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Mr. Chairman,
Ladies & Gentlemen.

I am indeed privileged to speak with a galaxy of "scientific spacemen" on a subject which perhaps is less distant than the stars, less expansive than the universe, although the objects under study are both geometrical and spherical in shape. Of course, the idea is something that is down to earth and located in a planet capable of human life and where we can count the bricks and mortar at a tangible level.

Ladies and Gentlemen, it is the Stupa in Sri Lanka that we propose to look at through the microscope of an engineer. The '<u>stupa</u>' is a term that is Sanskrit in origin. It is also called the '<u>thupa</u>' in Pali and '<u>dagaba</u>' in Sinhalese. Names such as '<u>caitya</u>', '<u>seya</u>', '<u>vehera</u>' etc., are also used and its origins date back to a period prior to Buddhism. Archaeologists have established that this monumental form originated as a human requirement for burial and served as such until it was transformed in concept and practice to enclose the bones or relics of either the Buddha or an important disciple. As such, despite the absorption of a pre-buddhist

concept, the stupa still retains the essential component of its original nature of being a container of human remains.

We may in the first instance look at the stupas of the Indian sub-continent with other parallels spread round the world in such edifices as the pyramids of Egypt, similar geometric monuments of Central America, the Imperial tombs of the Chinese and even the ziggurates of Messapotamia which have now been established to retain human burials as well. Even the recent temple types which we will not be discussing here such as the churches of Medieval Europe were raised above a central shrine of a tomb and therefore, a distant relative of the tomb concept. Hence, the origin of these collosal and early mounds of man were monuments of human effort which engulfed the common concept of a massive tomb. We have, as a matter of study, identified more or less the largest of such edifices scattered throughout the face of the earth from Egypt to Mexico, from Messapotamia to China and finally those in little Sri Lanka. We have also identified their heights, volume and even their approximate weight. The construction materials range from stone to bricks both baked and sun dried and even consolidated earth. The chart given below tabulates such data which are, to some extent, approximations and we have given two examples from Sri Lanka as the largest stupa considered was never completed. We are grateful to D.N.A.Jayamaha of the UNESCO - Sri Lanka Project of the "Cultural Triangle" for collating this data.

No.	Monument	Country	Material of construction	Height in feet	Volume in millions of cubic feet	Weight in millions of tons
1.	Pyramid No. 1 at Giza	Egypt	Granite	484	93.49	6.26
2.	Pyramid of Teoti-huscan	Mexico	Granite exterior adobe or sun dried bricks interior	213	35.10	1.76
3.	Nabo-nidus Ziggurat	Babylon	Burnt bricks	200	1.81	0.11
4.	Tomb of Thang Empress Wu-Tse Thien	China	Consoli-dated earth	200	52.33	2.10
5.	Demala-mahaseya Polon-naruva (incom-plete)	Sri Lanka	Burnt bricks	625	75.71	4.50
6.	Jetavana-rama Stupa Anura-dhapura	Sri Lanka	Burnt bricks	400	20.43	1.21

If we were to look at these edifices from the point of view of engineering and of the nature of materials used and if we were to isolate those constructed in brick and mortar, then we see a strange concentration of such collosal structures in this speck of an island in the Indian Ocean. Sri Lanka stands out as a promontory of the continent of Asia facing the South Pole. This island port that controlled all trade transactions between Rome and Peking enriched itself on such services to build these great wonders of mankind. This is why UNESCO has found it fit to declare the cities of Anuradhapura, Polonnaruva and Sigiriya of Sri Lanka as monuments and sites of world stature and heritage. Further, to have three items out of a total International List of seventy odd is indeed a proud possession for the Sri Lankan people.

The engineering principles followed in constructing these massive monuments have been, we trust, through knowledge achieved by a deductive process of trial and error, which is indeed, the oldest scientific principle followed by man through different phases of time. Basically, the growth pattern of this burial structure, which originally was a mass of soil, evolved with time to form a mound with better and more scientific treatment of the original material - earth. Subsequently, these monuments were built up and up, with due consideration given to their mathematical shape, their chemical and mechanical adhesion to prevent separation, and efforts launched to avert settlement or to let these succumb under their own load.

