THE ANCIENT SLUICE AT THE MĀDURU OYA RESERVOIR

Experimentation in Sri Lankan Traditions of Hydraulic Engineering

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A few years ago, the engineers who planned the layout of irrigation works in the Mahaväli Gaṅga project area decided to locate one of their largest reservoirs in the valley of the Māduru Oya, at a site where this river passes between the Dānagala and Kandēgamakanda ridges. They were to find that their counterparts who had preceded them by more than a millennium had already built a large reservoir at this very site. The workers who began to clear the site of the modern reservoir found the remains of the ancient weir. The river had broken through it, but a section of about 300 metres in length still remained. In September 1982, during the preparatory work for the construction of the dam, a machine used for earth-moving laid bare the remains of an old sluice at the site.[1] It is remarkable that, here again, the modern engineers had planned to place a sluice at the very position where their ancient counterparts had already located their own sluice. "The location of one of the irrigation outlets for the new dam is almost in exact alignment with the ancient sluice," the engineers who worked on the modern project have observed. "The similarity of the ancient and the modern projects," they note, "is startling."[2] It is commendable that a decision was taken to preserve the sluice, together with the remaining sections of the ancient dam which deserve careful study and further investigation. During the excavation work conducted by the Archaeological Department under the supervision of M. R. G. Kulatilleke, the whole length of the sluice was uncovered.[3] Consequently, students of the history of irrigation technology in Sri Lanka were provided with a rare opportunity to examine those sections of an ancient sluice structure which are located inside the earthwork embankment of a reservoir. The sluice has now been surveyed and section drawings and a plan of the structure have been published.[4]

The outlet conduits of the sluice are about 66 m. in length, and are encased in a brick structure which is about 9.5 m. wide and 2.84 m. in height (See Fig.1).[5] Bricks of an exceptionally strong type had been used in the construction of that section of the structure which is closest to the inner face of the reservoir. Specimens of bricks from this part of the structure measure about 45.5 cm. in length, 22.5 cm. in width and 6.5 cm. in thickness. Prof. M. P. Ranaweera and Vasantha Wijekulasuriya of the Department of Civil Engineering at the University of Peradeniya were kind enough to test two of the specimens obtained by the present writer. These tests revealed that the load-bearing capacity of these bricks could be as high as 2077 pounds per square inch or 385 kilograms per square centimetre. It was observed that the constituent particles of these bricks had been densely packed with a good binding giving the bricks an impervious quality. The materials used in the preparation of the bricks were not of the usual types of naturally-occurring clay, and the scattering of particles in the test samples suggests that they had been carefully sifted and blended.[6] These bricks reflect, in addition to the expertise of the brickmaker at the selection and gradation of materials, the availability of sophisticated kilns not often encountered in those times, for these bricks were probably fired at exceptionally high temperatures. It is noteworthy that, in respect of their load-bearing capacity, these bricks have to be compared not with the ordinary bricks of modern times but with "wire-cut" bricks produced through special industrial processes. Tests aimed at determining the type of production technique that these bricks represent should throw valuable light on an important aspect of the history of ancient technology. The progress which had been already made in such ancilliary fields as brick-making was an important factor behind the achievements of the ancient irrigation engineers of Sri Lanka. These bricks have been laid in "tight-packed" manner, apparently without any mortar. However, laboratory tests have shown that a fibrous vegetable matter forms a thin layer between each course of brick. It has been suggested that a resinous bonding has been used in the masonry work within this part of the structure.[7] Bricks used in those parts of the structure which are further away from the inner face of the reservoir are of a lower quality and do not appear to have been made with the same degree of care as those mentioned earlier. It is likely that the engineers did realize that those parts of the structure which are closer to the waterface of the reservoir would be subjected to much greater stress than the parts which are closer to the outer end.

In this paper we shall be focusing on some of the more important specific characteristics of the Māduru Oya sluice. In all the sluices previously examined by students of irrigation technology in Sri Lanka, the outlet conduits which stretch across the width of the embankment connecting the cistern with the initial point of the irrigation channel are laid out in a straight line. The Māduru Oya sluice provides a noteworthy exception in this respect. After laying the conduits in a straight line for about 59 m., the ancient designers decided to insert an obtuse-angled elbow which meant that the conduits turn sharply to the right before proceeding to the outlet point. Experimentation with the use of obtuse-angled "elbows" in the arrangements for the release of water from large reservoirs in order to help dissipate energy and minimize risks to embankments is not entirely unknown in Sri Lanka. However, the example we know is from a somewhat different context. The designers of the Periya Ōlukulam reservoir used this device, not in the outlet conduits leading water from the cistern as here, but in the inlet conduits which brought water to the cistern.[8] It is possible to suggest, that the unusual plan of the Māduru Oya sluice represents another attempt at similar experimentation. Of course, it is but correct to acknowledge that the use of such devices would have been of optimal benefit if they had been placed at an earlier point as at the Periya Ōlukulam reservoir. Another possible explanation of the layout of the outlet conduits has been suggested by Dr. Stuart Brown who believed that the sluice conduits follow the line of a natural layer of rock which provided the foundation for the conduit.[9] The fact that the sluice had been built on a very firm foundation is beyond doubt. The modern engineers who examined the sluice more than a millennium after its probable time of construction could find little evidence of subsidence.[10] Brown's explanation seems plausible though it is difficult to imagine that the ancient designers were at a loss to find an alternative site providing a firm foundation for sluice conduits laid out in a straight line.

An interesting and unusual element in the layout of the conduits is the incorporation of the so-called "wing wall". This wall, built of kiln-made brick, projects to the left of the path of the outlet conduits and extends along the line of the dam for about 10 metres. It seems probable that the designers of the Māduru Oya sluice realized that their construction. which had to withstand the effects of the passage of water at high pressure, needed, in addition to a good foundation, a means of securing its lateral stability. It is probably this purpose that the "wing-wall" was supposed to serve. Brown thought that it was an approach path[11]. This, however, does not seem likely since this part of the structure would have been within the embankment[12].

The outer end of the sluice is formed of a stone block of massive proportions which has been horizantally placed above three short stone pillars. The horizontal block is about 2.5 m. long and about 83 cm. in width. The central pillar is of similar cross-section but the pillars on either side are each about 35 cms. in width. Each of the two outlet orifices measure 70 by 95 cm. Though in general layout and appearance the outlets are quite similar to those of sluices in other ancient reservoirs, there is one feature which is specific to the Māduru Oya sluice. The brickwork to the north of the outlets had been carefully designed by a person who had a close acquaintance with the behavioural characteristics of fluids . As Dr. R. P. Benson *et al.* have pointed out[13], the flared construction of the brickwork had been probably designed to ensure a smooth hydraulic transition from the sluice conduits into the irrigation channel.

