DRAINAGE LAYOUT OF KHMER Temples IN THE ANGKOR COMPLEX

Orientation of the drains and the methodology of the drainage system arrangement

This paper is a study on the drainage systems and orientation of flow in both the temple-mountain and temples built on plain in the Angkor complex, by comparing them with the drainage system of Bayon in order to clarify the arrangement method of the drainage systems in the ancient Khmer temples. The results of the study on the drainage system in the Bayon indicated that the orientation of the drains was set up to the north and south, but according to the remodeling process in which the new drains were added, it was difficult to keep to the same rule as the existing layout of the drain. The methodology of the arrangement of the drainage system, the methods of directing the flow of rainwater, the typical layout of the drain and its orientation and the shape of the drain’s outlets are presented in this paper.

Keywords: Cambodia, Khmer Architecture, Angkor Monuments, Angkor Period, Drainage, Orientation

1. Introduction

The ancient Khmer temples were built for religious purposes, and show characteristics of integrated art in architecture and plastic art that remained in Cambodia and in a number of the temples scattered in Thailand, Laos and Vietnam today. This paper mentions only some of the temples in the Angkor site, particularly the temple-mountain and temples built on plain. (Fig. 1)

The drainage of Bayon has been studied in detail, to identify and distinguish each drain by its purpose, physical feature and function as well as to analyze how malfunction of those drains were the main purpose of the studies. In this paper, a comparative study between the drainage system of Bayon and those of the temple-mountain and temples built on plain in the Angkor site on the method of the arrangement of drain layout and the orientation flow of the drains, is the main objective. The drainage practices in religious ceremonies will be studied in detail in later chapters.

Some art decorations on the drains' outlets are in existence; mythological animals like makara, gajasimha, kala, lion, elephant and crocodile are represented in the temples.

2. Research Methodology

The drainage systems of Khmer temples were investigated at the beginning of the 20th century by l’Ecole Française d’Extrême-Orient (EFEO); however, their studies were not conducted in detail, such as Bakong, Eastern Mebon, Pre Rup and Angkor Wat. In 1967 and 1973, J. Dumarcay drew a drain plan of Bayon and gave a summary explanation on water evacuation of this temple.

The research methodology was based on the above document and carried out the investigations at the sites and collected the data of the drains and drew the plans of each temple. Many difficulties were encountered during these investigations because most of the temples were seriously damaged, with many drains buried under mounds of earth and piles of stones. At some temples, it was necessary to clear earth and pour water into the drains in order to clarify the drainage network. Measuring the size of the drain’s outlets and taking photographs for documentation for further studies were also one of main purposes of the study. All of the drains’ plans are presented but only the visible drains’ locations could be clearly confirmed. Only those drains that were visible were counted.

3. The construction and the management of drainage systems in Khmer temples

Generally, the construction of the temples, regardless of their size, required rainwater drainage systems or drainage to evacuate water used in religious ceremonies. Ancient Khmer temples were built singly or in complexes and built on natural
or artificial mountains or on plains, where ponds or surrounding moats are set. Moreover, it was necessary to evacuate rainwater from each temple. The arrangement of the drainage system was planned at the time of construction, but also some drains were later added when there were problems, with the system malfunctioning. The results, according to the investigations on each relevant temple, confirmed that the method of evacuating rainwater was from the top downward and from the inside outward.

3.1 The arrangement of drainage system

3.1.1. Drain arranged with plans

The drains arranged with plans are well done and the inner structure is curved as a groove, usually made by sandstone, laterite or brick. During the Angkorian era, the drains were arranged and located at proper places. The grooves were smooth, straight or serpentine according to the shape of the terrace platform. (Ph. 1) This type of drain was built across the galleries or enclosure and across the tower base. The galleries, walls and roofs were constructed over this, on the drainage.

