Archaeologia (2007): 11 - 22

Study of deterioration of ancient brick monuments -a case study at Polonnaruva

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Introduction

This study attempts to identify on going deterioration processes and their causes in selected ancient brick monuments at Polonnaruva. Three distinct deterioration processes could be identified by means of visual observations. It has been tried to identify causes responsible for the brick deterioration through chemical analysis in consideration with environmental factors. Tests results reveal that deterioration processes are consequences of complex interaction of prevailing chemical, physical and biological factors.

Brickwork can be identified as dominant structural element of architectural forms of Polonnaruva- the medieval Sri Lankan capital, in the North Central Province of Sri Lanka. Masonry structures undergo deterioration processes when exposed to aggressive action of the environment. The rate of damage and the mechanisms are determined by the properties of the building materials and by the environmental conditions prevailing at the site (Garrecht & Muller 1999, 507-515). This study attempts to understand the on going deterioration processes and their causes that are responsible for damaging brick monuments at Polonnaruva. Three major brick monuments at Polonnaruva, namely, Parakramabahu Palace, Lankatilake Image House, and Tivanka Image House were selected for the present study. Historical and archaeological evidence suggest that these monuments have a history of more than 900 years. With the collapse of the Polonnaruva kingdom, these monuments were abandoned. Since then, they have been directly exposed to the effects of the environment for several centuries. Proper understanding of the causes behind the deterioration processes is of utmost importance to take remedial measures and arrest further deterioration. Since the architectural heritage of Sri Lanka comprises a

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Key Words: Architecture, Conservation, Deterioration

considerable percentage of brick monuments, indepth understanding of this deterioration process is an important step towards their preservation.

Geographical and Climatic Context

Located within the dry zone of Sri Lanka, weather at Polonnaruva is almost warm and sunny throughout the year. The monuments at Polonnaruva also experience high winds, especially during the dry period. Day time temperature lies between 25 °C-35 °C, and the temperature difference between day and night would be as much as 10 °C. The area experiences a long dry period extending up to eight months of the year and rains mainly obtained during the period of the northeast monsoon (four months).Occasional showers can also be experienced during the dry period. Annual rainfall of the area is about 1500 mm-2000 mm. Humidity is relatively low, compared to the wet zone and the value lies between 60% - 90% (National Atlas of Sri Lanka 1988).

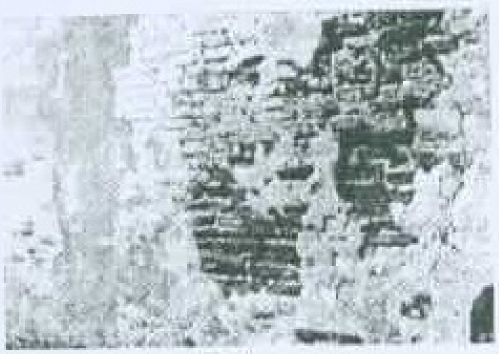

fig.1

Careful and close visual investigations of the above monuments paved the way to identify three distinct deterioration processes. Nature of each of the identified brick deterioration processes are as follows

Deterioration Type 1

In this process, the clay particles of outer surface of the bricks gradually get detached resulting in the wearing out of the bricks leaving concave coarse surfaces. But this process happens both on the mortar and on the bricks at almost the same rate (fig. 1 and 1.1). This deterioration process could be seen restricted to the patches, which were mostly located 1.0 m - 1.5 m over the ground level. The detached powdered brick and mortar particles could also be seen

fig.1.1

deposited at the bottom of the cavities formed due to this deterioration, confirming the on going process (fig. 2). It is important to note that the bricks underneath the layer of powdered brick and mortar particles (about 1 mm-2 mm thick) seem to remain intact. In some patches of affected brickwork, it can be seen that the cavities extend deep into the wall affecting its stability. There is more danger of having this damage in the cavities on wall surfaces of the Parakramabahu Palace, where the structural timber framework was originally embedded into the brickwork. This damage can also be seen to a lesser extent inbetween brick pilasters and in newly restored brickwork at Tivanka Image House (fig. 3 & 4).

