TECHNOLOGICAL ASPECTS OF ANCIENT STUPAS IN SRI LANKA

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Introduction

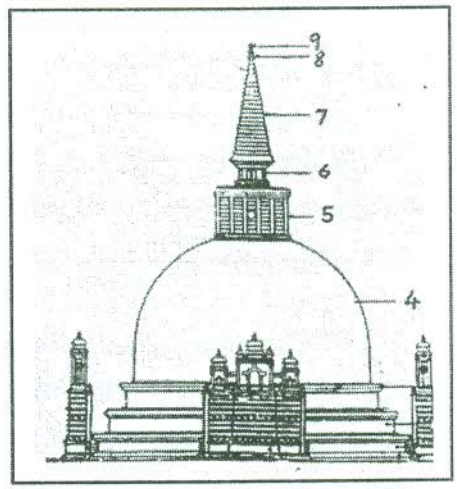
Prominent among the ancient technologies related to structural engineering in Sri Lanka are those associated with the Stūpas [1]. Some of these ancient Stūpas date back to the third century BC, and over the years they have developed into mega structures, some of which are amongst the largest brick structures in the world [2], and they have been carefully designed and constructed by the ancient builders in Sri Lanka.

Thuparamaya built in the 3rd century BC, is considered the oldest Stūpa in Sri Lanka.

Jetavanaya which reached a height of 121.9metreswas at one time the third tallest structure in the world, and it still is the largest brick structure in the world.

Architecture

Stūpa is a solid structure, mostly made of burnt bricks. Main components of a Sri Lankan Stūpa are shown in the Figure. The Stūpa rises from a stone paved terrace and at the bottom there are one, two or three (1,2,3) basal rings. The Stūpa dome (4) rises above them, and at its top, the dome carries the square chamber (5) -a solid having a square plan. Then comes one or more cylinders (6), theconical spire (7), the pinnacle (8), and the crystal (9).



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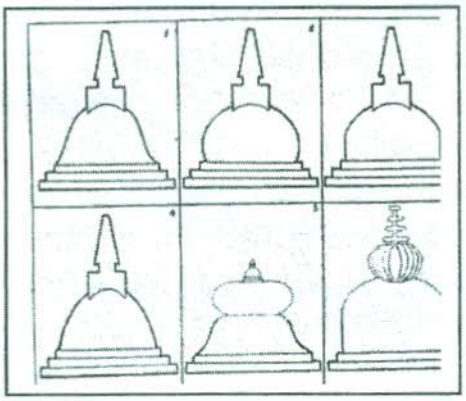
The dome is the biggest component of a Stūpa and several shapes have been used for the dome, and some examples are given below.



Stūpa Shapes [3]

Stupa	Dome Shape	Present Height(m)	Base Diameter (m)
Thuparamaya	Bell	19.2	18.0
Kirivehera (Kataragama)	Pot	28.0	26.8
Mirisavetiya	Bubble	43.0	54.0
Ruwanveliseya	Bubble	103.0	91.4
Abayagiriya	Paddy -heap	74.7	94.5
Jetavanaya	Paddy -heap	70.7	111.9
Kirirvehera (Polonnaruwa)	Bubble	24.4	25.6

Details of Some Stūpas

The bell shape(1) is the most common and next comes the bubble shape(3), followed by the paddy-heap shape(4).Domes of pot(2) and lotus(5) shapes are rare and there are no existing examples of the Nelli fruit shape(6).

Materials and Stresses

The main building block of a Stūpa is the burnt brick, and bricks much larger than modern bricks have been used in ancient Stūpas. Bricks of different sizes were used for different parts of the same Stūpa, larger ones for basal rings and the dome, and smaller ones for the spire. Typical sizes and masses of bricks used in Abhayagiriya are given below.

Laboratory tests have shown that ancient bricks are more stronger than modern factory made bricks in Sri Lanka; the strength of ancient bricks is around 8 -12 MP a whereas that of modern bricks is around 4 - 7 MPs. Mineralogical studies have shown that the ancient bricks from Jetavanaya have a sand content of 55- 65% compared with 35 - 45% in modern factory made bricks, and this may be the reason for the strength difference. The ratio

of silt to sand is even in the ancient bricks indicating better quality control in ancient brick making [2].

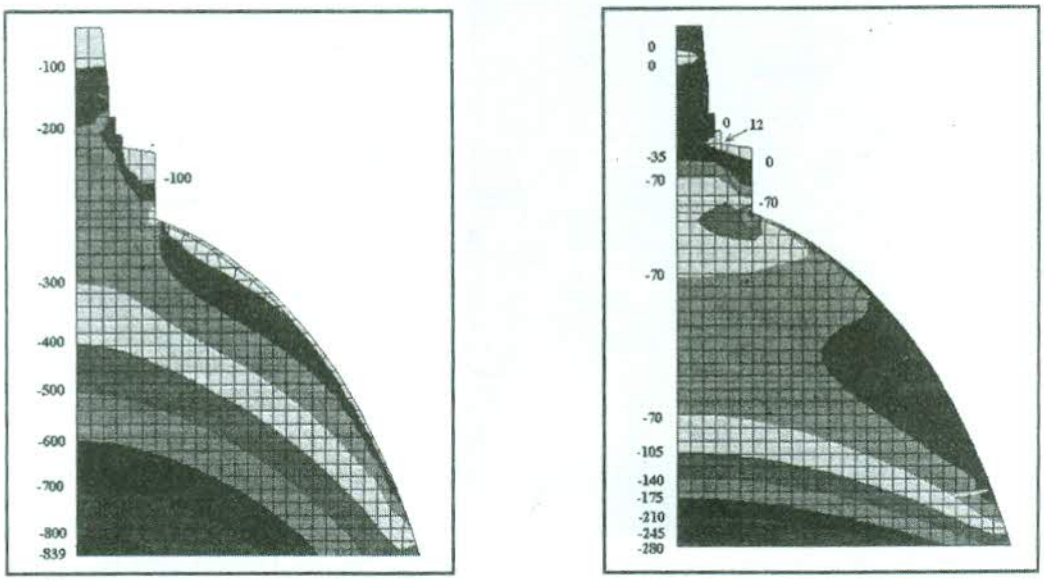
Location	Dimensions (LxWxT- mm)	Mass (kg)
Basal rings	320x280x85	12.3
Dome	450x230x80	13.1
Square chamber	250x160x70	5.15
Spire	210x150x55	2.48