Mathematical and Functional shape

While the shape of the stupa in a growth pattern provided for functional and symbolic evolution, the various units so designed were introduced not unaware of the scientific and mathematical requirements needed for stability and endurance. The symbolic feet or footings of the stupa were, therefore, rightly and scientifically called the 'piyavasava' then, or 'pesava' now; 'piya' or 'paya' meaning feet, and 'vasa' meaning cover. Thus the "three steps" at the base of a stupa are in fact the visual component of the uppermost "three steps" of the foundation of a stupa which was designed to carry the enormous weight of nearly 4.50 million tons of the proposed 625 feet high 12th Century A.D. Demalamahaseya at Polonnaruva (1) or the 1.21 million tons of the 400 feet high 4th Century A.D. Jetavana Stupa at Anuradhapura.(2) We are aware that the Ruvanveliseya has twenty seven such footings or foundation steppings as recorded in the 5th Century A.D. chronicle, the Mahavamsa, which says: "... the three terraces (pesava) ... did the Theras (monk architects) ... cause to sink down so soon as they were laid with bricks making them equally to the surface of the soil. Nine times did they cause these (three terraces) to sink down ..." (3)

The form of the first stupa erected in Sri Lanka is described in the 13th Century A.D., Thupavamsa as having a heap-of-paddy shape. (4) In fact, this is a familiar scientific form of the paraboloid shape which has been followed in all the largest stupas at Anuradhapura be it

Jetavana, Abhayagiriya, Ruvanveliseya or Mirisavetiya. Thus the concept of the angle of repose was established for these stupas of brick and mortar as much as these ancients were well aware of this need in terms of looser mounds such as that of earth concerning the large reservoir bunds wherein the right springing of the slope was achieved by tilting the angle of the mound when measured against its baseline and the centre. We are aware of very small stupas of bricks that form an obtuse angle of springing and are classically called '<u>ghatakara</u>' or pot-shaped. Medium size dagabas followed a form called '<u>bubbulakara</u>' or bubble-shape and all the collosal stupas without exception were of the '<u>dhanyakara</u>' form or the heap-of-paddy shape with an angle of springing or repose which was found to be scientifically suited for the stability of the monument. It is for this reason that these, the largest structures of brick ever built by man and dating to around two millenia, still stand up as near perfect edifices as when they were originally erected.

The stupa mound in its original evolution and when it was basically of consolidated earth, it was protected from the rain by a symbolic <u>varshasthale</u> or umbrella which original name records the functional meaning and purpose of the umbrella, in that it was primarily a weather protection for the mound against the natural deterioration due to wind and rain. The same <u>varshasthale</u> or the umbrella concept has evolved symbolically through many phases and by the 5th Century A.D. the three major stupas of Anuradhapura had 7, 8 and 9 umbrellas placed one above the other over the three major stupas respectively and by the 12th Century A.D.

these had as many as 45 to 51. The chattras or umbrellas were placed one above the other wherein each umbrella above the previous reduced in size so that the overall shape of the chattrasvali was that of a cone of umbrellas. This chattravali was finally crowned with a crystal tipped metal stud or spire.

This combination of a hard tipped precious stone or vajra (diamond) on a conical metal cap sitting on the moist brick masonry was considered by the ancients to have earthing properties which could disperse opposite changes of static electricity and thereby, dissipate the high voltage potential of floating clouds at this incredible height of around 300 and 400 feet. The Mahavamsa of the 5th Century A.D. and its commentary of a later date refer to these aspects in the following manner:

> "(In the same way) He had valuable stucco work made for the three big cetiyas and put up a golden (metal gilded) umbrella as well as a (diamond) ring for protection against lightning (vajiracumbatam)" (5)

To summarise this concept of the umbrella as a protection of the original mound we may record that the functional and stylistic chattravali or cone of umbrellas protected the massive brick dome of the stupa both symbolically and otherwise from rain, lightning and the other basic elements of nature. The stem of such a cone of heavy masonry supported on a yasti or stem was made of a more substantial and tensile material where in the outer work consisted of brick and an inner cone of stone. Symbolically the inner stone which was decorated was linked with a pre-Buddhist

concept of a yupa and in the case of the Abhayagiriya stupa, this reinforcement was as substantial as 2 feet 3 inches in diameter. The slender yasti or the stem of the chattravali was the weakest point of the stupa in its design and is comparable to an elegant neck on which the conical head of the stupa rested. This cylindrical neck of the stupa has, however, been renamed at a much later period as the devatakotuva due to the association of deities as figurines by its decorative make up.

