SIPHON FOR SHP PROJECTS

A DISSERTATION

Submitted in partial fulfillment of the requirement for the award of the degree

of

MASTERS OF TECHNOLOGY

in

ALTERNATE HYDRO ENERGY SYSTEMS

by

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CANDIDATE'S DECLARATION

I hereby declare the report which is being presented in this work, **" SIPHON FOR SHP PROJECTS "**, submitted in partial fulfillment of the requirement for the award of the degree of Master of Technology in "Alternate Hydro Energy Systems" and submitted in Department of Hydro and Renewable Energy, Indian Institute of Technology, Roorkee, is an authentic record of my own work carried out during the period from June 2018 to June 2019 under the supervision and guidance of Dr. Arun Kumar, Professor Department of Hydro and Renewable Energy, Indian Institute of Technology Roorkee, Roorkee (India).

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other Institution.

Gautam Narula

This is to certify that the above statement made by the candidiate is correct and to best of my knowldege.

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I would also like to thank my father to help me mentally in the situations when I felt helpless. I am grateful to my mother for showing confidence in me and motivating me. I thank my friends who always worked as backbone in my development.

Date:

Place: Roorkee

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ABSTRACT

Siphon as penstock/turbine intake and spillway are widely used in SHP projects in many countries like USA, Canada and China. In India, there are many low head SHP projects where siphon intake turbine have been used but there is no documentation reported on their performance.Use of siphon as penstock intake or as spillway at SHP projects are not reported in India. Under this dissertation use of siphon for penstock & turbine intake and spillway as a substitution to the conventional intake and spillway has been studied in details. Siphon penstock/turbine intake has been designed for fourteen SHP projects in India where the data of conventional design was available. Siphon spillway are also designed for seven SHP projects. The installed capacity of these SHP projects under study vary from 3 to 12MW. The Life Cycle Cost Analysis (LCCA) has been carried out for siphon penstock/turbine intake and siphon spillway taking a useful life of 30 years and same has been compared with the conventional design.

Based on the design, cost estimate and life cycle cost analysis, it was found that seven out of fourteen siphon penstock/turbine intakes worked out to be cheaper in the range of 1% to 33%. Siphon spillways were worked out to be expensive as compared to convintional spillways. It was also found that there is no set criteria for the selction of siphon penstock/turbine intake and siphon spillways for SHP projects. The application of siphon as penstock/turbine intake and spillway is to be decided based on economic and other reasons.

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CHAPTER 1
INTRODUCTION

1.1. GENERAL

The basic necessity of any country to develop is power. India is having many resources for power generation. These resources are broadly classified as Renewable and Non-Renewable resources. **Renewable resources** are resources that replenish over relatively short periods of time. This type of resource renews so fast that it will have regenerated by the time we have used it up [1]. **Non-renewable resources** are those resources that are not easily replenished in the environment [1]. These renewable energy resources include solar, wind, biomass, ocean and hydro energy.

1.2. HYDRO ENERGY

Hydropower is the most widely adopted renewable source of energy. It can act in various forms such as pump storage, dam based or runoff river projects. The best part of hydropower is that it gives electricity when there is a need if the required discharge is available. This source of energy is derived from the kinetic energy present in running water. The hydropower projects are classified as according to Table 1.1.

Table 1.1: Hydropower Projects on the basis of Installed Capacity [2]

S.NO.	Classification	Installed Capacity
1.	Micro	Up to 100kW
2.	Mini	101kW - 2MW
3.	Small	2MW- 25MW
4.	Large	25MW- 500MW
5.	Mega	≥500MW

The installed hydropower projects of top 10 countries till 2018 is as shown in figure 1.4.

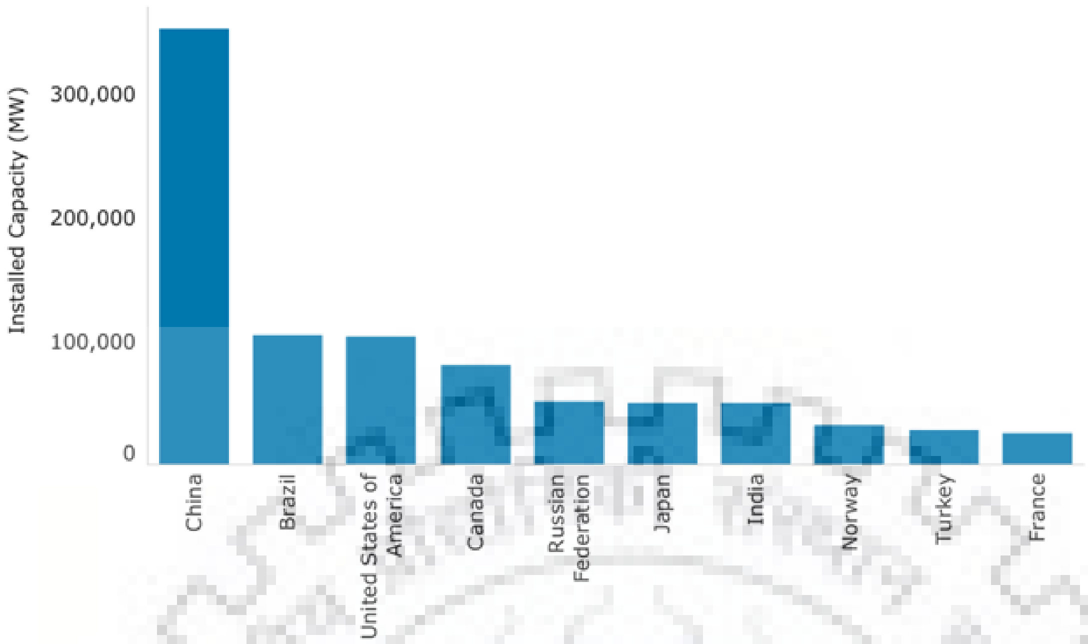


Figure 1.1: Installed Hydropower in Top 10 Countries [3]

1.3.SMALL HYDROPOWER (SHP) PROJECTS:

In India, hydro projects up to 25 MW station capacities have been categorized as Small Hydro Power (SHP) projects. While Ministry of Power, Government of India is responsible for large hydro projects, the mandate for the subject small hydro power (up to 25 MW) is given to Ministry of New and Renewable Energy. The SHP projects may be isolated or grid connected. They are vital for off grid supply of power to the remote locations.

Department of Hydro and Renewable Energy (formerly AHEC) was established in Indian Institute of Technology, Roorkee, now, with initial sponsorship of MNRE (formerly Ministry of Non-Conventional Energy Sources) in the year 1982. The mandate of the center was to promote power generation through the development of SHP projects in hilly as well as plain areas.

For development of SHP projects, the incentives are provided as Central Financial Assistance from MNRE [4] for:

1. Resource assessment and support for identification of new sites
2. Setting up new SHP Projects in the private / co-operative / Joint sector etc.
3. Setting up new SHP Projects in the Government sector
4. Renovation and Modernization of existing SHP projects in the Government sector

5. Development/up gradation of Water Mills (mechanical/electrical output) and setting up Micro Hydel Projects (up to 100 KW capacity)
6. Research & Development and Human Resource Development.

1.4.COMPONENTS OF SMALL HYDROPOWER PROJECTS:

The components of small hydropower scheme are broadly classified as:

1.4.1. Civil Works

1.4.2. Electro - Mechanical Works

1.4.1. Civil Works:

I. Diversion structure:

Diversion structure diverts water from the river or stream for the power generation. This may be a weir, barrage or dam. The weir may be temporary or permanent [5]. The barrage and the dam are the permanent structures.

II. Intake channel:

It conveys water from the diversion to the desilting tank.

III. Desilting Tank:

Desilting tank saves prevents entry of silt in hydropower plants. This saves the civil and mechanical equipment from hydro abrasive erosion. In desilting tank the cross sectional area is increased so as to reduce the velocity of flow and allow silt particles t setlle.

IV. Power Channel/Tunnel:

It carries water from the desilting tank to forebay tank.

V. Forebay or Surge Shaft:

It is used to create a temporary storage to absorb minor fluctuations. In case of sudden increase or sudden rejection of load, the forebay helps in regulation of water. According to the HRED guidelines, the capacity of the forebay tank is usually kept for 2-3 minutes of storage. The surge shaft is used to absorb the water hammer pressure during closure of turbine.

VI. Spillway:

Spillway is bypass for the excess water entering the forebay. The spillway may contain gates for maintenance of channel. The water is discharged from the spillway in such a way that it may not create any soil erosion on its downstream side. The crest level of the spillway lies at full reservoir level (FRL)

VII. Penstock:

Penstock is a closed conduit that carries water from the forebay/surge shaft to the turbine. Occasionally, the penstock is to be repaired hence the gates are provided at the penstock intake.

VIII. Gates and valves:

Gates and valves are used in small hydropower plants to regulate the flow of water in various civil and mechanical components. Various gates based on functions are intake/draft tube gates, bye pass gates, stop log gates, diversion barrage or dam gates and head regulator gates [7].

IX. Powerhouse Building:

Powerhouse building is a structure that houses the mechanical and electrical components of the hydropower project. The power house building is designed such that it has sufficient space and clear spacing for keeping the machineries. It also consists of service bay, control room and various levels for generator, turbine and other components.

X. Tailrace Channel:

When the kinetic energy of the flowing water is converted in to electricity , the water is allowed to flow back to the stream from where it was diverted or to any other stream nearby through the tailrace channel.

The enlisted civil components are shown in Figure 1.2.

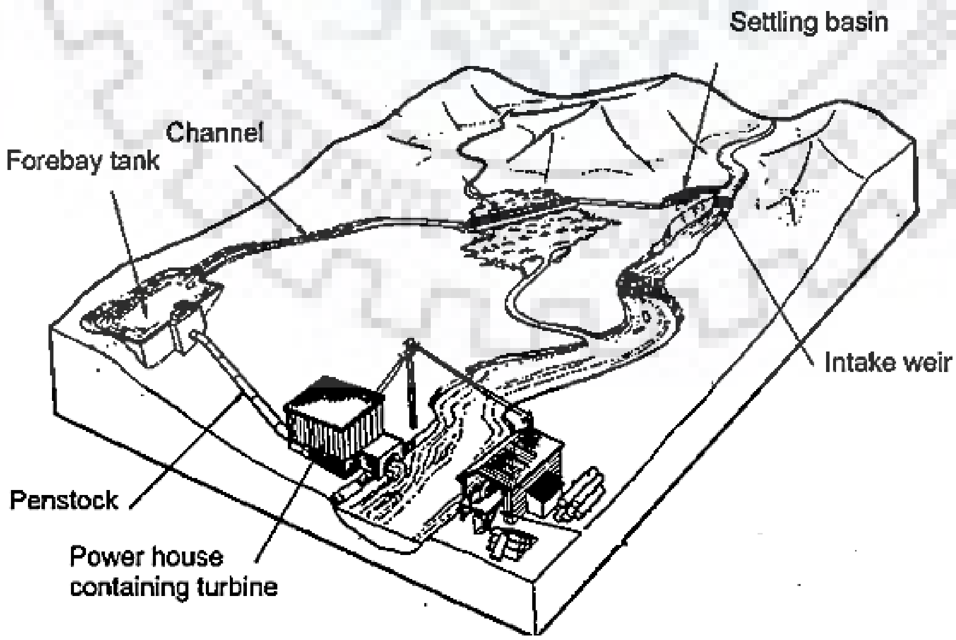


Figure1.2: Civil Components of Small Hydro Power Plant [6]

1.4.2. Electro- Mechanical Works:

I. Turbine:

Turbine is a mechanical component of hydropower plant that converts the kinetic energy of flowing water into the rotational energy. The turbines are broadly classified on basis of specific speed.

II. Governor:

Governor is the main controller of the hydraulic turbine. The governor varies the water flow through the turbine to control its speed or power output

III. Generator:

Generator is used to convert the mechanical energy of the turbine into the electrical energy. [8]

IV. Control, Automation, Protection and Monitoring System:

The control and automation system in a SHP project are for turbine governor for speed control, generator excitation control, supervisory control and data acquisition and retrieval. The protection stand watch and in the event of failures short circuits or abnormal operating conditions help de-energize the unhealthy section of power system and restrain interference with rest of it and limit damage to equipment and ensure safety of personnel.

V. Switchyard:

The switch yard includes instrument transformers, current transformer, potential transformer conductor insulators, bus bars, lightning arrestors circuit breakers, relays, capacitor banks etc.

1.5. APPLICATION OF SIPHON IN HYDRO PROJECTS:

Siphon can be used in hydropower projects as

a. Siphon Penstock intake for forebay

b. Siphon Turbine Intake for low head projects

c. Siphon spillways for the forebay tank.

Siphon is a reliable and cost-effective option for all of these components because of the following reasons:

a. Automatic operation

b. Control of headwater level within the close limits.

c. Omission of gates at the inlet

d. Independence from outside power supply

e. Low maintenance cost

f. Reduced intake of silt

g. Reduced floating debris

h. Ice problem is greatly reduced

1.6. SIPHON

Siphon is a conduit that conveys liquid from one point to another of lower elevation after raising the liquid to a higher elevation at an intermediate point [9]. This happens because negative pressure exists in siphon and negative pressure is greatest at the summit of the conduit. If the negative pressure approaches the vapour pressure of the liquid conveyed, the siphon will not flow full. For application purpose, the limiting height of the apex of the siphon is the barometric height of a column of the liquid conveyed at that location. These and other siphon characteristics may be comprehended more easily by examining the siphon shown in figure 1.3:

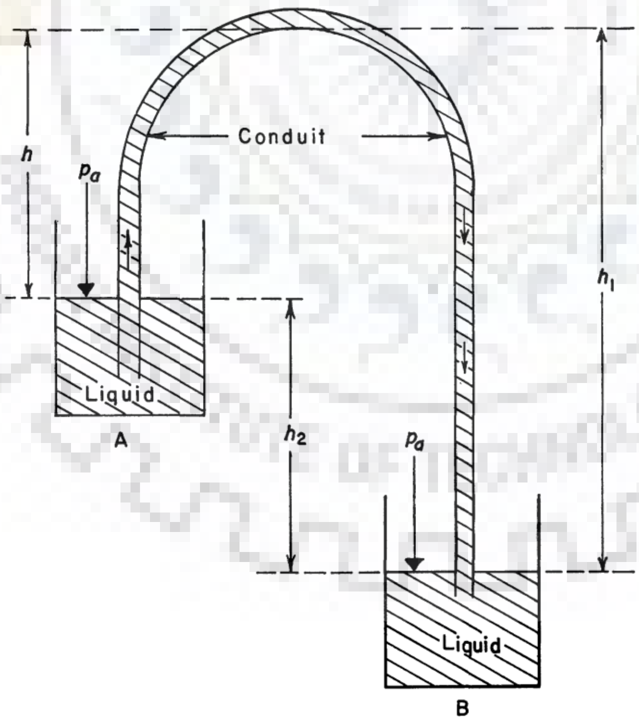


Figure 1.3 : Siphon[9]

1.7. WORKING OF SIPHON:

The working of siphon in hydro power projects as penstock /turbine intake and spillway is edescribed as follows:

a. When the water starts to rise in the reservoir above the Normal water level (NWL), then water starts to spill from the siphon.
b. When the water rise just above the depriming hood, the duct of the siphon is locked and the water from both the end create a water seal.
c. In order to increase the rate of priming of the siphon spillway, bay priming arrangement is made. The flowing water from the crest of the spillway will suck the entrapped air inside the duct.
d. This will cause a gradual increase of vacuum pressure (sucking pressure) inside the duct. The negative pressure will suck more water from the reservoir and finally, the duct will be running full of the water.

1.8. CLASSIFICATION OF SIPHONS

Siphons can be classified as follows:

1.8.1. On the Basis of Configuration:

a. Hood or Saddle siphon
b. Volute Siphon

1.8.2. On the Basis of Air Regulation:

a. Unregulated or black-water siphon
b. Air regulated or white-water siphon

1.8.1. Classification of Siphon on the Basis of Configuration:

a. Hood or saddle siphon:

Schematic diagram of saddle or hood siphon is shown in figure 1.4.

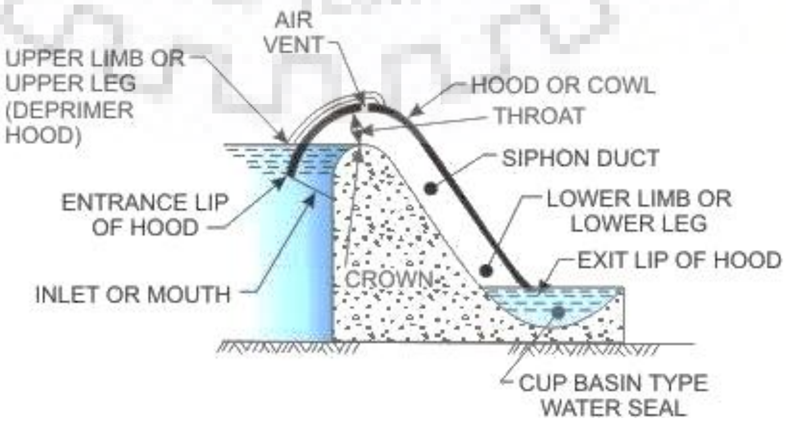


Figure 1.4: Saddle/Hood Siphon [9].

The crest is at full reservoir level. It has bell mouth entry and exit and a water seal to prevent entry of air from the downstream side. When the water goes above the crest level, the discharge passed down the lower limb carries away the air in the throat. The action is similar to weir overflow. With the increase in discharge more and more air gets dragged out resulting in fall of air pressure until the entire throat starts flowing full when it is said to be have primed.

To stop the siphonic action there is an air inlet pipe with its mouth up or above the FRL of the reservoir. As soon as the water goes below the desired elevation, the air rushes into the siphon stopping the flow of water and this is called de-priming.

b. Volute siphon:

In volute siphon the lip of the funnel is kept at full reservoir level (FRL) and a number of volutes are placed on the funnel to induce a spiral motion of water passing along them. When the water level rises above the FRL, it spills over the circumference of the lip of the funnel and flows along the volutes with a spiral motion, forming a vortex in the vertical pipe.

This creates a strong suction pool creating a powerful vacuum which sets the siphon in action. To stop the siphonic action, air is entred into the siphon through a small pipe.[9] Schematic diagram of volute siphon is shown in figure 1.5.

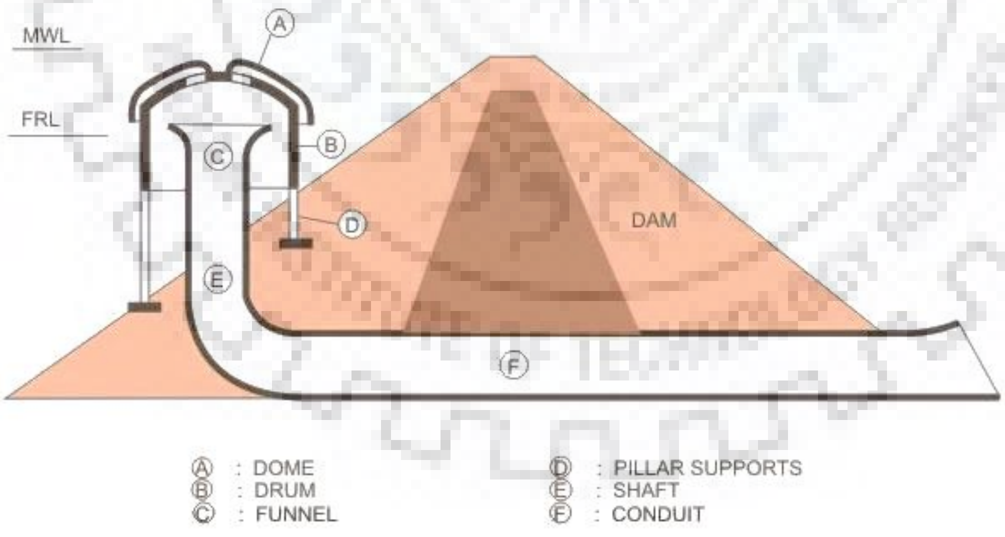


Figure 1.5 : Volute Siphon [9]

1.8.2. Classification of Siphon on Basis of Air Entrainment:

The siphons are classified as follows on the basis of air entrainment:

a. Blackwater Siphon:

In blackwater siphons air is not allowed to enter into the siphon barrel. They either run on or off. There is no scope for running the variable discharge in blackwater siphon. This poses a problem if the use of siphons for the cases when the discharge is not constant. This siphon is good for penstock intake as the penstock shall always run in either full condition or shall remain completely empty. Hence the property of on-off shall be used for the operation of penstock intake.

b. Aerated Siphon:

The aerated siphons allow the air to enter the siphon barrel. Due to this the siphon can be operated on variable discharge conditions and hence the siphon become a more reliable option. These siphons are preferred for the spillways or the land drainage works where the discharge is too much varying discharge.

