# ASSESSING THE CRACKS DEVELOPED IN DEMATAMAL VIHARAYA, BUTTHALA

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**Abstract:** Stupas of Sri Lanka stand as proud examples for the engineering excellence of ancient Sri Lanka. Dematamal Viharaya at Butthala is one of the oldest stupas in Sri Lanka built in the 2nd Century BC which is a, 19m tall non-plastered brick structure.

This stupa has developed cracks since 1998. Cracks have initiated from the pesawalalu and propagate to the top of the dome. The research covered in this report is aimed at the identification of the causes. A comprehensive study was carried out to identify the possible causes for the cracks which may be due to self weight and shape of the stupa, expansive nature of soil, arch action induced due to separation of old and modern masonry. Experiments were done to assess the expansive nature of the soil and a Finite element analysis was carried out using the Finite element software SAP2000.

The results revealed that the possible cause may be the arch action induced due to separation of old and modern masonry.

**Keywords:** Cracks, Arch Action, Expansive Soil

## 1. Introduction

The creation of stupas has been one of the greatest achievements of ancient Sri Lankans unmatched by anyone else in the world. Large and small stupas scattered all over the island have stood the test of time and conserving them for the future generation should be a non debatable priority of all Sri Lankans.

Dematamal Viharaya, in the Ruhuna region is one such stupa, located at Helagama on the Buttala-Okkampitiya road. It is one of the oldest stupas in the island. This 19m high non-plastered brick structure was built by King Mahanaga of Ruhuna.

This small stupa has unfortunately come under the threat of nature, and has developed some cracks in the recent past. This research is a study on these cracks, which suggests some possible reasons and analyses the reasons. This research would be helpful in the Sri Lankan context for future attempts at restoration of stupas and would give an idea of what should and should not be done. The cracks started to appear in 1998 and have been propagating since. They can be seen at the *pesawalalu*and the dome, the maximum width being 3mm.

The expansive nature of soil, shape and self weight of the structure and the discontinuity between the old and new parts of the stupa are few of the suspected reasons for the cracks.

## 2. Methodology

Expansive nature of soil in the area was analysed by collecting samples at the site and testing them for relevant soil parameters. They were compared with standard values to measure the expansive nature of the soil.

Drawings of the stupa were obtained from the Department of Archeology. Brick samples were collected at the site and tested for material properties. Properties of the ancient bricks were taken from associated literature.

SAP2000 was used to create models of the stupa to check the effects of self weight and the discontinuity between the old and modern structures.

## 3. Results and Discussion

The above mentioned three reasons for the development of the cracks have been analysed and the results are discussed below.

### 3.1 Expansive nature of soil

Expansive soils are capable of absorbing water and they increase in volume. Due to the volume increase in soil, it heaves and lifts the building which initiates cracks on it. Since this was one of the suspected reasons for the cracks it was decided to test samples for certain parameters and check whether the soil was expansive enough to cause cracks.

Samples were taken from two locations, near the Bo tree which was 10m away from the stupa and from the surrounding paddy field. Atterberg Limits, free swell index, swelling pressure test and hydrometer test were conducted on the soil samples. Table 1 shows the results obtained.

Table 1: Soil test results, conducted on soil samples collected in Dematamal Viharaya, Buttala

| | Sample 1* | Sample 2*[1] |
|---|---|---|
| **Dry Method** | | |
| Liquid Limit | 19.0% | 21.5% |
| Plastic Limit | 12.6% | 12.6% |
| Plasticity Index | 6.4% | 8.9% |
| **Wet Method** | | |
| Liquid Limit | 24.8% | 25.3% |
| Plastic Limit | 23.0% | 23.4% |
| Plasticity Index | 1.8% | 1.9% |
| **Clay percentage** | 18.0%* | 21.0%* |
| **Activity** | | |
| Dry Method | 0.36 | 0.42 |
| Wet Method | 0.1 | 0.09 |
| **Free swell Index** | NIL* | 9.0%* |
| **Swelling Pressure** | NIL* | 14.6kgcm-3*[2] |

According to its severity, expansive nature of soil can be categorised in to four, namely non critical, marginal, critical and severe. The results obtained from the tests were compared against limiting values for expansive soil obtained from IS 1498 and classified in to a group.

Comparison of results with the standard values revealed that the soil could be classified as a marginally expansive soil. Even though it is not possible to assess the expansive nature of a soil with few samples, these results give a fair idea of the expansive nature of the soil found in Dematamal Viharaya. Expansive nature of soil can be ruled out when deciding on a possible reason for the cracks developed in Dematamal Viharaya.

### 3.2 Self weight and shape of the stupa

The shape and self weight of the stupa was another suspected reason for the cracks formed in Dematamal Viharaya. A SAP2000 model was used to analyse the effects of self weight and shape.

The geometry of the stupa was taken from the drawings obtained at the Department of Archaeology. It was decided to analyse the stupa using ASOLID elements and the base of the stupa was to be fixed (Ranaweera 2000). A computer generated mesh was used.