The stem of the umbrella was from pre-Buddhist times protected by a simple fence with vertical and horizontal bars indicating its shape and original function. This same decorative feature of the square fence is seen in the stupa designs even today with the one difference that it has itself acquired a more substantial and solid form. The original square fence is now built of mass masonry and thereby, providing the engineering stability to a rather elongated stem for the chattravali and the fence members are themselves better protected in the form of mass construction then jointed members of a timber or stone frame. As such the original hataraskotuva or square fence that protected the umbrella and stem from being removed or damaged continued to perform this same function in a more consolidated sense by amassing the cube with masonry and eliminating the structural stresses on the stem of the umbrella.

Thus the whole design concept of the stupa in its mathematical proportions and scientific form has moved from stage to stage, from period

to period, each time consolidating its functional and structural position according to highly deductive engineering principles and thereby eliminating its risk elements well within the safety limits of stress and strain. The test of such precautions and principles is seen in the three enormous stupas which are substantially the same as they were once constructed except for the botanical invation of such edifices under tropical climate and resulting from a span of near 800 years of neglect wherein the normal care and maintenance was absent. These ugly accretions of giant bearded growths will, however, be soon removed and the pre-12th Century A.D. phase of care and maintenance re-established to save these massive monuments of man.

Chemical and mechanical adhesion of the materials used.

Properties covering chemical and mechanical adhesion can be applied to the bricks, mortars and plasters; and the techniques of keying to prevent their movement is the ultimate objective. We can systematically view this question from different angles such as:

(a) characteristics of moulded bricks
(b) brick bonding
(c) mortars and plaster types
(d) damp prevention
(e) micro-biological and paleo-botanical control.

A standard characteristic in the making of ancient bricks as used in the stupas is that one of the two largest surfaces of the unit is moulded

normally while the other is purposely roughened. This could have been achieved by providing a rough bed of grit, earth, or carbonic matter, all of which would have been eliminated in the firing and in the stacking process of such finished products. The purpose of this rough surface was to prevent the movement of bricks in the bonded bed. The rough pockets of the bricks retain the slurry of clay mortar and thereby, adhesion is ensured against any lateral movement.

Brick bonding principle was strictly adhered to and no vertical or horizontal joints are generally met with in the ancient stupas. However, the system is not as explicit and conventionalised to the extent of say Roman brickwork, or more precisely in terms of the modern patterns of English and Flemish bonding. In this regard the ancients often used different sizes of bricks to ensure the non overlapping of mortar joints. Keying of brickwork is often encountered specially with moulded bricks where the vertical unornate courses of masonry are held firmly by the upturned wedge of the lower course.

There are various mortar and plaster types with different ratios of materials mixed using lime, clay, sand, pebbles, crushed sea shells, together with various resins of woodapple, sugar syrup, white-of-egg, coconut water, plant resin, drying oil, glues and possibly even the saliva of the white ants. However, the application of such formulae are dependent on other factors as economics, availability of products and the conventions covering different periods of time.

The mortar used in the bricks of the stupa were distinctly the clay slurry type as seen in all the stupas and as recorded in the Mahavamsa thus:

> "The King commanded that the clay be spread over the layer of stones (foundation) and that bricks then be laid over the clay ... wherever throughout the work with the clay called butter-clay served (as cement) with resin of the Kapitha - tree (woodapple - Feronia Elephantum) dissolved in sweetened water (water of the small red coconut).. (6)

We have had the butter-clay which is said to have been spread between the different courses of bricks in microscopic widths analysed and the results were that this consisted of finely crushed dolomatic limestone mixed with sieved sand and clay in a ratio of 1 : 2. (7) The absence of organic binding media is conspicuous which may be explained on the grounds of decomposition as the specimens were tested from the exposed and weathered areas of the masonry. Plasters, however, vary in compositions depending on the circumstances of their use. R.H. de Silva who has carried out serious research in this regard specially with reference to painted plasters has identified some compositions which are referred to in the texts. Three such mixtures found one above the other at Sigiriya during the 5th Century A.D. is described by him thus:

> "Layer 1 - On the surface of the support is laid a reddish brown ferruginous (6.8% R_2O_3) clay mixture containing pieces of straw, fragments of leaves, paddy husks, finely chopped vegetable fibre and rough grains of sand .. the plaster contains no lime and its

cohesion is to be attributed to some organic admixed binding medium. This medium contains a vegetable gum and a drying oil."