CHAPTER 2

LITERATURE REVIEW

A literature review was conducted and the findings are summarized in following headings:

2.1. Design of Siphon

2.2. Blackwater and Aerated Siphon

2.3. Material for Siphon

2.4. Operation of Siphon

2.5. Model Studies

2.6. Case Studies

2.1. DESIGN OF SIPHON

Brown (1965) in his book described a lot of devices are been introduced to have early priming so as to get the best possible advantage of siphon's ability to give a big discharge with a small rise in reservoir level. The offset is the most important device which deflects the embryo jet across siphon passage, thus sealing it completely facilitating the evacuation of air hence syphon priming is accelerated. If T is the depth of syphon at the throat, a well-designed offset will induce priming at a depth of about 1/3 T.

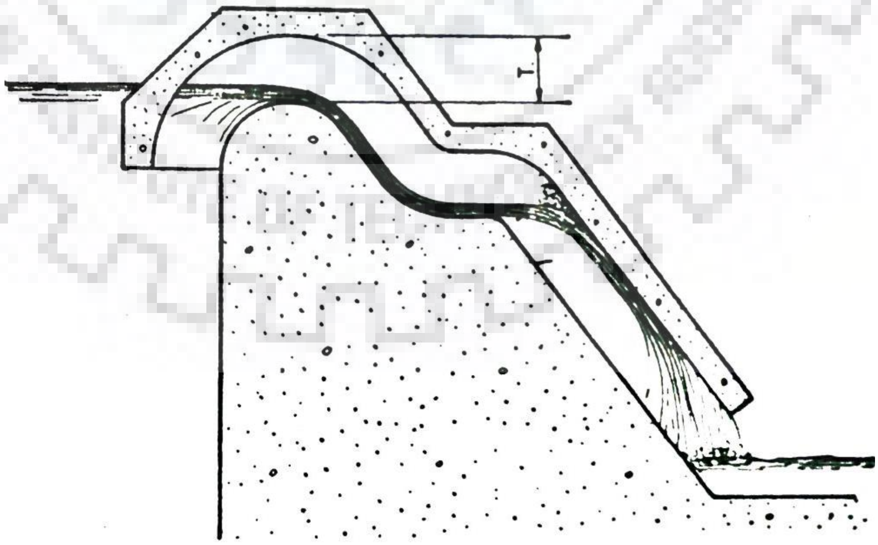


Figure 2.1: Siphon with offset[10]

Since there is a flow hence, the losses will be there. The various losses which occur in the siphon are shown in figure 2.2

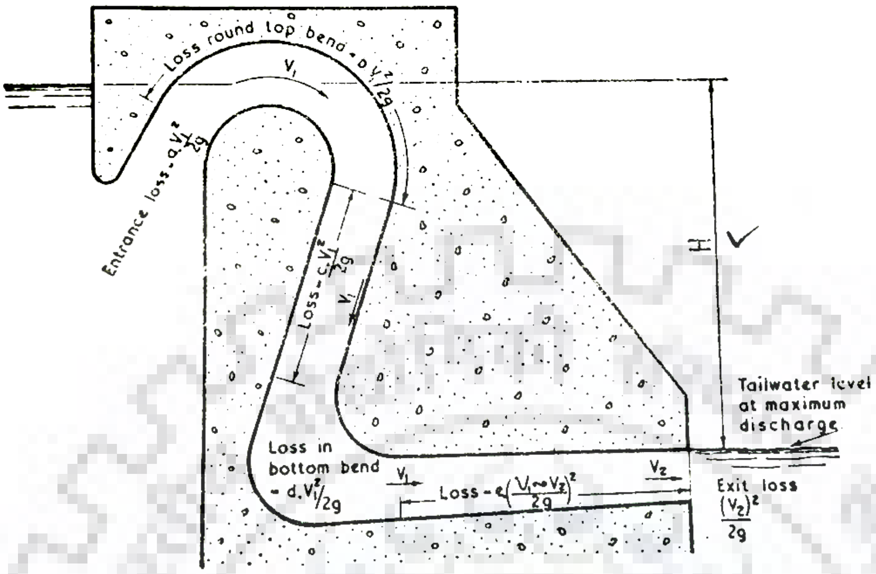


Figure 2.2: Losses at various points in siphon[10]

The important results that the author gave are

a. The mouth of the inlet is given twice the throat area.
b. Shape of inlet doesn't greatly affect the performance of siphon

Theoretically, large radius bends are more hydraulically efficient, but general practice is to adopt a relatively sharper bend.

Ervine and Elsawy (1975) described that siphons have been designed to pass the required catastrophic flood and prime by means of deflected nappe plunging into an exit sealing pool. Air regulation is achieved by using horizontal duckbill at the siphon Intel, the air being dragged into the siphon in quantities which will satisfy the rate of entrainment and evacuation within the siphon.

The optimum lip length was shown to be 3.63m, to prevent the excessive hunting and give the shallow priming characteristics. The variation of lip elevation had little effects on the priming characteristics but the lip elevation ensured more effective and early priming hence reduce the tendency to hunt.

Blaisdell and Hebaus (1975): This paper presents the result of experiments on a rectangular drop inlet having the width equal to barrel diameter, a flat or semi-cylindrical bottom, and a flat horizontal anti-vortex plate supported above the drop inlet crest by extension of drop inlet end walls. This structure is called a two-way drop inlet because the water enters over only the two sides of the rectangular drop inlet crest by extension of drop inlet.

Various formulas are given by the author to consider the losses in various conditions of siphons. These losses are to be taken care of while designing and an optimum solution should be sought.

Blaisdell and Yalamanshili (1975) presented the result of the experiments on hood drop inlet entrances for siphon spillway. The spillways performance for various drop inlet heights and size are described and criteria to ensure satisfactory performance are determined

Using the drop inlet in conjunction with a hood inlet entrance to the steeply sloping barrel of a siphon spillway allows the designer to select the head pool level rise which the spillway primes or flows full. The minimum sizes of hood drop inlet that ensure satisfactory performance are:

Table 2.1: Drop size inlet for various conditions [13]

Drop inlet in height	Drop inlet		
	Square	Circular	Square
	Hood		
	Reentrant	Reentrant	Flush
	Minimum B/D		
z/D =1	4	3.77	1.5
1<z/D<1.25	4	3.77	1.5
z/D=1.25	1.5	2	1.25

The priming head for low drop inlets: z/D <= 1. The priming head for intermediate drop inlets: 1<z/D<1.25. The priming head for high drop inlets: z/D >= 1.25

Bonvissutio (1975) proposed a rational criterion for a better refining of the preliminary design of siphons. The redefined designs should always be verified with specific very important experimental tests on small-scale models, which yet, in turn, normalize and simplified by criterion itself.

In case of a single syphon of self-levelling type, used for discharging floods of an artificial lake, the point of steady operation for the maximum predictable rate of flow can be reasonably fixed in the parabolic branch, just above the transition arc linking it with the rectilinear branch corresponding to the operation with the air-water mixture.

Blaisedell and Donnelly (1975) suggested the use of hood inlet for siphon spillways. It explains the advantages and importance of the hood.

A steeply sloping spillway barrel is one in which the hydraulic gradient line is below the barrel grade line. An anti-vortex device is required to prevent air from entering the spillway through the vortices that may form at low submergence of the hood. Barrel slope doesn't affect the spillway performance if the barrel slope is steep. The thickness of the conduit wall doesn't affect the hood inlet performance or its capacity as weir Presence of dam face somewhat reduces the entrance loss coefficient.

Blaisdell (1975) talked about various aspects of the theory of the parameters in the long siphon. According to the author, orifice and short tube control should be avoided by proper design of siphon. The head and discharge at which the control changes from one point to another can be determined in from the head-discharge curve.

2.2. BLACKWATER AND AERATED SIPHON.

Ackers and Thomas (1975) discussed the problems faced in use siphons and states their solutions. The advantages of siphon identified over the simple weir and gated crest weir and gated orifices are automatic control of headwater level within the close limits, the concentration of flow in restricted space, operation without mechanical parts, independence of outside power supply and low maintenance cost.

The disadvantages are discharge inhibited or reduced if obstructed by debris or ice and sudden increase of discharge on priming which might cause fluctuations in headwater level and flash flood downstream. The second disadvantage is often exaggerated except in areas where very thick ice and protection can be afforded by submerging the intake and providing brooms and grids for the air intakes.

Kenyon (1975) described the advantages is air regulated siphons in Land Drainage works and outline some of the principles adopted in the design of the sub atmospheric weir in this connection.

The area of intake is double the throat area to reduce the velocities at intake, and the ensuing entry losses and to reduce the vortex effect which would be set up by the high entry losses. The hood has a lip at its downstream end in form of the draft tube which suppress the boil at the outlet and to reduce the exit losses. The sloping apron is designed to contain the main turbulence at the outlet and form a transition to the natural channel.

2.3. MATERIAL FOR SIPHON CONSTRUCTION

Kelly (1975) described the material from which a siphon is constructed has pronounced effect on its performance. For example, siphons of mild steel and Perspex that are otherwise similar will give very different results. The paper sets out to show why this is so and to warn designers of pitfalls of the wrong material.

For various materials, the results were considered by varying the head. The results say that slow the flow, the greater is the time for the emergence and the greater the lift.

2.4. OPERATION OF SIPHON

Charlton and Perkins (1975) discussed the effect of the location and the type of inlet on the flow characteristics and air demand are examined. Although the air demand may vary depending upon the discharge and mode of flow, making suitable air inlet is a complex design problem, a practical solution is offered. Finally based on model studies of different air regulated siphons, a method of selecting suitable siphon geometry to be studied in the model suggested.

The paper says that the air regulated siphons have the operation over a large range of discharges. It also says that the priming level is dependent on the efficiency of the air entrainment. The improvement in one parameter for adjusting the variable discharge may affect the other parameters adversely.

Renner (1975) discussed the question of air entrainment by water jet with the surface roller; a conceptual model of air entrainment transport process was established. For the specific problem of air entrainment through the surface roller, formed by the impingement of a free plane jet on an inclined wall, systematic experiments were carried out.

Finally the author summarized that for the air entrainment by plane water jet with surface roller, quantitative amount of entrained air could be given. This study is restricted only to the first phase of priming action of siphon. To clarify the whole question of air entrainment during the priming action, further studies are to be done.

Ağiralioğlu and Müftüoğlu (1989) investigated standard type of siphon shaft spillway that operates under siphon effect as a complete unit from the inlet to the outlet. Experimental studies were carried out to determine the hood dimension and shape compatible with the bell mouth shaft design.

The paper describes that depression of the outlet by the addition of the S unit improves the overall performance of the spillway. The highest discharge coefficient values are obtained when the ratio of the cylindrical passage area over the crest to the outlet area = 4.4. The lowest sub atmospheric hood occurs when the ratio of the cylindrical passage area over the crest to the outlet area = 4.4. Vortex formation is unavoidable under low reservoir levels.

Charlton and Perkins (1975) investigated performance of air regulated siphons under waves. This paper described the effect waves had on such siphons and the modification that was made afterwards in order to improve the performance.

The air regulated siphons act quite satisfactorily in presence of waves. The amount of air entering the siphon has a dominant effect and it was found that by allowing the waves to throttle the air inlet, the performance of the siphon could be improved. The longer the water can stay at the lip of the siphon, preferably for the duration approximately equal to the wave period, the more uniform will be the siphon discharge. The reduction in the size of the air slot made it possible to take advantage of the water that spilt onto siphon hood from the waves.

Naibo et al (1989) studied the emergency cutoff during the emergency situation of fault. He compared the operation of gated intake and siphon intake for the emergency condition and stated that besides using the quick closing gates and valves with heavyweights, a siphon tube located at intake can be used to check water effectively. When needed, the vacuum break valve on the top is opened. Due to this, the air enters the siphon instantly. Hence the siphon in broken and the water flow stops.

Sharma (1984) suggested the baby siphon as one of the priming devices. The baby siphon is shown in the figure. When the water level rises slightly above the crest, the baby siphon which, which in addition siphon starts running full. This sheet of water issuing from it is arranged to shoot across the lower end of the main siphon so as to seal it from the atmosphere. The application of baby siphon for prining is shown in Figure 3.3.

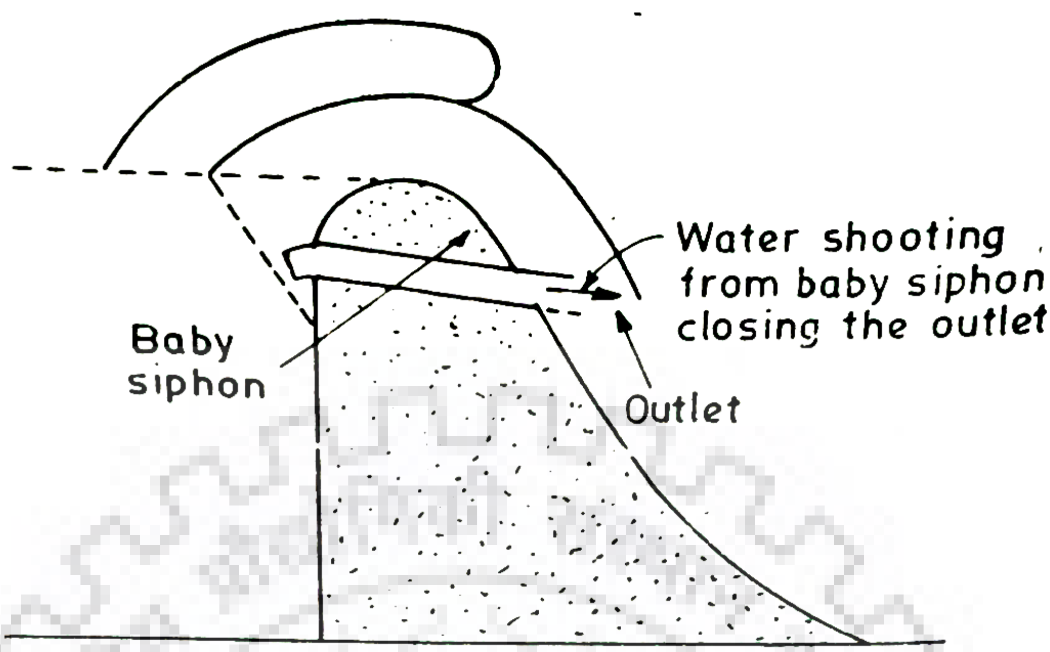


Figure 2.3: Baby Siphon as priming device[25]

Burogoine et al. (1989) investigtated that there is a lack of documentation of siphon penstock installation. He studied 11 penstock intakes installed in the United States. It was noticed that 7.8m was the maximum siphon lift noticed among the eleven power projects. The author described the advantages of siphon penstock intake in the sense that it allows the power generation in the existing dam without puncturing it. Secondly, there is the elimination of shutoff devices on the upstream of the turbine as the flow can directly be stopped just by stopping the siphon action. Thirdly, the siphon penstock intake allows construction without the building of cofferdams. He also stated that siphon penstock was evaluated as less costly than conventional intake and penstock design. The reduction in capital cost for the siphon penstock schemes ranged from 12-20 per cent.

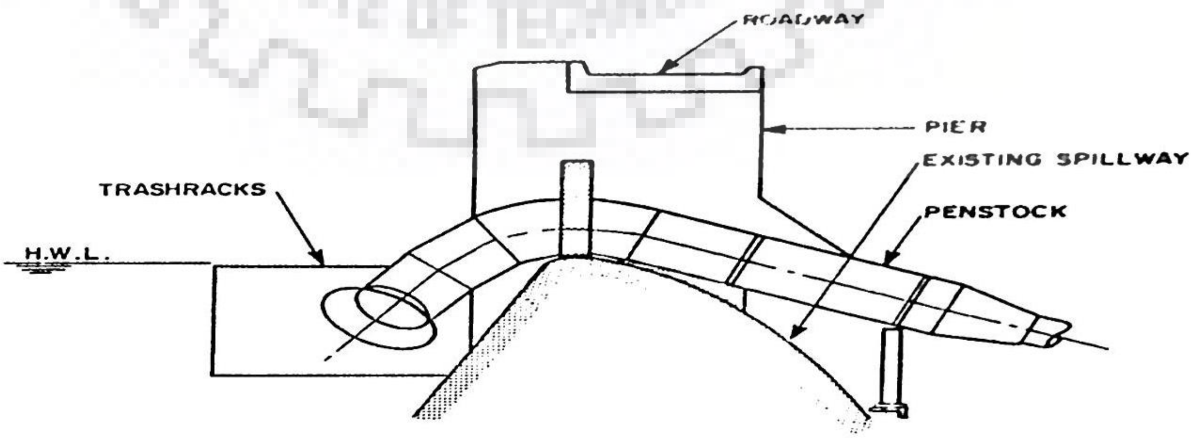


Figure 2.4: Inclined Intake of Pocono Lake Project [26]

2.5. MODEL STUDIES

Ervine and Elsawy (1975) investigated some of the major scale effects in siphon models by studying the behavior of six siphon scale models, three of high head reservoirs, three of low head river siphon, thus giving the broad cross-section of behavior.

The entrainment of air within the siphon barrel is greatly influenced by model scale, as is the degree of instability, hunting and priming characteristics. The modeling of siphon is governed not only by gravitational and inertial forces (Froude's number) but also on surface tension and viscous force (Weber and Reynolds's number). Larger scale models commence to prime at the lower head than the small-scale models, primarily because of the increased rate of the entrainment at the early stages of priming.

Unser (1975) described that the design of siphon spillways the discharge Q is normally computed from the available design head H and discharge coefficient Cd which depends on the shape of the siphon. This method of siphon design is not complete since the head above the crest h is not taken into account.

The formulas are given to compute the parameters of siphon spillway under dynamic conditions.

Ghafourian, et al (2011) studied the physical model and the CFD model and compared the results for the both. The author conducted same experiment from physical and numerical model and compared the result.

The calculated discharge coefficient in free state is 3.5 that is higher than expected for a ogee spillway. Therefore Siphon spillway has less effitiency than ogee spillway. Coefficient of dicharge increses with increase in flow. Piezometers show that 3D of the flow is neglegible

Jafarinia, et al (2010) investigated the scouring on the downstream of siphon by the model study. The tests were conducted for various grain size distributions.

The factors affecting the scouring are discharge, tail water depth, bed material, lip angle of the bucket. Increasing discharge increases the length and depth of the scour hole. The increase in tail water depth reduces the effect of scouring.

Musavi (2011) studied the longitudinal profile of the piezometric pressure in siphon spillway using the physical and numerical method. The third dimension effects are relatively small and negligible

Aydin, et al(2015) studied the siphon that is used as side weir and investigated to determine the hydrodynamic characteristics experimentally, theoretically and numerically. A good agreement is seen in the result of calculation and CFD in case of velocity profiles.

Ghafourian and Adlan (2012) compared the circular and rectangular cross-section and investigate the changes of discharge coefficient in the cross-section. In order to achieve the purpose, a double section physical model of siphon spillway with the equal cross-sectional area was made.

The coefficient of discharge increases with an increase in flow in both the models. For fixed tank level, the circular cross-section has a higher coefficient of discharge. The flow in the circular cross-section has higher Reynold's Number.

2.6. CASE STUDIES

Manley and Markland (1975) studied the partial siphon developed to provide overflow from the storm water tank of the main drainage in South Wales. One requirement is that large discharge can take place through the overflow in response to a small change in water level of the tank. This is achieved by using a siphon in which the discharge is moderated by the presence of air pocket at the highest point.

A simple air regulated siphon has been shown to be successful for the purpose of providing storm water overflow from the sewer.

Thatcher and Battson (1975) described the requirements and circumstances of a typical dock impounding installation and discusses the methods generally used to prevent a backflow of water through non-running pumps. Delivery valves are compared with siphons and the advantages are discussed

The delivery siphon represents a reliable and economical method of preventing backflow through large quantity/low head pumps used in dock projects. It prevents unwanted flow through a non-running pump in the normal direction. To ensure satisfactory priming conditions, a model investigation is a worthwhile preliminary. The models tend to predict longer priming time than were actually achieved; this can be probably attributed to the greatly increased Reynolds number. The models tend to predict shorter depriming times than were actually achieved were attributed to incomplete modeling of the whole culvert.

