installation of wooden stairs at the Southern stairs

Documentation and level surveys of the eastern and northern laterite stairs up to the hill have been completed and are expected to provide useful information for management planning for the site. WMF plans to conduct a LIDAR survey in coordination with the University of Sydney to obtain more helpful topographic information for water management, erosion control and landscaping options. Future site management workshops are planned to focus on topics to guide continuing conservation work and long-term stewardship planning and capacity building for APSARA. The approved visitor circulation plan below is an example of the result of meetings that allow topics to be explored in these workshops that are essential complements to the onsite conservation program.