THE SOUTHWEST PAVILION OF ANGKOR VAT TEMPLE: DAMAGE ENCOUNTERED AND CONSERVATION EFFORTS

Hans Leisen, Esther von Plehwe-Leisen[1], Long Nary[2], Simon Warrack[3]
Dana Krause, Johannes Kroner, Christine Schmaltz[4]
German APSARA Conservation Project (GACP)

Introduction

The temple of Angkor Vat, in the centre of Cambodia, is the most well known witness to the mighty Khmer past. One of the largest religious buildings in the world, it was constructed in an extremely short period, from 1113 to 1150. It is famous for its precious stone reliefs that cover large areas of the temple walls. The bas-reliefs of the galleries represent the finest examples of stone masonry from this period.

The temple opens to the west. Three sets of rectangular galleries enclose the central sanctuary (Figure 1). The corners of the galleries are constructed as pavilions. In the outermost enclosure (third enclosure) the Southwest and the Northwest pavilions are sculpted with precious bas reliefs depicting scenes from the Ramayana and other Hindu mythology (Figures 2 and 3).

The Southwest Pavilion is located at one corner of the western galleries of the third enclosure. Long periods of water intrusion, bat colonisation, anastylosis and other earlier restoration interventions have caused a multitude of different damages that highly endanger the reliefs.

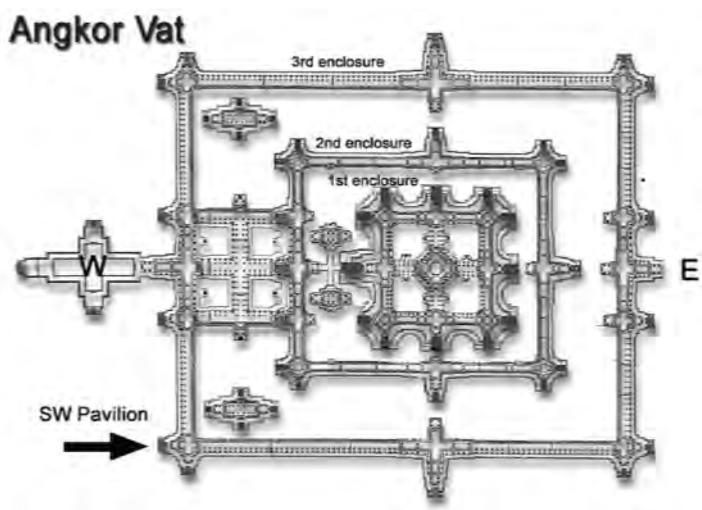

Figure 1: Construction Plan of Angkor Vat Temple, with the Southwest Pavilion marked.

[1] University of Applied Sciences Cologne, Institute of Conservation Science and Laboratory for Stone Conservation (LPL)
[2] GACP Conservation Team Siem Reap
[3] Capranica Italy
[4] Students GACP

Figure 2: View of the Southwest Pavilion in 1995.

Figure 3: The Southwest Pavilion walls are decorated with precious reliefs.

In 2001 conservation scientists and students of the German Apsara Conservation Project started to plan a comprehensive conservation intervention by preparatory investigations. The practical conservation work began in 2003. This is an on-going, time consuming de-restoration and conservation which will be finished by autumn 2005.

The special situation of the pavilion, its state of preservation, the complex damage situation as well as its restoration history have made high demands on the scientific preparation of the intervention, as on the skills of the executing team.

Damage situation

Angkor Vat temple is built from an argillaceous sandstone with a medium high capillary water uptake (Leisen et al. 1996, 1998). One most characteristic degradation phenomenon of this stone is contour scaling with scales of two or three centimetres thickness carrying the reliefs. In the Southwest Pavilion they appear specifically in the higher portions of the walls where high salt contents are existent due to rain water impact, soluble salts from bat droppings and wash off from cement mortars. After the scales are fallen off and the precious reliefs are lost, a brittle zone with flaking and total structural decomposition is revealed (Figure 4). On the Pavilion walls there are considerable areas of scales threatened by loss.