Petaccia and Fenocchi (2015) studied the hydraulic performance of the siphons installed at Bric Zerbino dam, to analyze their operation and to determine the discharge released during the 1935 event.

He used 1:30 physical model. Tests have shown that the siphon battery of Bric Zerbino dam had inferior hydraulic performances than the original design.

HEC(1987) described various components of penstock siphon installed at Black Bear Hydroelectric Project. The report says that siphons are considered to be practical for no more than 75% of atmospheric pressure. The intake of the siphon penstock was located 5 feet below the MDDL to provide submergence to reduce vortex formation and to protect intake from damage or clogging from ice. Submergence would also allow the small margin for error in project operation to prevent the break in the siphon action. The other details included the various components required for the siphon intake and their locations.

FitzPatrick (1993) investigated the siphon intake installation. He found that most of the turbines were semi Kaplan, adjustable blades design with no shutoff device such as wicket gates. Hence siphon priming and unit startup are executed in one operation. The normal suction lift was less than 4m in all the projects investigated. According to the investigation done, the most critical design consideration for an efficient siphon intake appeared to be the geometry and the location relative to the approach channel.

Recommended that a rectangular siphon hydro intake in a vertical configuration, the intake section should be maintained through the water column. If the conventional square or circular intake is to be used, a tailpiece is added to the intake pipe would enhance the operation.

Konviz, et al (1974) described the role of the vacuum pump. Air which enters the vacuum zone of the siphon through the concrete or through the gaps in vacuum breaking valves is periodically removed by the vacuum pumps, which automatically turns on under floating relay installed in the upper part of siphon. He also stated that the amount of construction work was practically equal in both siphon and conventional intake but the conventional intake proved better as the composition and the volume if technical instruments are far lower in siphon intake and the operation was simpler. Self-charging siphons are possible without the use of vacuum pumps. For loads close to the rated value on the units, the self-charging of the siphon took place very rapidly and the siphons were fully charged after 5-7 minutes.

DPR Devarabelakere described the application of siphon intake in a small hydropower project. The hydropower project on this site was developed on the water that was continuously found spilling. The project consists of two siphon intakes that are rectangular in section. The priming in this intake is done through the vacuum pumps. The DPR gave a detailed calculation work that can be used for designing of siphon intake and spillway for small hydropower projects.

Xianhuan(1989) investigated about the installation of the siphon penstock intake for siphon intake of small hydropower project. In case of Dieshui No.2 is done. The paper states that the intallation of siphon for intake of penstock in SHP projects proves a lot benificial in terms of elimination of intake gates, reduction in ice problems, reduction in intake of silt, fast cutoff in flow and reduction in maintenance cost. Figure 2.5 shows Profile of Dishan SHP.

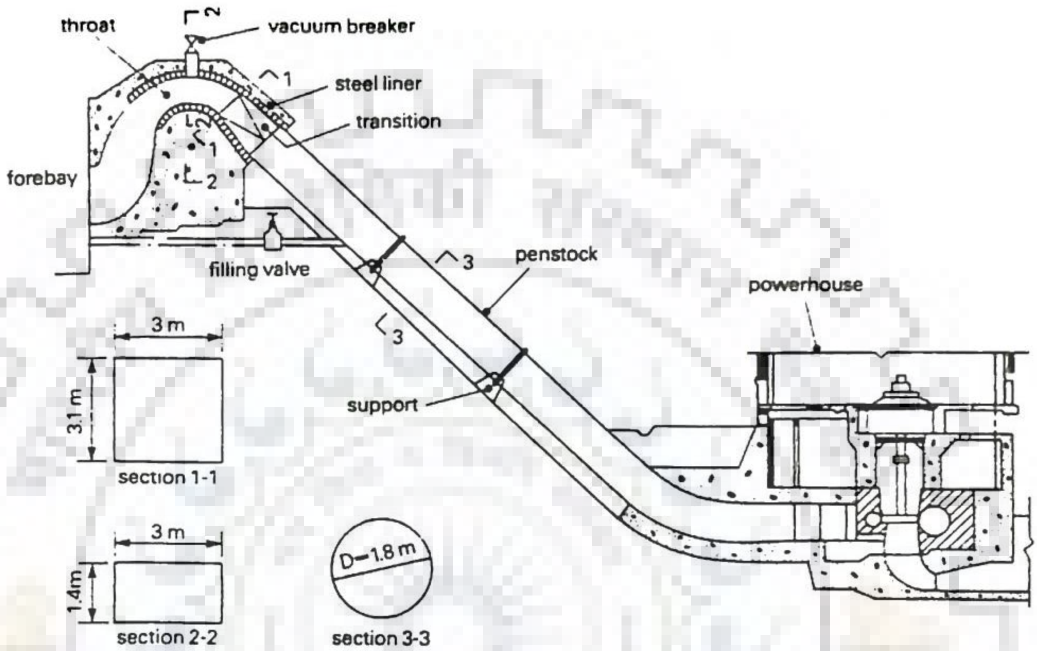


Figure 2.5 : Profile of Dishan Siphon Type Project[41]

2.7.GAPS IDENTIFIED:

Based on the literature review, following gaps are identified:

I. The siphon has been used extensively as the spillways but only for large hydropower projects. But the studies related to siphons in SHP Projects are very less in number.

II. USA, Canada and China have reported the application of siphon as penstock & turbine intake in SHP projects, not much literature has been reported in Indian scenario.

III. Even though there are few instances of siphon intake at low and ultralow head SHP projects in India, not much literature has been reported on the same.

2.8.OBJECTIVES:

The objectives of the research are as follows:

I. To design siphon penstock and turbine intake as an alternative to the conventional design for some typical SHP projects.

II. To design siphon spillway as an alternative to the conventional design for some typical SHP projects

III. To carry out life cycle cost analysis of the siphon penstock & turbine intake and spillway and conventional designs.

CHAPTER 3
METHODOLOGY

On the basis of literature studied, the gaps are identified and the objectives are defined. To fulfill the objectives, following methodology is adopted.

The methodology adopted for the research is been described in the flow chart described in Figure 3.1.

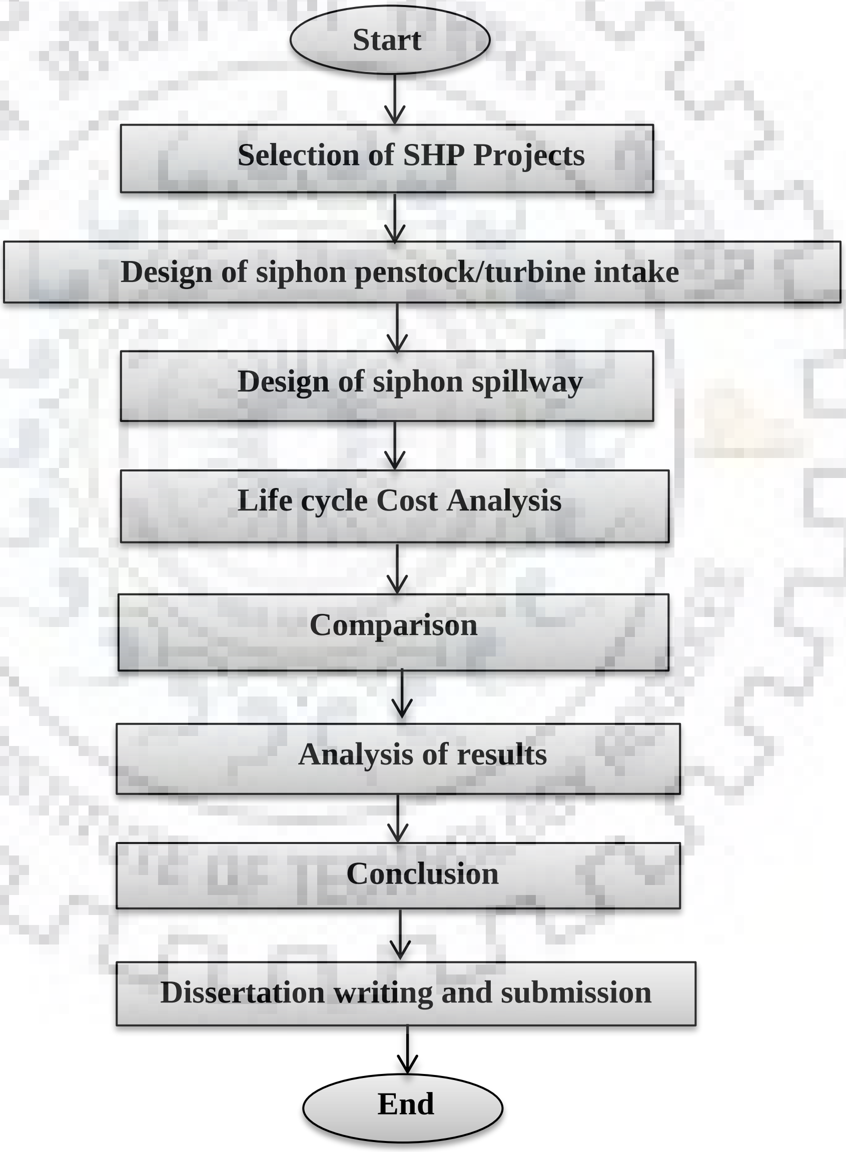


Figure 3.1: Methodology Flow Chart

3.1 SELECTION OF SHP PROJECTS:

Table 3.1 shows the projects that are selected from all over the India for design of Siphon penstock/turbine intake. The selected projects vary in location, head and discharge.

Table: 3.1 : List of SHP Projects Selected

S.N.	Project	Location	Installed Capacity (MW)	Head (m)	Discharge (m^3/s)	Available Suction Head (m)
1.	Suringad SHP- II [44]	Pithoragarh, Uttarakhnad	5	360.00	1.82	8.41
2.	Balsun River SHP[45]	Darjeeling, West Bengal	5	107.50	8.12	9.41
3.	Barun MHP[46]	Aurangabad, Bihar	3.3	3.57	124.61	9.65
4.	Yettinahole MHP[47]	Hassan, Karnataka	3	29.00	12.50	9.39
5.	Bremwar SHP[48]	Budgam, J&K	7	217.50	4.50	7.72
6.	Pareng SHP[49]	Papumpare, Arunachal Pradesh	6	68.10	13.20	8.76
7.	Rangbang SHP[50]	Darjeeling, West Bengal	5	165.11	4.36	9.16
8.	Rangit and Balwavyas SHP [51]	Darjeeling, West Bengal	7.5	74.88	17.03	9.52
9.	Singrauli SHP [52]	Sonebhadra, Uttar Pradesh	8	12.50	85.00	9.93
10.	Rangit SHP [53]	Darjeeling, West Bengal	5	121.00	5.94	9.37
11.	Luni II SHP [54]	Kangra, Himachal Pradesh	5	348.20	1.66	8.27
12.	Luni III SHP [55]	Kangra, Himachal Pradesh	5	352.00	1.7	7.89
13.	Upper Joiner SHP [56]	Chamba, Himachal Pradesh	12	282.90	5.08	8.18
14.	Upper Nanti SHP [57]	Shimla, Himachal Pradesh	12	247.80	5.80	7.64

Table 3.2 shows the detail of forebay and penstock of selected SHP Projects.

Table: 3.2 : Forebay and Penstock details of Selected SHP Projects

S.N.	Project	Forebay Dimensions				Penstock	
		FSL (m)	Length (m)	Width (m)	Depth (m)	Diameter (m)	Number of intakes
1.	Suringad SHP- II	1703.62	16.50	5.00	4.00	1.00	1
2.	Balsun River SHP	775.58	Not Available	13.75	8.02	1.78	1
3.	Barun MHP	106.94	Not Available	30.40	11.74	6.50	2
4.	Yettinahole MHP	797.413	Not Available	5.60	6.01	2.50	1
5.	Bremwar SHP	2394.50	20.00	25.00	3.60	1.50	1
6.	Pareng SHP	1364.20	50.00	10.00	5.00	2.00	1
7.	Rangbang SHP	995.11	10.00	10.00	6.64	1.32	1
8.	Rangit and Balwavyas SHP	684.88	16.00	20.00	12.00	2.53	1
9.	Singrauli SHP	273.50	20.00	13.20	7.50	3.50	2
10.	Rangit SHP	811.87	11.00	11.00	12.27	1.67	1
11.	Luni II SHP	1763.52	50.00	4.00	4.75	0.90	1
12.	Luni III SHP	2219.37	35.00	4.00	5.00	0.90	1
13.	Upper Joiner SHP	1920.01	50.00	11.00	5.08	1.20	1
14.	Upper Nanti SHP	2463.13	40.00	12.50	6.90	1.30	1

Figure 3.2 shows the location of selected SHP Projects on the map of India.

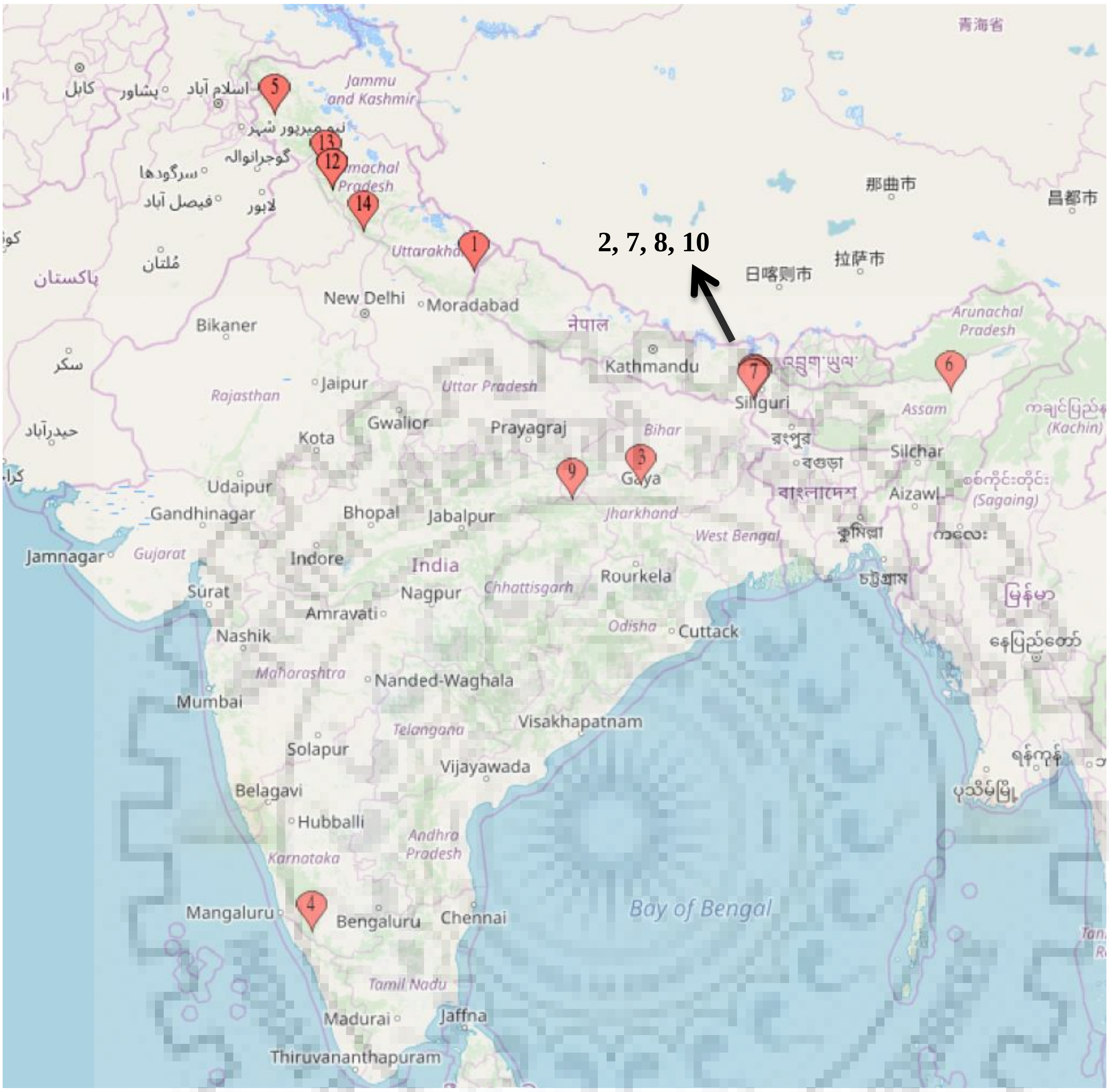


Figure 3.2: Location of SHP Projects Selected

3.2. DESIGN OF SIPHON PENSTOCK / TURBINE INTAKE:

The siphon penstock/turbine intake is designed using the following equations:

I. Velocity through penstock

The velocity of flow through the penstock play important role in the sense that the excess velocity may corrode the material and may create excess water hammer pressure. On the other hand, lower velocities lead to bigger and un-economical sections. Usually the velocities in the penstocks are limited to 3m/s

$$v = \frac{\text{Discharge through penstock}}{\text{Area of penstock}} \qquad \text{Eq3.1}$$

II. Velocity head

$$v_h = \frac{v^2}{2g} \qquad \text{Eq3.2}$$

Where v is velocity through penstock and g is acceleration due to gravity

III. Frictional Loss:

The friction loss in a closed conduit is governed by the equation

$$\text{Frictional loss} = \frac{flv^2}{2gD} \qquad \text{Eq. 3.3}$$

Where, f = Darcy Weisbach friction factor ; l is the length of conduit, v is the velicty of water through the conduit, and D is the diameter of the penstock.

IV. Intake and trash rack loss

The trash racks are installed so as to stop the floating debris or any other unwanted material from entering into the penstock. Usually rectangular trash is used to avoid all these mess. This trash do create losses and these losses are defined as

$$\text{Intake loss} = 0.05v_h \qquad \text{Eq. 3.4}$$

$$\text{Trash rack loss} = k_t v_h \qquad \text{Eq. 3.5}$$

Where K_t= 0.35 with the assumption that rectangular racks have been used and 80% free cross section at bars is available.

V. Bend Losses

There are various bends in designing of the siphon intakes. A lot of energy is been lost in these bends and hence are to be taken into consideration.

$$\text{Bend loss} = k_b v_h \qquad \text{Eq. 3.6}$$

Where K_b is the combined coefficient of bend losses [58]

Where, v_1 and v_2 are the velocities at narrow and broader sections respectively.

VI. Maximum Permissible vacuum at crest

In siphons it is required to raise the water to a height. The maximum height up to which water can be raised depends upon the vacuum pressure that is created for that specific location and the maximum losses that are occurring in the siphon. At mean sea level (MSL) the available suction head is 10.33m.The suction head other than MSL at different altitudes is governed by the equation

$$P = P_0 \left(1 - \frac{0.0065h}{T(K) + 0.0065h}\right)^{5.257} \quad \text{Eq. 3.7}$$

Where, $P = \text{Pressure at required elevation}$; $P_0 = \text{Pressure at MSL}$;

$h = \text{Elevation from MSL in meters}$; $T = \text{Temperature at elevation h in Kelvin}$

VII. Check for sufficient vacuum:

The total head to be raised reduced by the head losses must always be less than the available suction head. Only then the siphon can be used.

VIII. Diameter of intake

By the rule of thumb, the diameter of inlet is kept twice the diameter of the penstock. According to IS 11625-1986: Criteria for Hydraulic Design of Penstock,

$$D_{intake} = 1.4286 D_{penstock} \quad \text{Eq. 3.8}$$

In case if the intake is rectangular, the equivalent diameter can be found by the formula

$$D = \frac{4A}{P} \quad \text{Eq. 3.9}$$

Where A is the area of intake and P is the perimeter of intake. In rectangular intake, it's important to optimize the area according to the available dimensions of the forebay.

IX. Minimum submergence depth:

This is calculated using Han Boli's Formula

$$\frac{h_s}{d} = 1.5\, F_r + 0.5 \;\; for\ rectangular\ inlets \quad \text{Eq. 3.10}$$

$$\frac{h_s}{d} = 1.5\, F_r + 0.2\ to\ 0.3 \;\; for\ circular\ inlets \quad \text{Eq. 3.11}$$

Where Fr is the Froude's Number

hs is the minimum height of submergence

d is the diameter of inlet.

3.3.DESIGN OF SIPHON SPILLWAY:

I. Calculation of losses in siphon:

Head losses in siphon may be calculated as defined in section III, IV, V and VI of Section 2.4 in accordance with the Figure 2.2.

II. Optimization of diameter:

The diameter of the spillway can be optimized by analyzing the minimum losses and the maximum allowable velocity through the barrel that is 3m/s.

