INVESTIGATION OF HYDRAULIC CHARACTERISTICS OF ANCIENT INLET SLUICE BARREL IN NUWARA WEWA RESERVOIR

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ABSTRACT

The growth of the Sri Lankan hydraulic civilization developed new techniques in water management systems such as reservoirs, and irrigation canals. -They are considered as advanced irrigation systems that have survived throughout history. Basically, reservoirs were built to keep the water table up by storing water by clay embankments across valleys. This water has been conveyed as irrigation water, creating a life cycle existed for so many centuries. The sluice and sluice gate is -two of the most important components in a reservoir and these components are the control devices of a reservoir. Control devices save the reservoir bund without damaging it by the velocity and pressure created on outflow of water.

The ingenuity of the Sinhala irrigation engineers is best exemplified by the invention of the Bisokotuwa (which literally means queen - enclosure), later termed by Parker in 1909 Bisokotuwa, the enclosure where the water level lowers. As stated by parker in "Ancient Ceylon (1909)", there is a special arrangement before Bisokotuwa which is called inlet barrel extended towards the middle of the irrigation tank and some of these barrels extended more than 100fts and spectacularly "Nuwara wewa" ancient sluice barrel extended up to 147fts which was constructed in 1st century B.C. Therefore, there must be an unrevealed hydraulic mystery about this kind of sluice barrel in some reservoirs in ancient Anuradhapura and Polonnaruwa era since our ancient engineers may not misspend their time and labor in vain for such kind of construction.

To investigate the performance of inlet sluice barrel, physical model testing -is done based on the measured roughness values of ancient sluice structures made out of granite. The hydraulics of this ancient mechanism is revealed in this research.

Keywords: *Ancient irrigation systems, sluice, Physical model, Sinhalese*

1. INTRODUCTION

Sri Lanka is an island comprised of south-central mountain range of 7000 to 8000ft which influences the island's climate. The south-west wind prevails from May to September and, as it meets the high ground, monsoon precipitation occurs reaching 200 inches on the mountain slopes. From October to January the wind blows from the north east over the Bay of Bengal and results in the monsoon in the plains of the north with an average rainfall of 50 to 75 inches. Thus there is a wet zone to the south and central part of the island, and a dry zone in the north and south-east where the people were initially settled. They had to overcome the twin challenges of drought and monsoon in order to survive and thrive *(Turpin,2006).*

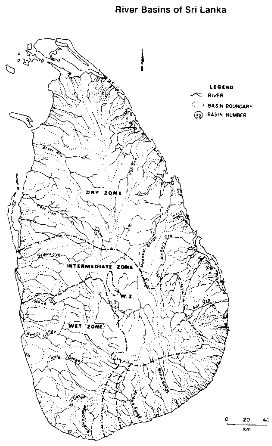
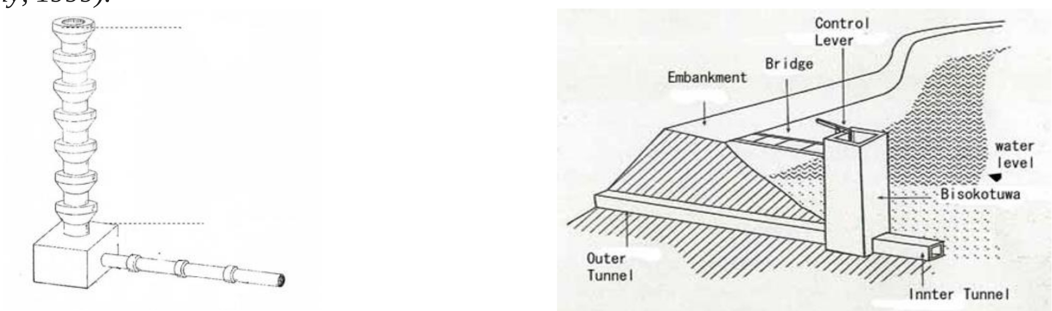