The two outlet conduits of the Māduru Oya sluice are not of the same cross-section at the upper-stream end. Both orifices are approximately 86 cm. in height, but the northern orifice has a width of 75 cm. while the southern is only 60 cm. wide. This arrangement is rather unusual. Another feature in the design of the sluice conduits distinguishes the Māduru Oya sluice from the other sluices about which information has been previously available. In most sluices the conduits are formed of stone slabs which are surrounded by brickwork. Often, as at Pāvaṭkulam, the brickwork was made water-proof by a fairly thick layer of puddle clay.[14] At the Māduru Oya reservoir, too, a brick structure is to be found behind the stone lining. However, there is an important difference in that the brickwork above each conduit forms a corbelled arch, leaving a space just above the stone slabs which form the roofs of the conduits (See Fig.2). The arches are roughly about 70 cm. wide at the base and about 115 cm. high. As Benson *et al.* have noted, there is no evidence of erosion within this space above the conduit. This probably implies that it would not have been used or intended for use as a passageway for water. Hence, the authors hypothesised that "the arch was probably constructed to prevent direct loading onto the roof of the rectangular conduit."[15] Without the arches, the stone slabs used in the construction of the conduits would have had to bear the weight of the upper parts of the earthwork dam. These designers had obviously considered the possible calamity which could be caused by the outlet conduits collapsing under the heavy load that they had to bear. The use of arches was an immensely useful innovation which reduced this risk by helping to distribute the load to the walls on either side of the conduit.

The closely laid brickwork which surrounds the conduits in the Pāvaṯkulam sluice prevented seepage of water from the conduits into the earthwork embankment. The builders of the Māduru Oya sluice laid a thin course of bricks over the stone roof of the rectangular outlet conduit. It is likely, they reasoned, that it was sufficient to prevent seepage under normal pressure. And if, under exceptional circumstances, an unusual increase in pressure led to seepage, the thick brickwork forming the corbelled arch would have been meant to provide the second line of defence against seepage. One may very well pose the question why they opted to use this complicated combination of a stone-lined conduit of rectangular cross-section placed within a brick-built structure with a roof formed of a corbelled arch. One could also argue that a single passage with a corbelled roof would have solved the problem that the designers faced. However, it appears that their solution was the best possible with the materials they had to work with. Well-burnt brick was an ideal material for that part of the construction which was meant to counteract seepage and, in comparison with stone, it represented a lighter load. On the other hand, stone was more useful for a construction meant to withstand erosion through friction. The stone-built conduits of rectangular cross-section had been proved in use over centuries. This particular combination of material and design enabled them to introduce a dependable means of ensuring the security of the dam with "a second line of defence".

Unfortunately, a good part of the cistern which would have been situated by the waterface of the reservoir was completely destroyed by the earthmoving machinery, and, in fact, unless this part of the ruins is examined with great care, one could easily form a wrong impression about the inlets of the sluice. Brown, who arrived at Māduru Oya when the sluice had already been partially covered up,[16] probably had this difficulty. It was his opinion that the sluice did not perform a regulating function since it did not possess any elements which would facilitate such regulation of the outflow of water. He was therefore inclined to believe that the sluice was what he called a "free-flow outlet."[17] On the the basis of this hypothesis he proceeded to conclude that the capacity of the Māduru Oya reservoir was "determined by the elevation of the free-flow high level sluice and the left bank spillway."[18] The hypothesis that this elaborately constructed structure was not expected to perform a regulating function but was meant merely to be a free passageway for water raises several problems which are not easily explained away. If the designers were in fact expecting it to function as a free-flow conduit, a good part of the effort that obviously went into its design and construction would not have been necessary: an open drain would have very well served the same purpose. Further, the left bank spillway and the sluice under discussion are not situated on the same elevation as Brown's statement would seem to imply. The sill of the left bank spillway is located at an elevation of 85 m. above Mean Sea Level, and therefore 4.2 m. *above* the level of the sill of the sluice. And, as such, if the designers did want to have a "free flow" type outlet, it is most likely that they would have located it at the same elevation as the spillway. Hence it seems necessary to make the most thorough investigation possible before we conclude that the sluice was not intended to serve a regulating function.

Though a good part of the evidence about the cistern has disappeared as a result of the use of heavy earthmoving machinery near the waterface of the old dam, a careful examination of what remains of the inner end of the sluice reveals several interesting details. The floor of the cistern was paved with stone slabs, and beneath it is a foundation built of brick. The side walls of the cistern were also faced with massive stone slabs, some of which still remain and are 30 to 35 cm. in thickness. Between these stone pavings and the earthwork of the dam was a structure of brick which made the cistern waterproof. There is a space between the brickwork and the stone slabs which seems to have been originally filled with clay, again as a means of preventing seepage of water.

The cistern appears to have been divided into two compartments by a wall running across the middle of the cistern, parallel to the dam. A "trench", 47 cm. in width, is to be found in the middle of the cistern, and was probably meant to receive the foundation of this wall. (Pl. 1) Though it is a possibility that this wall was built of stone or brick, no remains of the constituent elements of the original structure can be identified with certainty, hence it cannot be ruled out that it was built of timber. It is also noteworthy that recesses had been cut into some of the stone slabs now lying near the inlet apertures of the conduits. It appears that they were meant to receive vertical posts, about 15 cm. in thickness. Since no remains of these posts have been found, it is very likely that they, too, were made of timber rather than stone. That there had been a large wooden structure within the cistern is also evident from the fact that eight iron nails, of lengths varying from 17 to 27 cm., were found there. (See Pl. 2) The sizes of these nails are suggestive of a wooden structure of large propo-rtions. In none of the cistern sluices previously excavated and examined in Sri Lanka have the remains of a gantry arrangement for the regulation of the outflow of water been found. One plausible explanation for this phenomenon has been that the gantry, or a good part of it, was made of wood and had therefore perished without leaving any trace.[19] The nails found at the Māduru Oya sluice may be considered as evidence which lends support to this hypothesis.

The layout of the cistern as evident from the remains of the Māduru Oya sluice is strongly reminiscent of a cistern sluice from South India. A detailed description of this sluice, found at the Poṉṉēri reservoir near Gaṅgaikoṇḍa-cōḻapuram in the Tañjāvūr District has been already published.[20] As noted in that publication, this cistern-type sluice is clearly different from the piston sluices typical of the Tamilnāḍ area and appears to represent an instance of Sri Lankan influence on the hydraulic technology of South India. However, unlike in Sri Lanka, the South Indian engineers preferred to use stone, rather than wood, for the construction of the gantry located inside the cistern. This preference has proved to be most useful to the present-day students since the information provided by the Poṉṉēri sluice helps us to understand certain basic features of Sri Lankan sluices, including the Māduru Oya sluice.