3.1.2. Additional drains

Additional drains can be identified by their carving type, in which the traces of chisel marks remaining visible indicate that the drain was added after construction was finished. This additional construction is especially seen at Bayon as the construction phases were conducted at different times and the drains were undertaken accordingly. Moreover, the additional new drains were carried out when the old drains were not flowing adequately or its drain began to malfunction when evacuating water from inside the temples. (Ph. 2)

3.1.3. Uncompleted drains

This type of arrangement is seen at Ta Keo, and in one drain at Phimeanakas. These drains were not additionally constructed, but were located at the planned places, with the connections not yet done between inlet and outlet; probably it was postponed until the construction was completed. At Ta Keo, most of drains of the second gallery were uncompleted.

1. Prasat Bakong (▲)
2. Prasat Lo Lei (▲)
3. Prasat Bakong (▲)
4. Prasat East Mebon(▲)
5. Prasat Pre Rup (▲)
6. Prasat Banteay Srei
7. Prasat Ta Keo (▲)
8. Prasat Phimeanakas (▲)
9. Prasat Baphuon (▲)
10. Prasat Angkor Wat (▲)
11. Prasat Banteay Samre
12. Prasat Ta Prohm
13. Prasat Preah Khan
14. Prasat Banteay Kdei
15. Prasat Neak Pean
16. Prasat Ta Som
17. Prasat Bayon (▲)

(▲): Temple-mountain

Fig. 1. Site plan of Angkor monuments.

Ph. 1. Angkor Wat, first gallery, drain with planned, which the inner structure was dug before the construction.

Ph. 2. Bayon, outer gallery, northern face, the inlet and outlet of drain were dug from outside faces.

3.2. Type of the drain's outlet

Typical drain outlets can be categorized in various shapes and sizes, from one temple to another. Sometimes, a temple got many types of shapes, such as circular, rectangular, square or lozenge-shaped etc. Fig. 2 shows the shapes of drain outlets that classified into four main types, which are the shapes commonly found in Angkor monuments. The classification was conducted by identifying the characteristic of its shape: circular or curving, rectangular and the plectrum type and was given its name by alphabet. (Table 1, Fig. 2)

4. Comparison of the water evacuation systems in Khmer temples

In general, Khmer temples were built as single towers or in group complexes. The water evacuation system was designed to allow the rainwater flow from upper levels downwards and from inside the temple complex to the exterior. The water evacuation systems were arranged by many methods, depending on the layout of the temples and the period of their constructions. The water evacuation system has been classified into the following
Table 1. Typical drain outlet of Angkor monuments.

<table>
<thead>
<tr>
<th>No</th>
<th>Name of monuments</th>
<th>Outlet in G-1</th>
<th>Outlet in G-2</th>
<th>Outlet in G-3</th>
<th>Outlet in G-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bakong</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Ta Prohm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Pre Rup</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>East Mebon</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Keo</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Ta Keo</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Ta Som</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Bayom</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Phimeanakas</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Angkor Wall</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Ta Prohm</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>12</td>
<td>Ta Keo</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Ta Som</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Bayom</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Fig. 2, Section plan of drain outlets, type of outlet.

Table 2. Orientation of the drain and method of rainwater evacuation of Angkor monuments.