"Layer 2 - This plaster is lighter in colour than the first layer and is of buff appearance. It is composed of clay, grains of unworn sand, lime, finely chopped vegetable fibre (closely resembling straw) and fragments of leaves."

"Layer 3 - The final layer of plaster is richer in lime (33.3%) than the previous layer and contains no appreciable amount of clay (0.43% of $R_2 O_3$). It is off-white in colour and consists of lime and unworn sand together with finely chopped vegetable fibres that are observed to be white in colour and are very probably straw." (8)

Some of the stupas have heavily coated plasters forming layers which are sometimes as thick as 9 or 10 inches. The thick plasters are rather like a lime concrete than normal stucco and retain an aggregate of ¼ to ½ inch thick. The finer plasters also have an aggregate of either selected small pebbles as seen in the 2nd Century A.D. phase of the Kirivehera, Kataragama or crushed sea shells mixed with lime and sand as found in stupas during the 5th to 12th Centuries A.D. John Hughes who analysed a sample of ancient plaster in 1889 from the Anicut of Giants Tank, Ceylon has reported thus:

"I have much pleasure in sending you the results of a careful analysis of the specimen of concrete handed me by

> Mr.A.M.Ferguson. ... If you will compare the analytical results with those of good mortar as given in my paper in"The Builder", August 18, 1888, on the composition of ancient mortar, you will see that in many respects there is a strong resemblance. In really good mortar a portion of the lime is always present as silicate of lime .. as it exists in cement on the composition of some mortar of the third century (Roman), four analyses of specimen are given by Dr.W.Fohrion. In none of these does the soluble silica exceed 2.50 per cent, whereas in this concrete (from Ceylon) there is 7.10 of silica soluable in alkali". (9)

Much research still awaits the careful analysis and study of such plasters and indeed the refined pigments of painted surfaces.

Damp prevention as a deterrent to chemical decomposition and the deterioration of adhesiveness has been consciously provided for by the ancient builders at various times. Even the stupa foundations have had such protective layers as is the case with the Mahathupa at Anuradhapura where the chronicle records thus:

> ".. the lord of charriots laid over the stones (foundation) a sheet of copper ..." (10)

Parallel details of damp rising as seen in other bricks as at Polonnaruva and Panduvasnuvara where layers of tiles have been placed across the foundation wall is directly comparable to the European parallel of using sheets of slate. The external use of high quality plasters with rare resins as a water proofing membrane over the exposed stupa

domes is once again a positive statement in this regard concerning water penetration. The most recent studies of plaster from the largest stupa at Anuradhapura, the Jetavana, has revealed that there is a quantity of phospate in the mix. This is being studied further and the most likely source seems to be from the crushed bones of animals which is the technique of making animal glues. We are grateful to Mohan Abeyratne of the UNESCO - Sri Lanka Project of the "Cultural Triangle" for this piece of research. (11)

The micro-biological and paleo-botanical deteriorations have also been looked at seriously as far back as the 3rd Century B.C. where in the construction details of a stupa it is stated that the foundations be daubed with arsonic thus:

> " ... over the stones (foundation) a sheet of copper ... and over this, with arsonic dissolved in sesamum-oil ..." (12)

This type of micro-biological and paleo-botanical prevention is not isolated. If one views the meticulous detailing adopted in the construction of leaf-huts which were synonimous with the forest monks of the 5th Century A.D. we see the seriousness of such attempts and in the conventions adopted and followed by the architects of these royal monasteries with a view to protecting the structures from such destructive agents as white ants and plant life.

<u>Load aspects and settlement</u>

The principles of settlement concerning such enormous monuments which have been found by us to weigh millions of tons have to be

viewed in terms of :

(a) bearing capacity of the soil,

(b) the homogeneity of the masonry work in terms of the bricks and the mortar and the likelihood of settlement taking place in the weaker material of the bond which in the case of the stupas was clearly the clay joints that were likely to creep under loading.

