# ANCIENT STUPAS IN SRI LANKA – LARGEST BRICK STRUCTURES IN THE WORLD

Munidasa P Ranaweera, Department of Civil Engineering, University of Peradeniya, Sri Lanka.

## 1. Introduction

Stupas (also called Chetiyas, Dagobas, etc.) in Sri Lanka (earlier known as Ceylon) are monumental structures built to honour Lord Buddha, and they are an indispensable feature of any Buddhist temple. Stupas house sacred relics of Buddha, or mark the sacred spots at which some important event connected with the religion had taken place. Stupas are venerated by the Buddhists, and their imposing, yet simple, features give one a feeling of stability, strength, nobility, and grandeur [Paranavitana 1946].

Stupa as a structural form has been in existence for a long time, in the East as well as in the West. In India, it developed into a structure very special to Buddhists, Hindus, Jainas alike, and the construction of Buddhist stupas started while Buddha was alive. Buddhist stupa is not a tomb, but a memorial which symbolizes the supremacy of the Master and his Dhamma, or teachings.

## 2. History

Buddhism came to Sri Lanka from India, during the third century BC, when Emperor Asoka was ruling India and Devanampiya Tissa was the king of Sri Lanka. Mahawamsa or the great chronicle of Ceylon [Mahawamsa], which is a written record of the history of the country from the 6$^{th}$ Century BC, vividly records these events and gives details of stupas constructed by the rulers of Sri Lanka.

Thuparama built by King Devanampiya Tissa (307-267 B.C.) in the then capital city of Anuradhapura, is considered the oldest stupa in Sri Lanka, even though there are legends relating to two other stupas built during the life of Buddha (623-543 BC). With the passage of time more stupas have been built by the kings and some, notable for their importance and special features, are shown in Figs. 1 – 8, and their historical details are given in Table 1.

| Stupa Name | Founder King | Period |
|---|---|---|
| Thuparama | Devanapiya Tissa | 3$^{rd}$ Century BC |
| Tissamaharama | Kavan Tissa | 2$^{nd}$ Century BC |
| Mirisaveti | Dutu Gemunu | 161-137 BC |
| Ruwanveli | Dutu Gemunu | 161-137 BC |
| Abayagiri | Valagambahu | 88 -76 BC |
| Jetavana | Mahasena | 269–296 AD |
| Kirirvehera | Parakramabahu | 1140-1173 AD |
| Rankothvehera | Nissanka Malla | 1174-1183 AD |

Table 1. Historical details of some notable stupas

Figure 1. Thuparama Stupa

Thuparama (Fig. 1), when it was originally built was of very modest size, and it was Tissamaharama (Fig. 2), which started the tradition of building mega stupas in Sri Lanka. It was followed by the Mirisaveti (Fig. 3) and then the Ruwanveli (Fig. 4). Ruwanveli Stupa, aptly called the Great Stupa because when it was built there were no other shrines rivaling it in size not only in Sri Lanka but in the whole of the Buddhist world, is the most revered stupa in Sri Lanka, and is also the tallest (height 91.4 m) at present.

Figure 2. Tissamaharama Stupa

Figure 3. Mirisaveti Stupa

Ruwanveli was surpassed by Abayagiri (Fig. 5), which attained a full height of 106.7 m, which in turn was overtaken by Jetavana (Fig. 6). Jetavana, which attained a full height of 121.9 metres (400 ft), was at one time the third tallest structure in the world, surpassed only by the two great pyramids in Giza [Silva 1982]. Due to the failure of a part of its spire, its present height is 70.7 m above the platform, but its volume of 233,000 cubic metres, still makes it the largest brick structure in the world.


Figure 4. Ruwanveli Stupa

Figure 5. Abayagiri Stupa

Figure 6. Jetavana Stupa

The last mega stupa built by the kings is Rankothvehera (Fig. 8), or the Golden Pinnacle Stupa, in Polonnaruwa, the medieval capital of Sri Lanka. King Parakramabahu who reigned there was responsible for the enlargement of many stupas built by his predecessors and his Kirivehera (Fig. 7) is important due to the fact that it still retains the original brickwork and plaster. Mirisaveti (Fig. 3) was enlarged several times by kings who came after Dutu Gemunu (Fig. 9), and its latest restoration was completed by the Sri Lankan government in 1995.