<table>
<thead>
<tr>
<th>No</th>
<th>Name of monuments</th>
<th>Type of Temple</th>
<th>Location and orientation of the drain</th>
<th>Method of rainwater evacuation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bakong</td>
<td>Mountain</td>
<td>Rainwater</td>
<td>1. Suitable</td>
</tr>
<tr>
<td>2</td>
<td>Ta Prohm</td>
<td>Mountain</td>
<td>Rainwater</td>
<td>2. Not Suitable</td>
</tr>
<tr>
<td>3</td>
<td>Pre Rup</td>
<td>Mountain</td>
<td>Rainwater</td>
<td>3. Not Suitable</td>
</tr>
<tr>
<td>4</td>
<td>East Mebon</td>
<td>Mountain</td>
<td>Rainwater</td>
<td>4. Not Suitable</td>
</tr>
<tr>
<td>5</td>
<td>Keo</td>
<td>Mountain</td>
<td>Rainwater</td>
<td>5. Not Suitable</td>
</tr>
<tr>
<td>6</td>
<td>Ta Keo</td>
<td>Mountain</td>
<td>Rainwater</td>
<td>6. Not Suitable</td>
</tr>
<tr>
<td>7</td>
<td>Ta Som</td>
<td>Mountain</td>
<td>Rainwater</td>
<td>7. Not Suitable</td>
</tr>
<tr>
<td>8</td>
<td>Bayom</td>
<td>Mountain</td>
<td>Rainwater</td>
<td>8. Not Suitable</td>
</tr>
<tr>
<td>9</td>
<td>Phimeanakas</td>
<td>Mountain</td>
<td>Rainwater</td>
<td>9. Not Suitable</td>
</tr>
<tr>
<td>10</td>
<td>Angkor Wall</td>
<td>Mountain</td>
<td>Rainwater</td>
<td>10. Not Suitable</td>
</tr>
<tr>
<td>11</td>
<td>Ta Prohm</td>
<td>Mountain</td>
<td>Rainwater</td>
<td>11. Not Suitable</td>
</tr>
<tr>
<td>12</td>
<td>Ta Keo</td>
<td>Mountain</td>
<td>Rainwater</td>
<td>12. Not Suitable</td>
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<tr>
<td>13</td>
<td>Ta Som</td>
<td>Mountain</td>
<td>Rainwater</td>
<td>13. Not Suitable</td>
</tr>
<tr>
<td>14</td>
<td>Bayom</td>
<td>Mountain</td>
<td>Rainwater</td>
<td>14. Not Suitable</td>
</tr>
</tbody>
</table>

Method 1: Evacuate rainwater over the stairway
This method is seen only at Bakong. (Fig. 3-1, Table 2) This system was designed to accumulate water on the terrace pavement, where the water is prevented from flowing over the terrace steps by creating higher eddies all around the terrace; and water is allowed to flow down only over the stairway to the lowest gopura, before flowing out through the drains constructed on both sides of the walls between the gopura and the terrace walls (there are four gopuras, one at each direction, and two drains were set at each gopura; the drain facing in four directions: southeast, southwest, northwest and northeast).

Method 2: Evacuate rainwater over the terraces steps of mountain temples
This method is particularly seen at Bakheng, drainage not being constructed in this temple. (Fig. 3-3, Table 2) The rainwater that accumulates on the terrace pavement flows from the upper terrace over the terrace steps (six tiers) downwards. Using this method of rainwater evacuation system caused the destruction of most parts of the terrace walls. Rainwater has flowed and infiltrated into the gaps opening at the terrace edges causing the accelerate erosion of the laterite, the walls were tended to collapse.

Method 3: Evacuate rainwater over the terrace steps and follow the flow through the drains network before flowing outward
This method is seen at Eastern Mebon, Pre Rup and Ta Keo. (Fig. 3-4, 3-5 and 3-7, Table 2) The arrangement of the drainage system was better developed than previously, but the terrace of uppermost is no drain and follows the concept of method 2 like at Bakheng.

Method 4: Evacuate rainwater through the drainage and flows over the terrace steps
This method is seen only at Phimeanakas. (Fig. 3-8) The plan of this temple itself was developed from those of Mebon, Pre Rup and Ta Keo, in which the enclosures become the gallery and the construction of the drain was set across and beneath the galleries outwards. (Fig. 3, Table 2)

Method 5: Evacuate rainwater through a group of drains to another group
This method is seen at Mebon, Pre Rup, Ta Keo, Banteay Srei, Baphuon, Angkor Wat, Banteay Samre, Ta Prohm, Preah Khan, Banteay Kdei, Ta Som and Bayon. The rainwater is evacuated from the top through the groups of drains that are set up at the enclosures or galleries into other groups of drains set up at the outward enclosures or galleries. Mebon, Pre Rup and Ta Keo could be counted in this method, but are more appropriate for

*Drain used for religion ceremony are 13, if included drain inside the shrine would be 15. **Original drains were 28, but present exist only 9. (●) Appropriate. (○) Perhaps.
Fig. 3, Plan of temples and its drainage layouts. (M: Method of water evacuation, T: Type of drainage layout, (): Tower or pavilion, ( ): Drain)
Method 4, because these monuments have uppermost terraces where the drains were not set up.