The foundations of Jetavana, Dakhina Vehera, Mirisavetiya and Kirivehera, Kataragama have been excavated to their foundations. It has been observed that the foundations rest on either bed rock, or in some instance due to a fissure or some other reason, the basements had to be artificially prepared to meet the loads. In such instances the man made bases have been described in the texts as early as the 5th Century A.D. wherein it states:

> "... had the place for the stupa dug out to a depth of seven cubits (16 feet) to make it firm in every way. Round stones that he commanded his soldiers to bring hither did he cause to be broken with hammers, .. command that the crushed stone, to make the ground firmer, be stamped down by great elephants whose feet were bound with leather". (13)

The excavation at Kirivehera, Kataragama revealed that the stupa rested on bed rock which was fairly widespread at about 14 feet below the terrace. At Mirisavetiya it was the same, where bed rock occurred at a level around 10 feet below the terrace, but there were definite fissures and these were filled in a manner identical to that described in the old text.

In terms of the homogeneity of the brick masonry, important construction principles were followed. The engineers and scientists constructing these stupas were well aware of the strengths and limitations of their products. The bricks were of an extraordinarily high quality with a large bearing capacity. At the same time the mortar used therein was an economic product and non-load bearing if applied as a thick course. The use of such a mortar would have resulted in a sandwich effect under loading wherein the clay would have oozed out on all sides under the effect of creep due to the increased application of load in the stupas reaching such stupendous heights. The mortar referred to as butter clay in the texts and if this had been used in thick layers of ¼ to ½ inch as is the practice today, then the 400 feet of stupa would have been subjected to a mortar settlement factor of around 33 feet.

The ancient builders who were well aware of this dispensed with the thick mortar joints and reduced such spaces to zero height by applying a clay slurry which is referred to as"butter clay" in the chronicle. The ruined stupas of Sri Lanka display such mortar joints. As such the compression over the vertical load of the mass of nearly 1,200 courses of bricks , as is the case of the Jetavana stupa where in the brick courses sat one upon another, transmitted the load from one brick directly to another and not through an intermediatory mortar layer. The fact that there was a distinct roughening on one of the two flat sides of each brick, the clay slurry was trapped in these crevices and thereby, provided an adhesion which prevented any lateral movement.

Why the collosal stupas did not succumb under their own load?

If we were to check the full load of the mass of masonry on the bottom most course of bricks the weight of the 400 feet tall Jetavana stupa would have been approximately 1,213,000 tons with an average distributory load of 92 pounds per square inch. On the other hand if we consider the unfinished Demalamahaseya at Polonnaruva which has been conjectured to have been 625 feet tall, its total weight would have been 4,639,000 tons, and the weight on the bottom most course of bricks at 150 pounds per square inch. The ancient bricks have been tested by us and the initial stress cracks appeared at 621 pounds per square inch. In fact, the modern bricks that were turned out to replace the lost ancient bricks and despite these being made under factory conditions of the Ceramic Corporation, Weuda Factory, the results achieved were that of a brick which yielded a first stress crack at 265 pounds per square inch.

If we visualised the weight on the bottom most course of the brick structure and if the stupas did not have the footings as it was the case of the early monuments in India, then the weight would have been 165 pounds per square inch for Jetavana and 240 pounds per square inch for Demalamahaseya. It has been customary even in the 20th Century A.D. to permit a safety factor in the ratio of 4 for brickwork so that a safety factor ratio of 4 in 165 pounds per square inch for Jetavana and 240 pounds per square inch for Demalamahaseya would have resulted in a load capability of 660 pounds per square inch for Jetavana and 960 pounds per square inch for Demalamahaseya which figures are well above the capabilities of even the best ancient bricks of 621 pounds per square inch. It is for this reason that the stupa design in sites like Sanchi in India had to be modified when introduced to Sri Lanka and the base brick footings extended to reduce the direct load component from 165 pounds per square inch to 92 pounds per square inch for Jetavana and from

240 pounds per square inch to 150 pounds per square inch for Demalamahaseya or a load reduction of nearly 40%. Considering the unfinished stupa at Demalamahaseya, we are, therefore, convinced that the bricks of this stupa were well capable of resisting its self-load as the design followed indicates quite clearly the same extended and spread foundation. However, the work at Demalamahaseya was not stopped due to any deficiency in its structure, but in all probability, due to the lack of resources after the 12th Century A.D. Is the 20th Century going to complete this historic monument is yet another question?