Fig. 1.1. River basins and climate zones of Sri Lanka *(Turpin,2006).*

As a mitigation to overcome the above challenges, the ancient Sri Lankans had to manage and utilize available water with great care. The growth of the Sri Lankan hydraulic civilization developed new techniques in water management systems such as reservoirs, and irrigation canals. They are considered as advanced irrigation systems that have survived throughout history *(Parker, 1909).*
Basically, reservoirs were built to keep the water table up by storing water by clay Embankments across valleys. This water has been conveyed as irrigation water, creating a life cycle existed for so many centuries *(Arumugam,1969).*
The sluice and sluice gate are two of the most important components in a reservoir and these components are the control devices of a reservoir. Control devices save the reservoir bund without damaging it by the velocity and pressure created on outflow of water. The outgoing water from small village tanks -was controlled by using temporary cuts through earthen bunds. In medium size tanks, this was performed by using a technique called “Keta Sorrowwa”(Figure 1.2(a)). The flow rates of the outgoing water from the reservoir were controlled by a number of Ketas kept one on top of each other *(Ausadhahamy, 1999).*
This method was used to control the head of water entering the sluice. Keta Sorrowwa cannot be used to control the outgoing water in much bigger reservoirs because of the excessive head. To counter this problem, ancient Sri Lankan had invented Bisokotuwa which is attached to the bund of the reservoir. It could help to control water effectively without existing high velocity and high pressure on the reservoir bund *(Ausadhahamy, 1999).*



(a) Keta Sorrowwa

(b) Components of Ancient Sluices

Figure 1.2. Ancient sluices of Sri Lanka

Parker (1909) described that there are three components of ancient sluices of large reservoirs (Figure 1.2(b)),

- A rectangular Bisokotuwa chamber built near the point where the water level meets the inner slope of the embankment.
- An inlet Tunnel (conduit) through which the water passed into this Bisokotuwa chamber.
- A discharging Tunnel (conduit) from the Bisokotuwa chamber to the foot of the outer slope of the bank.

As stated by Parker in “Ancient Ceylon (1909)”, there is a special arrangement before Bisokotuwa which is called inlet barrel extended towards the middle of the irrigation tank and some of these barrels extended more than 100fts and spectacularly “Nuwara wewa” ancient sluice barrel extended up to 147 fts.

Therefore, there must be an unrevealed hydraulic mystery about this kind of sluice barrel in some reservoirs in ancient Anuradhapura and Polonnaruwa era since ancient Sri Lankan engineers may not misspend their time and labor for such kind of construction.

Therefore, it is easily realized that every component of a reservoir was built with a special need and some of those systems still functioning. What were the concepts, theories, knowledge that they possessed? How did they determine the dimensions of “Bisokotuwa” according to the capacity of the reservoir? Why did they built such a long inlet sluice barrel? What are the theories behind such designs?

We must find answers to these questions in order to “Determine the purpose of construction such inlet sluice barrel”. But there is no valuable research of the hydraulic performance of inlet sluice barrel which had been built at great cost and effort during 1st century B.C. Hence the prime intention of this research is to uncover the mystery of constructing an ancient inlet sluice barrel with a motive of regenerating purposeful engineering knowledge.

The ancient reservoir “Nuwara wewa” which was built in 1st century B.C. is selected for the prime analysis since all the details were catalogued by Henry Parker in 1909 before the sorrowful fate of the structure in the face of modern engineering.

2. AIM AND OBJECTIVES

2.1 AIM

To investigation the performance of ancient inlet sluice barrel of Nuwara wewa reservoir.

2.2 OBJECTIVES

1. Model analysis on laboratory scaled model for the ancient inlet barrel of the higher sluice of “Nuwara wewa” reservoir
2. Determination of the purpose of constructing the inlet sluice barrel

3. METHODOLOGY

Methodology of this research comprised of two segments based on above two objectives.

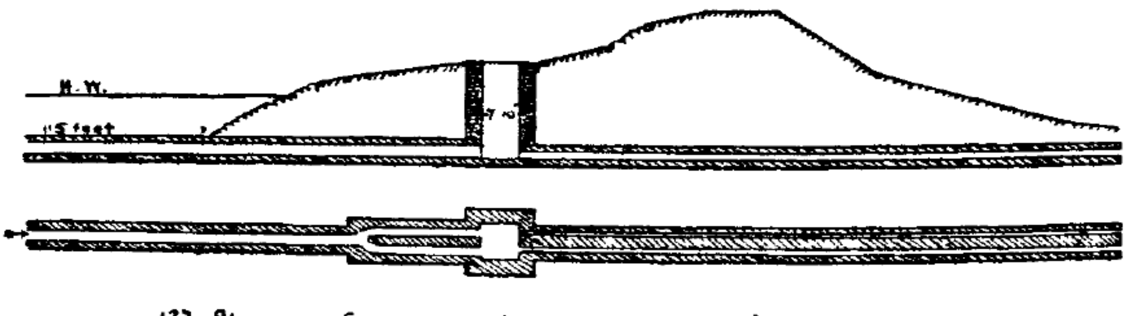
3.1 Laboratory scale model analysis of Nuwarawewa reservoir