fig.2

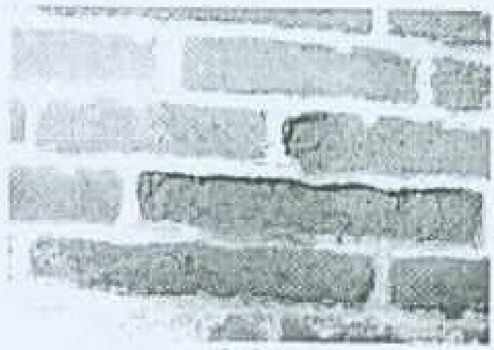

fig.3

Deterioration Type 2

The bricks that are being subjected to this damage wear out leaving smooth, hard convex surfaces. No detached particles could be seen. This damage could only be observed on pilasters and on other projected decorations on the southern exterior walls, both at the Lankatilake and Thivanka Image Houses. As a result of this damage, most of the fine details of the decorated wall surfaces are being worn out leaving rounded surfaces (fig. 4 & 5).

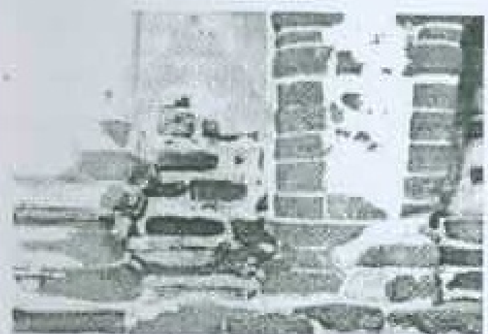

fig.4

Deterioration Type 3

External white patches about 1 cm -2 cm in diameter on brick surfaces were the main visual observation of this damage. These white patches could be easily removed with scraping. When removing each selected white patch, a small hole, leading deep into the brick wall could be observed (fig. 6). The diameter of the hole increases from the exterior surface towards the interior of the brickwork. This damage could clearly be attributed to the activities of a particular insect, since both sack (puparium) and dead insect larvae were found inside almost all the inspected holes. (Figs. 7, 8 & 9).

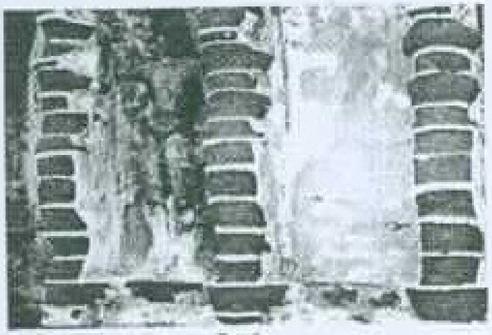

fig.5

Nature of damages

Parakramabahu Palace

Mainly deterioration Type 1 was seen. This was observed 1m-1.5m above the ground level on wall surfaces and inbetween the pillar cavities of both inside and outside of the monument. Since the pilasters or any other decorations are absent, deterioration Type 2 is not present. Moreover deterioration Type 3 was also rarely seen in this monument.

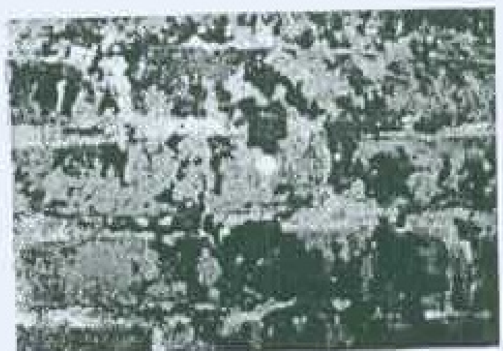

fig.6

Lankathilaka Image House

Deterioration Type 1 was mainly observed inside and outside of the monument. In addition to that deterioration Type 2 was also observed associated with the pilasters and other projected decorations on the exterior southern wall. Deterioration Type 3 was hardly seen in this monument.

fig.7

Tivanka Image House

Deterioration Type 2 was mainly seen on the exterior southern wall of the monument. Deterioration Type 1- was also observed on some bricks and appeared as isolated small patches of restored new brickwork specially on the upper areas of the monument. But generally, deterioration Type 1 at Tivanka Image House is rare with respect to the other two monuments. Efflorescence can also be seen associated with the damaged areas of the new brickwork (fig. 9). Besides that, deterioration Type 3 was also seen to a considerable extent.