Among Angkor monuments, Angkor Wat is the best, both in arrangement and the construction work. The inner construction of the drain was fine, wide and well finished. (Fig. 3, Ph. 1)

Method 6: Evacuate rainwater through a group of drains to another group, finally flowing into the pond or moat

This method is seen at Banteay Srei and Neak Pean (Fig. 4-4) in particular. At Neak Pean the drainage system allowed water flow from the central pond to the four small ponds in order to celebrate religious occasions. The drainage at Ta Prohm, Preah Khan, Banteay Kdei and Ta Som were similar to that of Banteay Srei: there moats and ponds can be seen surrounding inside the enclosures. But at present, the drainage network connecting the drain of the galleries or enclosure to the pond or moat cannot be identified since earth and trees have covered them. Logically, water is being drained from inside the temple outward into the pond or moat. (Fig. 3, Table 2)

5. Locations and orientation of the drains

The orientation of the drains for rainwater evacuation of each temple were set in location that were decided according to the period of construction and their religious purpose. The drainage systems of Khmer temples are divided into two types: the drainage used for religious ceremonies and drainage to evacuate rainwater outward. The orientation and location of the drains are clearly divided and set. At Bayon, investigations of the drainage were carried out and analyzed, and the layout of the drainage was found to be closely linked to construction phases. Moreover, based on archeological and architectural studies and field investigations, the fundamental concept of the drainage layout was based on the north and south direction. On the other hand, the location and orientation of the drainage in the Angkor monument was designed according to the period of the construction, but some temples even has time span from Banteay Srei and Bayon, the drainage method seems re-utilize again.

5.1 Locations and orientation of the drains used in religious ceremony

The orientation of drains was set according to the evolution of the architecture and styles. In the pre-Angkorian era, the drain was constructed facing to the north or west. At the time most temples were constructed singly and there was only one entrance, generally facing east, the orientation of the drain always faced to the north; even though some temples faced west, as in Ashram Maha Rosei (Phnom Da), Preah Theat and Sambor Prei Kuk temples etc. But there is special case as Badom temple (Stung Treng) the orientation of the drains were directed to west. The decorations of the drains' outlets in pre-Angkorian temples were usually ornamented by a makara or lion head.

During the Angkor period, the layout of temples was developed. In general, the main tower was opened to four directions. Therefore, construction of the drainage used in religious events generally faces northeast to avoid disturbances of access, for instance, in Angkor Wat, Banteay Samre, Preah Khan, Ta Som and Bayon. However, at Preah Khan, both mentioned methods were used because some towers have only one entrance or two entrances. No decoration is seen at drain outlets during the Angkor period. (Fig.4, Ph. 3)

Moreover, at Neak Pean, the drainage was constructed and faced in cardinal direction and was connected from the central pond. Each outlet was decorated with a human face at the east, a lion head at the south, a horse head at the west and an elephant head at the north. (Ph. 4) At Lo Lei, the grooves used in religious ceremonies were constructed at the center inter section of the four towers let water flow from the center in cardinal directions, but the purpose of this was not clear. (Fig.3-2)

5.2 Locations and orientation of drains for rainwater evacuation

The theory for the settling of the drainage orientation is very interesting, following the periods and styles of the construction and its evolutions. The following are typical layouts and characteristics of the location and orientation of the rainwater drainage systems of each temple and group of temples.

Type 1: Drains set at the corner of the gopura wall

This type of drain settlement is only seen at Bakong. (Fig. 3-1, Table 2) The drain's orientation was directed outwards from the corner of the wall between the gopura and the wall of the lowest terrace platform. The drainage of Bakong does not face the cardinal point and is neither directed towards the north or the south. As in Fig. 3-1, the drainage layout set up two drains at each gopura. The angle of the drain's orientation is 45° compared with the wall of the gopura and the wall of the terrace platform.