The development of -lab model to investigate the functionality of ancient sluice at Nuwarawewa was performed on following sequence;

- Investigate the dimensions of the ancient sluice at Nuwarawewa based on the literature survey.
- Investigate the properties of the materials in the ancient structure by visiting currently available ancient sluice structures
- Dimensional analysis of the model
- Development of the laboratory model

3.1.1 Investigate the dimensions of the ancient sluice at Nuwara-wewa

All the dimensions of the ancient sluice at Nuwara Wewa was recorded by Parker in 1909 before the demolition of these structures by British to construct new structures. An extract from the actual drawing from Parker is shown in figure 4.1.



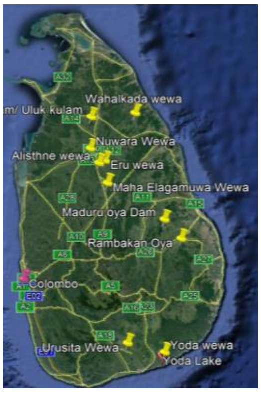
137. Plan and Section of Nuwara-waewa High-level Sluice

Figure3.1: Extracted drawing from the book "Ancient Ceylon by Henry Parker (1909)
All the detailed dimensions extracted are presented under results.

3.1.2 Property analysis of the materials of the ancient sluice

Ancient sluice is a granite structure made out of stone slabs. The most significant property for hydraulic conveyance of this material is the surface roughness which governs the resistance to the flow.

Measurement of surface roughness values of ancient rock surfaces which were used to construct inlet sluice barrel is essential to obtain scale down value for the physical laboratory model. Several archaeological concurrent sluice sites currently available were investigated and measured the surface roughness values during the study, since the Nuwara wewa sluice was currently shattered due to various reasons. The location map indicating the ancient sluices which were available as shown in figure3.2(a).



(a)Location map

(b)Roughness measurements

Name of The Reservoir	Coordinates
Urusitana Wewa	6°19'39.00"N,80°56'18.00"E
Yodha Wewa	6°15'36.34"N,81°18'35.54"E
Maha Elagamuwa Wewa	7°59'28"N,80°37'6"E
Alistane Wewa	8°11'35.69"N,80°31'25.52"E
Wahalkade Wewa	8°44'20.53"N,80°51'10.23"E
Eru wewa	8°13'21.00"N,80°34'57.00"E
Rambakan oya	7°27'22.12"N,81°23'55.88"E
Maduru Oya	7°38'42.50"N,81°13'1.80"E

Figure -3.2: locations of the existing ancient sluices of Sri Lanka

The surface roughness gauge (BOYN, SRT-6223) was used to measure the roughness of material at all these locations (see Figure -3.2(b))

When measuring the roughness of a surface using SRT 6223, the sensor is placed on the surface and then is uniformly -moved along the surface by driving the mechanism inside the tester. The sensor gets the surface roughness by the sharp built-in probe. This roughness causes displacement of the probe which results in change of inductive amount of induction coils, so as to generate analogue signal, which is in proportion to the surface roughness at output end of phase-sensitive rectifier. The exclusive DSP processes and calculates and then outputs the measurement results on LCD. The obtained results are presented under results.

3.1.3 Dimensional Analysis of the model

A three-dimensional representation of a person or thing or an existing structure or of a proposed structure, typically on a smaller scale than the original is called a model. Model is used to find out the behaviors of the original structure and carry out different studies related to it within the context of space and user needs. Models can be similar to their prototypes in three different ways, namely, geometric similarity, kinematic similarity and dynamic similarity.
For the similarity between the model and the actual prototype we have to consider all three similarities. For our project, we are building the model of the Nuwara wewa high level inlet sluice barrel and as it is subjected to pipe flow and flow behavior governing factor is Reynold's number. The Buckingham pi theorem is used to substantiate the relation between Reynold's number of actual higher level sluice and the model by dimensional analysis (Yunus, 2016).

3.1.4 Development of the laboratory model

Based on the scaled factors obtained through the dimensional analysis, the dimensions and the surface roughness values of the model are derived. The roughened Perspex sheets are used to develop the model since there is a need to perform flow visualization to understand the hydraulic functionality.

3.2 Determination of the purpose of constructing the inlet sluice barrel

The purpose of the structure was a mystery for many of us since the first inspection. But flow visualization was performed to study the behavior of flow lines thus trying to conclude its functionality.