fig.8

In addition to the above main deterioration processes, several moss and lichen growths on several areas could be seen in all three monuments, specially on the shaded areas of the Tivanka Image House. (fig.10).


fig.9

Identification of Causes for Deterioration

Samples were taken from surfaces of damaged and undamaged bricks from all three monuments. Few selected samples were subjected to soluble salt measurements and XRD analysis. Due to several practical restrictions, only limited number of samples were analyzed.


fig.10

Sample description

PB -Parakramabahu Palace; LT- Lankatilake Image House; TV- Tivanka Image House

PB1 - from damaged areas related to deterioration Type1

PB2 - from an undamaged area two feet above the place where the PB1 was taken

PB3 - from a damaged area related to deterioration Type 1

PB4 - from the undamaged area, below a place where the deterioration Type 1 was present

LT1 - from a damaged area related to Type 1, close to ground level (exterior of the building)

LT2 - from an undamaged area, 3m above the ground level

TV1 - from a damaged area 3m above the ground level related to Type 2

TV2 - from undamaged area close to ground level

Sample Analysis and Results

Water Soluble Salt Content

Sample	Mass (g)	Cl %	K %	Na%	Ca%	Mg%	SO_4^{2-} %	NH_3%	(NO_3^- +NO_2^-)% as NO_3^-	Total %
PB 2	15.0422	0.60	0.27	0.64	0.02	0.14	<0.01	0.001	0.010	1.57
PB 3	11.0134	0.32	0.24	0.47	0.05	0.04	0.04	0.002	0.295	1.45
LT 1	13.9203	0.56	0.09	0.37	0.05	0.32	0.01	0.002	0.269	1.39
LT 2	14.8740	0.27	0.03	0.34	0.05	0.03	0.02	0.001	0.114	0.90
TV 1	7.8632	0.02	0.12	0.23	nd*	nd	0.03	0.002	nd	0.40
TV 2	10.4835	0.02	0.02	0.03	0.01	0.01	0.02	0.001	nd	0.11

Table: 1 **nm- not detected*

XRD Measurements

PB1 and PB 4 samples were subjected to XRD analysis. XRD spectrums were obtained using JEOL X- Ray Diffractor meter. Identification was done using XRD data books.

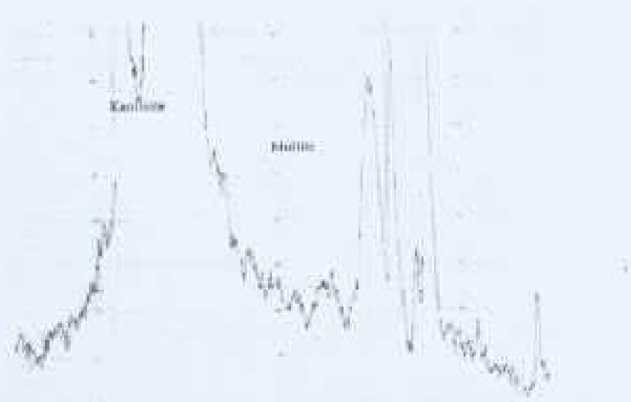

Table: 2 XRD graph for sample PB 1

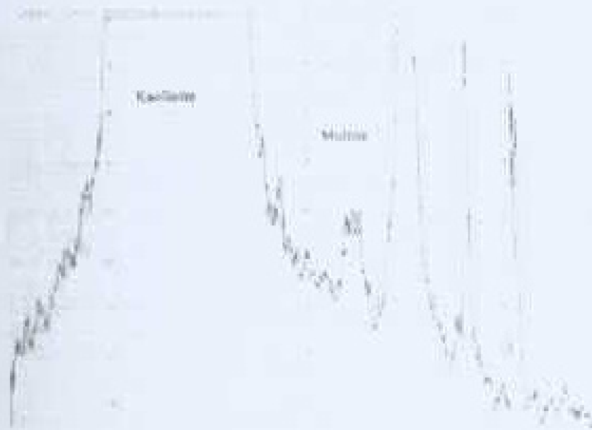

Table: 3 XRD graph for sample PB 4

(1) All major peaks of both samples are from kaolinite.
(2) A small peak (compare to major peaks) correspond to mullite was observed in both XRD patterns.
(3) Other minerals are in small quantities and cannot be identified due to high intensity of kaolinite peaks