The longer side of the Poṉṉēri sluice measures 2.97 metres. The two shorter sides are of different lengths, one measuring 80 cm. and the other 63.5. The main element in the regulating mechanism, housed inside the cistern, consists of a pillar of stone, about 38 by 23 cm. in cross-section and about 1.86 m. in height. It is held in place by six cross-beams. (Fig. 3) Grooves, about 7.5 cm. in width, have been cut on either side of the pillar, and there are corresponding grooves in the stone pillars built into the walls of the cistern. (Fig. 4) By inserting two sets of slabs, of stone or wood, through these grooves it would have been possible to close the sluice or to regulate the amount of water flowing through it.

It is very tempting to suggest that the Māduru Oya sluice possessed a similar arrangement for the regulation of the outflow of water. Since its cistern is much larger than that of the Poṉṉēri sluice, a single pillar would not have been sufficient to support the gantry mechanism. One has to think more in terms of a wall linking the northern and southern sides of the cistern with an aperture or apertures which could be closed at will. On considering this possibility it is particularly striking to note that the 47 centimetre-wide "trench" mentioned above is located at such a position within the cistern that it seems very likely that it provided the foundation for a structure housing the regulating mechanism.

Some more items of evidence found at the site of the cistern of the Māduru Oya sluice seem to support our view that it was not a "free-flow" outlet as Brown surmised but incorporated as one of its constituent elements a device for the regulation of the outflow of water. Apart from the eight nails mentioned above, two iron frames and seven other pieces of metal were discovered by the inlet apertures of the Māduru Oya sluice. (See PL. 2) Brown, too, was aware of these finds. In the note on the artifacts discovered at the sluice appended to his report, he refers to two "iron grilles".[21] However, he concluded that these fragments were parts of "gratings and not doors that could have been opened and closed to regulate the water flow,"[22] thereby summarily dismissing the possibility that what he called gratings could have been parts of a regulating mechanism.

The two iron frames, which Brown referred to as "grilles" and "gratings", are of special interest. Of these the better-preserved one is rectangular in shape and measures 27 by 40 cm. It had been fashioned out of a metal band about 5 cm. in width. The other frame is smaller and measures 34 by 27 cm. On the inner side of the frames are to be found remains of nail-ends. It appears very likely that these frames encased wooden slabs which were held in place by these nails.

In our previous discussion on the remains of the Poṇṇēri sluice, we noted the arrangements that had been made for the control of the outflow of water by means of slabs which were moved along the grooves especially cut for the purpose. Evidence for the use of somewhat similar devices has been found in Sri Lanka as well. In a description of the arrangements for water control in the ancient park named Ran Masu Uyana, situated by the Tissa reservoir at Anurādhapura, the present writer has drawn attention to two cistern sluices found there.[23] The smaller of the two cisterns fed the "cool chambers" (*dhārāgṛha*) in the park: it measures 1.3 m. square and 80 cm. high. The stones placed on either side of the outlet of this cistern have been cut in such a manner that a slab measuring 27 cm. wide and 13 cm. thick can slide in or out vertically, thereby regulating the outflow of water from the cistern. The larger cistern controls the outflow of water along the drainage channels. It is 1.73 m. long and 1.27 m. wide and has an outlet which measures 27 cm. square. A slot measuring 38.7 cm. long and 14.6 cm. wide had been cut through the wall of the cistern. It is possible to regulate the flow of water in the outlet aperture by sliding a slab vertically through this slot. In 1869 L. Liesching had noticed a similar arrangement for the regulation of the outflow water at the Kuḍāvilacciya reservoir. He refers to a "a sluice the 'door' of which was of stone that slided up and down in another stone."[24] Unfortunately, no remains of this sluice are to be found today.

The metal frames found at the Māduru Oya sluice are probably the remains of two similar valves which regulated the outlets of the sluice. Though types of local timber with suitable hygroscopic properties, like *dom̆ba* (*Calophyllum inophyllum*), *hora* (*Dipterocarpus zeylanicus*) or *kum̆buk* (*Terminalia arjuna*), would have been used in the construction of the gantries of sluices,[25] the operation of wooden valves inside wooden grooves would have been rendered difficult due to the effects of being immersed in water. These valves had to be moved upwards to open the sluice and downwards to close it. It is possible to suggest that the wooden valves were encased in metal frames to enable easier movement inside wooden grooves.

Some of the other pieces of metal found with the frames support the hypothesis that these frames encased wooden valves. One of these is a metal band about 45 cm. in length. It had been bent at two points, at an obtuse angle in one direction at 7 cm. and again in the opposite direction at 22 cm. (See Pl. 2b) The remaining 23 centimetre-long section of the band is straight. At a point about 13 cm. from the end, a protrusion, about 1 cm. in length, probably what remains of a nail, is to be found. A section of another similar band, but not as well-preserved as the previous example, is among the finds from the very same trench. It is most likely that originally the two bands were parts of the two frames as demonstrated in the accompanying drawing (Fig.5b) and that the nail on the band helped to keep it attached to the wooden slab encased in the metal frame. A person standing on the cross-wall of the cistern could have opened or closed the valves, using a pole attached to the hooked section of the band.

If our explanation of the functions of the metal frames found inside the cistern of the Māduru Oya sluice is correct, it would imply that there were two apertures on the wall which stretched across the middle of the cistern and that these two apertures were of such dimensions that it would be possible to close each of them with the corresponding valve. Since the area of an aperture would be less than the area of the sluice-valve, it would appear that the total area of the two apertures was less than 2,160 square centimetres. It is interesting to note that this amounted to only about a fifth of the total area of the cross-sections of the two outlet conduits which was about 11,610 square centimetres. With such an arrangement, the outlet conduits were adequate to easily handle the quantity of water released by the sluice-valves. This design, it may be suggested, would have contributed to limiting the pressure of water within the outlet conduits.

In order to form an idea of the levels of pressure that this sluice was expected to handle, it is necessary to examine the information available on the size of the ancient Māduru Oya reservoir. The height of the earthwork dam, as it is found today, varies between 88 and 95 m. above MSL. Benson *et al.* were probably right in suggesting that the higher figure represents the original height of the dam.[26] Usually, it is possible to easily compute the "full supply level" of a reservoir on the basis of information on the level of its spillway. It is true that in the monsoon season there could be instances of the level of water rising above this mark if, as is usual, the capacity of the spillway is inadequate. However, the level of the spillway points to the "normal full supply level". In the case of the Māduru Oya reservoir, the problem of computation is somewhat complicated. It has two spillways and these are situated at two different levels. As we have noted already, the left bank spillway is located at an elevation of 85 m. above MSL, but the sill of the right bank spillway is located 5.5 m, above this. Confronted with this problem of explaining the difference in levels of the two spillways, Benson *et al.* hypothesized that both spillways would have been raised by means of "fuse plugs" to a level of 94 m. above MSL.[27] In the drawings published by them, the level of the base of the reservoir is placed at about 60 m. above MSL. This would imply that the head of water in the reservoir could be as high as 34 m., a figure unmatched in any of the ancient reservoirs.