Figure 7. Krirvehera Stupa

Figure 8. Rankothvehera Stupa

The construction of mega stupas in Sri Lanka by the kings, which started in the 3rd century BC, virtually came to an end in the 13th century AD, due to the decline of the kingdoms as a result of warfare and foreign invasions. The great stupas gradually fell into decay and became shapeless mounds due to neglect and actions of nature, and in some cases treasure hunters.

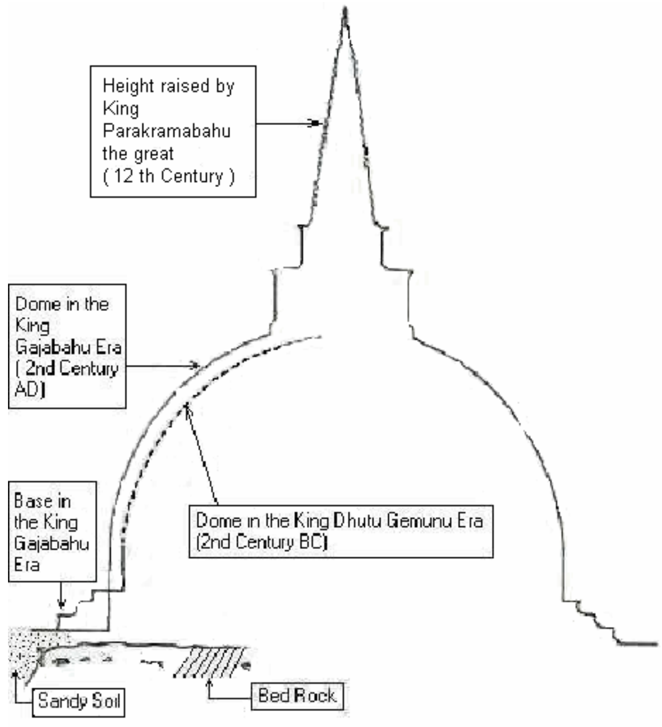


Figure 9. Development of Miriseveti Stupa

## 3. Architecture

Architecturally also, stupa is the most important Buddhist structure. Unlike a pyramid, it is a solid structure, mostly made of bricks. Over the years the shape of the Sri Lankan stupa has changed from the original Indian form to a form of its own.

Main components of the Sri Lankan stupa are shown in Fig. 10. The stupa dome has one, two or three cylindrical terraces or basal rings at the bottom. At its top, the dome carries the square chamber, which is a solid structure having a square plan. Then comes one or more cylinders, the spire and the pinnacle. All these components, except the square chamber, are axisymmetric.

Originally the components above the dome were similar to the Indian form (Fig. 11), and consisted of a hollow square chamber, inside which there was a column carrying one or more umbrellas. The umbrellas protected the stupa from rain when the stupa was of very small size, but when the

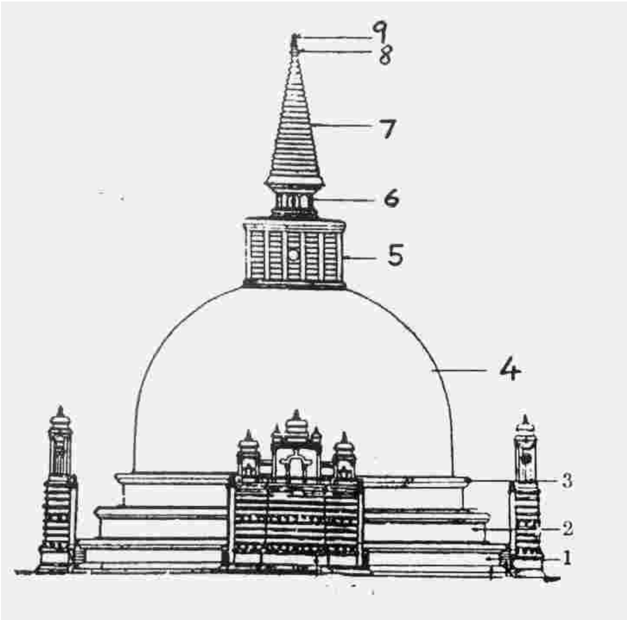

Figure 10. Main components of a Stupa
(1,2,3-Basal rings, 4-Dome, 5-Square Chamber, 6-Cylinder/s, 7-Spire, 8-Mineret, 9-Crystal)