According to the drawings given by the Department of Archaeology the restored Stupa had been built on the remains of the ancient stupa. So it was decided to create model of the stupa with the ancient bricks in the bottom part and the modern bricks above.

Literature on the ancient stupa materials was used to obtain the properties of the old bricks. The values used are given in the Table 2. These values had been obtained from tests done on samples collected from Sandagiri Stupa which was built during the same period as Dematamal Viharaya and is approximately of the same size.

Few modern bricks were collected from the site and tested for their compressive strength, wet and dry densities. Values for Poisson's ratio, elastic modulus and the Tensile strength were taken from literature (Ranaweera 2004). Table 3 shows the values used for modern bricks.

Table 2: Material Properties of Ancient Bricks found at Sandagiri Stupa, Tissamaharama [3]

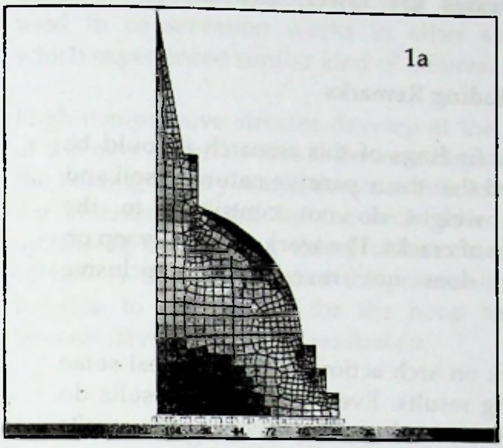
| | |
|---|---|
| Density | 18.4 kNm-3 |
| elasticmodulus | 9790000 kNm-2 |
| Poisson's Ratio | 0.27 |
| Compressive Strength | 11.6 Nmm-2 |
| Tensile Strength | 1.54 Nmm-2 |

[1] Sample 1 - Near the Bo Tree
Sample 2 - In the Paddy field
[2] Tests done by the NBRO

Table 3: Material Properties of Modern Bricks

| | |
|---|---|
| Wet Density | 19.1 kNm-3 |
| Elastic modulus | 1920000 kNm-2 |
| Poisson's Ratio | 0.21 |
| Compressive Strength | 3.71 Nmm-2 |
| Tensile Strength | 0.55 Nmm-2 |

SAP2000 Models were created using the above material properties and the stress contours are given in figure 1



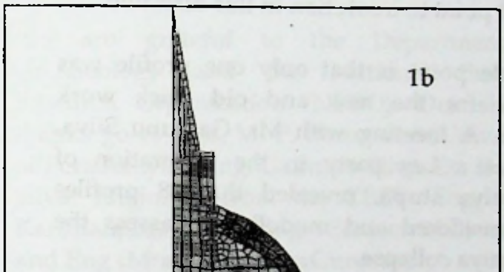




Figure 1:Vertical (a) and Hoop (b) Stresses due to self-weight of the stupa modelled with modern brick properties

Figure 1 shows the vertical and hoop stresses in the stupa. The vertical stresses are wholly compressive in the range of $0.156Nmm^{-2}$ to 0.003Nmm-2 and steadily increase from top to bottom. Maximum Compressive stresses can be noticed at the base. Hoop stress is mainly compressive and has a variation similar to the vertical stress, but tensile stresses also can be seen at the outer surface of the dome and in the edge of the pesawalalus but they are less than $0.01\ Nmm^{-2}$ and approximately one fifth of the tensile strength of the modern bricks. So it canbe concluded that the self weight had not been the reason for the cracks.

**3.2Discontinuity between the old and new parts of the stupa**

The drawings obtained from the Department of Archaeology shows that before restoration Dematamal Viharaya had been a ruin of ancient brickwork which was about 12.5 m in height and consisted of three *Pesawalalus*. The new stupa had been constructed on top of this mound using modern bricks and mortar.

Reports on the collapse of stupas such as Mirisavetiya and SandagiriStupa reveal, that the same method of construction had been employed in those stupas prior to collapse. The main reason for the failure of Mirisavetiya in 1987 was the crushing of the new brickwork at the base of the dome, which was only 2-3 feet wide (Silva WNG 2002). These findings helped to the development of the hypothesis described below.

Inadequate cleaning of decayed surface of the old brick work, improper keying of bricks between old and new brickwork and the expulsion of water which seeped into old brick work during and before construction may have led to the separation of the new brick work from the old brick work. The fact that no proper measures such as reinforcement were used to strengthen the bonding would ensure that separation of brick work was inevitable. This could result in the new brickwork acting like an arch. The arch action may lead to the increase of the hoop tension in the *pesawalalu*in two ways which might lead to cracks.