But we also see a different type of scale, atypical for Angkor Vat's building stone. These very thin scales measure only 3 millimetres thick (Figure 5). The appearance of very thin scales is a typical result of ill-adapted impregnation treatment, carried out with insufficient intrusion depth and using agents with a vapour permeability. Coatings of this type can be identified all over Angkor Vat temple by the glossy and sometimes whitish appearance of the walls. The widespread distribution of this damage form in the Southwest Pavilion became manifest through a detailed mapping of all reliefs at the beginning of conservation activities.

Figure 4: Thick scales are typical decay phenomena with the Angkor Vat sandstone.

Figure 5: Thin scales are a common damage feature in the Southwest Pavilion.

Water intrusion is ubiquitous in the pavilion. Rain water enters the building by open joints and leaking roofs, even though all joints have been closed with cement mortar during former restoration interventions (Figure 6).

In the base areas salt accumulations are quite visible. Due to the damaging effect of the salts considerable parts of the decorated surface are already lost in this zone. Salt margins also line the cement stone repair mortars applied all over the pavilion walls during the former restoration phase. The original stone substance of the margins is not only affected by salt deterioration but also by the influence of the very hard and dense cement repair mortars themselves. Metal plates introduced into the walls for stabilisation are rusting and bursting the surrounding stone blocks (Figure 7).

Figure 6: Water infiltration from open joints and leaking roofs is a very serious damaging factor.

Figure 7: Rusting iron jacks from former restoration affect the original stone by bursting.

Iinvestigation into conservation problems

1. Restoration history of the pavilion

The restoration history of the Southwest Pavilion includes a comprehensive intervention during the Indian Mission in 1993, and earlier French preservation work. The Pavilion was partly dismantled and reassembled. Displaced ashlars were relocated, leaking roofs were impermeabilised. During this intervention the inside walls were cleaned with brushes, applying ammonia solution and a detergent, and were subsequently treated with biocides. The joints were closed and missing parts were filled in using cement mortars. The walls were impregnated with methyl methacrylate (Narasimhaiah 1994, Bhandari 1995). Besides the short summaries in the publications cited no detailed documentation of the whole intervention is available.

2. Damage Factor: Soluble Salts

Some soluble salts figure among the most damaging factors in the deterioration of building materials. Depending on the humidity of the stone, they transform from a dissolved to a crystalline state. This process combines with volume changes that weaken and finally destroy the bonding of the stone minerals. Additionally there are several more very complex damage mechanisms linked to soluble salts in the pore space.

The soluble salts found today in the building stones of the Southwest Pavilion come from different sources: –Bat deposits –Rain water intrusions –Cement repairs –Dissolution of mineral components of the stone.

High salt contents are widespread in the pavilion. They are visible in the upper walls and the vaults, on the floor and in the base areas of the walls, around the margins of the cement pointings, washes and joint mortars. In addition to gypsum, nitrates and chlorides make up a large portion of the soluble salt content. Phosphates are also present to a considerable degree. In the Southwest Pavilion contamination with soluble salts normally surpasses 1 wt.% of the stone surface. This large quantity of soluble salts requires a salt reduction measure (WTA 2003). In addition to their immediate damaging effect, large quantities of salts also render conservation measures like pointing and washes less sustainable and make necessary steps, such as consolidation impregnation, harmful to the stone blocks.

- Salt reduction

The most effective method of salt reduction on walls is desalination by poultice application. A wet poultice made from clay and cellulose fibres is applied to the wall. As a first step the salts have to be dissolved by wetting the wall very thoroughly. Poultices with high soaking abilities on the one hand, and a good capacity to store humidity over a long time period on the other, have to be applied. Salts inside the stone are dissolved, migrate to the drying poultice and are stored there. In this way they can be removed together with the dried poultice. The salt reducing effect is influenced by the chemical nature of the salts present, by the soaking properties and the drying velocity of the poultice and by climatic conditions. Test areas with different poultices and varying drying times were carried out in order to determine the most effective materials and parameters for the measure. Analysing the qualitative and quantitative salt contents in the poultice serves as quality control for the desalination procedure. The process of salt reduction was repeated up to two times before obtaining satisfying results.

Preceding the poultice treatment thick salt crusts were thinned out by small particle blasting

Figure 8: Thick salt layers have to be thinned out before they are reduced by water poultices.

equipment with low pressure (Figure 8). The particles mixed with salts were properly collected and disposed of before the salts could re-enter the pore space of the stones.