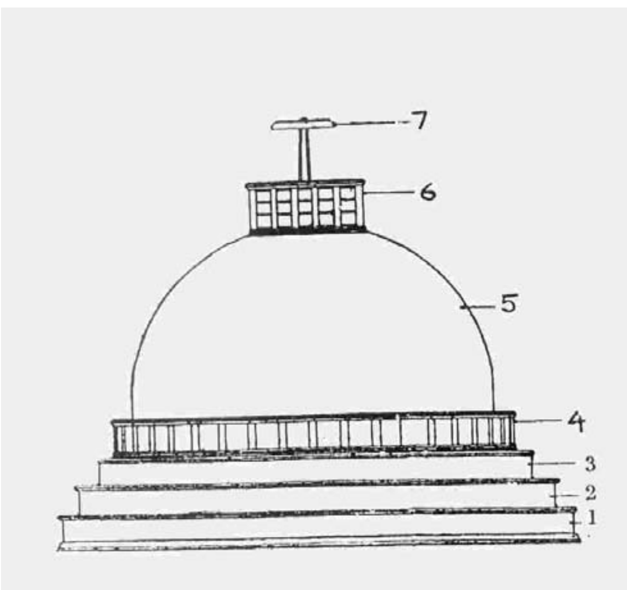

Figure 11. Indian Form of Stupa
(1,2,3-Basal rings, 4-Railing, 5-Dome, 6-Square chamber(hollow), 7-Umbrella)

stupa became large the umbrellas became only symbolic. In Sri Lanka by the 7$^{th}$ Century AD, this form has changed to the present form having a solid square chamber, cylinders and a conical spire.

Originally when the stupas were of small size, devotees kept flowers and other offerings on the basal rings, but as the stupas got bigger so did the basal rings and separate structures with tables to offer flowers etc. were built. In some stupas the basal rings were added after the dome was built (Fig. 9), and in some the they formed the plinth for the dome. Some of the large stupas were also provided with projections called *vahalkadas* (Fig. 10) or frontispieces [Paranavitana 1946]. These, numbering one to four are placed at cardinal points of the stupa, and some of them have developed into beautifully ornamented structures.

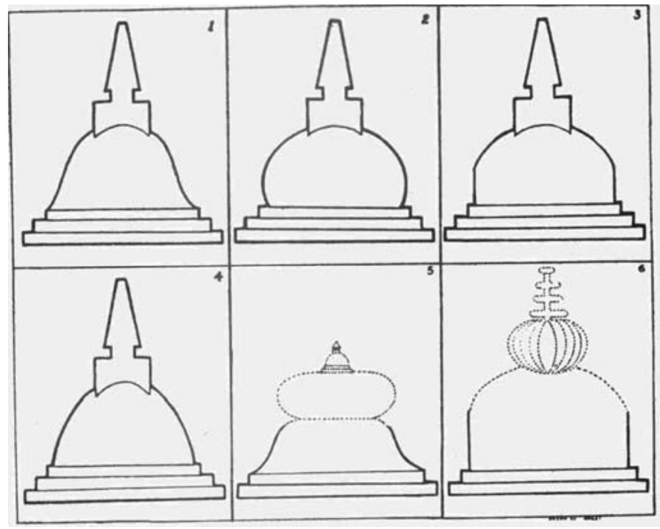

Figure 12. Stupa Shapes [Godakumbure 1976]
(1-Bell, 2-Pot, 3-Bubble, 4-Paddy-heap, 5-Lotus, 6-Nelli fruit)

The dome is the biggest component of a stupa and it contains the relics, in a relic chamber, either at the level of the basal rings at the bottom, or at the square chamber at the top. Several shapes have been used for the dome (Fig. 12), and some examples are given in Table 2 and in Figs. 1 – 8.