Bricks Used in Abayagiriya

The mortar used in ancient Stūpa construction is a very thin butter clay, like a slurry. With this thin mortar the bricks essentially sit one on top of the other, the slurry filling the gaps. This gives strong brickwork, unlike the modern brickwork which uses a thick mortar which can weaken the brickwork. At the outer surface, Stūpa brickwork was water proofed using a thick plaster. Some of the Stūpas have several layers of plaster reaching overall thicknesses of up to 250 mm. One of the best preserved examples is the Kirivehera at Polonnaruwa.

Stūpa dome is solids of revolution whose main loading is due to its self-weight, and hence it's primarily stresses are compressive. Finite element analyses [2] have shown that in Jetavanaya, the largest Stūpa ever built, the maximum vertical compressive stress is around 840 k Pa, which is about one tenth of its compressive strength. Circumferential tensile stresses also can develop at the outer surface of a Stūpa dome, and it was found that they are largest in the domes of pot shape whereas in domes of paddy-heap shape

there is no tension at all. Hence, as bricks are weak in tension, paddy-heap shape is the most stable from a structural point of view, and ancient builders have used this shape for the mega Stūpas they built.



Vertical stresses circumferential stresses

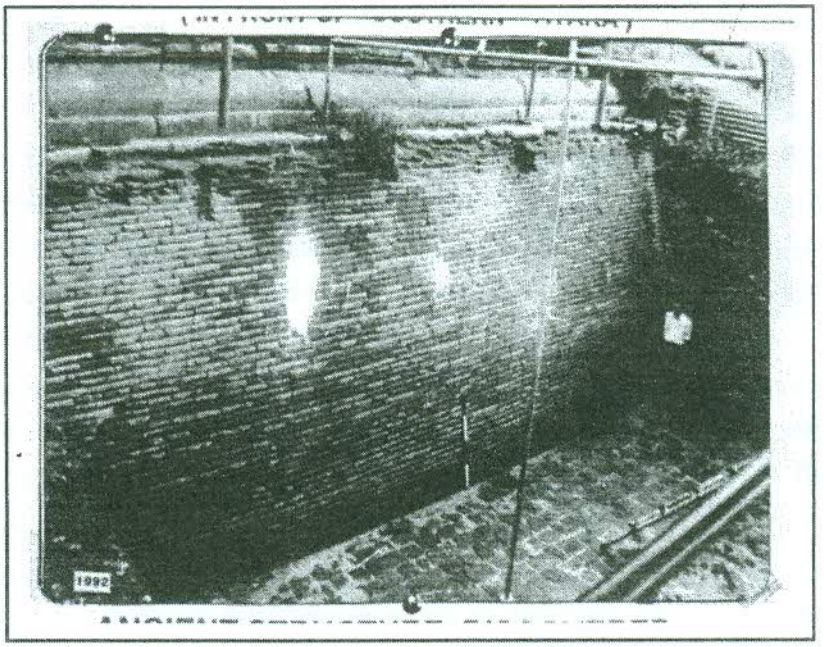
Contours of Stresses in Jetavanaya Dome (kPa)

Construction

Our ancient builders have shown much technological as well as management skills in the construction of Stūpas. There were strict supervision and quality control.

Great care has been taken in selecting the sites and laying out the foundations. Most Stūpas have been founded on rock and for others elaborate preparations of the foundations have been made. Mahavamsa [4] describes how the foundation of the Ruwanveliseya, was laid. "*First the land was dug out to a depth of 7 cubits and then crushed stones were stamped down by elephants whose feet were bound by leather. Then butter clay was spread over the stones and bricks were laid over the clay. Over these a rough cement and a network of iron were laid. Finally a sheet of copper and, over*

it a sheet of silver with arsenic, were laid". This more or less gives a reinforced concrete type foundation with damp and insect proofing. In Jetavanaya, brick foundation rises 6 m from the rock up to the level of the basal rings. A device has been fixed at the top of the Stūpa for lightening protection.



Jetavana Stūpa Foundation

Brick Foundation of Jetavanaya

Settings out of Stūpas have been done very accurately. In Abhayagiriya, the top of the spire is almost in the same vertical line passing through the centre of the base (maximum shift is 23 mm over 75 m height), and orientation of the boundary walls (length 268 m) are within 1.5 degree accuracy. Accurate surveying has shown that Abhayagiriya dome is a perfect paraboloid [2].

Conclusions

Stūpas are the finest examples of our structural engineering heritage, and some of them are amongst the largest brick structures existing today. Our ancient builders have used techniques, far ahead of their times, in the construction of Stūpas.

References

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