Considering the very thin and fragile scales on the surfaces, salt reduction is a very delicate and extremely complex intervention. It has to be prepared by pre-consolidation in order to prevent loss of the scaling surface. Previous tests showed that a conventional consolidation with ethyl silicate yields undesirable results (Kroner 2002). So a special gluing technique was developed to attach the fragile scales.

3. Damage Factor: Acrylic Resin Coating

The Indian documentation describes an impregnation of all walls with a solution of 2% methyl methacrylate (MMA) dissolved in toluene (Narasimhaiah 1994, Bhandari 1995). Former Infra Red Spectroscopy Analysis (FTIR) carried out by GACP had also proven the coatings to consist of MMA (Snethlage 1998, Albers 2000). The thickness and the strong gloss of the coatings, as well as the fact that voluminous runs frequently appear, suggest however a higher percentage of MMA in the solution. One pre-condition of stone impregnation agents is good penetration ability. Artificial resins are known to have low penetration abilities and therefore to be highly problematic for stone impregnation (Domaslowski 1979, 1988).

When impregnated with water repellents with low intrusion abilities the stone parameters are changed merely at the surface. There is virtually no transition zone developed. Two isolated zones of basically different properties co-exist near the stone surface.

The surface areas of the stone blocks are most subject to climatic changes.. Therefore abrupt changes in stone properties near the stone surface are known to lead to subsequent damage. So the acrylic layers on the pavilion walls may be explained as catalyzers for the formation of the thin scales endangering the decorated surfaces.

Considering the medium water uptake of Angkor Vat sandstone, an intrusion depth of 2-3 cm is required for consolidation agents and water repellents (Snethlage 1997, WTA in prep.). Impregnation tests with MMA solution showed an intrusion depth of 3-4 mm only (Albers 2000). It is here that the detaching zone of thin scales is developed in the Pavilion, clearly demonstrating the risk of damage after treatment with insufficient intrusion depth.

Humidity and water transport behaviour figure among the most important characteristics of the stone. These two transport mechanisms control wetting and drying and have a high influence on salt deterioration. For testing purposes Angkor Wat sandstone samples were coated with MMA. It was shown that capillary water uptake, intrusion velocity and water vapour permeability are considerably reduced by the coating. But the total water uptake is not reduced, showing that merely a thin surface zone is affected by the treatment. In addition to these parameters, thermal and mechanical properties are also modified by treatment with acrylic resins. This implies additional damaging effects.

Non-destructive measurements at the Pavilion demonstrated the reduced water uptake of the treated walls. But these also revealed a nearly complete air impermeability. Water vapour transport and drying are impeded by the coating. The reduction of water transport into the stone from the surface concerns only the impregnated front. The stone still absorbs water from the top, the bottom and behind. Soluble salts accumulate behind the coated zone and contribute significantly to the formation of thin scales. All facts cited above, as well as the necessity of further conservation activities, indicated the need to dissolve and remove the damaging coatings.

- Removal of the coatings

Two main issues had to be investigated in order to achieve good removal results. First, the most effective solvent for the MMA coatings had to be detected. Secondly, the most efficient procedure had to be found. Favourable solvents were first selected by using the TEAS - Triangle (Teas, cited in Horie 1987: 194 & 200). In the case of the Southwest Pavilion, an appropriate solvent had to fulfil the following requirements: good solving properties, deep intrusion as well as only light adhesion to the stone substrate and a low evaporation rate. In a comprehensive test routine suitable solvents were selected and then used for removal tests. The risk of the dissolved resins migrating deeper into the stone was lowered by the application of absorbing poultices. New tests were performed to find the best poultice material.

Stone samples were coated with MMA and removal experiments were carried out in the laboratory in order to identify the best combinations of solvent and poultice (Albers 2000). These were then applied at test areas at Angkor Wat (Figure 9). Covering the poultices prevents fast evaporation of the solvent and prolongs the reaction time. The success of removals was controlled through tests of water uptake and air permeability (Figure 10).

Figure 9: After the removal of the poultice the underlying wall has to be washed with solvent.

In a very time consuming activity, patches of 20 x 20 cm were covered with poultice materials for one hour, after which the poultice was taken off and the area washed with acetone. The whole process was repeated twice. In this manner all inside walls were treated from top to bottom (Figure 11). Fans were installed to provide ventilation and to limit release into the air of harmful substances from the solvents.