The bell shape is the most common and next comes the bubble shape. The paddy-heap shape, having a gradient equal to the angle of repose, is the most stable from a structural point of view [Ranaweera 1998], and the ancient builders have used this shape for the colossal stupas they built [Silva 1982]. Domes of pot and lotus shapes are rare and there are no existing examples of the nelli fruit shape. The shape of the dome of some stupas has changed from their original form during repairs and enlargements which have taken place at later times. For example, the Thuparama (Fig. 1) was originally constructed with a paddy-heap shaped dome, which later took the shape of a bell.

| Stupa | Dome Shape | Present Height from Platform (m) | Dome Diameter at Platform (m) |
|---|---|---|---|
| Thuparama | Bell | 19.2 | 18.0 |
| Tissamaha-rama | Pot | 45.9 | 43.0 |
| Mirisaveti | Bubble | 55.0 | 43.0 |
| Ruwanveli | Bubble | 91.4 | 90.8 |
| Abayagiri | Paddy - heap | 73.0 | 99.1 |
| Jetavana | Paddy - heap | 70.7 | 102.0 |
| Kirirvehera | Bell | 24.3 | 21.3 |
| Rankoth-vehera | Bell | 61.0 | 56.7 |

Table 2. Architectural details of the stupas in Table 1

Miniatures of stupas found in relic chambers give an idea of the old form of the stupa.

The square chamber at the top of the dome was hollow at ancient times, and even after it became solid, its faces show railings (Fig. 10). On top of the square chamber there are one or more cylinders, some known as the abode of gods, having figures of deities. The conical spire, on the top of the cylinder is a solid, giving the impression of a number of umbrellas put together, and at its top rests a crystal set on a gilt minaret (Fig. 10).

Some of the small but important stupas, like the Thuparama (Fig. 1), were found on a raised platform with a circular plan (Fig. 13), and enclosed within a circular structure called the *vatadage*, with a roof (Fig. 14). Concentric circles of stone pillars carried the wooden roof of the structure, of which only some of the stone pillars remain at present (Fig. 1).

The large stupas sprang from a square stone-paved platform or an upper terrace raised from the ground and bounded by a retaining wall, and surrounded by a lower sand terrace at the ground level, also bounded by a wall, as shown in the plan of Abayagiri stupa (Fig. 15). Entrance gates and stone stairs are located at cardinal points, and the sand terrace was used by processions, with elephants, which go round the stupa.

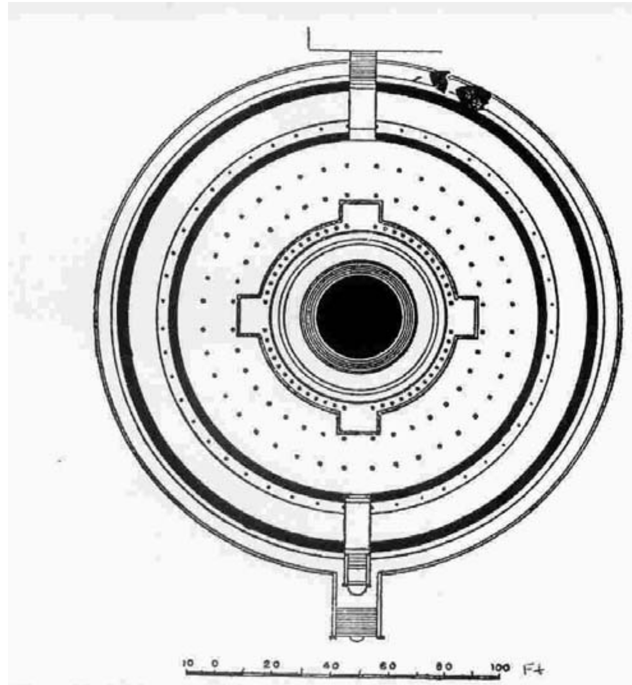


Figure 13. Ground Plan of Thuparama

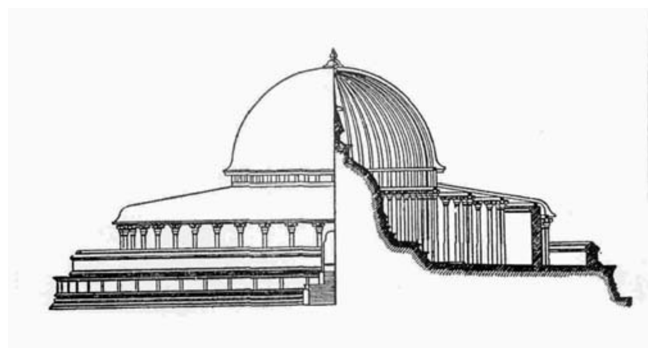

Figure 14. Conjectural Restoration of *Vatadage* of Thuparama [Paranavitana 1946]