Discussion

Deterioration Process I

The above mentioned deterioration processes on exposed masonry structures could occur by following means:-

a Weaknesses of individual affected bricks

b Stresses due to temperature and moisture gradient of the surface and immediate interior (Moropoulou 1995, 137-150)

c Crystallization of water soluble salt within pores of the bricks: Prevailing climatic conditions (heat, strong wind and relatively low humidity) favored the evaporation of absorbed water either by capillary action or leach out from the upper level due to rain concentrating the salt solution in brick pores.This water evaporation finally makes super-saturated salt solution by initiating the crystallization process (Garrecht & Muller 1999, 507-515/ National Atlas of Sri Lanka 1988/ Moropoulou 1995, 137-150/ Puertas 1995, 171-178/ Macchiarola 1999, 191-210/ Moropoulou 1999, 475-484) These crystal formations within the pores create large forces and it is responsible for the detachment of brick and mortar particles (National Atlas of Sri Lanka 1988).

XRD analysis shows the presence of mullite minerals, having an orthorhombic crystal structure in both the damaged and undamaged brick samples. Mullite is formed only at high temperatures (Deer 1966, 37) and availability of mullite indicates that both damaged and undamaged bricks are properly burnt. This emphasize that this deterioration is not due to inferior burning of bricks.

The results of water soluble salt content shown in table 1 and the results clearly indicate the presence of high total soluble salt contents of brick samples at Lankatilake Image House and Parakramabahu Palace where damage due to deterioration Type 1 is seen more prominently. (Total soluble salt content responsible for more than 1% of the sample weight). These results, therefore, provide an important clue as to the deterioration process of the brickwork.

This increased salt content of the brick samples could either be the result of dissolving soluble anions and cations contained in bricks and mortar due to rain water which percolates from upper levels of the tall brick walls or ground water containing soluble salts rising through the brickwork by means of capillary action. A thorough investigation with series of brick samples from top to ground level is necessary to assess the exact direction of the salt flow through the brick walls. But these exposed thick brick walls could absorb fair amounts of rainwater at the upper levels. During a four hour rain, it is calculated that 8 kg of water per square meter could penetrate a wall surface oriented perpendicular to the wind direction (Garrecht & Muller 1999, 507-515). The two samples taken from the brick walls that are not exposed to rain water at Tivanka Image House show low water soluble salt content. On the other hand, salt measurement results show the presence of high level of sodium and chloride ions in bricks. However, it is an established fact that the ground water in the North Central Province contains high amount of calcium and magnesium ions, and hence, it is considered as hard water. If the salt flow is only due to the capillary action of the ground water, bricks must contain considerable amount of calcium and magnesium ions along with other ions. But the test results shows that it is not so. This may also be another evidence to suggest that the ground water might not be the main salt source of the brickwork. So percolation of rain water from the upper levels may also a considerable contributing factor. Moreover, it is impossible to neglect the contribution of air pollution for the content of soluble salt in bricks. The area does not have a high degree of pollution from local sources except during the festival periods. However, there is a possibility of trans boundary pollution affecting the area especially during the north east monsoon owing to emissions carried out from the Indian sub continent. A research conducted in Anuradhapura city using three critical pollutants (Abeyratne 2004, 29-30) nitrogen dioxide, sulfur dioxide and ozone (passive sampler method was used) revealed high level of nitrogen dioxide and sulfur dioxide concentrations during both monsoonal periods compared to inter monsoonal periods. Though this factor needs to be subjected to further investigations, this factor will be a major threat for most of the outdoor and indoor cultural properties available in the area in future.

