

Explication of messages left in trust at the time of construction of the Angkor Wat Western Causeway

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The following is the substance of an explanation of techniques of the earthen construction part that was presented at the ICC conference in December 2002.

Basic investigations such as taking measurements and making a structural survey of parts of the interior were started in 1995. Subsequently, dismantling of the Area I work zone work began on 30 October 1998. As the work of dismantling progressed, we started to decipher various messages from the past, such as Khmer construction methods, technical skills, masonry, rammed earth construction and materials analysis.

We thought it absolutely necessary to clarify the real technical situation to follow on from the oral tradition of handing down Khmer working methods. We started to obtain an understanding of the techniques and work methods devised by the old stonemasons, which cannot be explained by modern engineering analysis. And some very interesting discoveries were made as a result. (As a result of the dismantling, we were able to confirm the construction of the Causeway as shown in Slide 10.)

The dismantling proved that the way laterites are laid in the corners of the walls is as shown in Slide 5. Also, as shown in the right hand part of Slide 5, the laterites are not always parallel but in some places they are laid slightly obliquely. Moreover, as shown in Slide 7, up to a height of about 1.2 m the earthen strata within the causeway are made up of beds of very pure clay. For about another 2 m up from there, the layers are alternated with layers of rubble inserted between the layers of clay.

Close observation of the clay layers shows that overlapping layers are formed by a method of construction known in east Asia as "hanchiku" (rammed earth), which involves spreading a layer of earth in formwork and tamping it down hard to produce an effect that is not likely to collapse or subside unevenly. Above these layers is a layer of extremely well sorted fine sand about 60 cm thick. Laterite is laid over this and finished with sandstone packed in sand.

Slide 7 shows the remaining parts that have not collapsed since the time of their original construction. When we look at these we see that they are packed so tightly that the Khmer earth construction method bears no comparison with the rammed earth construction that flourished in China. From these characteristics we see that the method of filling the laterite wall involves first placing a row of laterites along a line then filling the inside with earth and pounding it hard with a stick. The laterite row is about 30 cm thick and when the inside has been filled up to the top of the laterites and well rammed, it comes down by half to about 15 cm thick. Another layer of filling is then rammed down to about the thickness of the laterites and a second row of laterites are laid on top. At this time the laterite is well rammed before being filled inside with earth and the filling is then rammed tight. This process is then repeated and we believe that the rammed earth structure seen on the causeway is the result of work such as this. If this is so, what was the purpose of adopting this form of construction?

In considering this question, we used the rammed earth construction method to make a model having sand and clay layers and conducted an experiment to see what sort of reaction was produced when it was flooded from the top with water (Slide 9). The result is that the movement of water in the waterproof clay layer is extremely slow and it was intended to be dispersed horizontally in the laterite rubble layer. So it served to stop the movement of water entering from the top. We also believe that the clay layers at the bottom of the causeway may have been the result of a technique to stop the water entering from the moat. Should the insertion of layers of rubble between the strata and ramming them down tight be caused by the "Khmer rammed earth method"? In any case we believe this kind of construction method was derived from the Khmer people's long experience with devices for natural drainage of rainwater but we wish to hold back the details pending future investigation.

As above, the original construction methods that can be seen in the method of providing laterite paving beneath the sandstone

paving, the bonding of laterite wall stones in the corners of the central terrace, the internal earthen filling (rammed earth method) and the laying of laterite stones in the foundations that support the side walls, show the characteristics of Khmer construction in which structures of stone are made as unified as possible by combined masonry methods that can be seen in the use of wedge shaped stones and notched jointing. Moreover, the earthen construction of internal Suing that supports the laterites and sandstones in this way is so well compacted that it can be called the "Khmer rammed earth method". Furthermore, the technique of using alternating layers of clay and rubble is probably the result of devices to somehow slow down the movement of rainwater and for natural drainage to prevent the loss and movement of sand and earth. Restoration work requires reconstruction to restore natural drainage using the same "Khmer rammed earth method" as the original sections.

Also, concerning the retaining walls and causeway foundations of laterite masonry, the header bonds of the side walls are laid slightly obliquely so that the walls will withstand the earth pressure caused by infilling the interior of the causeway. Vee-shaped laterites have been inserted in some places for compression (Slide6).

The ground under the foundations has been improved by sand foundations, above which the sand layers are jammed between rammed earth layers and covered by a five-Step laterite platform to prevent sand loss and uneven subsidence. These and other matters were reported at the ICC Conference in July 2001(Slide10).

It is well known that Khmer masonry, whether laterite or sand stone, Was Put together with "dry masonry" (that is, with no adhesive or other material inserted between the stones to prevent gaps) but how that was actually done was never adequately explained. This point has also been clarified by the work on the causeway.

From time to time the bonding surfaces of dry masonry are described as being "too tight to insert a razor blade". At one part on the Western Causeway the work is so finely done and the bonding between the stones is so tight that rainwater actually collects on top of the joints. We found many grindstones in the earth inside the causeway that we think were used for processing surfaces such as these. This is based on the fact that those stones are rounded all over with only one artificially smooth face. When the materials were being processed, it is highly probable that the Final Smooth surface finish was applied with these grindstones after they had been worked with a chisel.

By conducting experiments in surface polishing using these grindstones on sandstones and laterites, we were able to make smooth surfaces more quickly than we had thought possible (Slide 1 I). The bonding surfaces between the stones are the most important part of dry masonry. That is where the minutely processed shape of the bonding surfaces is verified. With porous laterite, it is hard to prove and difficult to measure the shapes in milli-units. So I will take a sandstone paving stone as an example here. But we believe the same technique was used for laterite.

On close examination of the bonding surfaces we found that the paving stones do not actually fit together evenly. The stones fit most tightly for several centimeters at the top. Also, they have not been worked so diligently at the bottom where round chisel marks can be seen and we found that the processing had been done less diligently than at the top. The center of the surface was white with powder, raising a question about the closeness of the fit of the stones in this section. When measured by applying a carpenter's square, the actual lowering of the central part was of the order of one or two millimeters. In other words, in order for the paving stones to fit closely near the top surface the other parts had been very slightly hollowed. This is difficult to express diagrammatically but we can say that stonemasonry was one of the very important techniques that made Khmer dry masonry substantially successful.

We have been aware of a high probability that grindstones were used to process the surfaces of stones for dry masonry. If we accept rubbing the stones together as one of the causes, it is true that fine stone dust would remain in the hollows that had been cut into the matching faces of the stones. Abrasion with sand as the grinding medium is also conceivable but there is no confirmation of sand being included in the stone dust buried in the holes in the matching faces of the paving stones in the Western Causeway.

The bonded surfaces appear to have been coated with an extremely fine powder. This shows that the stones were sprinkled with water while they were ground and the milky emulsion that was produced acted as a kind of adhesive (Slide12).

The matching surfaces of the stone appear to be straight but on closer examination many are curved. To make adjacent faces with the same curve or far closely fitting materials with two or more faces, it would have been rational to grind them both straight. It is probably natural to think of adjusting the grindstones or using replacements. We still know nothing about problems such as a stone having a large step that would have been difficult to grind directly or the technology for precision working, grinding and installation of a single sandstone weighing several hundred kilograms or more than one ton.

When we pay close attention to observing all of the parts that make up the causeway, we begin to understand the devices that have been applied with the use of natural materials to make it strong enough to enable its original form to be preserved without collapsing over a long period of time.

Although they did not write in words; by leaving us the causeway, the 12th century engineers seem to be telling us proudly, "How about this?"