## 4 Materials

The main building block of the stupas is the burnt brick, which has come in different sizes. Parker [Parker 1909 ] has tabulated the sizes of bricks used in many stupas. The bricks used in ancient stupas are much larger than modern bricks, and need the use of both hands to handle. Bricks of different sizes have been used for different parts of the same stupa, larger ones for the basal rings and the dome, and smaller ones for the spire. Typical sizes and masses of bricks used in Abayagiri stupa are given in Table 3.

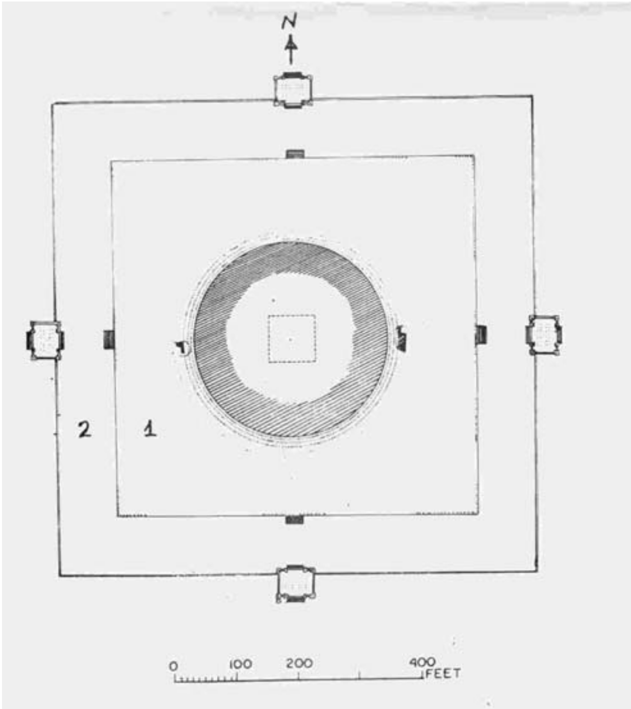


Figure 15. Ground Plan of Abaygiri Stupa
(1-Platform, 2-Sand Terrace)

| Location | Dimensions (LxWxT- mm) | Mass (kg) |
| --- | --- | --- |
| Basal rings | 320x280x85 | 12.30 |
| Dome | 450x230x80 | 13.10 |
| Square chamber | 250x160x70 | 5.15 |
| Spire | 210x150x55 | 2.48 |

Table 3. Details of bricks of Abayagiri stupa

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| Property | Value |
| --- | --- |
| Compressive strength | 8500 kPa |
| Tensile strength | 850 kPa |
| Young's modulus | 4.5 GPa |
| Poisson's ratio | 0.25 |
| Specific weight | 16.9 $kN/m^3$ |

Table 4. Mechanical properties of Jetavana bricks

Laboratory tests have shown [Abeyratne 1982, Ranaweera 2000] that the ancient bricks are more stronger than modern factory made bricks used in Sri Lanka, the strength of the former is around 8 - 12 MPa whereas that of the latter is around 4 - 7 MPa. Minerological studies [Siritunga ] have shown that the ancient bricks from Jetavana have a sand content of 55- 65% whereas the modern factory made bricks have a sand content of 35 - 45%, and this may be the reason for the strength difference. Typical mechanical properties of Jetavana bricks are given in Table 4.

The mortar used in ancient stupa 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 (Fig. 16). This gives a strong brickwork, unlike the modern brickwork which uses a thick mortar which can weaken the brickwork. At the outer surface brickwork is water proofed using a thick plaster (Fig. 7, 16). Mahawamsa also describes stringent quality control of the materials used in ancient stupas.

Figure 16. Ancient brickwork of Jetavan Stupa

## 5. Stresses

In Sri Lanka, where seismic effects are minimal, the main loading on a stupa is its self weight. Finite element studies done on stupas [Ranaweera 1993, 1998, 2000, 2001] have shown that, under self weight, most parts of a stupa are under compression. Few tensile zones are present in the square chamber and the cylinders, and at the outer surface of the domes having shapes other than the paddy-heap.