We have also been fortunate to find out the reason for the vast difference in the bearing capacity of the ancient bricks when compared with the modern factory made examples to the same size with sophisticated and controlled equipment. H.W.S.Siritunga of the UNESCO - Sri Lanka Project of the "Cultural Triangle" who carried out these tests using a thin section from each example have found the following facts in terms of the clay mix: (14)

		Modern(Weuda)	Old (Jetavana)
Minerology ratio	Quartz (sand)	30 - 40%	60 - 50%
	Clay	65 - 55%	35 - 45%
	Voids	1 - 5%	3 - 8%
Sand Analysis	Silt	12.7%(∠ 1/16 mm)	48.5%
	Very fine sand	33.8%(⅛ - 1/16 mm)	48.5%
	Fine sand	17.8%(¼ - ⅛ mm)	-
	Medium sand	22.2%(¼ - ½ mm)	1.9%
	Common sand	11.1%(½ - 1 mm)	1.1%
	Very common sand	2.3%(1 - 2 mm)	-

This analysis will show the graded and fine composition of sand in the ancient bricks as against the course mix in the modern specimens. Further, the 60 - 50% ratio of load bearing sand that has been used in the ancient bricks when compared to half this amount of 30 - 40% ratio as used in the modern bricks advances us the reason for this sad retrogression of

standards. A comparative study of the two slides will also show the clear homogeneity of the materials in the ancient bricks as against the messy outlook of the modern.

Design details and construction

The marvel of these monuments is to a large extent the concept, for which credit must flow to the head of state - the king. These kings have often been restrained in their over enthusiasm by the monk architects as seen in relevant comments in the chronicles.

> "But the great thera of wonderous power named Siddhatta, the far-seeing, prevented the king as he did this (drawing a large circumference for the stupa). Reflect: 'If our king shall begin to build so great a thupa death will come upon him, ere the thupa be finished; moreover, so great a thupa will be hard to repair." (15)

This was a comment in the 2nd Century B.C. when King Dutthagamani was laying the foundation to a 300 feet tall stupa. We presume that no such comment would dare have been made with King Parakramabahu I when he, not only laid the foundation to the Demalamahaseya which was to be more than twice the height of Ruwanvalisaya at 625 feet, but also began work on two other dagabas, one at the site of his birth place, Dedigama (180 feet) and the other at the side of his mother's birth, Yudaganava (300 feet). The outcome was obvious and all three stopped work at the end of the reign. Whatever it be, the devotion of the generations that followed was usually that a religious monument begun previously was completed in the years that followed and to that extent the Ruvanvalisaya was finished by his brother who succeeded him, but the

12th Century, unfortunately marked the collapse of the whole nation when Sri Lanka entered the dark ages and the country overrun by foreign domination in 1505 A.D. until independence which was gained only thirty five years ago. As such it is only now that Kings and Presidents of the modern era have extended their serious interests towards cultural and religious edifices.

The design of a stupa was perhaps the easiest exercise for an architect for the conventions were rigid and any changes were strictly minimal. It was only the size that generally mattered. A simple illustration of this is when the royal architects were summoned for a plan to construct the Mahathupa at Anuradhapura. The architect is then said to have called for a basin of water and with this in front of the king he splashed the water so as to produce a large bubble which was immediately shown to the king as the symbolic model of the stupa he proposed to construct.(16)

The plotting of such a drawing on the ground was a ceremonial event for the day of the foundation laying ceremony. The centre of the stupa was fixed with a golden pin and a gilded cord tied to the turning staff of silver. It was the task of a minister of the king's court to move the latter along the outer circle of the proposed stupa foundation. (17) The rise in every course of bricks one upon another was followed in the self same way upwards with the end of the radial cord indicating the edge of each course. The length of such a cord for each course was measured against a full scale cross-section of the stupa marked on the ground on a flat plain. Descriptional details are recorded in the various texts like the Dipavamsa, Mahavamsa, Thupavamsa, Bodhivamsa, Manjusri's vastusastra etc., about the construction of stupas and such rituals connected with the painting and the deposit of objects in the sealed

relic chamber. These ceremonies are followed meticulously even today in the simplest of village shrine where stupas are constructed. The incompleted historical stupas have also given us much data as to the construction process. We have seen at the site of the Dedigama dagaba the brick kilns and the abandoned earth ramps and brick steps leading to the top of the dome which were, no doubt, used for the transport of materials along a human conveyor.