There are strong reasons which would lead one to believe that the figures suggested by Benson *et al.* amount to a gross exaggeration of the proportoins of the ancient Māduru Oya reservoir. The authors themselves appear to have realized that the velocities created by the release of water from a reservoir with such a head were well beyond the capacities of the sluice in question.[28] Hence a re-examination of the question of the size of the reservoir appears to be necessary. The head of water in this reservoir, as suggested by these writers, would be more than double that of Kantalē, the ancient Sri Lankan reservoir with the tallest dam. Thus the figure appears to be most unlikely. Further, if the planned level of water in the reservoir at full capacity was 94 m. above MSL as Benson *et al.* hypothesized, it would have meant a lack of adequate allowance to meet such contingencies as flash floods. An allowance of only one metre would have been certainly inadequate for this purpose. It does not require complex calculations to suggest that, with such limited "freeboard" capacity, overtopping during the rainy season would have undermined the stability of the dam. In this context, it has to be pointed out that the hypothesis about the use of "fuse plugs" is quite controversial. A nine-metre high "fuse plug" which, according to these authors, was in use at the left bank spillway, does not appear to be a likely possibility. Even if we were to accept the possibility that "fuse plugs" were in use, it would be more credible if one were to suggest that this device was of smaller proportions and was used only to raise the level of the left bank spillway to that of the right bank spillway, i.e. to 90.5 m. above MSL.

However, it is important to note that this is not the only possible explanation of the disparity in level between the two spillways. What seems to be the more plausible explanation is that the ancient Māduru Oya reservoir was the work of a careful designer who had a close understanding of the demands of a reservoir dependent on the resources of a river which could display a phenomenal variation in discharge between the dry and the rainy seasons. It is very likely that the designer intended the normal level of the reservoir at full capacity to be that of the left bank spillway, i. e. 85 m. above MSL. Such an arrangement would have provided a "freeboard" capacity[29] of about 10 m. One of the problems that led to the destruction of several ancient reservoirs was the inadequacy of spillways to handle the massive input of water during the height of the monsoon. The arrangements at Māduru Oya reservoir provide for an increase of its level by 5.5 m. under such special circumstances. At this point the second spillway situated on the right bank comes into operation. There would still be a safety margin provided by a further "freeboard" capacity of about 4.5 m. before overtopping could occur. It is very unlikely that, with such precautions to meet situations of excessive inflow of water during the monsoon season, there was ever a possibiiity of the dam being destroyed as a result of overtopping. Here, too, as in the case of the design of the sluice, we see the concept of several lines of defence being applied. In a sense the designer was simply putting to good use elements of the natural physical environment. At the same time, in its totality, the structure he created represented a complex concept incorporating several lines of defence against likely threats to its stability and durability.

The figure of 60 m. above MSL which Benson *et al.* cite for the base of the reservoir is probably based on the level of the bed of the river. Though in a very strict sense, this was the lowest point of the reservoir, it is most doubtful that the bed of the reservoir near the dam would have been much below the level of the sill of the lowest sluice. This sluice which has not been fully excavated so far is at an elevation of 70 m. above MSL.[30] Designers of ancient reservoirs did make some allowance for a possible rise in the level of the bed of the reservoir as a result of the accumulation of silt. However, it is most unlikely that this allowance was more than two or three metres. It has already been pointed out that the maximum level of the reservoir would have been determined by the level of the sill of the left bank spillway which is 85 m. above MSL. Hence it would seem very likely that the head of water in the reservoir was about 18 m., a figure comparable with the Kantalē reservoir mentioned above.

The fact that the maximum level of the reservoir was at 85 m. above MSL meant that the high level sluice, which was at 80.8 m., had to deal with a head of 4.2 m. This was slightly higher than the head of water that each sluice had to deal with at the Pāvaṭkulam reservoir, but well within the tolerances provided for by the techniques of construction described above. The low level sluice is situated about 10.8 m. below the high level sluice. Since the designer expected the carefully built high level sluice to handle a head of water of about 4 m., it seems very likely that he made similar provisions in the layout of the other sluices as well. Hence one could suggest that there was at least one more middle level sluice, probably at a level of about 75 m. above MSL and located in the northern section of the dam which was subsequently destroyed.

The date of the construction of the reservoir is another problem which has to be investigated at this point. We are most fortunate in that material which could be used for C^{14} dating was found beneath the so-called wing wall of the reservoir. These were some "carbonized chunks and flakes of woods" found within the layer of dark brown earth in the dam. Above this was a second layer of dark brown earth which was compacted to a greater degree and then a third layer of highly compacted "fine granular yellow quartz". The brickwork of the wing wall rests on this third layer.[31] This material, analysed at Beta Analytic Inc., gave a date of 1500 ± 60 B.P. This calculation was based on the old half-life of 5,730 years. Brown, who has converted it to the new half-life of 5,730 years and then calibrated it to the MASCA dendrochronology, has suggested a date of A. D. 540 ± 62.[32] A second sample of material for the purpose of C^{14} dating was obtained subsequently from the lowest portions of the dam and has been sent to the Tata Institute of Fundamental Research in Bombay.[33] The results of this analysis should be most useful for the purpose of cross-checking the dating given above.

Brown holds the view that the reservoir was constructed in two major stages and that the wing wall of the sluice belonged to the second stage. Hence he hypothesized that the C^{14} dating points to a dividing line between the end of the first phase and the beginning of the second.[34] Benson *et al.*, on the other hand, postulated a three-stage sequence of construction.[35] The two-stage theory as well as the three-stage theory are based on similar assumptions. It has been suggested that, during the first stage, a smaller reservoir with only the low level sluice was in existence and the crest of the dam was at a level of about 78 m. above MSL. The second assumption pertains to the sluice which forms the subject matter of this paper. About halfway from the cistern of this sluice is to be found a structure decorated with figurines some of which had been mutilated. The obtuse-angled elbow described above has been inserted at a point beyond this structure. It has been suggested that the inner part of the sluice up to the structure decorated with figurines was completed during the second stage and that, at this stage, the dam of the reservoir was of such proportions that it did not enclose the brick structure with figurines. This hypothesis implies that the outer part of the sluice and the obtuse-angled elbow were later additions. The fact that two types of bricks had been used in the construction of the sluice has been cited as further evidence to support this hypothesis. Benson *et al.* believe that, at this second stage, the crest of the dam was at an elevation of 90 m. above MSL. According to them, only the left bank spillway was in use at this stage and the sill level of the spillway had been raised by means of a "fuse-plug" to 89 m. above MSL. The crest level of the dam was raised to 95 m. above MSL during the third stage of construction and as a result, the brick structure with figurines was covered up. The extension of the outlet conduits and the incorporation of the right bank spillway are ascribed to this stage.[36] Brown differs from this line of conjecture in suggesting that the water level in the reservoir was never substantially higher than the sill of the upper sluice which he identifies as a type of spillway. According to him, the next stage of construction became necessary because of a geological fault discovered in the base of the dam, not so much to raise the capacity of the reservoir as to to prevent the dam from collapsing. His views imply that the low level sluice was the only means for controlled discharge of water from the reservoir and that the distinction that Benson *et al.* make between the first and second stages is not valid.[39]