4. Damage Factor: cement repair mortars

The properties of cement mortars differ substantially from those of natural stone. Cement mortars tend to be harder and denser. This incompatibility renders the adhesion of the mortars to the stone unsustainable, and even worse, causes damage to the original stone substance. Furthermore, Portland cement mortars import high quantities of alkaline salts into the building structure.

Decay mappings at the Southwest Pavilion revealed that large portions of cement-based pointings and washes are partly detached from the substrate. The joints closed by cement mortars are open again and let rainwater intrude into the Pavilion. It is even possible to see the sky through some of them. During the former intervention joint mortars in the upper regions of the walls were only applied superficially, not as

Figure 10: Tests of air permeability help to determine the success of the removal.

Figure 11: Step by step, small areas are cleaned of acrylic resin.

sealing mortars. Therefore they have not been sustainable. All facts cited led to the conclusion that all cement-based mortars had to be removed if possible.

- Removal of cement mortars

Removal of the cement mortar is a very delicate task if reliefs are not to be damaged. The thin cement-based washes and pointings require particular skill and micro-tools to take off. The conservators of the GACP team have considerable experience with careful removal of cement mortars. Vibrating micro-chisels serve well for taking off thin layers from sensitive surfaces (Figure 12). To open big joints full of mortar bigger chisels are used. No big electric equipment is employed.

Figure 12: Like a dentist the conservator takes off the cement parts from the precious reliefs.

After removal of big cement parts in the base areas, rusting iron bars appeared. These are a notable risk factor and must be removed. As they are hidden in the cement mortars, the GACP conservation team was supported by the CMAC demining team in locating the invisible metal bars with metal detectors.

Planning and execution of the conservation intervention

Figure 13: Traces of line drawings and polychromy survived long periods of neglect and invasive restoration interventions.

The problems encountered at the Southwest Pavilion are very intricate, such that the conservators' task is a highly complex intervention. The whole measure was preceded by a detailed photographic documentation survey. The actual situation was archived by mappings and reports. In addition to all decay phenomena, tool marks and polychromy were recorded by mapping. It turned out that traces of polychromy remain (Figure 13). This fact implies that special attention be accorded during all conservation measures, especially during cleaning and removal of the acrylic coatings and soluble salts.

Investigations into the diversity of special problems caused by the history of the building and former interventions occupied a significant amount of the time devoted to the overall project. Every conservation step had to be prepared very carefully. Every step of the conservation work was documented, mapped and described in reports.

Another most important task was to lead the GACP team to a new field of activity. Removal of the acrylic layers provided new scope to the team's work. The tested and optimised procedures were taught and after a short initial period the Cambodian conservators became specialists in that matter (Figure 14). A small "Handbook of Removal of Acrylic Layers" was compiled in English and Khmer to guide all aspects of practical execution of further conservation interventions.

Up to this point, all conservation measures had been applied to the interior of the Southwest Pavilion. The first step performed was the removal of the cement repairs. The cement mortars were taken out of the joints. Then acrylic coatings were stripped, followed by salt reduction. Joints were filled with mortars specially adapted to the needs of the Angkor Vat sandstone. The iron bars were removed (Figure 15). Special mortars developed in order to match the stone properties were used to close the open joints. Very broad joints were first filled with stone pieces, before the mortars were pressed into the joints.

Figure 14: Training in the new field of removal techniques for acrylic resin coatings is a pre-condition for a successful intervention.

Figure 15: The "crop" of iron jacks from two weeks' work.

Now the GACP conservators can continue with their usual every-day conservation tasks like consolidating fragile parts of the walls, re-attaching the loose scales and closing holes and edges (Figures 16 and 17). There is still a good deal of work to do! We must not forget that joints have to be closed from the exterior, too.

When the conservation intervention at the Southwest Pavilion is finished, six to eight specialised conservators will have worked actively for around 2 years, not to mention the time needed for scientific and technical preparation. Compared to the three-month mission ten years ago (Bhandari 1995), this is indeed a long period, and demonstrates the time-consuming character of de-restoration measures. Approximately 2.5-3 tons of poultices and 3 tons of solvents will have been used all in all.