III. Diameter of inlet

By the rule of thumb, the diameter of inlet is kept twice the diameter of the penstock. According to IS 11625-1986: Criteria for Hydraulic Design of Penstock,

$$D_{intake} = 1.4286 D_{penstock} \quad \text{Eq. 3.12}$$

In case if the intake is rectangular, the equivalent diameter can be found by the formula

$$D = \frac{4A}{P} \quad \text{Eq. 3.13}$$

Where A is the area of intake and P is the perimeter of intake. In rectangular intake, it's important to optimize the area according to the available dimensions of the forebay.

IV. Thickness of barrel:

The minimum handling thickness is provided to the barrel. [59]

V. Check for sufficient vacuum:

The total head to be raised reduced by the head losses must always be less than the available suction head.

3.4.LIFE CYCLE COST ANALYSIS:

The cost of designed siphon penstock intake and siphon spillway is calculated. The cost for the existing systems is also calculated. This cost calculation will include many factors such as capital cost, operation and maintenance cost, cost electricity gain or lost due to installation of siphon etc.

The following parameters are adopted for life cycle cost analysis

I. Capital cost:

Derived from the construction cost and the cost of required equipment (if any) of the existing and siphon intake and spillway.

II. Interest during construction:

IDC is the amount of interest that accumulates over the construction period of siphon penstock/turbine intake and spillway.

III. Interest repayment:

The amount of interest that is to be paid for the debt used in construction of siphon penstock/turbine intake and spillway is called interest repayment.

IV. Operation and maintenance cost:

O&M cost is the cost that is to be paid for continuous running of the siphon penstock/turbine intake and spillway. Annual O & M cost is usually 1.5% of the capital cost.

V. Working capital cost:

Annual working capital cost is usually one month cost of O & M cost.

COMPARISON:

The comparison of the analysed cost for the existing intake and the siphon penstock/turbine intake is done.

ANALYSIS OF RESULT:

The result obtained after comparison are analysed and the results are noted

CONCLUSION:

The whole research is concluded in the.

DISSERTATION WRITING AND SUBMISSION:

Dissertation report is prepared and submitted.

CHAPTER 4

DESIGN OF SIPHON PENSTOCK/TURBINE INTAKE AND SPILLWAY

The siphon penstock/turbine intake is designied for fourteen SHP projects and Siphon Spillway is designed for seven SHP Projects. For design it is importat to study the installed conventional sytem.

4.1. CONVENTIONAL SYSTEM

4.1.1. Penstock/Turbine Intake:

All the fourteen SHP projects are installed with penstock intake that draws from the bottom of the forebay tank. The flow in the intake is controlled using the gates and the debris is stopped from entring penstock using the trash racks.

4.2.2. Spillway:

SHP projects are usually installed with the straight drop fall or ogee or stepped spillway.

The example of conventional system of intake and spillway are shown in Figure 4.1. and Figure 4.2.

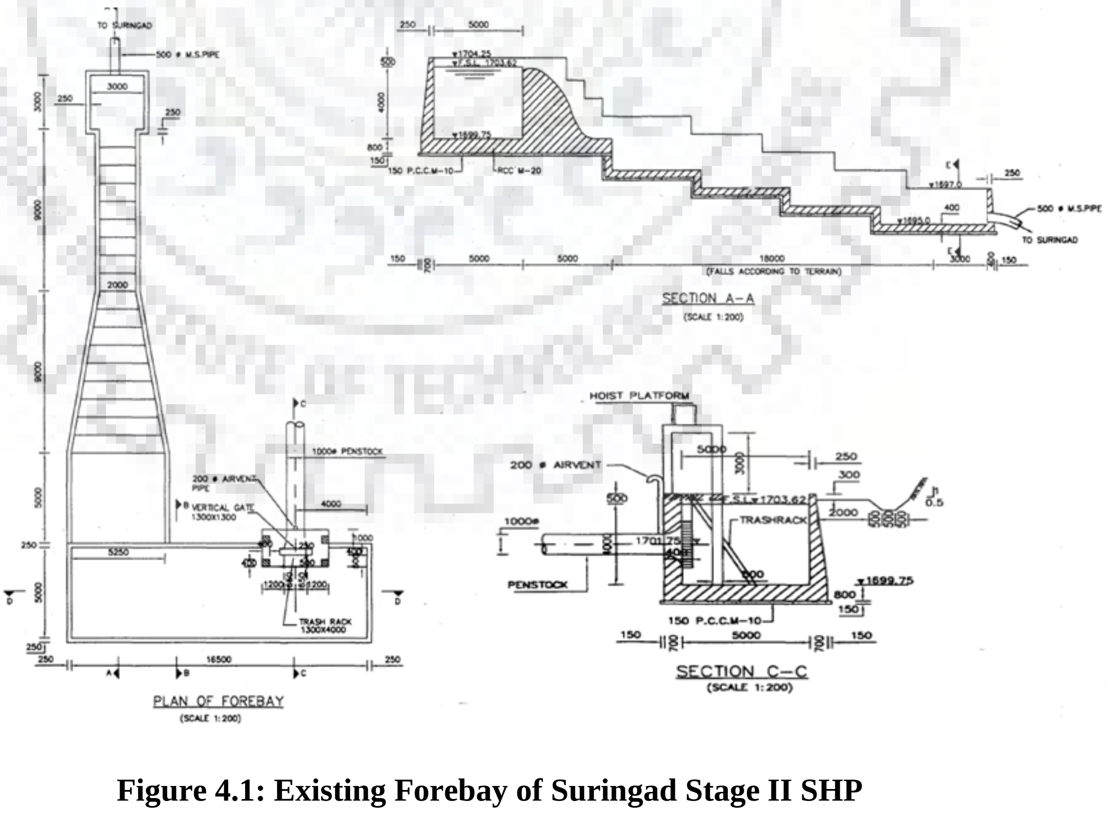


Figure 4.1: Existing Forebay of Suringad Stage II SHP

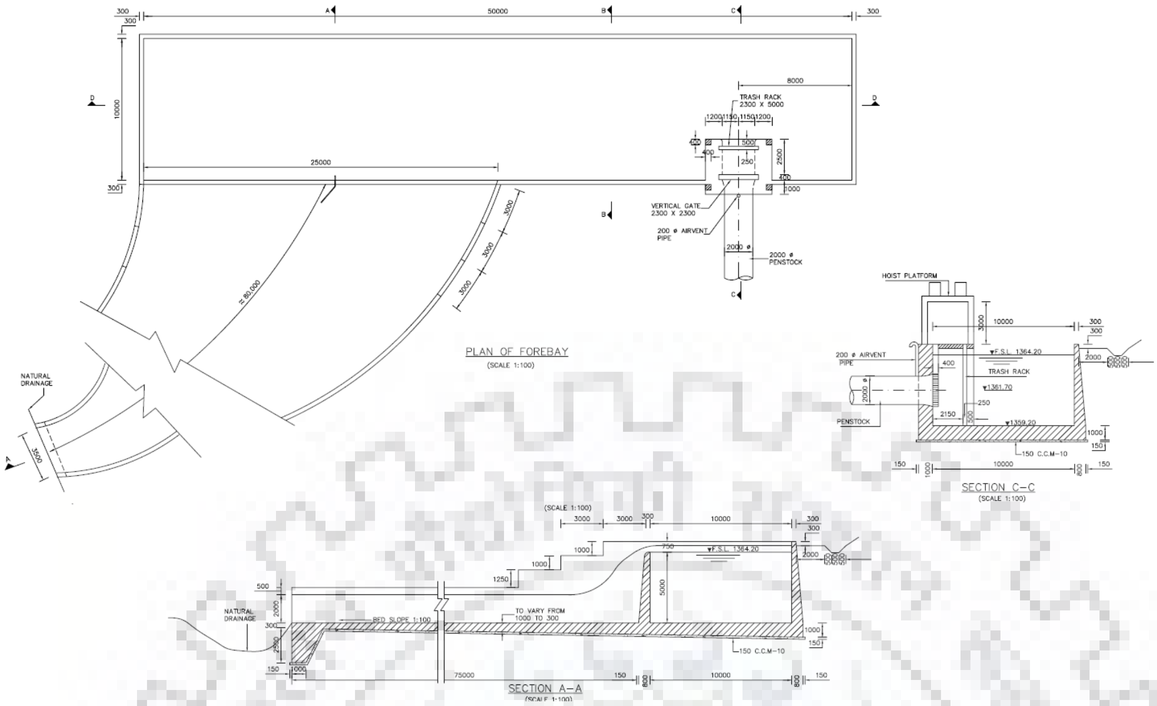


Fig 4.2. Existing Forebay of Pareng SHP

4.2. SIPHON PENSTOCK/TURBINE INTAKE DESIGN

The design is done considering all the hydraulic aspects. The basic design criteria are based on Indian Standard codes. Example design can be referred in Annexure A. The design of siphon penstock/turbine intake for fourteen small hydropower projects in provided in Table 4.1.

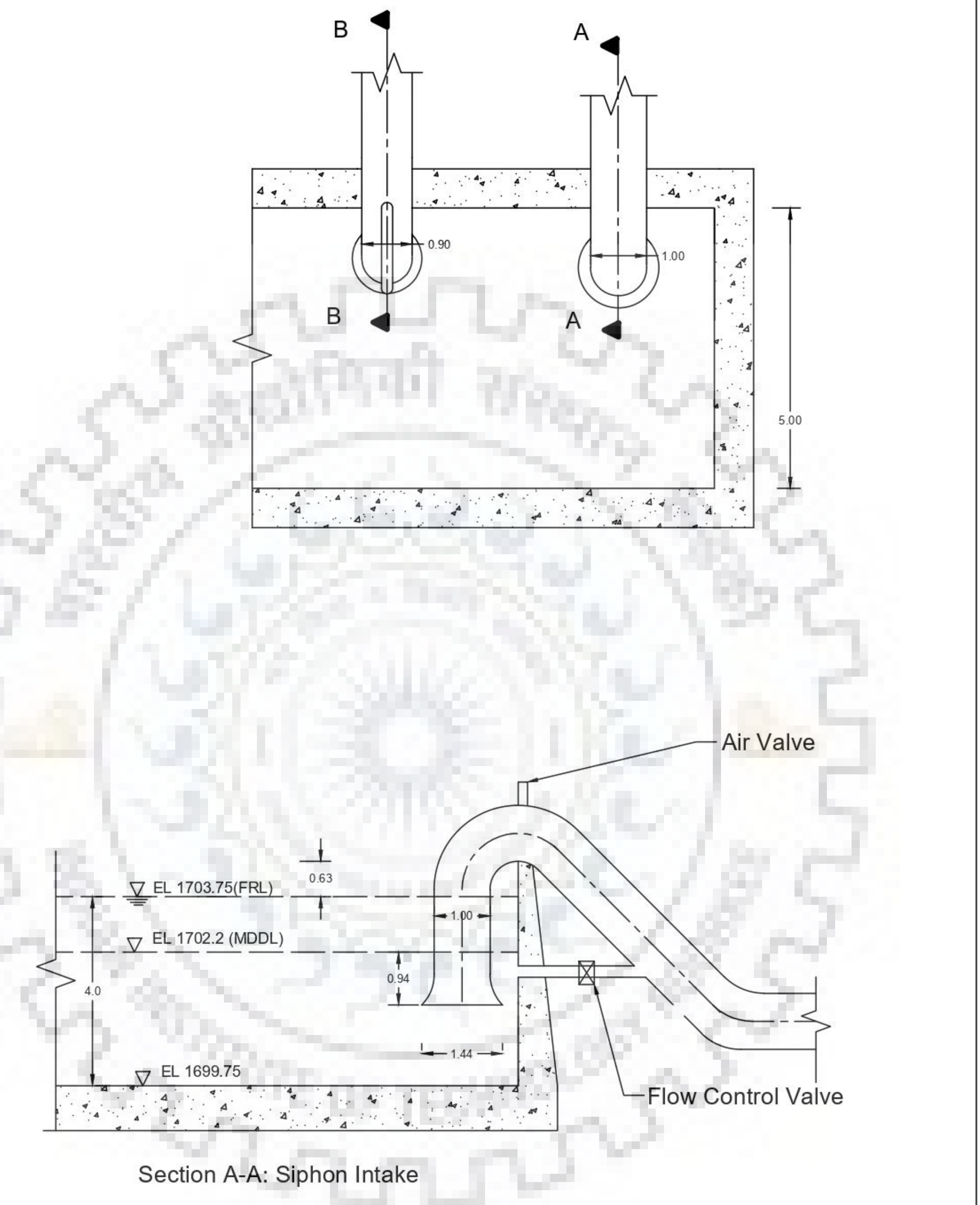
The drawings of all the designs are shown in Figures 4.3 to 4.16.

Table 4.1: Design of Siphon Penstock/ Turbine Intake

S.N.	Project	Diameter of intake (m)	Velocity through intake(m/s)	Froude's Number at inlet	Submergence (m)	Depth including submergence (m)	Length of siphon (m)
1.	Suringad SHP- II	1.43	1.14	0.30	0.94	3.00	6.00
2.	Balsun River SHP	2.54	1.60	0.32	1.73	2.73	5.46
3.	Barun MHP	9.29	0.92	0.10	3.20	7.43	21.00
4.	Yettinahole MHP	3.57	1.25	0.21	1.84	7.00	14.00
5.	Bremwar SHP	2.14	1.25	0.27	1.30	3.05	6.10
6.	Pareng SHP	2.60	2.49	0.49	2.44	5.52	13.62
7.	Rangbang SHP	1.88	1.56	0.36	1.40	6.00	12.00
8.	Rangit and Balwavyas SHP	3.61	1.66	0.28	2.24	6.00	12.00
9.	Singrauli SHP	5.00	2.17	0.31	2.36	6.00	12.00
10.	Rangit SHP	2.38	1.33	0.27	1.46	7.00	14.00
11.	Luni II SHP	1.28	1.28	0.36	0.95	2.15	4.30
12.	Luni III SHP	1.28	1.31	0.37	0.97	2.20	4.40
13.	Upper Joiner SHP	1.71	1.88	0.44	1.60	2.40	4.80
14.	Upper Nanti SHP	1.85	2.14	0.50	1.77	3.58	7.15

Table 4.1: Design of Siphon Penstock/ Turbine Intake (continued)

S.N.	Project	Velocity Head (m)	Head Loss (m)				
			Entry	Trash Rack	Bend	Friction	Total
1.	Suringad SHP- II	0.066	0.002	0.023	0.003	0.020	0.048
2.	Balsun River SHP	0.130	0.005	0.045	0.006	0.020	0.076
3.	Barun MHP	0.043	0.001	0.015	0.001	0.007	0.024
4.	Yettinahole MHP	0.079	0.003	0.027	0.002	0.022	0.054
5.	Bremwar SHP	0.079	0.003	0.027	0.003	0.016	0.049
6.	Pareng SHP	0.315	0.012	0.110	0.015	0.074	0.211
7.	Rangbang SHP	0.124	0.005	0.043	0.006	0.056	0.110
8.	Rangit and Balwavyas SHP	0.141	0.005	0.049	0.006	0.033	0.073
9.	Singrauli SHP	0.239	0.009	0.083	0.011	0.041	0.134
10.	Rangit SHP	0.090	0.003	0.021	0.004	0.028	0.046
11.	Luni II SHP	0.083	0.003	0.029	0.004	0.020	0.046
12.	Luni III SHP	0.087	0.003	0.030	0.004	0.021	0.048
13.	Upper Joiner SHP	0.179	0.007	0.052	0.008	0.033	0.100
14.	Upper Nanti SHP	0.234	0.009	0.081	0.011	0.064	0.165

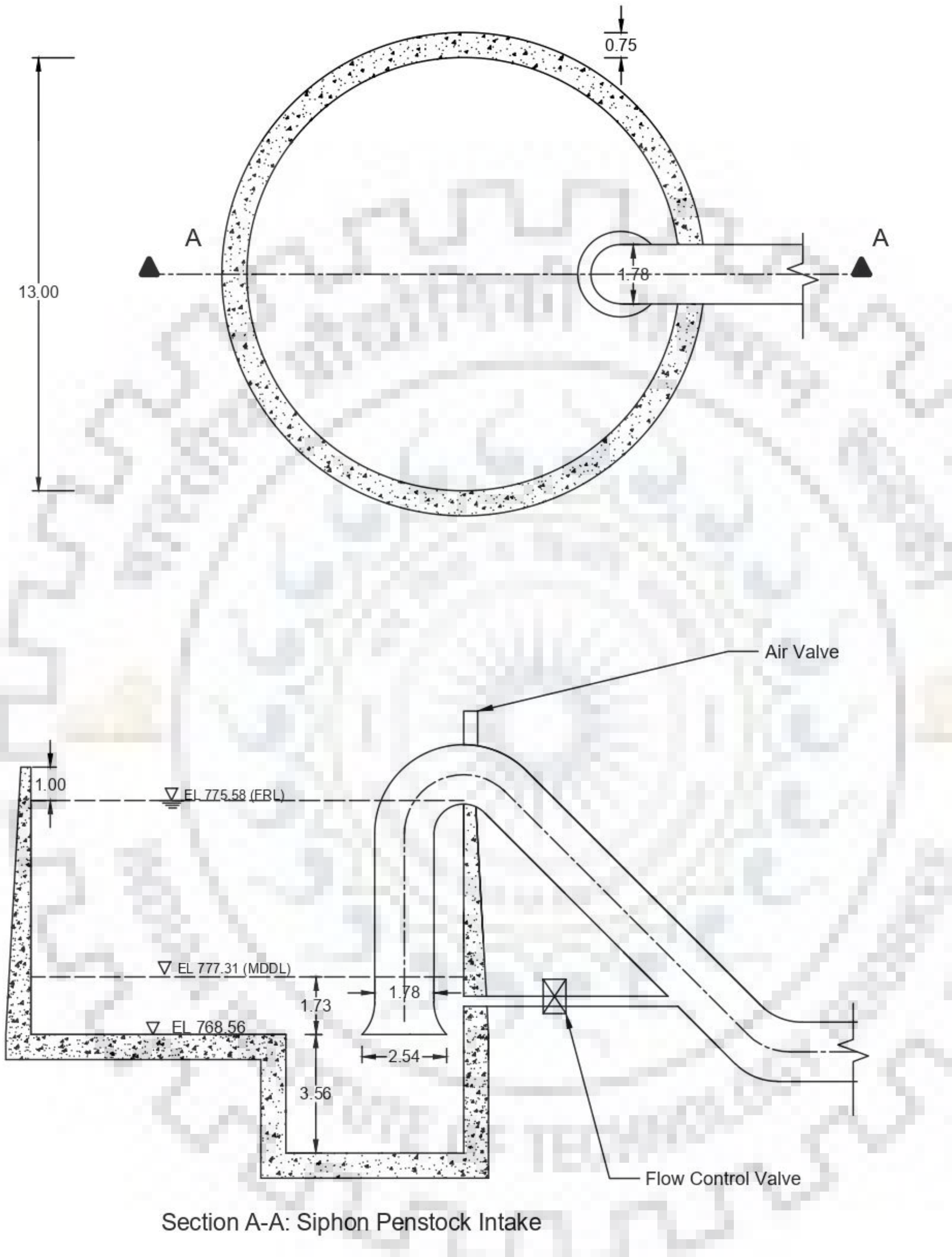


SURINGAD SHP STAGE II (2 X 2.5 MW)