Though it seems to be a likely possibility that a reservoir had been built in several stages, it is only by a close examination of the section of the dam that one could get clear indications of different phases of construction. Neither has such evidence been cited by Brown or Benson *et al.* nor has any been found so far. It is noteworthy that not a single of the two spillways at the site would have been operational at this hypothetical first stage. The resources of the Māduru Oya are quite extensive. It would have been highly unusual for a hydraulic engineer of those times to have thought of constructing a reservoir at this particular location without providing for a well-situated spillway. Hence it does not appear likely that a reservoir of the type that Benson *et al.* suggest by their hypothesis of the first stage was ever in existence.

Is it then possible to speak of two different phases of construction in the manner Brown has suggested ? One of the main arguments for this differentiation of phases is the presence of the brick-built structure with figurines. This is the first instance when a structure located *inside* a dam which appears to be ritually significant has been found. It is not a necessary assumption that a ritually significant structure should have been invariably situated at a place which is always accessible. It is not rare for objects or groups of objects with a magical significance to be buried under a structure as part of a ritual. On the other hand, it is particularly important to make a further study of this structure especially with a view to ascertaining whether it could have been expected to serve a hydraulic function. The second argument based on the presence of two different types of bricks at the site of the sluice is equally indeterminate. The production of a type of brick with an exceptional load-carrying capacity would have demanded careful control at all different stages of a cumbersome process of manufacture. It is understandable that the builders did not use this type of brick for all types of brickwork in the construction of the sluice but reserved it for those sections which would be subjected to severe stress and preferred to use in the other sections of the sluice a type of brick which could be procured more easily. In other words, these builders were probably trying to prevent wastage of material and labour. If this was indeed the case, the use of bricks with different load-carrying capacities implies not necessarily a hiatus between two phases of construction but more probably an attempt at careful selection of materials to suit the specfic purposes for which they were being used.

It would thus appear that the hypotheses of multiple stages of construction do not necessarily follow from the evidence before us and that alternative explanations are possible. Despite its appearance during the dry season and during a good part of the year, the Māduru Oya swells to surprising proportions during the rainy season. According to investigations carried out by the Irrigation Department, it has a mean annual yield of 380 million cubic metres and, among all rivers in the Dry Zone of the island, it occupies the fourth place in average yield.[38] The construction of a reservoir based on a dam across such a river was a formidable task, and it appears that the designers were in fact aware of the problems they would have to face and made ample provision to meet them. The provision of extensive "freeboard" facility and spillway accommodation, including a second spillway which came into operation when the discharge from the river into the reservoir was at its height, implies careful planning. The actual construction of the reservoir would certainly have been spread out over a long period, perhaps more than a single reign. However, it is clear that the builders were carrying out a uniform, well-thought-out design. In this sense it seems preferable to think of a long-drawn out but single phase of construction. And, if it was indeed so, it is possible to utilise the evidence from the carbonized material mentioned earlier and to suggest that A. D. 540 ± 62 provides the *terminus ad quem* for the construction of the reservoir. Since the carbonized material used for dating has been obtained from the earthfill of the dam, it is possible, however, that this date relates to a period quite anterior to the date of the actual construction of the dam.

The period from the third decade of the sixth century to the second decade of the seventh century witnessed intense state involvement in the construction of hydraulic works in Sri Lanka. The works attributed by the chroniclers to the reigns of Moggallāna II (531–551), Aggabodhi I (571–604) and Aggabodhi II (604–614) are particularly relevant in this context. Of the three reservoirs attributed to Moggallāna,[39] the Pattapāsānavāpi and Dhanavāpi were identified by the late Professor S. Paranavitana with the reservoirs known by the names Naccadūva and Vāhalkaḍa at present,[40] but the Garītaravāpi has not been identified so far. Aggabodhi I's reign was particularly significant due to the interest he took in developing the upper reaches of the river Mahavāli, but the locations of all the works attributed to him have been satisfatorily identified.[41] The same cannot be said, however, of the irrigation works associated with the reign of Aggabodhi II. Several of the reservoirs attributed to him, like Neraḷu, Hovaṭu, Maha-udalu, Kangomu and Kalam defy clear identification.[42] Of these, Neraḷu and its Pāli equivalent Nālikeravatthu appear to refer to a place to the east of the river Mahavāli.[43] This is an indication that this ruler took an interest in the development of irrigation facilities in the region where the Māduru Oya reservoir is situated. The sophisticated technology that this reservoir represents also points to a similar rather than an earlier period. It will not be a surprise if this reservoir turns out to be a yet unidentified work associated with the reign of Aggabodhi II since, in its conception, it bears some similarity to another work attributed to this reign, the Kantalē reservoir which has been already mentioned.

It will have been evident from the preceding discussion that the designer of the Māduru Oya reservoir took extraordinary precautions to ensure its safety. He made quite adequate "freeboard" provisions to allow for sudden increases in inflow. Further, the carefully built sluices in his reservoir were capable of handling pressures well beyond their normal requirements. This reservoir clearly incorporates a design which has taken into consideration the challenges posed by the Māduru Oya and had made ample provisions to meet those challenges. How then did such a product of careful design come to be destroyed? An oft-repeated explanation for the collapse of irrigation civilization in Sri Lanka comes first to one's mind: deliberate destruction in times of warfare. Destruction of irrigation works in enemy territory has been a tactic adopted in warfare in many parts of South Asia from very early times and finds mention in the *Sangam* literature.[44] It was not necessarily the foreign invaders who adopted such tactics in warfare. In fact, it is in its description of the long-drawn out struggle among the sons of Vijayabāhu I for the throne of Polonnaruva that the *Cūlavaṃsa* refers to combatants using such tactics with disastrous effects:

> "......by piercing tanks filled with water, by destroying everywhere the weirs on all the canals and by hewing down all useful trees like the coconut palm and others, they in fighting each other, so devastated the kingdom that it was impossible to trace even the sites of the old villages."[45]

However, this is not the only possible explanation for the destruction of the reservoir and, in this context, it is particularly important to consider an observation that Brown has made:

> "Geologically, the entire Māduru Oya basin is a shear zone and the topography indicates the presence of numerous bedrock faults. One such fault runs through the defile between the Kandēgama and the Dānagala ridges...... The eventual failure of the ancient *bund* in all likelihood must be attributed to the erosion of its base by water escaping from the reservoir through the fissures and cracks of the fault zone."[46]

Despite the level of sophistication of hydraulic technology that the Māduru Oya reservoir represents, it is questionable whether the irrigation engineers of those times had the capacity to detect such geological faults. Brown's hypothesis probably provides the most likely reason for the final collapse of the dam.