Type 2: Drains set at both sides close to stairways, its
orientation was set in cardinal directions
This type of drain settlement is seen only at Lo Lei. (Fig. 3-2, Table 2) This layout has evolved from Bakong, but here the gopura was eliminated, so the drainage was constructed at both sides of the stairways. At the east entrance, there are two drains facing towards the east and crossing the second terrace and continuing to the first terrace. The south entrance has two drains facing south. At the west entrance, two drains face west, and one drain on the southern side of the stairway has been repaired and replaced with concrete gutters. Of the drain on the north side of the stairway at the second terrace, the bottom part of a makara's mouth is all that remains. At the north entrance, on the drain on the west side of the stairway of the second terrace a head of a makara remains. This drain also continues to the first terrace. The drain on the eastern side of the stairway projects from the second terrace in the same way as the drains at the east entrance. In summation, the drains at Lo Lei were constructed to face in cardinal directions and located at the side of stairway.

Type 3: Drains set facing in cardinal directions and run across the enclosures or galleries, located between gopura and the corners of enclosures or galleries
This type of water drainage is seen at east Mebon, Pre Rup, Ta Keo and Phimeanakas temples. In Banteay Srei, Banteay Samre, Ta Prohm, Preah Khan, Banteay Kdei and Ta Som, the orientation of some drains were directed to the east or west, but these are not counted in this type. The drains in type 3 have features similar to those of type 2. There are two drains at each face but their locations are little different, while the drain is located far from the stairways. In general, each drain is located between the stairways and the corner of the enclosure or galleries. However, the drains at the second enclosure of east Mebon on the west face, and those at the first enclosure of the east and west faces of Ta Keo, still kept the same location as those of Lo Lei. The drains of type 3 generally were installed to face in cardinal directions by setting one drain between gopura and the corner of the enclosure or gallery. However, at Ta Keo, the first enclosure of the eastern wing north face and north wing west face, two drains were set at these parts. According to our investigation the north face of the west wing the are about 15m long of the enclosure at eastern part, the wall was collapsed or the construction was unfinished and perhaps left this part as a path for carrying construction materials. (Fig. 3, Table 2)

Type 4: Drain set to face in cardinal directions and run across the galleries; each two drains were set between gopura and the corner of the enclosure
This type is seen at Baphuon and Angkor Wat. However, at the second and third galleries of Baphuon, and at the third gallery and cruciform galleries of Angkor Wat, there is only one drain set across the galleries similar to the drains of type 3. Baphuon and Angkor Wat are similar in layout and in their tiers of galleries. (Fig. 3-9, 3-10, Table 2) Furthermore, at Angkor Wat and Baphuon the drain at the outermost gallery of the front face was never installed.

Type 5: Drain set to face to the north and south, and run across the enclosure and or gallery
This type is seen at Banteay Srei, Banteay Samre, and in the temples in the style of Bayon, especially the drains of Bayon. According to the construction phase of Bayon, the chronological order of drainage construction was also conducted phase by phase. Beginning from the first phase the main purpose was to set the drainage up to the north and south. Following the phases of construction (third stage-2) the orientation of the drains followed the above theory, but according to the remodeling process where the new drains were added, it was difficult to keep to the same rule as the existing layout of the drain. (Fig. 3-17)