For paddy-heap shape domes the stresses are all compressive, making them the most stable from a strength point of view [Ranaweera 1998]. In the paddy-heap shaped dome of Jetavana, the largest stupa ever built, the maximum compressive stress occurs at the centre at foundation level and its value is 839 kPa (Fig. 17), around one tenth of the compressive strength of the ancient bricks used (Table 4). Hoop and radial stresses in Jetavana dome are also compressive having a maximum of 280 kPa at base centre. Pot shape domes have the largest tensile hoop stress region, as in the case of Tissamaharama stupa.

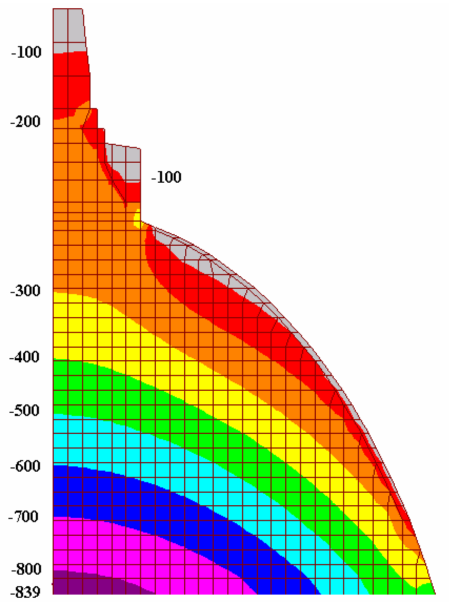


Figure 17. Contours of vertical stresses in Jetavana stupa (kPa)

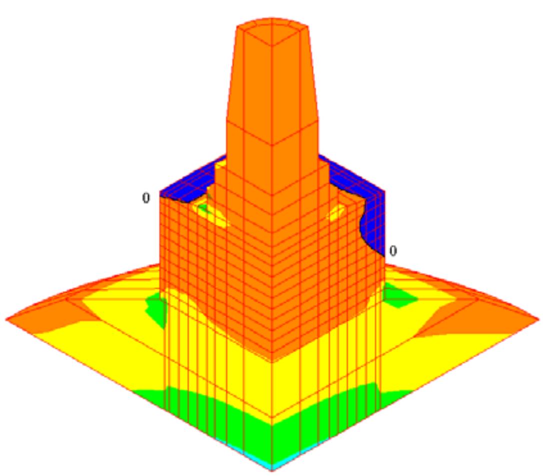


Figure 18. Stress contours in Jetavana stupa square chamber (tensile region shown darker)

The square chamber also has some tensile regions at the top, shown darkened in Fig. 18 for Jetavana.

## 6. Construction

A stupa has a more complicated shape than a pyramid, and ancient builders of Sri Lanka have shown much technological as well as management skills in the construction of large stupas. There were no forced labour, and workmen were paid. There were strict supervision and quality control. Mahavamsa gives elaborate descriptions of the construction of great stupas like Ruwanveli.

The stups are oriented along North-South East-West axes, and setting out has been done very accurately. In Abayagiri (present height 73.0 m, outer basal ring diameter 108.8 m) orientation of the boundary walls (Fig. 15) are within 1.5 degree accuracy and the top of the spire is almost in the same vertical line passing through the centre of the base (maximum shift is 23 mm) [Dampegama, 2001].

Great care has been taken in selecting the sites and laying out the foundations. Most stupas have been founded on rock and for others elaborate preparations of the foundations have been made. Mahavamsa describes how the foundation of the Ruwanveli stupa, was laid. “First the land was dug out to a depth of 6 metres 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 was laid. Finally a sheet of copper and a sheet of silver were laid”. This more or less gives a reinforced concrete foundation with damp proofing.

The dome is a perfect solid of revolution, which is an ellipsoid for the Jetavana [Ranaweera 2000] and a paraboloid for the Abayagiri [Ranaweera 2001]. In some cases, for inner regions of the dome brickbats and earth have been used, while the outer regions were of strong large bricks. The surface was plastered with a thick lime plaster to prevent ingress of water (Fig. 7, 16).