4. RERULTS AND DISCUSSION

The results of this study is presented here with the same order of the methodology

4.1.1 Dimensions of the ancient sluice at Nuwara Wewa reservoir

The "Nuwara-wewa" reservoir was provided with two sluices, one being at a low level, and the other having a sill 3 feet 1 inch higher. At the low level sluice, the Bisokotuwa measured 11 feet in the line of the culvert, and 15 feet in a transverse direction; it had walls 3 feet 6 inches thick, which rose 14 feet above the sill. It was lined with stone slabs.

There were two inlet and two outlet culverts built of stone. The former were only 17 feet 6 inches long, and were separated by a masonry wall 6 feet 6 inches thick; they were 2 feet wide, and 4 feet 2 inches high. An open paved inlet channel, 71 feet 6 inches long and feet wide, led up to them; this had side walls 3 feet 6 inches thick.

The outlet culverts were about 156 feet long, and were separated by a wall 7 feet thick. They rested on a floor 18 inches thick. Each culvert was 2 feet wide and 2 feet 9 inches high; their outer walls were 18 inches thick, and they were covered with large stone slabs. The Bisokotuwa of the high level sluice was built of brick and not lined with stone; it measured 8 feet 4 inches transversely, and 7 feet 10 inches in the line of the culverts. It was 22 feet high, and had walls 3 feet thick (parker, 1909).

4.1.2 Surface roughness analysis of the materials of the ancient Sluice

In order to estimate the roughness of the model, an accurate measurement of roughness of stone slabs is required. To fulfill this need, roughness values of existing stone culverts were measured and are shown in table -4.1.

Table4.1 Average Surface Roughness values of the ancient Sluices

Name of The Reservoir	Period of Construction	Average Roughness value (µm)
Urusitana Wewa	3rd Century BC	612.2
Yodha Wewa	1st Century BC	603.6
Maha Elagamuwa Wewa	-	635.0
Alistane Wewa	-	632.0
Wahalkade Wewa	-	657.6
Eru wewa	-	655.6
Rambakan oya	3rd Century BC	636.6
Maduru Oya	1st Century BC	649.3
Average Roughness value of the Granite		**635.2**

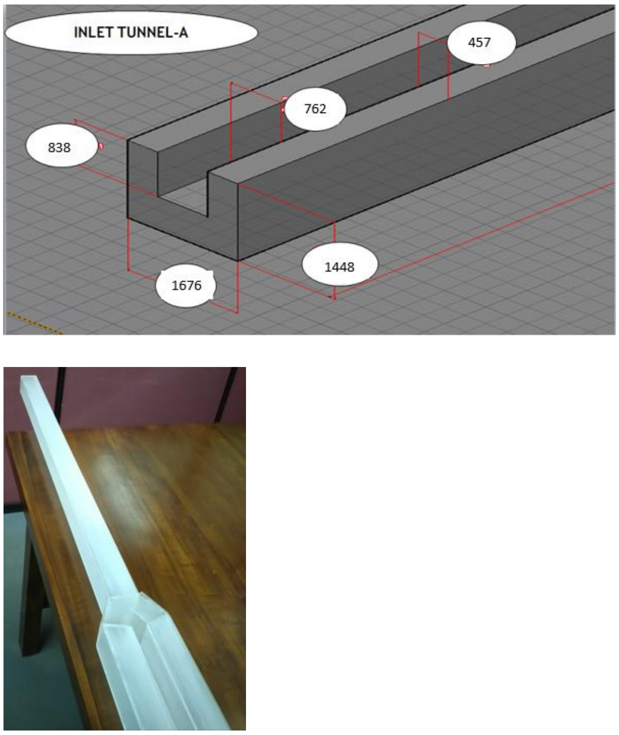
4.1.3 Dimensional Analysis of the Model

The inlet channel of the ancient sluice (See figure 1.2(b)) acts likes a conduit to convey water. Based on this feature, the selected effective parameters are, friction force of pipes (F), density of water ($\boldsymbol{\rho}$) , velocity of flow(u),height of inlet/outlet(d), Revolution per seconds(N) and Viscosity of water (µ) (Yunus, 2016).