Our study of certain features of the sluice at the Māduru Oya reservoir directs our attention to a question of fundamental significance in the study of the history of technology in precolonial South Asia. It has often been argued that experimentation is specific to the European tradition and that precolonial technology in Asia has to be distinguished from science as such since there is no evidence on the presence of an experimental tradition in this region. The information we have examined on various aspects of the Māduru Oya sluice is indicative of an innovative approach. The designer responsible for this structure was influenced by the long tradition of hydraulic construction which he had inherited, but his was not a case of mechanically following an ancient design without any variation. In building a sluice he was trying in several ways to improve upon the earlier methods of construction and adapting previous designs to suit the specific requirements of this particular location. He was obviously experimenting with new ways of solving some of the problems that builders of irrigation works had been facing for ages. In fact, this spirit of innovation and experimentation appears to be an essential feature of hydraulic engineering in Sri Lanka, especially during the period from the third to the seventh century.[47] It is quite usual to find these engineers experimenting with the design of their sluices as regards the size of the cisterns, the area of the inlet and outlet orifices as well as the layout, the gradient and the tapering of the outlet conduits. The Pāvaṭkulam and Māduru Oya reservoirs present two of the most noteworthy examples of the results of attempts of ancient designers to search for new solutions to problems of hydraulic engineering. Students of the history of modern technology usually associate experimentation with laboratory work. The engineers of ancient South Asia were experimenting in the field. Though mistakes made in this type of experimentation would have been rather costly, the work of these engineers embodied the essence of the experimental tradition: the constant search for better solutions through an improved understanding of the relevant problem. Such experimentation implies that these hydraulic engineers did have access to a certain basic theoretical knowledge of the behavioural characteristics of liquids. It is quite clear that this spirit of innovation and experimentation remained very much alive, at least up to the time that the Māduru Oya reservoir was being built.[48]

REFERENCES

1. Details about this most interesting discovery have appeared in two previous publications. Dr. Stuart Brown, who was invited by the Government of Sri Lanka to study the Māduru Oya area, devotes special attention to the old sluice in his report, *Archaeological Investigations and Cultural Resource Management in the Maduru Oya Reservoir Area, Sri Lanka, 1982, A Report Prepared for the Department of Archaeology of the Government of Sri Lanka and for the Canadian International Development Agency.* Colombo, 1982. Subsequently, three engineers from the firm which handled the contract for the construction of the modern reservoir have published a paper specifically on the ancient sluice. See R. P. Benson, W. P. Harland and I. L. Pinkerton, "The Ancient Maduru Oya Sluiceway," *Water Power and Dam Construction,* Vol. 35, No. 12, December 1983.

2. Benson *et al., op. cit.,* p. 26.

3. The author wishes to thank Mr. M. R. G. Kulatilleke for allowing him to examine and photograph the finds from the excavations and Mr. K. A. Tilakaratna for making it possible for him to visit the site of the sluice.

4. The plans and section drawings have been published in the works by Brown and Benson *et al.* cited above.

5. Information from the writings of Brown and Benson *et al.* has been used in the preparation of this drawing.

6. A more detailed account of the results of these tests will appear in a forthcoming publication.

7. I am indebted to Dr. Raja de Silva, Consultant, Department of Archaeology, for this information.

8. See R. A. L. H. Gunawardana, "Hydraulic Engineering in Ancient Sri Lanka: The Cistern Sluices" in L. Prematilleke, K. Indrapala and J. E. van Lohuizen-de Leeuw, ed. *Senarat Paranavitana Commemoration Volume,* Studies in South Asian Culture Vol. VII, Leiden, E. J. Brill, 1978, pp. 61–74.

9. Brown, *op. cit.,* p. 19.

10. Benson *et al., op. cit.,* p. 27.

11. See Brown, *op. cit.* p. 19.

12. See *infra*

13. Benson *et al., op. cit.,* p. 28.

14. See Gunawardana, *op. cit.,* p. 66.

15. Benson *et al., op. cit.,* p. 28.

16. Brown, *op. cit.,* p, 20.

17. *Ibid.,* p. 28.

18. *Ibid.*

19. See Henry Parker, *Ancient Ceylon: An Account of the Aborigines and of Part of the Early Civilization,* London, 1909, p. 381.

20. See R. A. L. H. Gunawardana, "Intersocietal Transfer of Hydraulic Technology in Precolonial South Asia: Some Reflections Based on a Preliminary Investigation" *Southeast Asian Studies,* Kyoto, Vol. 22, No. 2, 1984, pp. 115–142.

21. See Brown, *op. cit.,* p. 48.

22. *Ibid.,* p, 28.

23. See Gunawardana, "Hydraulic Engineering in Ancient Sri Lanka: The Cistern Sluices" in *Senarat Paranavitana Commemoration Volume,* p. 68.

24. *Ceylon Administration Reports,* Colombo, 1870, p. 104.

25. The author wishes to acknowledge his debt to Professor S. Balasubramaniam for the botanical data cited here.

26. See Benson *et al.,* p. 27, Fig. 2.

27. *Ibid.,* p. 28.

28. See *ibid.,* p. 28.

29. The term "freeboard" denotes the difference between the level of the crest of the reservoir and the maximum level of water in the reservoir and reflects the spare capacity in the reservoir before water overflows its crest.

30. See Brown, *op. cit.,* p. 33.

31. See *ibid.,* p. 45, Fig, 3.

32. *Ibid.,* pp. 29–30.

33. The sample was obtained by Mr. Sirhan Deraniyagala of the Archaeological Department.

34. Brown, *op. cit.,* p. 20.

35. Benson *et. al.,* p. 28.

36. *Ibid.,* p. 27, Fig. 2.

37. Brown, *op. cit.,* pp. 5–29.

38. See J. F. P. Kreuze *et al., Mahaweli Ganga Development Program Implementation Strategy,* Colombo (?), 1979, pp. 17–18.

39. *bandhāpesi kadambaṃ ca nadiṃ pabbatamajjhato*
pattapāsānavāpiṃ ca dhanavāpiṇ garītaraṃ. Cūlavaṃsa, ch. 41, *v.* 61.

Geiger translated this strophe as follows: "He dammed up the Kadamba river among the mountains forming thereby the Pattapāsānavāpi, Dhanavāpi and Garītara tanks.' *Cūlavaṃsa,* translation, Pt. 1, p. 57. The word "thereby" is not derived from the original text and, as such, there is no evidence to support the view that all three reservoirs were located in the Malvatu valley.