SIPHON INTAKE

ALL DIMENSIONS ARE IN METERS

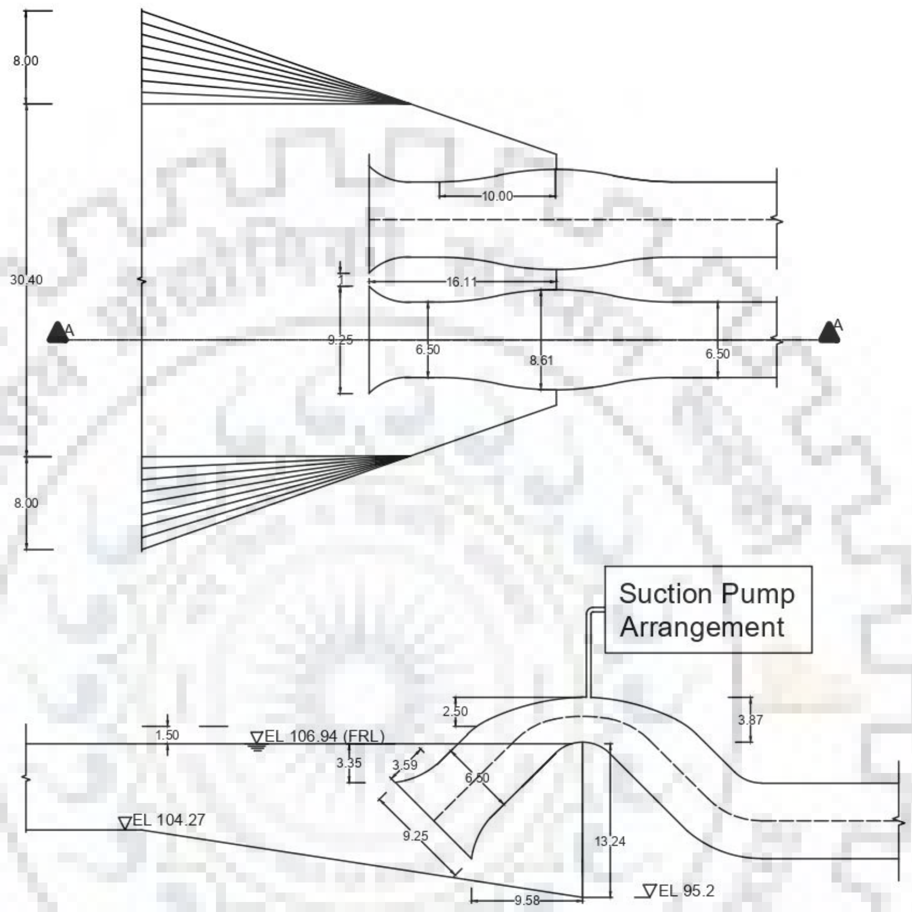
Figure 4.3



Section A-A: Siphon Penstock Intake

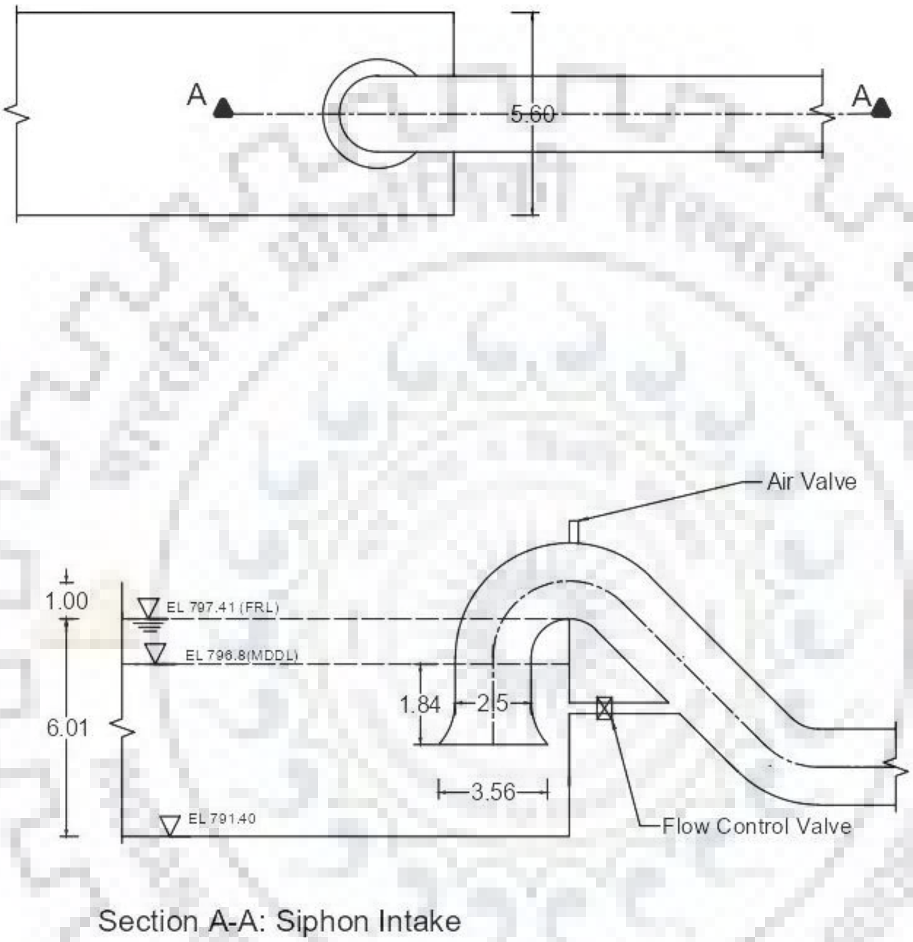
BALSUN RIVER SHP (2 X 2.5 MW)	
SIPHON INTAKE	
Figure 4.4	

ALL DIMENSIONS ARE IN METERS



Section A-A: Siphon Intake

	BARUN MINI HEP (2 X 1.6 MW)
	SIPHON INTAKE
ALL DIMENSIONS ARE IN METERS	Figure 4.5

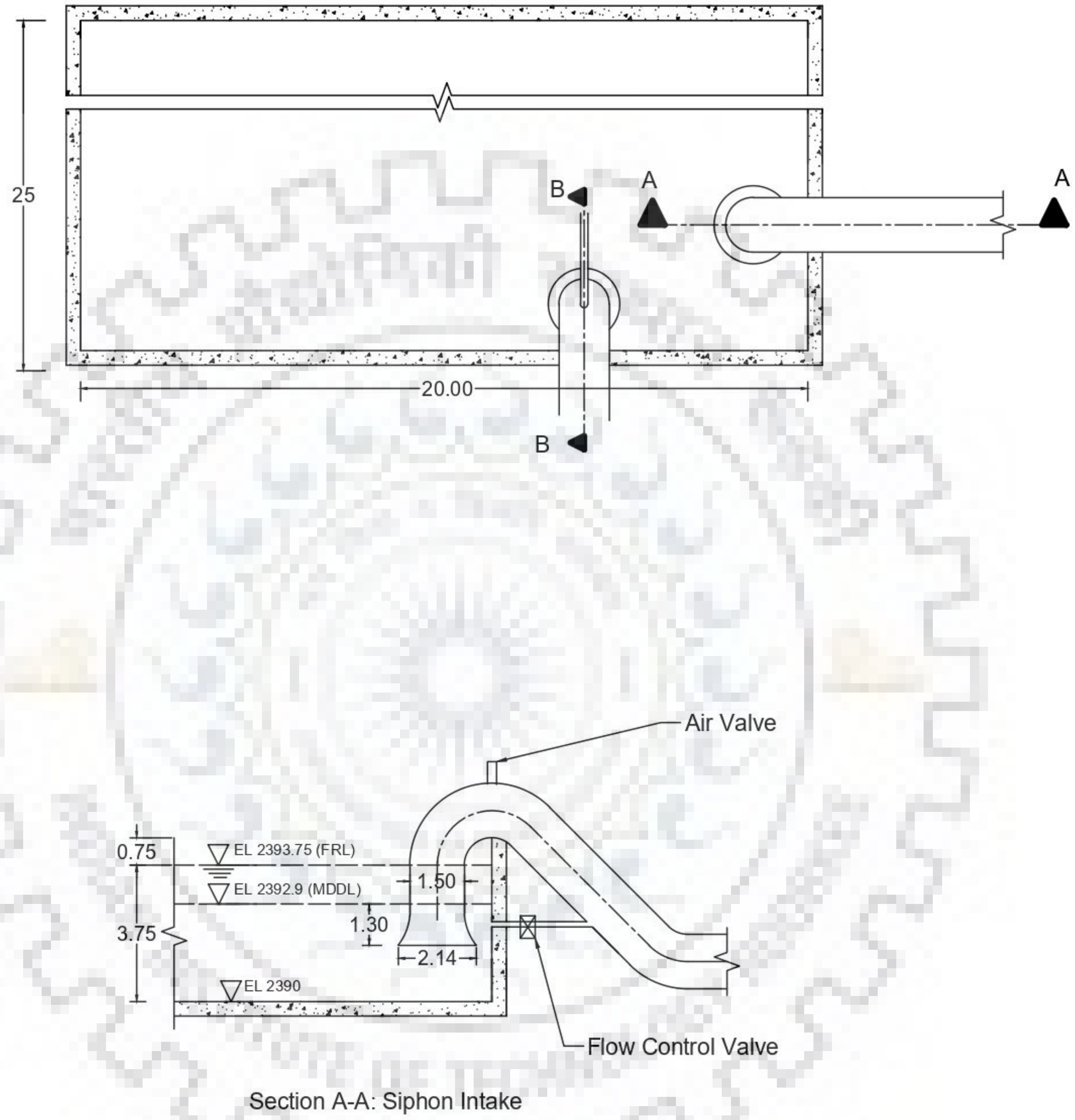


YETTINAHOLE HEP (2 X 1.5 MW)

SIPHON INTAKE

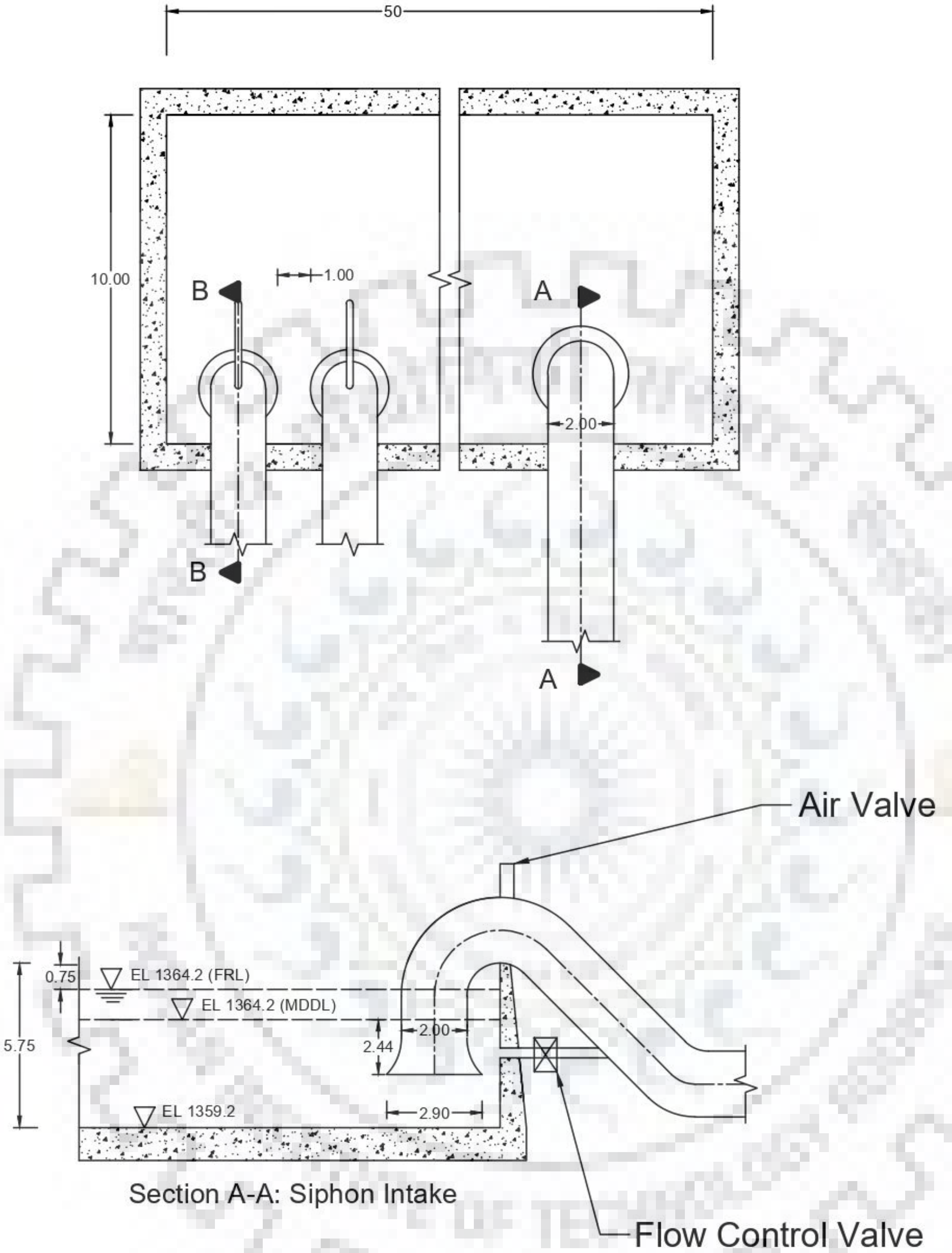
ALL DIMENSIONS ARE IN METERS

Figure 4.6

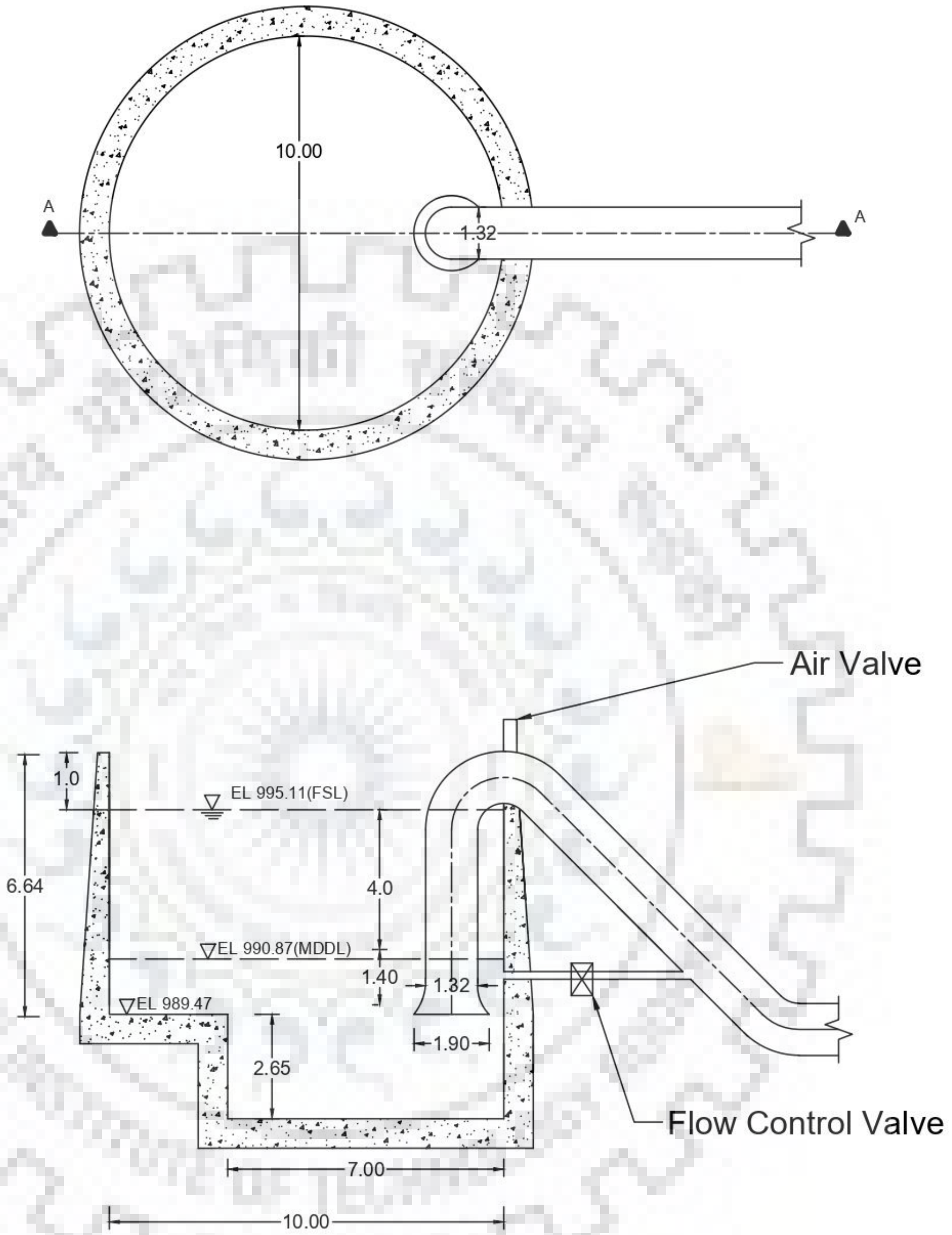


BREMWAR HEP (2 X 2.5 MW)	
SIPHON INTAKE	
Figure 4.7	

ALL DIMENSIONS ARE IN METERS

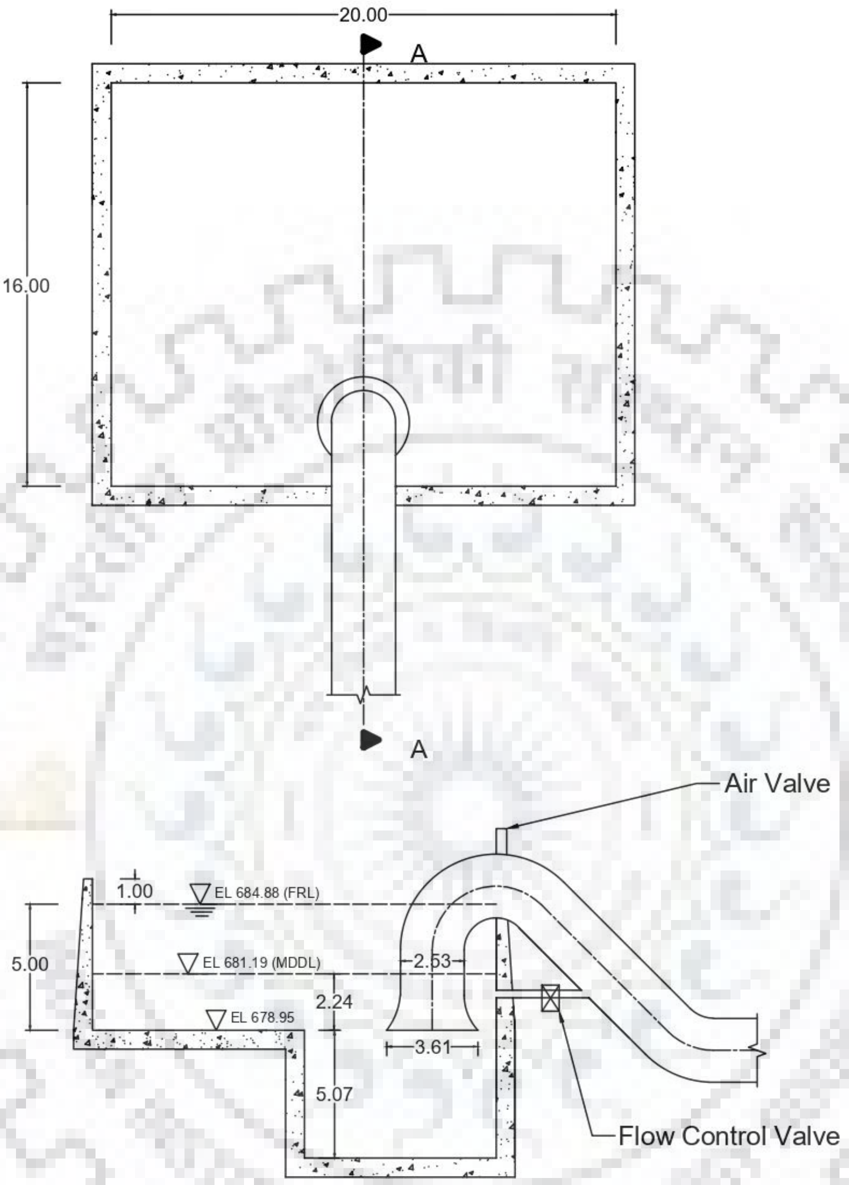


	PARENG SHP (2 X 3 MW)
	SIPHON INTAKE
ALL DIMENSIONS ARE IN METERS	Figure 4.8



Section A-A: Siphon Intake

	RANGBANG SHP (2 X 2.5 MW)
	SIPHON INTAKE
ALL DIMENSIONS ARE IN METERS	Figure 4.9



Section A-A: Siphon Intake

RANGIT AND BALWAVAS SHP (2 X 3 + 1X1.5MW)