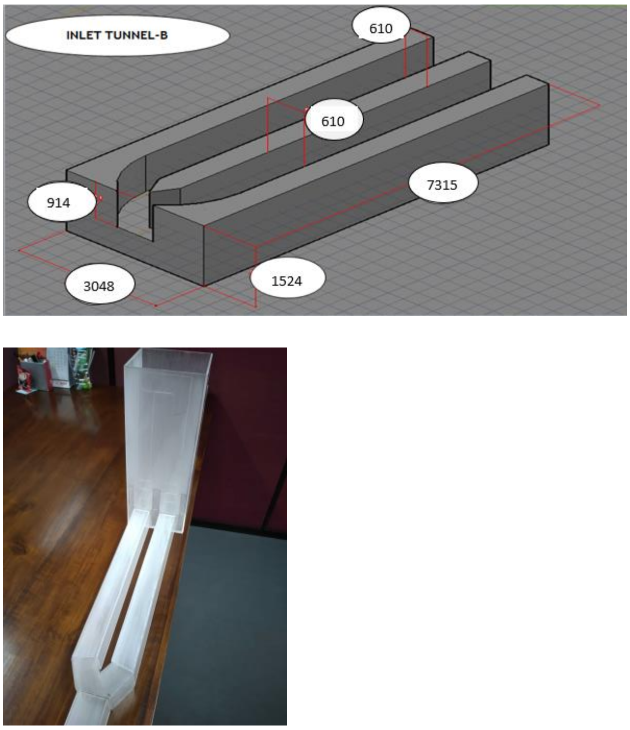
The dimensional analysis reveals that $\prod = f(F/\rho ud, Nd/u, \mu/\rho ud)$ and since the subjected fluid for the study is water, the parameters F, ρ, N, µ are same for both model and prototype. Also, the Reynold's number is similar for the model and the prototype to maintain the dynamic and kinematic similarities. The linear dimensions u and d are decided by geometric similarity after considering reasonable scale factor for the model. For this purpose, the dimensions of the original inlet tunnel were considered and the scale for the model was decided according to the convenience of constructing and the ability to study flow behaviors in the model. Thus it leads to conclude a scale factor of 1:20 for the model to study the flow behaviors of the proposed model.

4.1.4 Development of the Laboratory Model

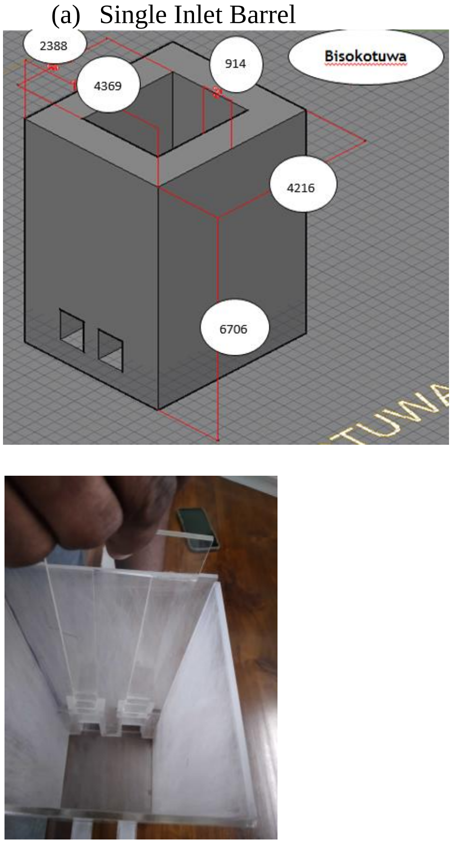
Based on the scale obtained through dimensional analysis which is 1:20, all the dimensions and roughness value of the model were determined. The dimensions of the model are shown in figure 5.1. The challenge was to establish the scaled down surface roughness 31.8 µm. To overcome this issue, uniform application of roughening was performed on the surfaces of Perspex sheets (Figure4.2). The developed lab model then was placed in constant head water stilling basin to conduct experiments. The experiment was performed by stabilizing the water flow along the channel. A schematic diagram of the experimental setup is sown in figure4.3. The water is fed to the system under gravity from an overhead tank into a glassed wall channel where a constant water head is maintained. A series of hydraulic baffles were utilized at the point of entry to the channel in order to dampen the fluctuations of pool level.