40. See S. Paranavitana, "The Ancient Names and the Builder of the Padaviya and Naccadūva Tanks, "*University of Ceylon Review*, Vol. 16, Nos. 3 & 4, 1958, pp. 70–77 and R. A. L. H. Gunawardana, "Total Power or Shared Power ? A Study of the Hydraulic State and its Transformations in Sri Lanka from the Third to the Ninth Century A. D.," *The Indian Historical Review*, Vol. 7, 1981, especially pp. 75-77.

41. These are Kurundavāpi, Nāgasoṇḍi, Mahindataṭavāpi, a canal leading water from Manihīravāpi and Sirivaḍḍhamānavāpi. The last was built by the king's brother. *Cūlavaṃsa, ch.* 42, *vv.* 8,15,29,34. For a discussion on their identity, see C. W. Nicholas, "A Short History of Irrigation Works up to the 11th Century," *Journal of the Ceylon Branch of the Royal Asiatic Society*, New Series, Vol. 7, Pt. 1. pp. 43–69.

42. For a list of irrigation works attributed to this reign, see *Pūjāvaliya*, ed. A. V. Suravīra, Colombo, 1961, p. 101.

43. See C. W. Nicholas, "Historical Topography of Ancient and Medieval Ceylon," *Journal of the Ceylon Branch of the Royal Asiatic Society*, Vol. 6 (Special Number), 1958, p. 37.

44. "The fields and tanks made waterless are so confused," the bard sings in the *Paṭṭinapālai* of the destruction caused by invading armies. See *Pattupāṭṭu*, ed. and trsl. J. V. Chelliah, Madras, 1962, p. 43.

45. *Cūlavaṃsa*, ed. and trsl. W. Geiger, Colombo, 1953, Pt. 1, p. 230.

64. Brown, *op. cit.*, p. 27.

47. See Gunawardana, "Hydraulic Engineering in Ancient Sri Lanka: The Cistern Sluices" in *Senarat Paranavitana Commemoration Volume*, pp. 61–74.

48. The author is grateful to Professsors M. P. Ranaweera and V. K. Gunawardana for reading through and commenting on this paper; to Mr. K. A. Tilakaratna for taking one of the photographs (Pl. 1) used as an illustration; to Mr. J. G. Mahawatta for processing the photographs; and to Mr. M. A. Navaratna for drawing the figure illustrations. Figs. 1 and 2 are modified versions of illustrations published by Benso *et al.*

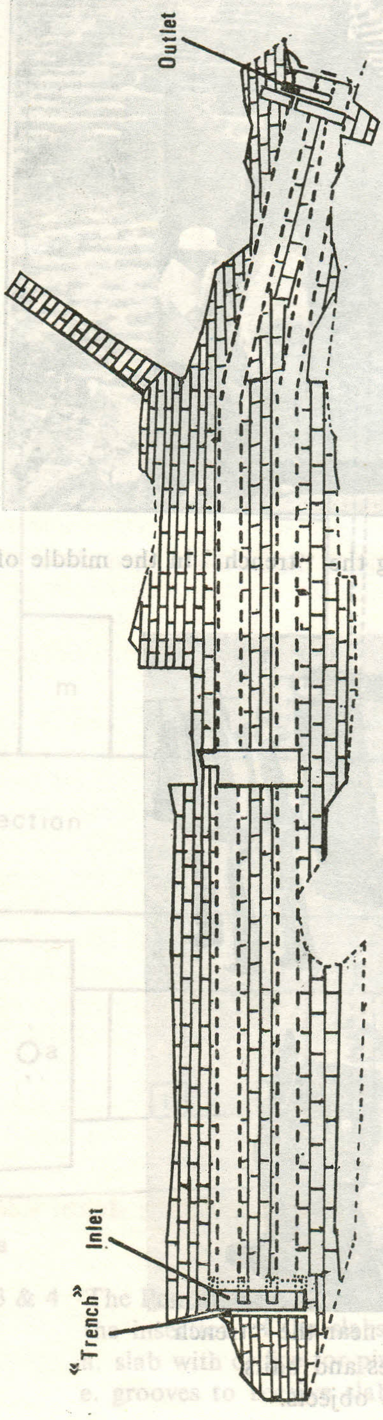


Fig. 1. Plan of the sluice discovered at the Māduru Oya reservoir.

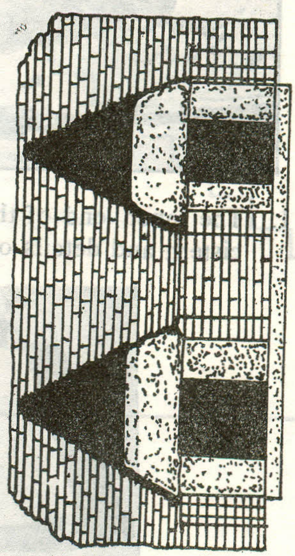
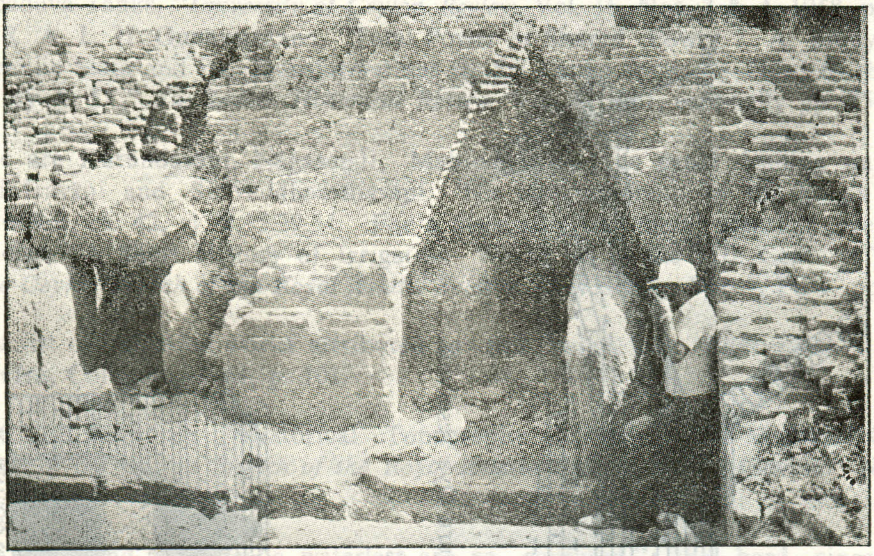
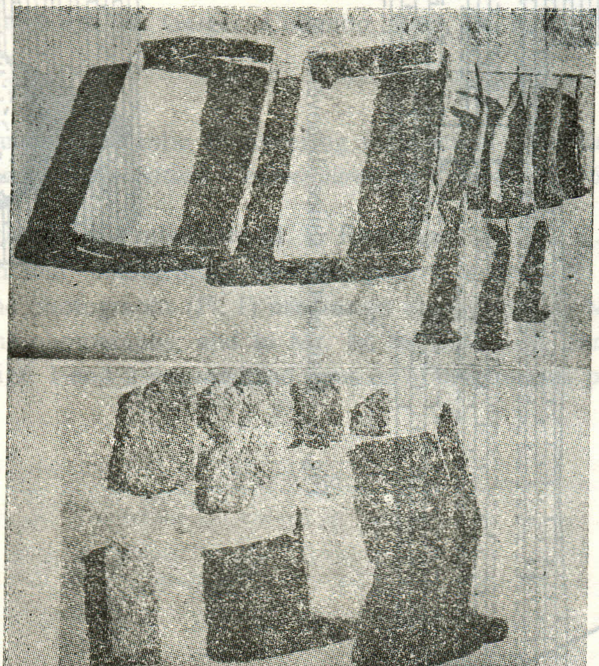


Fig. 2. Section drawing of the inlets.