Figure 16: Team members executing the final conservation operation.

Figure 17: Joints after closing with adapted mortar.

When conservation is finished, regular controls must be made. A maintenance program, like others carried out by GACP at Angkor Vat, must be implemented.

Conclusion

Documentation and investigations in the Southwest Pavilion have shown that a large portion of the damages we see today were caused by former restoration work. In addition to the thick scales, common for Angkor Vat sandstone, thin scales appear typical for stone treated with film-forming impregnations with insufficient intrusion depth. Together with the alkaline salts dissolved from the cement repairs, these coatings have a high risk potential for the sandstone reliefs. The removal of the coatings and the cement repairs requires detailed investigation and tests of materials and procedures. These measures require well trained and highly skilled conservators, and are costly.

Acknowledgements:

GACP is financed by the German Ministry of Foreign Affairs. We are grateful to FOKCI (Friends of Khmer Culture, Inc.) as well as to CMAC for financial and technical support. We are obliged to the constant and reliable Khmer conservator team of GACP that skillfully translates scientific results into conservation practice.

References Cited

Albers, M., 2000, *Untersuchungen zum Einfluß des Acrylharzüberzugs einer früheren Restaurierung am Tempel Angkor Vat, Kambodscha, auf die Gesteinsparameter und Möglichkeiten zur Abnahme (Investigation on influence of the acrylic resin coating applied during a former restoration at Angkor Vat Temple in Cambodia on the stone parameters and possibilities of removal:* in German), Diploma thesis University of Applied Sciences Cologne (unpubl.).

Bhandari, C.M. 1995, *Saving Angkor*, White Orchid Press, Bangkok.

Domaslowski, W. 1979, *Die strukturelle Verfestigung der Kunstdenkmale aus Stein mit organischen und anorganischen Substanzen (The structural consolidation of stone monuments with organic and inorganic substances*: in German), Restautorenblätter, Vol. 3, 191-205, Wien.

Domaslowski, W. 1988, The Mechanisms of Polymer Migration in Porous Stones, *Wiener Berichte über Naturwissenschaften in der Kunst* 4/5, 402-525, Wien.

GACP 2003, *Handbook for Removal of Acrylic Layers* (Engl. and Khmer), 36 pp., unpubl.

Horie, C.V. 1987, *Materials for Conservation - Organic Consolidants, Adhesives and Coatings*, Butterworths, London.

Krause, D. 2003, *Angkor Vat – SOUTH-WEST Pavilion: Removal of Acrylic Resin Coatings – Tests in Situ*, Internal Report GACP (unpubl.).

Kroner, J., 2002, *Internal Report GACP* (unpubl.).

Leisen, H., Plehwe-Leisen E. von and Sattler, L., 1996, "Weathering and Conservation of Apsara Reliefs at Angkor Vat, Cambodia – Project Angkor," *Proceedings of the 8th International Congress on Deterioration and Conservation of Stone*, Vol. 2, 1137-1146.

Leisen, H. and Plehwe-Leisen E. von, 1999, "Conservation of the Bas Reliefs at Angkor Vat Temple in Cambodia, Research - Practice - Training," *Proceedings of the 12th Triennial Meeting*, Lyon.

Narasimhaiah, B. 1994, *Angkor Vat – India's Contribution in Conservation 1986 – 1993*, *Memoirs of the Archaeological Survey of India*, No. 91, New Delhi.

Snethlage, R. 1997, *Leitfaden Steinkonservierung (Guideline Stone Conservation*: in German), Fraunhofer IRB Verlag.

Snethlage, R. 1998, *Untersuchungsbericht Proben Angkor Vat (Report on analysis of samples from Angkor Vat Temple*: in German), BLfD (unpubl.)

WTA-Merkblatt 3-13-01/D 2003, *Zerstörungsfreies Entsalzen von Naturstein und anderen porösen Baustoffen mittels Kompressen (Non-destructive desalination of natural stone and other porous building materials by poultices*, in German), WTA Publications, Freiburg.

WTA-Merkblatt 3-14 in prep., *Hydrophobierende Imprägnierung von mineralischen Baustoffen (Hydrophobic impregnation of mineral building materials*, in German), WTA Publications, Freiburg.