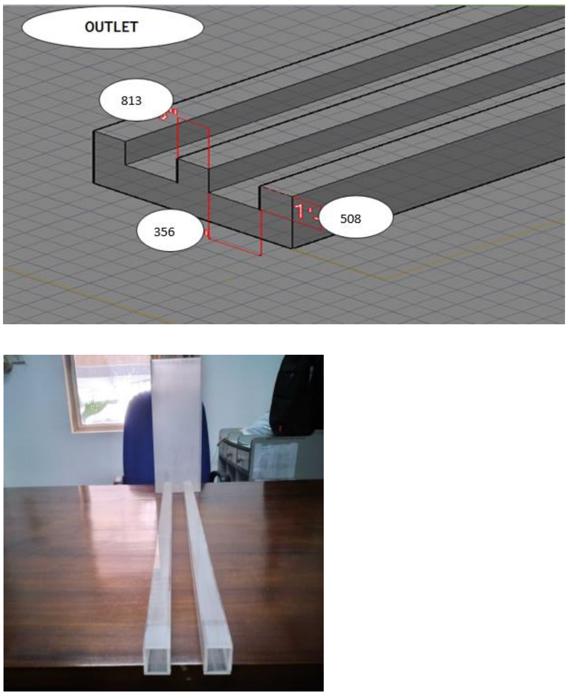


(a) Single Inlet Barrel



(b) Double Inlet Barrel





(d) Outlet barrel

(c) Valve pit (Bisokotuwa)

Figure 4.1: Dimensions of the model

Figure4.2 : Roughing process of Perspex sheets

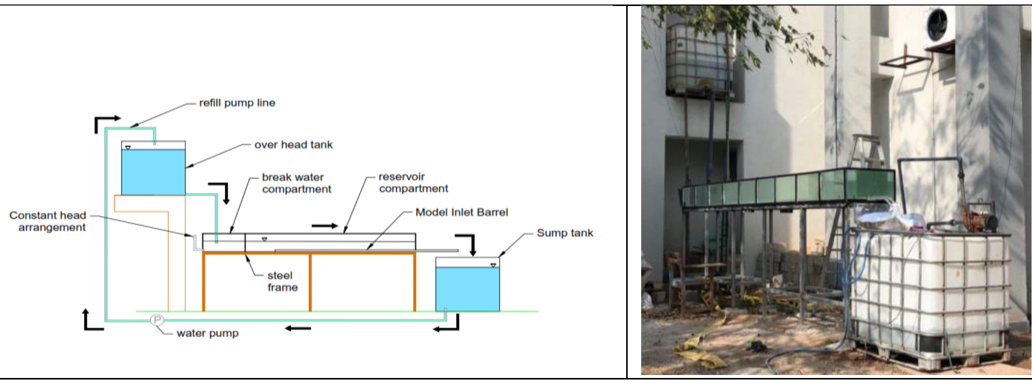
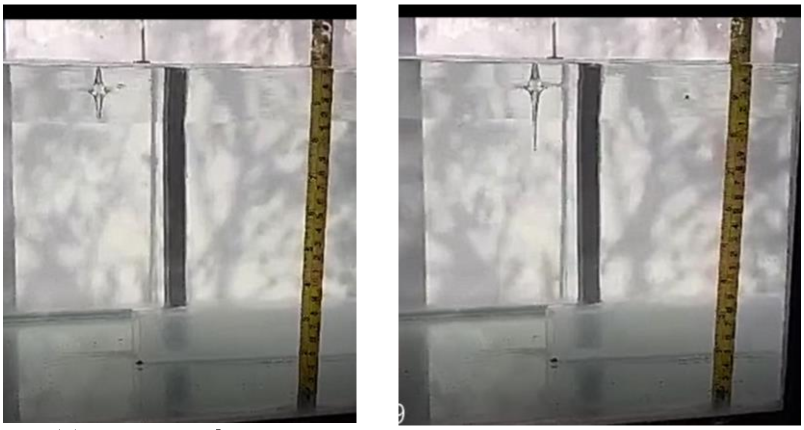


Figure4.3: Experimental setup

4.2 Determination of the purpose of constructing the inlet sluice barrel

We were able to perform only initial visual observations of the performance of the model by the time of compiling this paper. But it clearly concluded very important discovery of the functionality of the inlet barrel. The figure4.4 clearly indicates that there is a formation of a vortex starting from the water surface leading into the inlet. The formation depth of water of the model was 9.8 inches which represents a water height of 16.3 feet. According to Parker's records, this is almost equal to full supply level of the ancient Nuwara-wewa reservoir. This is an unexpected discovery of this research even before starting any significant measurements of the hydraulic performance of the structure.



(a) At 9.8 inches (b) At 9.7 inches

Figure 4.4: Formation of vortex at the inlet barrel of the sluice

ACKNOWLEDGMENTS

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