The marvels of such constructions especially with the collosal stupas have been brought together by a civil servant of the British regime, Emerson Tennent, in a book compiled in 1860 which is, even today, a ready reference to many a scholar. He states that the bricks of the largest stupa at Anuradhapura, Jetavana (400 feet) were sufficient to raise eight thousand houses each with twenty feet frontage, and these would form thirty streets half-a-mile in length. These could also line a railway tunnel twenty miles long, or form a wall one foot in thickness and ten feet in height extending from London to Edinburgh. Another romantic, Harry William says of the Ruvanvalisaya (300 feet) that it would take five hundred bricklayers, working English union time for fourteen years to build this stupa.

Financial and Management Resources

The Sri Lankans, both by convention and practice, have been an agricultural people. The vast irrigation works launched at the very dawn of settlement are still in use and this tradition is yet the life style of the population of this country. The collosal Mahaveli Scheme of the present day

did not come out of a magician's hat, but a project encouraged and developed by all governments in power since its inception perhaps fifteen or more years back. The implicit outcome of this basic agricultural economy is that there was no major surplus of cash that could be set aside for investment which could pay for such gigantic work as these identified in this paper. But this broad based policy of a well provided, well fed and well settled people meant that there was a high peak in the "quality of life". In fact, the measure of such a social set up was the "quality of contentment" a standard set by the serious preaching and practice of the teachings of the Buddha. This life style, in many ways, was far superior even to our daily reckonings in a modern context. Such a society, nurtured by the basic wants and leavened by the spiritual standards, was indeed the fertile base upon which these collosal religious edifices were founded. The richness of such a social make-up was not counted in coins of gold for we knew the reply of King Datusena in the 5th Century A.D. when he was asked by his son to identify his treasures and as a prisoner requested that he be led to the vast reservoir of the Kalaveva and as he descended the waters and there clasped a handful of water, raised it and said: "this is my wealth, this is my wealth". In the same breath of thought one is reminded of yet another philosopher king, in fact the very personage that left the Demalamahaseya unfinished, who said and indited these thoughts not only to a rock inscription, but into the very heart and soul of the Sri Lankan people . "Let not a drop of water that fall on the good earth lead out to

the sea without serving man". (18) All these and many more cases from history established the backdrop which provided the base economy of our people towards spiritual and temporal contentment which left a massive surplus of "good will" which was harvested using the right motivation and that was indeed the secret of a major component of construction - shramadhana or free labour; "shrama" meaning effort and "dhana" meaning donation. The sensitive use of labour as a return of "good will" to state and religion is reflected in a thought process noted in the Mahavamsa when the construction of the Great Thupa at Anuradhapura was considered by the king:

> "I will build the Great Thupa .. at the conquering of the Damilas (Chola invaders) this people was oppressed by me. It is not possible to levy a tax; yet if without a tax I build the Great Thupa how shall I be able to have the bricks duly made? " (19)

We know even today that labour is around a third of the cost of construction work, but if we compute the labour involvement in the manufacture of building materials such as bricks, supply of sand etc., it will be well over two thirds. The raw materials for the massive stupas were bricks and clay mortar and this came out of the neighbourhood. The firewood was provided by the flush vegetation of a tropical forest. The balance ingredients were a few specialised wants like rockstones again found in the vicinity, and lime for plaster which was available in the coasts of the island. Thus, when we analyse the work components the results of construction were an outcome of the neighbourhood, but intelligently transformed into products of man which today are

wonders of human achievement.

Thus management was indeed the answer to this question of construction where technology was available. Our examination of various stupa and especially those of an incompleted nature provide us with the maximum data. At the Rankot Vehera in Polonnaruva we have seen an unusual feature where every twenty second or twenty third course of bricks on the dome had a layer of lime mortar. Now we knew that lime mortar was expensive and was used very economically only for water proofing. This evidence at the Rankot Vehera points to the suggestion that this water proof membrane was to protect the brickwork at the end of one season of work by one shramadhana group of workers probably from one particular village. This indicates the possibility of the king assigning to each voluntary village a portion of work to be carried out on every stupa. The three unfinished stupas at Polonnaruva, Dedigama and Yudaganava also had a small heaping-up of bricks at the centre of the last completed course in the form of a miniature stupa. This too points to the same thought that at the end of the shramadana of a voluntary village the team heaped-up the balance bricks at the centre of the stupa dome, paid their respects to the relics of the stupa beneath, and returned home.