At Ta Prohm, Preah Khan and Banteay Kdei, particularly the dancing hall where the drain was constructed to face to the north and south, it is difficult to come to a conclusion regarding the whole layout of the above temples due to the scattered stone covering the enclosures and galleries.
At Banteay Srei, the drainage was constructed to face to the north and south at the first and second enclosure and at the causeway between the east gopura of the second enclosure and the east gopura of the third enclosure. Furthermore, along both sides of the east gopura of the third enclosure, the two drains flanking the gopura were connecting from the fourth enclosure into the third enclosure, which was very recently discovered by the Swiss organization of Banteay Srei Conservation Project in late 2004. The drains were installed to face to the west, because rainwater accumulated inside the fourth enclosure area was made to flow to the moats, in order to accumulate the water to be used for daily life, so the drains should face to the west.
At Banteay Samre, the drainage system was constructed to face to the north and south too. But at the second gallery, there is a drain face east at the east face of the south wing. However, there has not been any confirmation about the existence of any drains at the north part. Similarly, there are no drains at the first gallery of the northeast part. Banteay Samre has been included in this type because the majority of the drains face to the north and south. (Fig. 3, Table 2)

6. Malfunctioning of drainage system and the deterioration of the monuments
Deterioration of Angkor monuments is caused by many factors. One is the malfunctioning of drainage systems as a result of lack of maintenance over time; it is expected to contribute to the degradation of the buildings at the present. On other hand, the original technical arrangement of drainage system is closely linked to the damage affecting the architecture. For instance, Bakheng is one of the so-called mountain temples, and was built on the natural hill Phnom Bakheng, its foundation mass was directed to the hill rock by laying laterite blocks inside, against the sandstone and hill rock. Here the drainage system was not set up, the method for evacuating rainwater was in method 3 that let the rainwater flow over the terrace steps from upper levels downwards. The displacement of terrace platform conducted by laterite material effected decay caused by rainwater penetration and flow cycle occurring in the foundation mass; furthermore, its terrace walls have slipped and giving serious damage by collapse. (Ph. 5) Moreover, on the upper terraces of Eastern Mebon and Pre Rup, the terrace platform was displaced, as it was at Bakheng.

At the Bayon, all towers confirmed that the tendency of inclination to lean outward is related to structural weakness and also caused by the water that penetrates inside the foundation mass causing sand and soil to come out with rainwater through the small joint openings of the foundation walls. (Ph. 6)

The conservation of Banteay Srei was conducted by choosing the method of renovation and reactivating the existing drainage system and creating trickle shafts to absorb rainwater that
accumulated on the terrace courtyards. This method would be the best for this temple, which lets water drains out as fast as possible to avoid damp remaining inside the courtyard.

The conservation and restoration of each temple should be firstly considering how to restore and renovate its drainage system; and it should be raised up as the intervention method.

7. Conclusion
The main result of this study shows that the arrangements of the drainage systems of the Angkor monuments are as follows:
1) The drainage system arrangement in Angkor temple was constructed in the initial plans; some additional drains were required in order to improve the original system or followed the modified construction works. Moreover, there are uncompleted drains existing according to the temples' construction was uncompleted.
2) Method for evacuation rainwater was classified into six types.
3) The section size of drains' outlets were divided mainly into four groups with each group including various types of shape. Sometimes the drain outlets on a temple have various types of shape.
4) The arrangement of orientation and setting the location of the drains are:
   a) The drainage practice in religious ceremonies in Angkor was divided into three types: the drain directed to the north, northeast and to the cardinal direction.
   b) The drainage serving for rainwater evacuation was divided into five types.
5) The comparison of drainage systems between Bayon and mountain and plain temples, shows that during 500 years of construction there is a wide variety of system types. Moreover, it could be said that the evolution of the drainage arrangements are related to the chronological order of the temples construction period.

Finally, most Angkor temples drainage systems have fallen into malfunctioning, which greatly contributes to the degradation of the buildings, displacement of their foundation mass, so draining off the rainwater from the temple is required for future conservation.

Notes:
3) Gajasimha: Lion with elephant head (style of Preah Ko), J. Boisselier, op.cit., p. 319.
4) Kdau: a head of monster also is representing Rahu, J. Boisselier, op.cit., p. 318; V. Roveda, op.cit., p. 173.
7) So Sokunheuy, op.cit.
8) Unpublished report of Banteay Srei Conservation project and data collected by authors in August 2004.