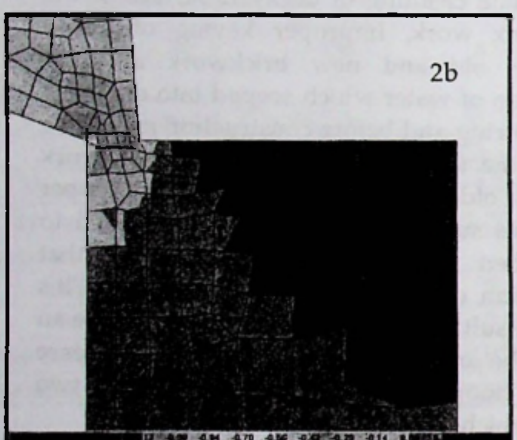
*I. Development of high compressive stress at base.*
Since the new brick work acts like an arch the whole of the modern brick work may be made to bear on the base of the arch. This may develop high compressive stresses at the base. If these stresses exceed the compressive strength of the brick they will crush. When the base crushes the arch may tend to slide out. This sliding out action will cause the arch to push out the *pesawalalu*. This would develop hoop tensile stresses and will initiate cracks in the *Pesawalalu* and the dome.

*II. Thrust at the base due to Arch Action inducing Hoop tensile stresses in the Pesawalalu.*
The arch action in the new brick work may create a horizontal thrust outwards at the base which is connected to the *Pesawalalu*, this thrust

will push the circular *pesawalalu* outwards. Since this action will be resisted by the *Pesawalalu* hoop tensile stresses will be developed in the *Pesawalalu*.

These two actions would lead to the initiation of cracks in the *Pesawalalu*.

The drawings give one cross section of the ancient brick work. A SAP2000 model for only the new brickwork and the *Pesawalalus* was created using the obtained geometry. Since it was assumed that complete separation takes place, ancient brick work was not included in the model. The model was created with ASOLID elements. Figure2 shows the hoop and vertical stress contours.

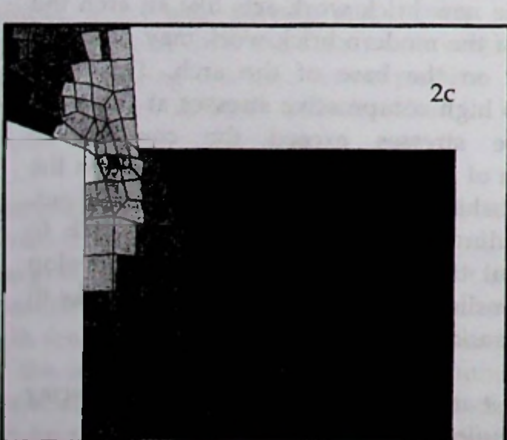




Figure 2: (a) Model used to analyse arch action (b) Hoop stresses at the base of the arch (c) Vertical stresses at the base of the arch

It can be clearly noted that an increase in stress occurs at the base, whether it be vertical, or hoop. In the case of vertical stress, the increase compared to the self weight model with both materials is 30 times higher. The model also shows the development of high hoop tensile stresses in the *pesawalalu* edges thus proving the second part of the hypothesis to be true. The general range of the hoop stress at the *pesawalalu*is 0.14-0.28 $Nmm^{-2}$, an increase of 250 times compared to the self weight model. But these stresses are lower than the material strength.

## 4. Concluding Remarks

From the findings of this research it could be concluded that the expansive nature of soil and the self weight do not contribute to the formation of cracks. The work done on creep on masonry does not reveal any conclusive evidence.

The work on arch action seems to reveal some promising results. Even though the results do not definitely lead us to a conclusion the results obtained point to a solution in this direction.

A notable point is that only one profile was available for the new and old brick work interface. A meeting with Mr. Gamunu Silva, who was a key party in the restoration of Mirisivatiya stupa, revealed that 18 profiles were considered and modelled to assess the Mirisivatiya collapse.

Other points to mote are only 3 brick samples were used to assess the .strength of the new brick material, the old material was not assessed at all and the values for comparison and modelling were taken from literature. Proper results could be obtained if more representative material properties could be used.

All of the above should be taken into account while arriving at a conclusion. The analysis done helps to come to a conclusion that if the separation of materials result in arch action then it would lead to the development and increase of vertical compressive and hoop tensile stresses which would in turn lead to the formation of cracks. Accordingly remedial actions have been proposed for the stupa to overcome the problem.

Apart from above mentioned reasons there are possible reasons which have not been explored and analysed. The roots of the Bo tree, which is just 10m away from the stupa, could be the inducing factor for the cracks. Settlement of foundation could also be a contributory factor for the formation of cracks. Foundation details, bed rock depth are required to do further analysis on this.

Assuming the arch action has in fact induced the formation of cracks, two types of remedial action are proposed. Both methods have been used in conservation works in other stupas which experienced similar kind of failures.

High compressive stresses develop at the base of the new material. This is because the area of the bearing is very small, thus not able to carry the stresses induced by the arch action. By increasing the bearing this problem could be solved. A tie beam around the *pesawalalu* will be able to compensate for the hoop tensile stresses developing at the *pesawalalu*.

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