SIPHON INTAKE

ALL DIMENSIONS ARE IN METERS

Figure 4.10

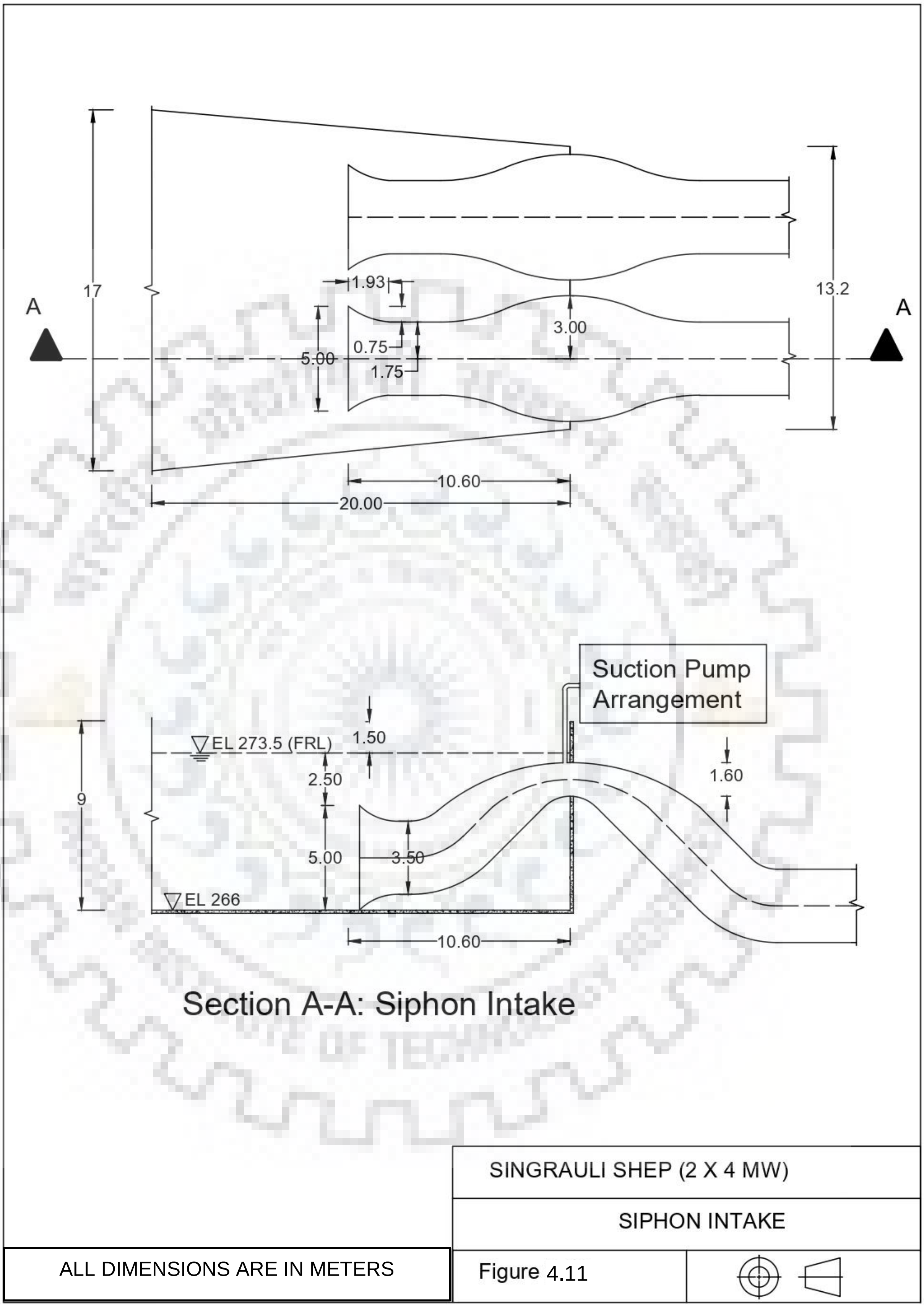
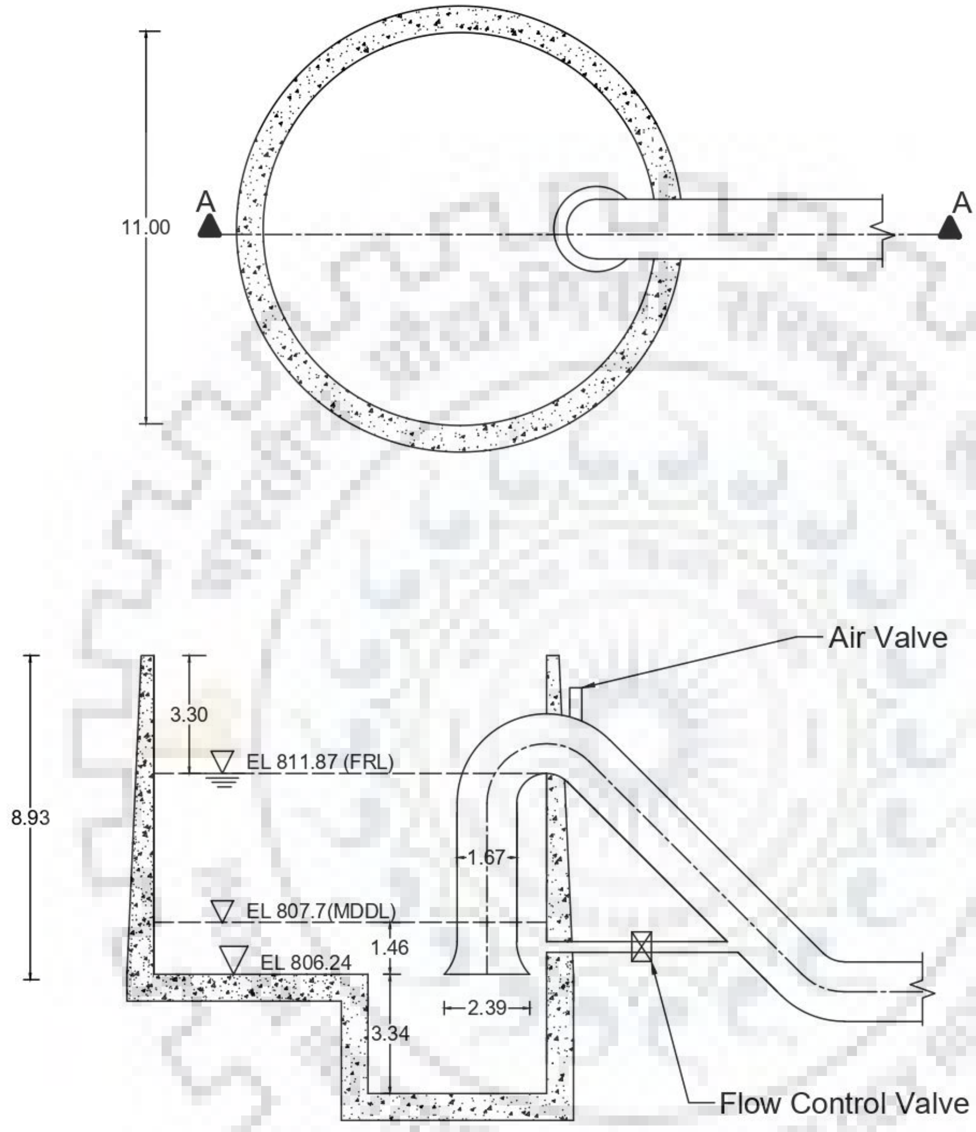

17
A
A
1.93
0.75
5.00
1.75
3.00
13.2
10.60
20.00
Suction Pump Arrangement
EL 273.5 (FRL)
1.50
2.50
9
5.00
3.50
1.60
EL 266
10.60
Section A-A: Siphon Intake
SINGRAULI SHEP (2 X 4 MW)
SIPHON INTAKE
ALL DIMENSIONS ARE IN METERS

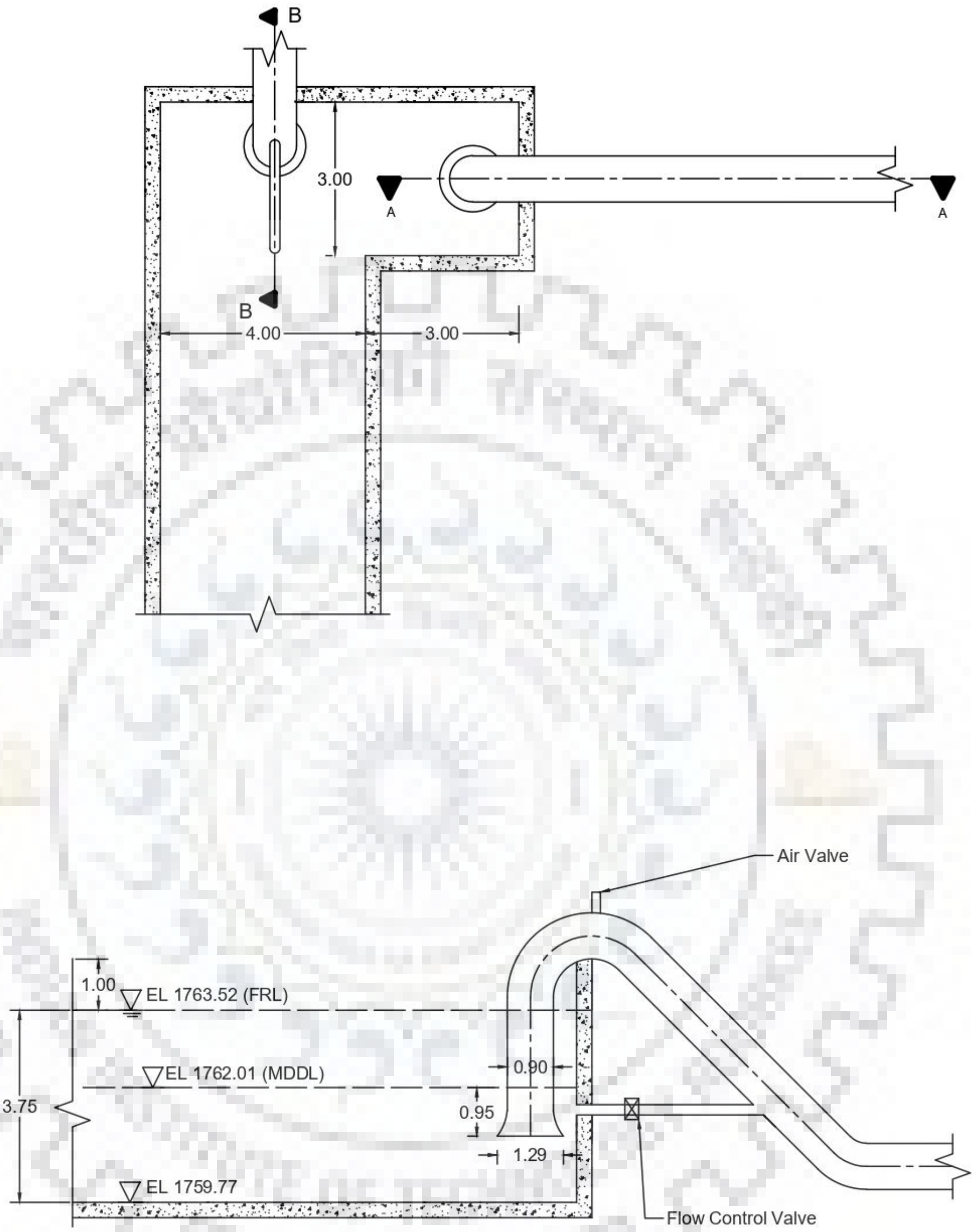
Figure 4.11



Section A-A: Siphon Intake

RANGIT SHP (2 X 2.5 MW)	
SIPHON INTAKE	
Figure 4.12	

ALL DIMENSIONS ARE IN METERS



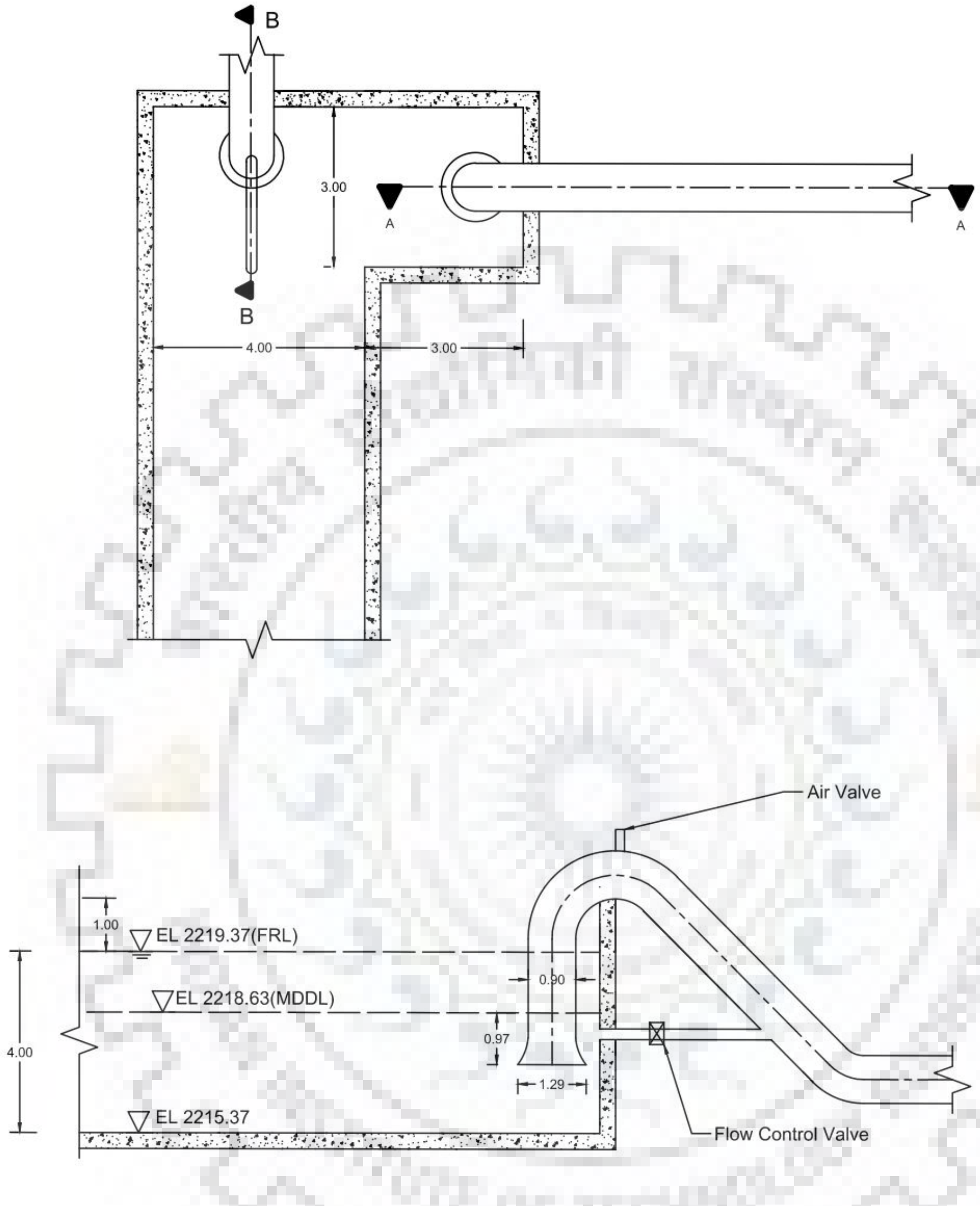
Section A-A: Siphon Intake

LUNI II SHEP (2 X 2.5 MW)

SIPHON INTAKE

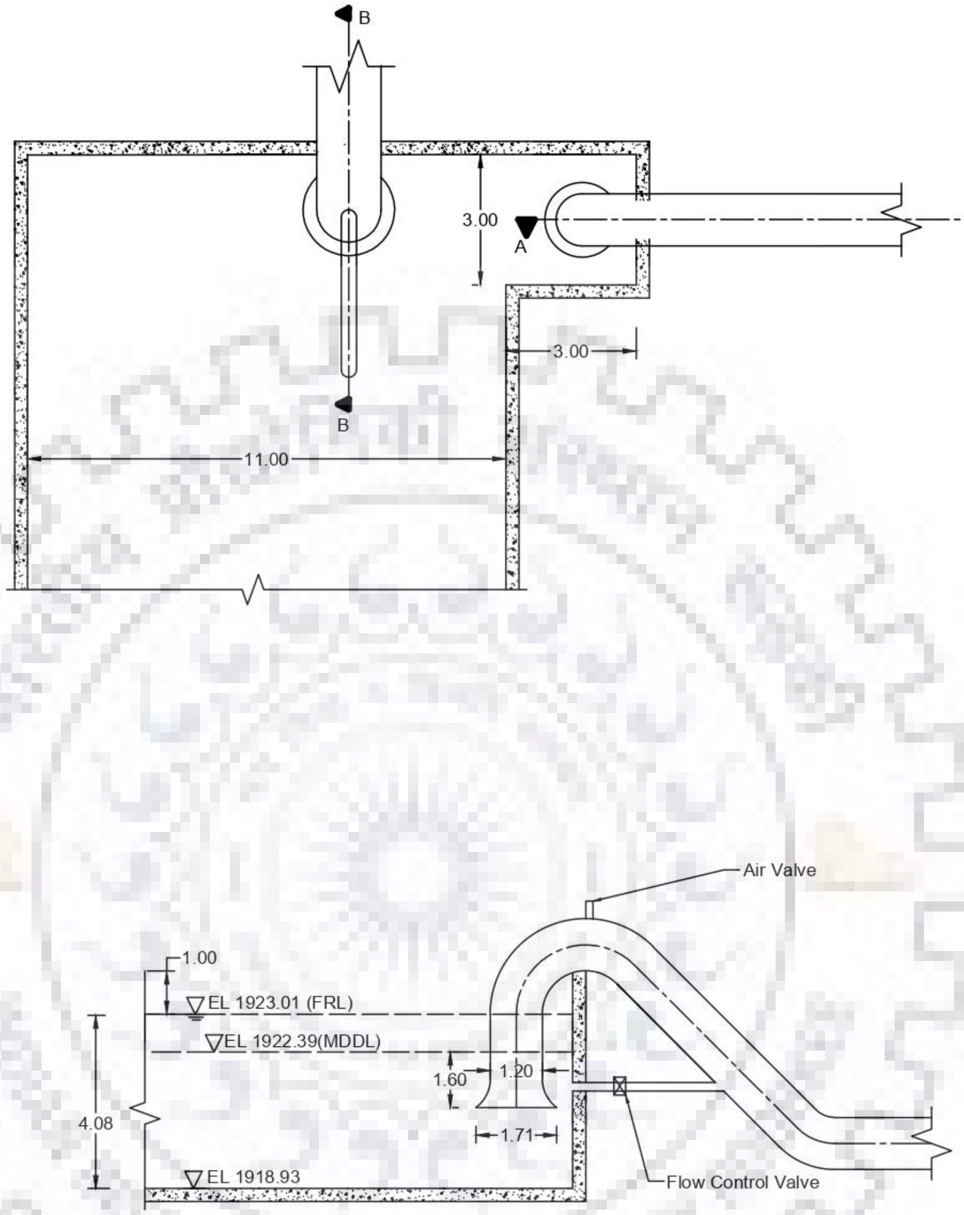
ALL DIMENSIONS ARE IN METERS

Figure 4.13



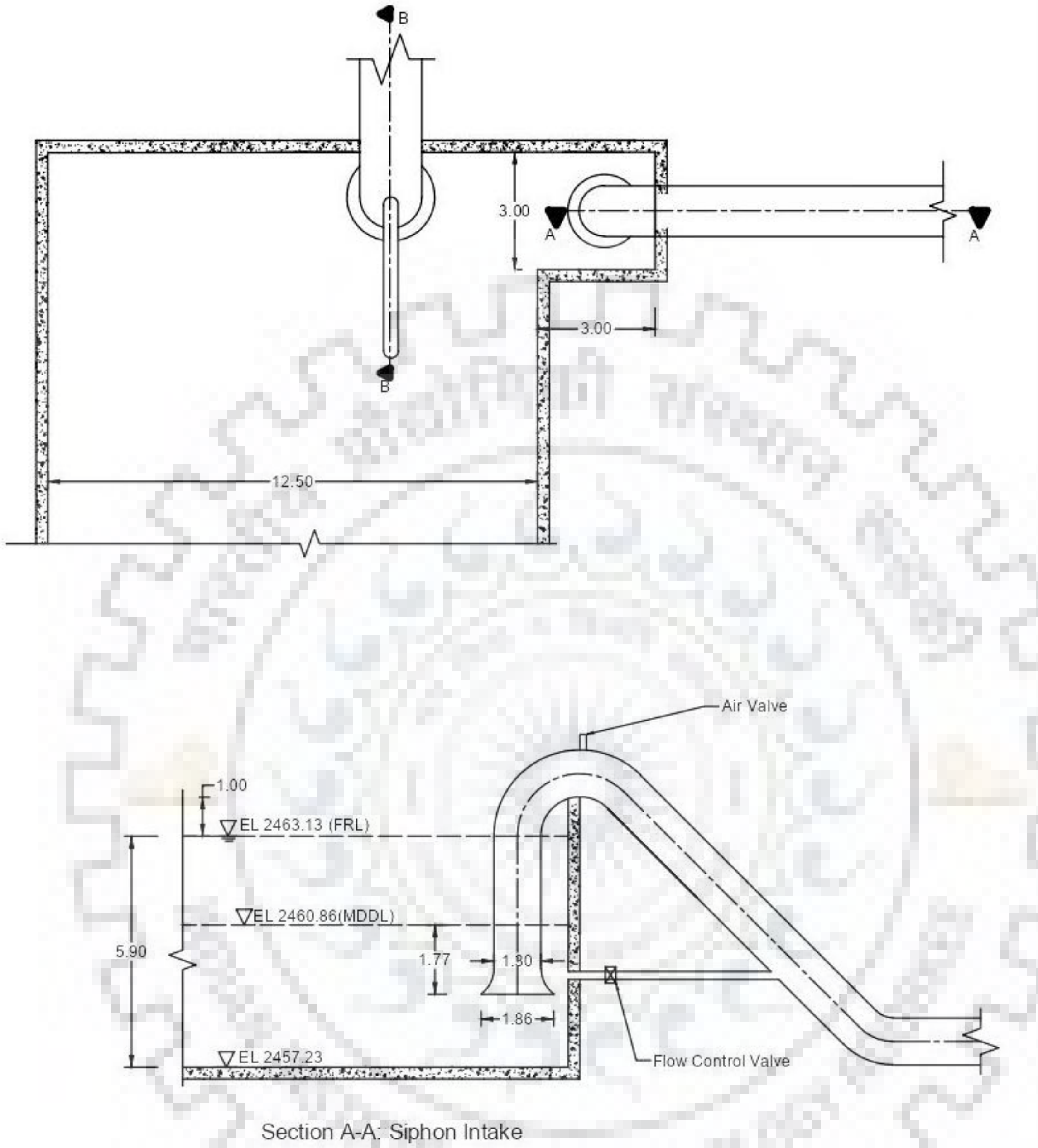
Section A-A: Siphon Intake

	LUNI III SHEP (2 X 2.5 MW)
	SIPHON INTAKE
ALL DIMENSIONS ARE IN METERS	Figure 4.14



Section A-A: Siphon Intake

	UPPER JOINER SHEP (4 X 3 MW)
	SIPHON INTAKE
ALL DIMENSIONS ARE IN METERS	Figure 4.15



	UPPER NANTI SHEP (2 X 6 MW)	
	SIPHON INTAKE	
ALL DIMENSIONS ARE IN METERS	Figure 4.16	

4.3. Design of Siphon Spillway:

The design is done considering all the hydraulic aspects. The basic design criteria are based on Indian Standard codes. Example design can be referred in Annexure B. The design of siphon spillway for seven small hydropower projects in provided in Table 4.2.