Deterioration Type 1 is also seen in the new brickwork on the restored sections of Tivanka Image House. Efflorescence has also been observed above the bricks that are affected by deterioration Type 1. During the recent restoration work, bituminous tar sheet has been laid on the interface of the new and old brickwork and efflorescence has occurred at this brick - tar sheet interface. This efflorescence problem is due to thick mortar joints and usage of high proportion of cement and lime as the constituents of mortar as the unbind cement and lime have increased the amount of soluble salt content and movement of the ions.

Deterioration Process 2

Unlike deterioration Type 1, no detached particles were seen deposited in the immediate vicinity. There are also no loosely bound particles on exposed surfaces of the brickwork that are affected by the deterioration process 2. In contrast to the concaved coarse surfaces of the bricks affected by deterioration Type 1, this process produces smoothly rounded hard, as well as fine surfaces with aerodynamically stable shapes. This damage always occurs on pilasters and other projected decorations, and on wall surfaces that are exposed to the wind direction (fig. 5). Bricks samples (TV1 and TV2) from the areas that are affected by deterioration type 2 show relatively low soluble salt content. It could most probably be attributed to the friction of seasonal high winds prevailing in the area. A comprehensive study of the wind pattern and analysis of several samples from different areas are necessary to have a firm conclusion in this regard.

Figure 4 shows the bricks close to each other on exterior wall surface at Tivanka Image House that have been affected by both deterioration Type 1 and 2. In this case, deterioration Type 1 is active on isolated bricks. Plaster on such bricks has already disappeared, and the exposed brick surfaces continued to be worn out creating concave surfaces. This clearly indicates that deterioration Type 1 is a result of inside force (i.e salt crystallization within the pores) rather than an outside force, such as wind. In this case, the wind performs only a supportive role to enhance the evaporation of moisture within the bricks, thus creating a super saturated solution, and then accelerating the removal of loosely bound particles present on the brick surface.

Deterioration Process 3

This damage can be clearly attributed to a particular insect. Although the effect of this process is relatively low at present, it could subsequently initiate further deterioration (fig. 11). This biological factor needs to be studied in detail to arrest the deterioration process.

In addition to the above identified deterioration processes, growth of moss and lichens can also be seen on the wall surfaces. This may also contribute in a small scale to the deterioration of fine details on the brick surfaces.

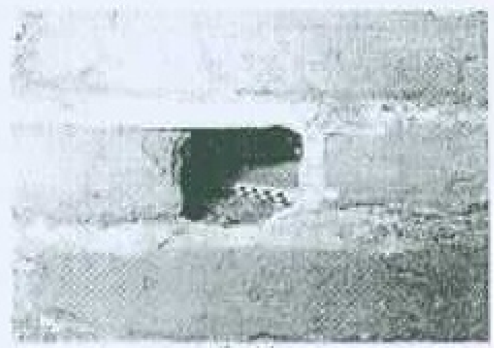

fig.11

Conclusion

According to both visual observations and experimental results, this study emphasize several interlinked environmental factors such as temperature, humidity, wind, rain, together with other chemical and biological causes which are responsible for ongoing deterioration processes of the brickwork at Polonnaruva. The damage caused by the crystallization of soluble salts could be seen as more destructive than any other cause.

Due to several practical restrictions, this study is limited to the analysis of few samples obtained from the affected surfaces of the monuments. In order to reach more definite conclusions, it is necessary to take samples from top to ground level and carry out analysis of core samples to identify the exact gradient and the direction of the salt flow.

Damages similar to this study can be observed in most of the ancient brickwork which have been distributed throughout the country. It is necessary to take immediate remedial measures including desalination of affected walls using appropriate methods, arrest the rising damp, avoiding movements of salts, minimizing wind erosion and improving drainage facilities etc. for the minimization of further deterioration of these valuable archaeological treasures of the island.

Acknowledgment

Authors greatly appreciate the cooperation extended by Sirinimal Lakdusinghe, Former Director, PGIAR and W. H. Wijayapala, Director General, Department of Archaeology during the field work, and also would like thank the Central Cultural Fund for providing financial assistance and other logistics for the chemical analysis. We also grateful to Dharmarathne (Head security guard - Dept. of Archaeology) for the help given us during the field work.

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