There would have been efficient construction management to handle material and labour in the construction of mega stupas [Silva 1990]. Jetavana built in 27 years required a total of around 62 million bricks. Considering 230 working days per year, this required the laying of 10,000 bricks per day. Making these bricks and transporting them to site, let alone laying them with mortar would be a massive task undertaken by the builders of the 3rd century AD.

## 7. Conservation & Restoration

Due to foreign invasions and the shift of the Capitals from place to place, stupas have been neglected and decay started. The decay would have followed a progressively worsening process initiated by cracking of the surface due to thermal stressing, followed by rain water penetration, animal infestation, vegetation growth and root penetration in cracks, and would have been compounded by surface water erosion

Conservation and restoration of stupas had been carried out by Kings of Sri Lanka from time to time. However by the turn of the 19th century most of the ancient stupas were in ruins, some turned into mounds of earth. During the last decade of the 19th century the British, ruling the country, did some restoration work, and later religious organizations undertook restoration works of many important stupas such as the Ruwanveli. However at the turn of the 20th century some major stupas such as the Jetavana (Fig. 20), Abayagiri (Fig. 5), and Miriseveti (Fig. 19) were still in ruins.

Figure 19. Miriseveti stupa after an unsuccessful restoration attempt

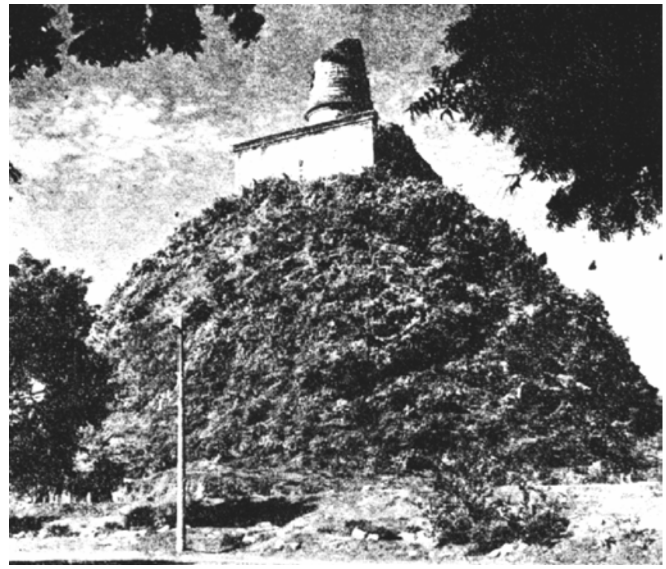

Figure 20. Jetavana stupa after decay

With the formation of the Central Cultural Fund (CCF) in 1980, and the declaration of some ancient stupas as World Heritage Monuments, there was a revival of restoration and conservation work of ancient stupas of Sri Lanka [Silva 2002].

Restoration of Mirisaveti stupa is a good example of a complete restoration work by CCF. The stupa had only the cracked dome at the turn of the 19th century, and an ill planned restoration attempt in 1987 resulted in a collapse of the stupa which left only a conical mound of the weak inner core(Fig. 19). After much discussions and a thorough study including finite element analyses [Ranaweera 1993] the stupas was restored in 1995 to its original form with complete plastering (Fig. 3).

After the restoration of Mirisaveti stupa, the interest turned to Jetavana, the largest stupa. However, by that time the thinking has changed in favour of conservation rather than restoration, as it was felt, quite rightly, that a full restoration ruins the unique character of the monument. Hence the Jetavana stupa was conserved with minimum intervention, and doing (reversible) repairs where necessary using like-for-like material. The dome, which was covered with vegetation (Fig. 20), was cleaned and a new layer of brick was added, on top of old bricks, and this was pointed giving a rather unsymmetrical, but stable, profile (Fig. 6). The square chamber had to undergo major repairs as some parts of it had suffered serious damage.

To take up the hoop tension at the top (Fig. 18), a reinforced concrete ring beam was provided.

In the case of Tissamaharama, equally spaced meridianal cracks appeared on the surface of the dome towards its mid height. These were most probably due to the hoop stresses inherent in the pot shaped dome, as mentioned earlier. In order to halt the spread of these cracks and prevent the collapse of the dome, external pre-stressing was done using circumferential cables fixed to the dome (Fig. 2).

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*CHS Newsletter No. 70, December 2004,* London, Construction History Society.