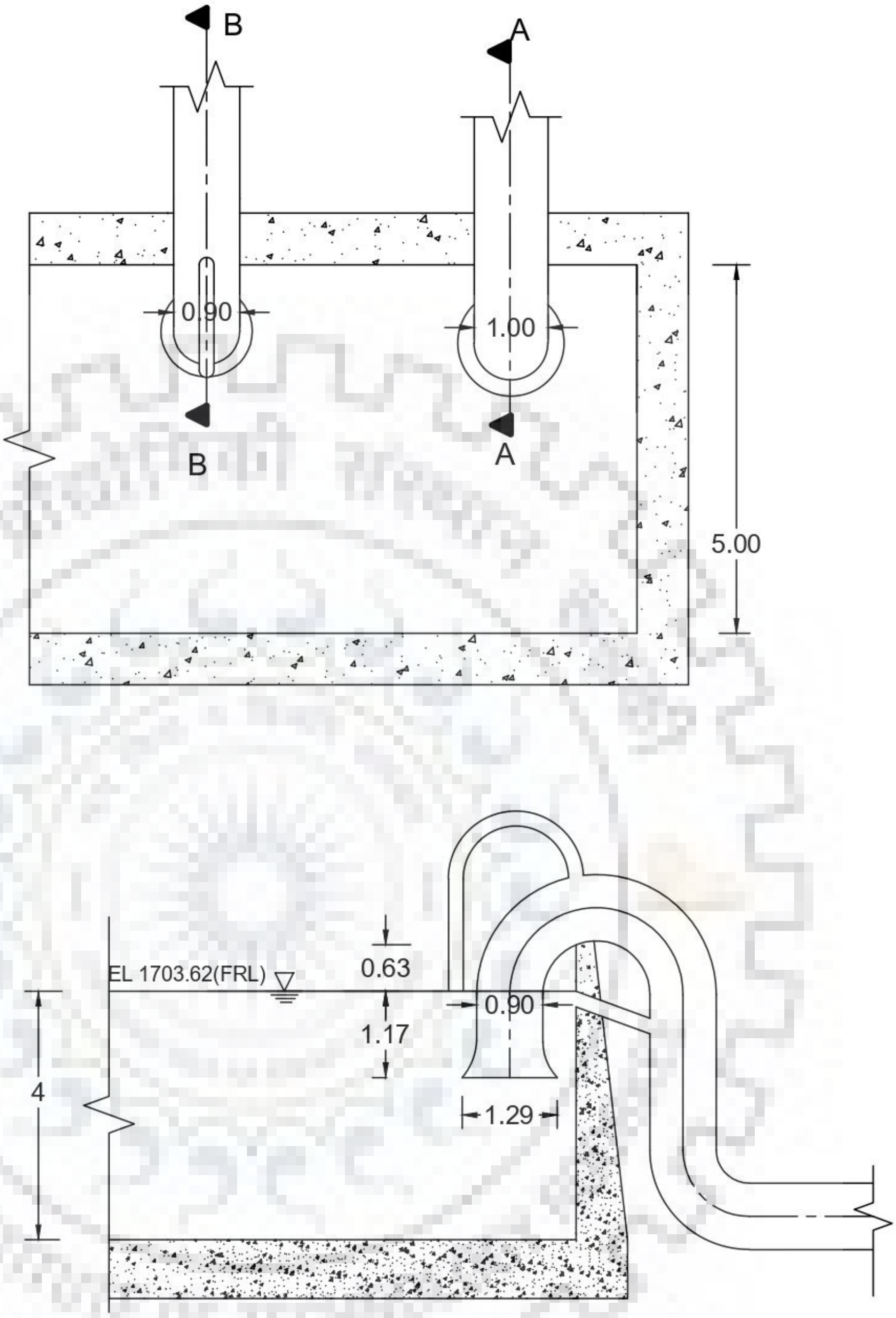
The drawings of all the designs are shown in Figures 4.17 to 4.23.

Table 4.2: Design of Siphon Spillway

S.N.	Project	Number of barrels	Design Discharge per barrel (m^3/s)	Diameter assuming velcity of 3 m/s (m)	Adopted Diameter (m)	Diameter of spillway Intake (m)	Velocity at spillway intake (m/s)	Froude's Number at inlet	Submergence Required (m)
1	Suringad SHP - II	1	1.82	0.88	0.900	1.29	1.40	0.47	1.17
2	Bremwar SHP	1	4.5	1.38	1.38	1.97	1.47	0.40	1.58
3	Pareng SHP	2	6.6	1.67	1.67	2.39	1.48	0.36	1.78
4	Luni II SHP	1	1.66	0.84	0.85	1.21	1.43	0.50	1.15
5	Luni III SHP	1	1.7	0.85	0.85	1.21	1.47	0.51	1.17
6	Upper Joiner SHP	1	5.08	1.47	1.47	2.10	1.47	0.39	1.64
7	Upper Nanti SHP	1	5.8	1.57	1.58	2.26	1.45	0.37	1.70

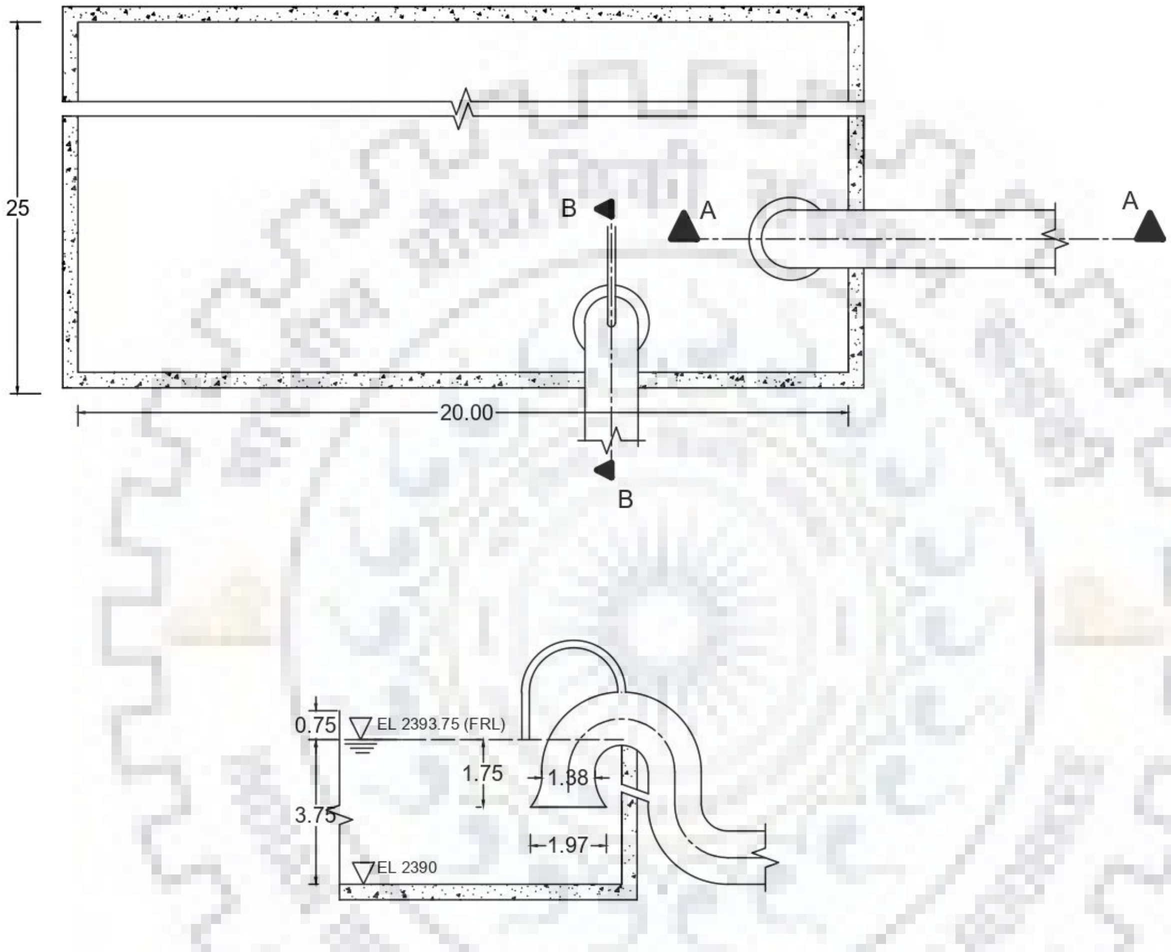
Table 4.2: Design of Siphon Spillway (Continued)

S.N.	Project	Difference in Wall top and FSL (m)	Total Depth required(m)	Length of siphon (m)	Head Loss (m)				
					Entry	Trash Rack	Bend	Friction	Total
1	Suringad SHP - II	0.63	1.80	3.59	0.0017	0.0118	0.002	0.022	0.0375
2	Bremwar SHP	1.5	3.08	6.16	0.0015	0.0105	0.001	0.025	0.038
3	Pareng SHP	0.8	2.58	5.17	0.0014	0.0096	0.001	0.017	0.029
4	Luni II SHP	1	2.15	4.29	0.0018	0.0127	0.002	0.028	0.0445
5	Luni III SHP	1	2.17	4.34	0.0019	0.0133	0.002	0.028	0.0452
6	Upper Joiner SHP	1	2.64	5.27	0.0014	0.0101	0.001	0.020	0.0325
7	Upper Nanti SHP	1	2.70	5.40	0.0014	0.0095	0.001	0.019	0.0309



Section B-B: Siphon Spillway

	SURINGAD SHP STAGE II (2 X 2.5 MW)	
	SIPHON SPILLWAY	
ALL DIMENSIONS ARE IN METERS	Figure 4.17	



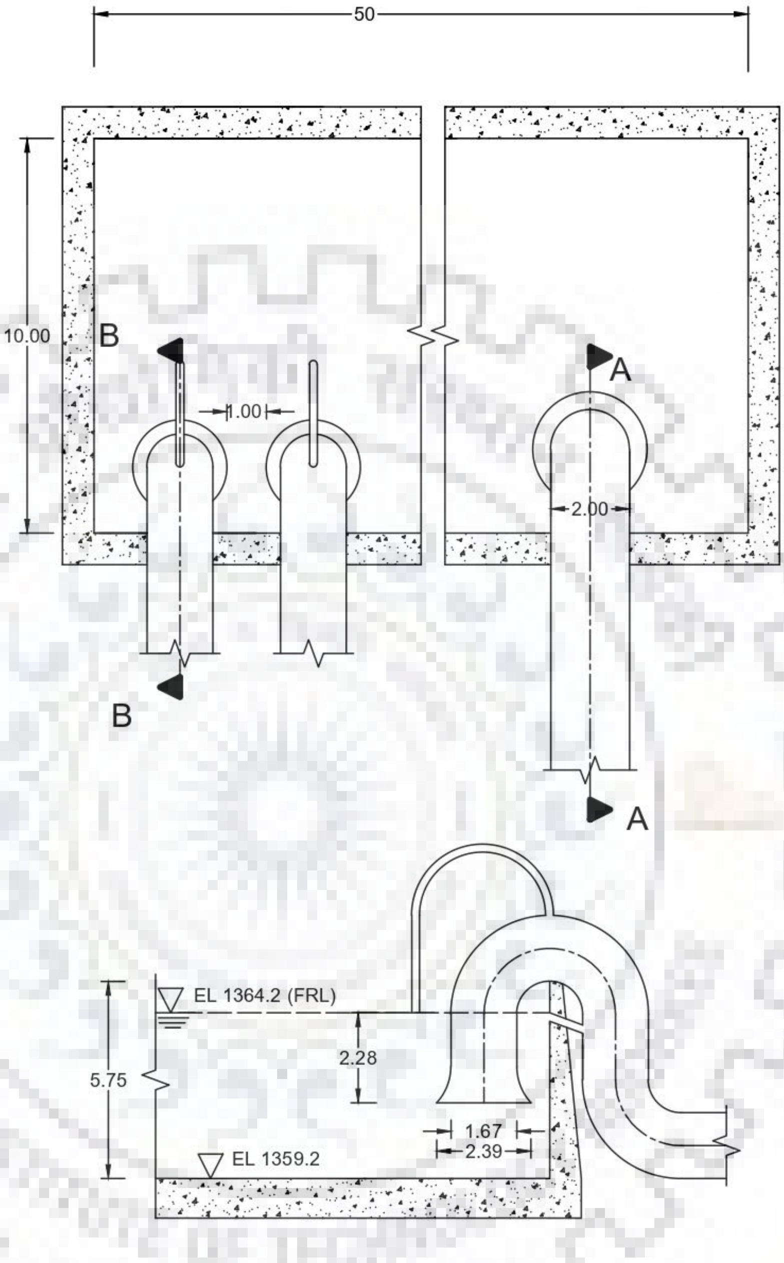
Section B-B: Siphon Spillway

BREMWAR HEP (2 X 2.5 MW)

SIPHON SPILLWAY

ALL DIMENSIONS ARE IN METERS

Figure 4.18



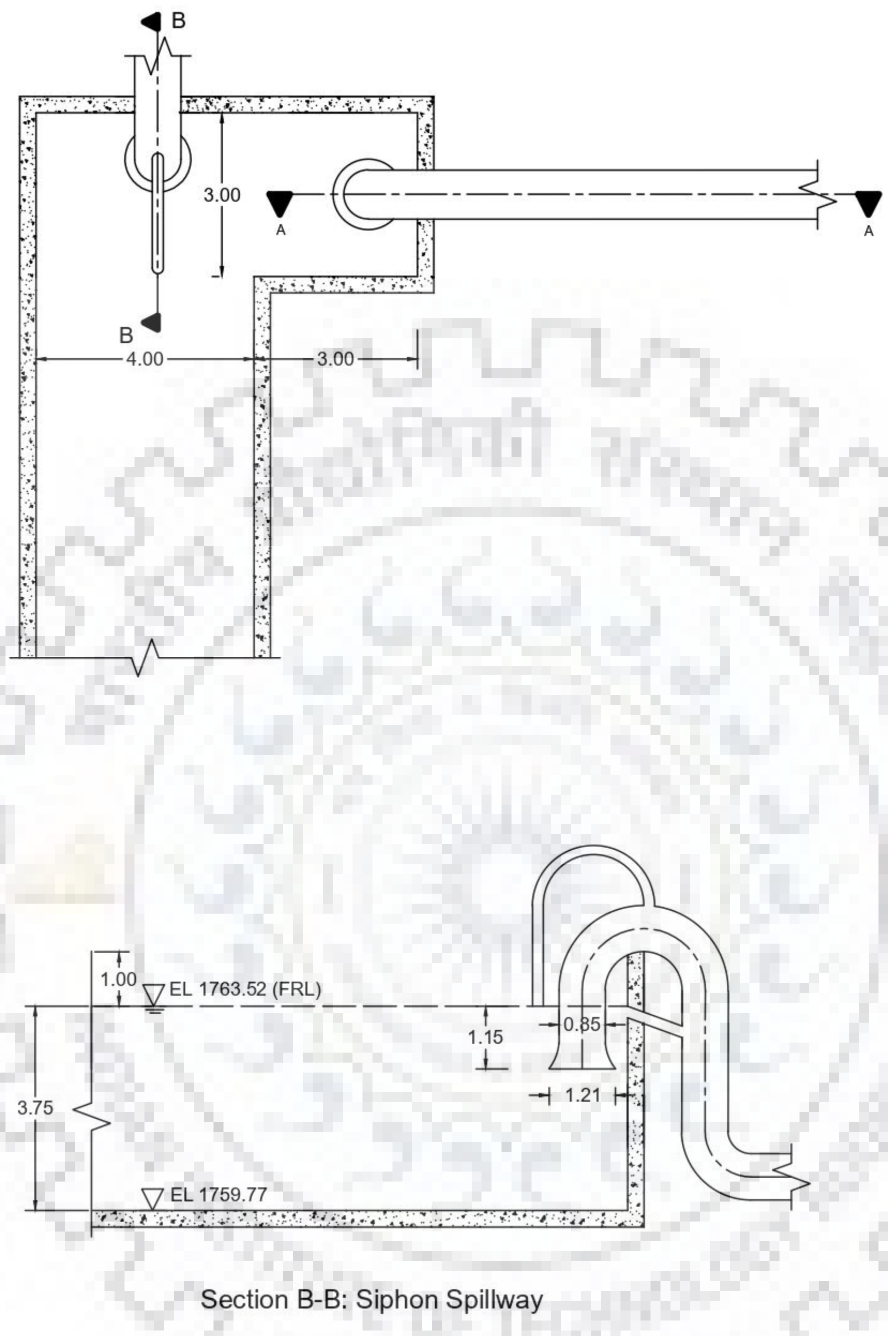
Section A-A: Siphon Spillway

PARENG SHP (2 X 3 MW)