Ladies and Gentlemen, we have here tried within forty five minutes to identify an area of fundamental research that has transformed the living styles of people of this planet, where the good earth has been scientifically converted to living products of man in bricks and mortar. It was the pressure of construction by our forefathers that produced these scientific achievements, the parallel of which we have yet to see elsewhere. Our investigations of such areas of speciality will, no doubt, elevate

our knowledge of such uses and this data will surely form a springboard for future study and endeavour.

May I take this opportunity to thank the Board of Governors of the Institute of Fundamental Studies, Sri Lanka in giving me the honour to address this august assembly.

Thank you, Mr.Chairman.

Foot Notes

(1) The circumference of this is given in the Culavamsa as 1,300 cubits which is equal to 1,950 feet. We excavated this in 1969. A trial trench was opened and we established the circumference to be 2,011 feet. This unfinished stupa stands at a height of around 80 feet today under thick tropical jungle and is scheduled for excavation under the UNESCO - Sri Lanka programme of the "Cultural Triangle".

(2) Paranavitane S., The Stupa in Ceylon, Colombo, 1946, p.8.

(3) Mahavamsa, translated by W.Geiger, Colombo, 1950, chapter 30, verses 51 - 52.

(4) Thupavamsa, Pali Text Society Edition, p.50.

(5) Culavamsa, translated by W.Geiger, Colombo, 1953, chapter 38, verses 74.

(6) Mahavamsa, translated by W.Geiger, Colombo, 1952, chapter 29, verses 7 - 11.

(7) Abeyratne M., Analysis of lime mortars in ancient stupas in Sri Lanka, Research Paper No.CH/2, UNESCO - Sri Lanka Project of the "Cultural Triangle", Colombo, 1982, (unpublished). Here the composition of the mortar is given as follows:-

SiO_2 - 68.21%; CaO - 12.05%; Mg O - 5.03%;
$R_2 O_3$ - 3.35%; $Fe_2 O_3$ - 1.47%; $P_2 O_5$ - 0.40%
and other substances - 9.59%

(8) de Silva R.H., The Technique of Ancient Sinhalese Wall Painting - Sigiriya, Paranavitane Felicitation Volume, Colombo, 1965, pp.96 - 99.

(9) Hughes J., Analysis of Concrete Six Centuries old from Anicut of Giant's Tank, Ceylon, History of the Public Works Department, Ceylon, 1796 - 1896, P.M. Bingham, Vol.2, Colombo. 1922. pp.86 - 87

(10) Mahavamsa, translated by W.Geiger, Colombo, 1952, chapter 29, verse 12.

(11) Abeyratne M., Analysis of lime mortar in ancient Stupas in Sri Lanka, Research Paper No.CH/2, UNESCO - Sri Lanka Project of the "Cultural Triangle", Colombo, 1982, (unpublished).

(12) Mahavamsa, translated by W.Geiger, Colombo, 1950, chapter 29, verses 11 - 12.

(13) Mahavamsa, translated by W.Geiger, Colombo, 1950, chapter 29, verses 2 - 4.

(14) Siritunga H.W.S., Minerological and textural report of the Weuda modern bricks and Jetavanarama old bricks, Research Paper No.GM/2, UNESCO - Sri Lanka Project of the "Cultural Triangle", Colombo, 1982, (unpublished).

(15) Mahavamsa, translated by W.Geiger, Colombo, 1950, chapter 29, verses 52 - 53.

(16) Mahavamsa, translated by W.Geiger, Colombo, 1950, chapter 30, verses 11 - 13.

(17) Mahavamsa, translated by W.Geiger, Colombo, 1950, chapter 29, verses 49 - 51.

(18) Culavamsa, translated by W.Geiger, Colombo, 1953, chapter 68, verse 3.

(19) Mahavamsa, translated by W.Geiger, Colombo, 1950, chapter 28, verses 3 - 5.