Pl. 1. The inner end of the sluice showing the "trench" in the middle of the cistern and details of the inlets.

Pl. 2a.

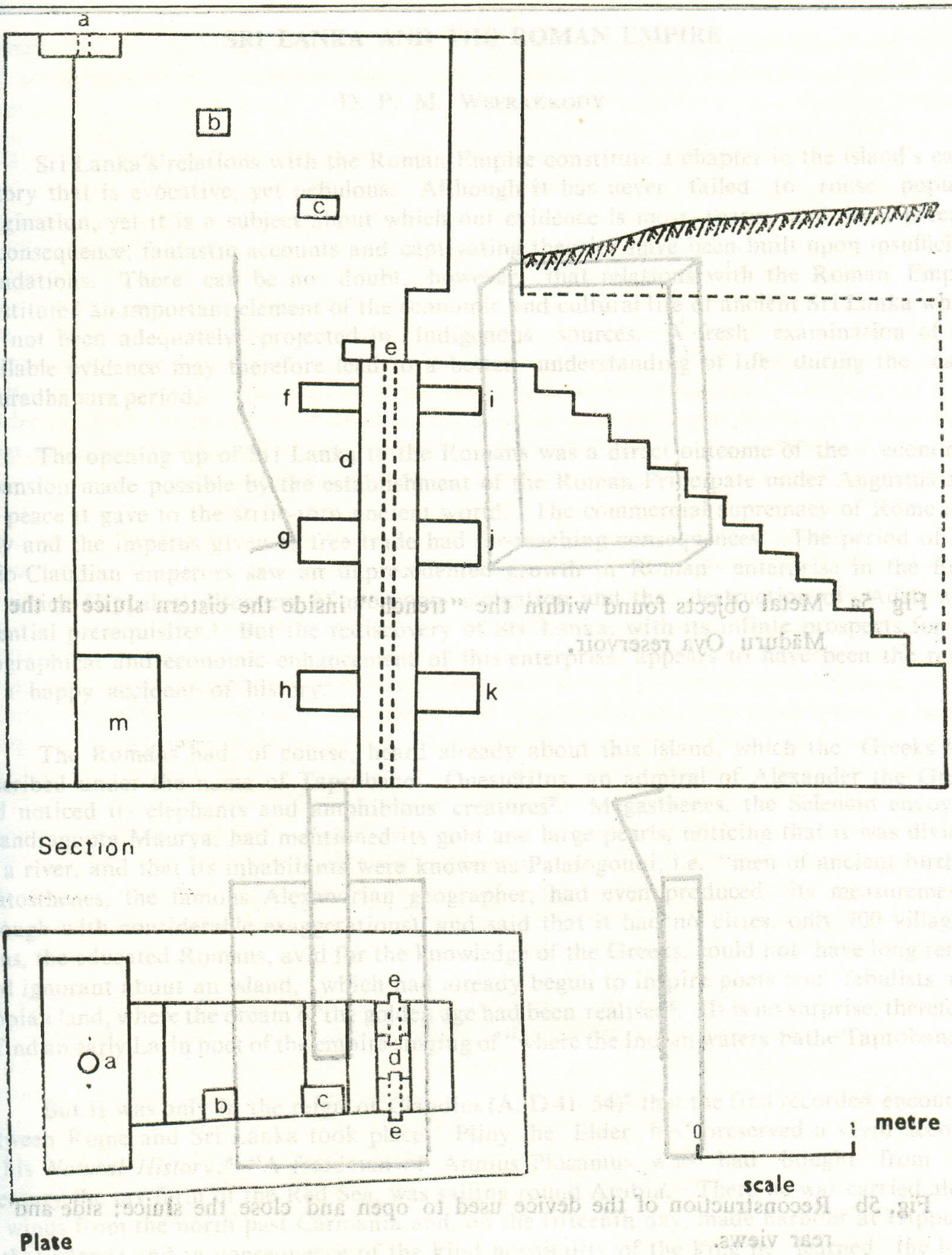


Pl. 2b.

Objects found inside and near the "trench"

Pl. 2a. Metal frames and nails.

Pl. 2b. Other metal objects.



Figs. 3 & 4 The Poṇṇēri sluice: section drawing and plan. Note the grooves (e) for the insertion of the slabs.
a. slab with orifice for piston. b & c. steps providing access. d stone pillar e. grooves to receive slabs. f–k. cross-beams. m. receptacle for piston.

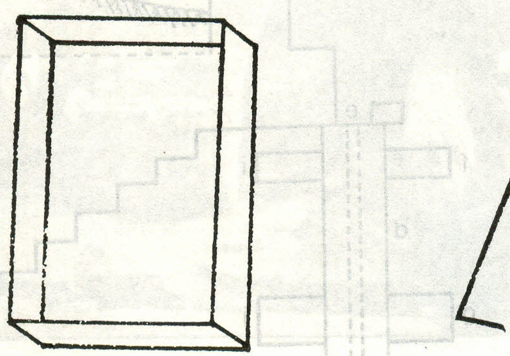


Fig 5a Metal objects found within the "trench" inside the cistern sluice at the Māduru Oya reservoir.

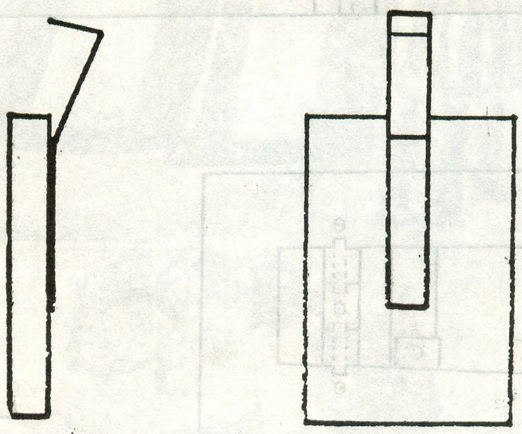


Fig. 5b Reconstruction of the device used to open and close the sluice: side and rear views.