SIPHON SPILLWAY

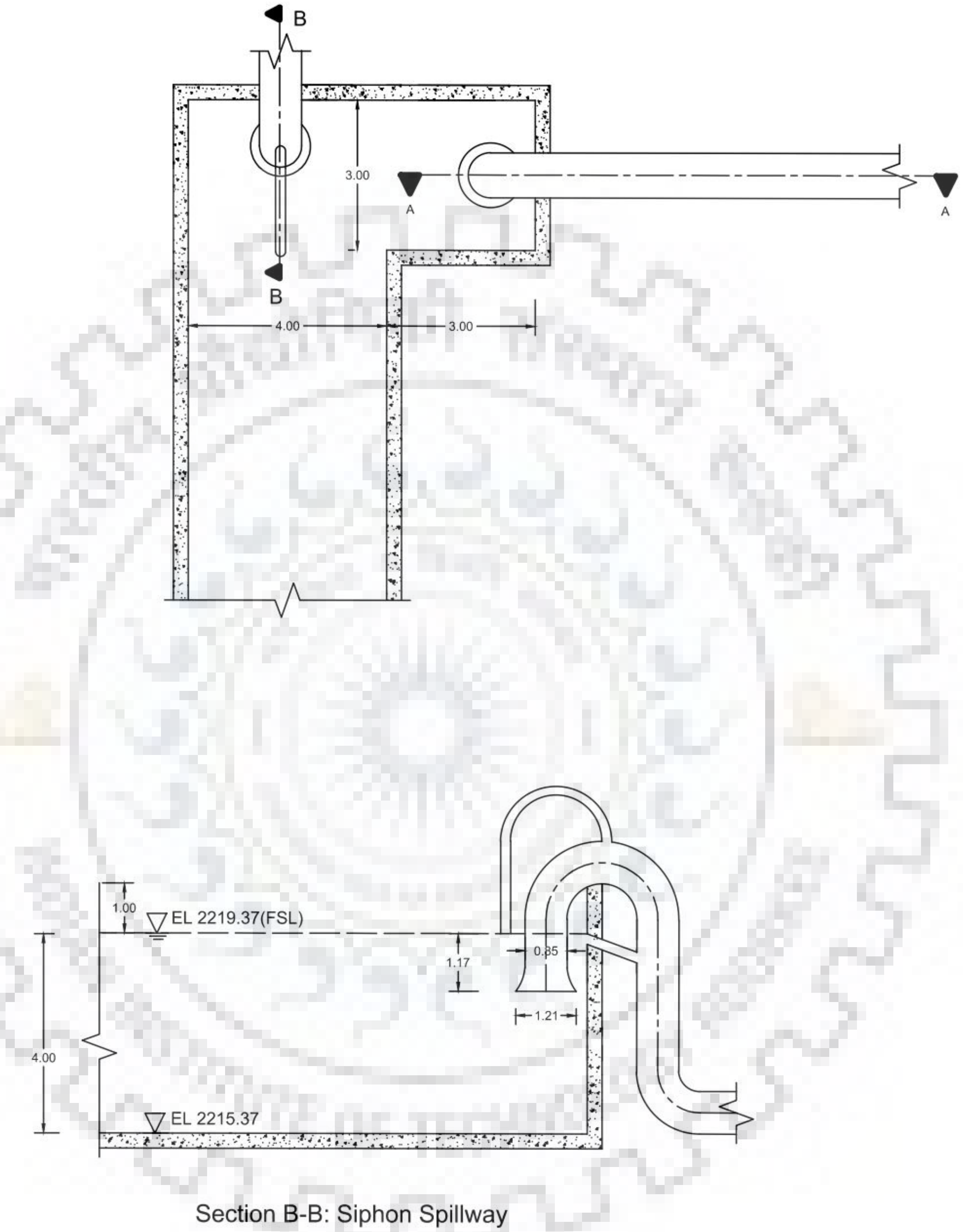
ALL DIMENSIONS ARE IN METERS

Figure 4.19



Section B-B: Siphon Spillway

	LUNI II SHEP (2 X 2.5 MW)
	SIPHON SPILLWAY
ALL DIMENSIONS ARE IN METERS	Figure 4.20



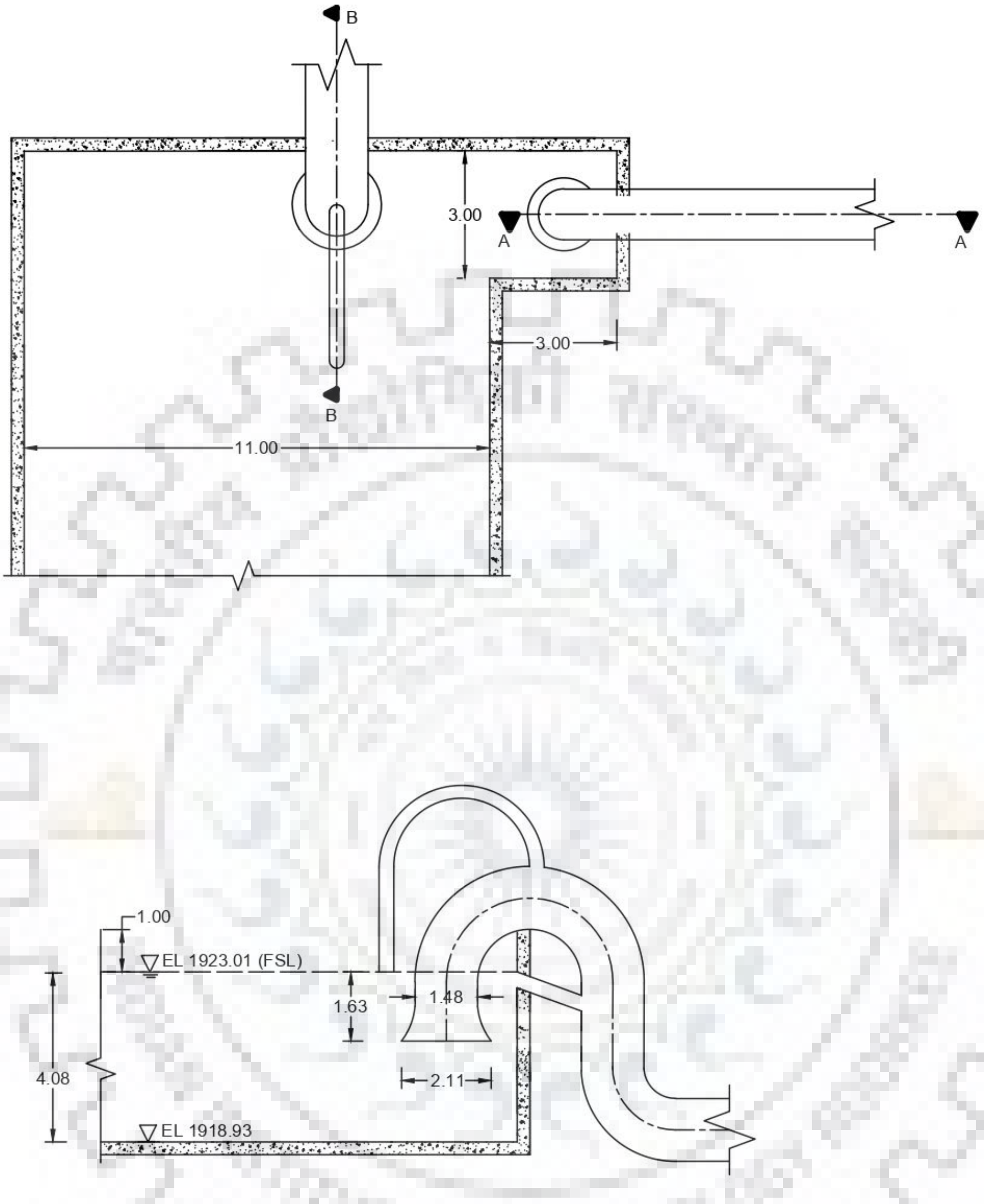
Section B-B: Siphon Spillway

LUNI III SHEP (2 X 2.5 MW)

SIPHON SPILLWAY

ALL DIMENSIONS ARE IN METERS

Figure 4.21



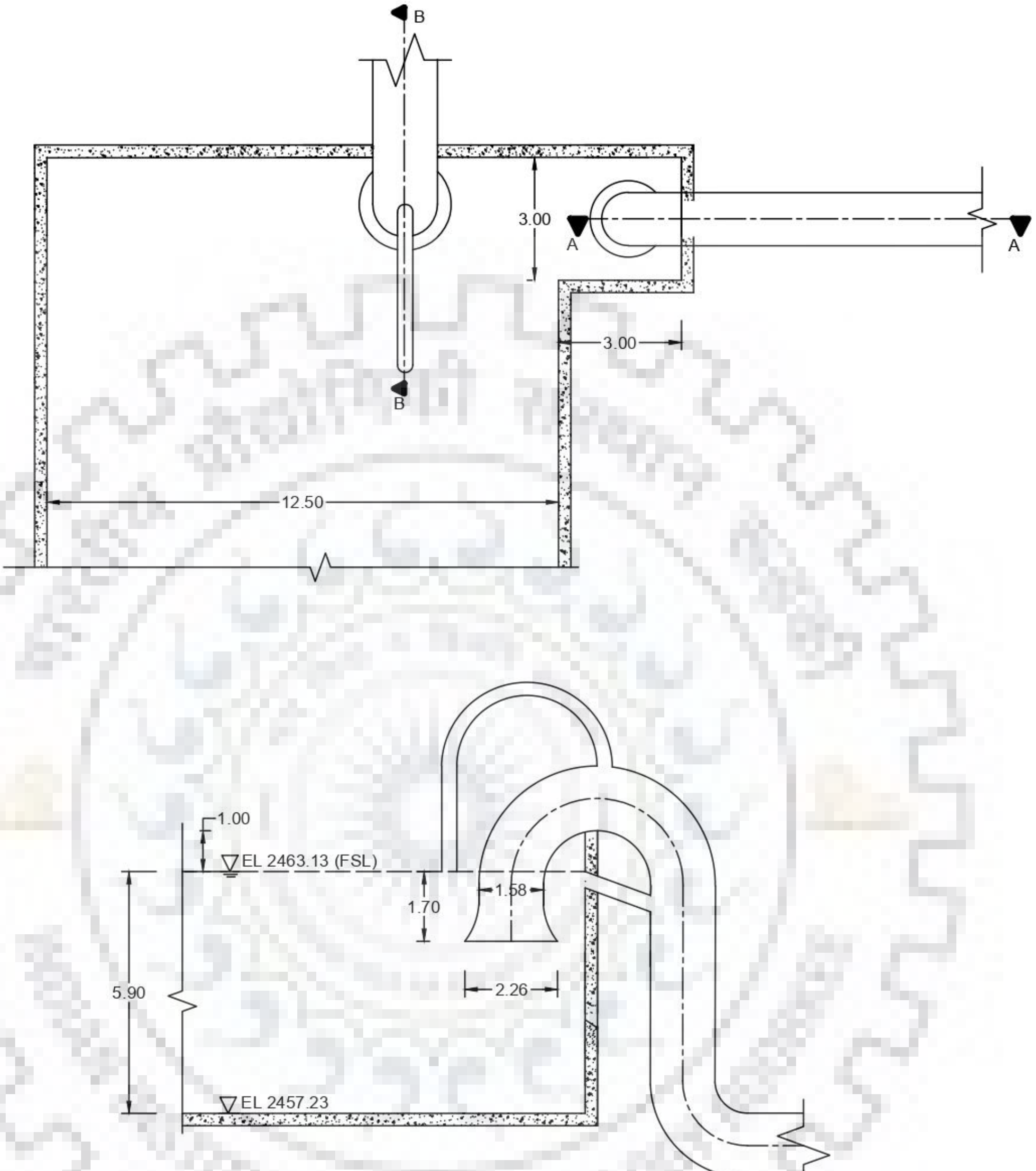
Section B-B: Siphon Spillway

UPPER JOINER SHEP (4 X 3 MW)

SIPHON SPILLWAY

ALL DIMENSIONS ARE IN METERS

Figure 4.22



Section B-B: Siphon Spillway

UPPER NANTI SHEP (2 X 6 MW)

SIPHON SPILLWAY

ALL DIMENSIONS ARE IN METERS

Figure 4.23

CHAPTER 5

LIFE CYCLE COST ANALYSIS

The financial analysis is done for the existing system at site and siphon penstock/turbine intake and spillway. The financial analysis will follow the cost calculation on various factors. The difference of cost will occur because of following changes:

1. On installation of Siphon Penstock/Turbine Intake
   a. Removal of gates
   b. Removal of Trash Racks
   c. Reduction in losses due to removal of gates
   d. Reduction in losses due to removal of trash racks
   e. Increase in losses due to increment in length of the penstock
   f. Increase in cost of due to siphon construction
   g. Increase in cost due to suction pump arrangement(if any)
2. On installation of Siphon Spillway
   a. Increase in cost of spillway due to construction of barrel

The comparison is made for both siphon penstock intake and siphon spillways based on the above mentioned factors.

5.1. SIPHON PENSTOCK/TURBINE INTAKE:

As according to the mentioned factors, the LCCA is done for siphon penstock intake and conventional installed system in Table 5.1-5.8 and the exemplar calculation is provided in Annexure C and D.

5.2. SIPHON SPILLWAY:

As according to the mentioned factors, the LCCA is done for siphon spillway in Table 5.9 and the exemplar calculation is provided in Annexure E.

Table 5.1: Cost calculation of Existing Intake Gates/Valves and Trash Rack

S.N.	Project	Area of gate/valve(m^2)	Weight of gate/valve (MT)	Cost of gate/valve (Lakh INR)	Area of trash rack (m^2)	Weight of trash rack (MT)	Cost of trash rack (Lakh INR)
1	Suringad SHP- II	1.69	1.69	2.70	5.20	1.04	1.24
2	Balsun River SHP	9.00	9.00	14.40	9.00	1.80	2.16
3	Barun MHP	46.00	92.00	147.2	50.00	20.00	24.00
4	Yettinahole MHP	5.06	5.06	8.10	5.06	1.01	1.21
5	Bremwar SHP	5.25	5.25	8.40	11.25	2.25	2.70
6	Pareng SHP	5.29	5.29	8.46	11.50	2.30	2.76
7	Rangbang SHP	2.61	2.61	4.18	4.48	0.89	1.07
8	Rangit and Balwavyas SHP	22.04	22.04	35.26	35.45	7.09	8.50
9	Singrauli SHP	16.20	32.40	51.84	28.80	23.04	27.64
10	Rangit SHP	8.38	8.38	13.41	17.57	3.51	4.21
11	Luni II SHP	3.60	3.60	5.76	9.15	1.83	2.19
12	Luni III SHP	3.60	3.60	5.76	10.50	2.10	2.52
13	Upper Joiner SHP	5.13	5.13	8.20	12.24	2.448	2.93
14	Upper Nanti SHP	5.67	5.67	9.072	11.70	2.34	2.80

Table 5.1: Cost calculation of Existing Intake Gates/Valves and Trash Rack (continued)

S.N.	Project	Total Gate and trash rack Cost (Lakh INR)	Interest rate (%)	Interest during construction (Lakh INR)	Total Cost (Lakh INR)	Interest Repayment (Lakh INR)	Final Cost (Lakh INR)
1	Suringad SHP- II	3.95	12.00	0.71	4.43	1.53	6.20
2	Balsun River SHP	16.56	12.50	3.11	19.67	8.75	28.41
3	Barun MHP	171.20	14.00	35.95	207.15	101.26	308.41
4	Yettinahole MHP	9.32	10.50	1.47	10.78	4.54	15.32
5	Bremwar SHP	11.10	12.50	2.08	13.18	6.32	19.51
6	Pareng SHP	11.22	12.00	2.02	13.24	6.19	19.44
7	Rangbang SHP	5.26	12.50	0.99	6.24	3.00	9.24
8	Rangit and Balwavyas SHP	43.77	12.50	8.21	51.98	24.94	76.92
9	Singrauli SHP	79.49	12.00	14.31	93.80	17.66	111.45
10	Rangit SHP	17.63	12.50	3.31	20.94	10.04	30.98
11	Luni II SHP	7.96	10.00	1.19	9.15	3.14	12.29
12	Luni III SHP	8.28	10.00	1.24	9.52	3.27	12.79
13	Upper Joiner SHP	11.15	12.00	2.01	13.15	6.15	19.30
14	Upper Nanti SHP	11.88	12.50	2.23	14.11	6.77	20.88

Table 5.2: Cost calculation of Siphon Intake Barrel and Trash Rack

S.N.	Project	Thickness of penstock (m)	Material	Volume of Penstock (m^3)	Weight of penstock (MT)	Cost of siphon barrel (Lakh INR)	Area of trash rack (m^2)	Weight of trash rack (MT)	Cost of trash rack (Lakh INR)
1	Suringad SHP- II	0.010	Steel	0.38	2.99	4.79	1.60	0.32	0.29
2	Balsun River SHP	0.008	ERW pipes	0.49	3.87	6.19	5.08	1.02	0.91
3	Barun MHP	0.016	steel	10.98	86.74	138.79	67.69	27.08	24.37
4	Yettinahole MHP	0.012	Steel	2.22	17.55	28.08	10.01	2.00	1.80
5	Bremwar SHP	0.014	Steel	0.81	6.38	10.22	3.60	0.72	0.65
6	Pareng SHP	0.014	Steel	2.40	18.99	30.38	5.31	1.06	0.96
7	Rangbang SHP	0.012	Steel	1.20	9.47	15.16	2.79	0.56	0.50
8	Rangit and Balwavyas SHP	0.010	Steel	1.91	15.09	24.15	10.25	2.05	1.85
9	Singrauli SHP	0.018	Steel	4.76	37.60	60.16	19.63	7.85	7.07
10	Rangit SHP	0.014	Steel	2.06	16.31	26.09	4.47	0.89	0.80
11	Luni II SHP	0.016	Steel	0.39	3.09	4.96	1.30	0.26	0.23
12	Luni III SHP	0.016	Steel	0.40	3.17	5.07	1.30	0.26	0.23
13	Upper Joiner SHP	0.025	Steel	0.99	7.81	12.50	2.31	0.46	0.42
14	Upper Nanti SHP	0.016	Steel	0.94	7.42	11.88	2.71	0.54	0.49

Table 5.2: Cost calculation of Siphon Intake Barrel and Trash Rack (continued)

S.N.	Project	Total Siphon Inatke and trash rack Cost (Lakh INR)	Interest rate (%)	Interest during construction (Lakh INR)	Total Cost (Lakh INR)	Interest Repayment (Lakh INR)	Final Cost (Lakh INR)
1	Suringad SHP- II	5.07	12.00	0..92	5.68	1.97	7.96
2	Balsun River SHP	7.10	12.50	1.33	8.43	3.75	12.18
3	Barun MHP	163.16	14.00	34.26	197.42	96.51	293.93
4	Yettinahole MHP	29.89	10.50	4.71	34.59	14.57	49.16
5	Bremwar SHP	10.86	12.50	2.04	12.90	6.19	19.09
6	Pareng SHP	31.33	12.00	5.64	36.97	17.29	54.26
7	Rangbang SHP	15.66	12.50	2.94	18.60	8.92	27.52
8	Rangit and Balwavyas SHP	25.99	12.50	4.87	30.87	14.81	45.68
9	Singrauli SHP	67.23	12.00	12.10	79.33	14.93	94.27
10	Rangit SHP	26.90	12.50	5.04	31.94	15.32	47.26
11	Luni II SHP	5.19	10.00	0.78	5.97	2.05	8.02
12	Luni III SHP	5.31	10.00	0.80	6.10	2.10	8.20
13	Upper Joiner SHP	12.92	12.00	2.33	15.24	7.13	22.37
14	Upper Nanti SHP	12.37	12.50	2.32	14.68	7.04	21.73

Table 5.3: Cost calculation of units lost due to losses in Siphon Penstock/Turbine Intake in 30 years

S.N.	Project	Cost (INR/kWh)	Head Loss due to siphon(m)	Total Units lost (Lakh INR)	Cost of units lost (Lakh INR)
1	Suringad SHP- II	2.50	0.048	1.45	3.617
2	Balsun River SHP	3.26	0.076	10.50	34.231
3	Barun MHP	0.40	0.024	43.42	17.152
4	Yettinahole MHP	1.74	0.054	11.03	19.185
5	Bremwar SHP	2.47	0.049	3.50	8.649
6	Pareng SHP	1.45	0.211	48.02	69.633
7	Rangbang SHP	4.04	0.110	8.16	32.968
8	Rangit and Balwavyas SHP	4.00	0.073	21.16	84.628
9	Singrauli SHP	1.01	0.134	206.72	208.791
10	Rangit SHP	3.08	0.046	4.53	13.938
11	Luni II SHP	1.29	0.046	1.28	1.65
12	Luni III SHP	1.39	0.048	1.44	2.01
13	Upper Joiner SHP	2.27	0.100	8.30	18.84
14	Upper Nanti SHP	2.99	0.165	16.28	48.69

Table 5.4: Cost calculation of units lost due to losses in Gates/Valves in 30 years

S.N.	Project	Cost (INR/kWh)	Head Losses of gate (m)	Head Losses of trash rack (m)	Total Head loss (m)	Total Units lost (Lakh INR)	Cost of units lost (Lakh INR)
1	Suringad SHP- II	2.50	0.02	0.02	0.04	1.19	2.97
2	Balsun River SHP	3.26	0.03	0.05	0.08	10.81	35.25
3	Barun MHP	0.40	0.01	0.02	0.03	46.88	18.52
4	Yettinahole MHP	1.74	0.04	0.06	0.10	19.54	34.01
5	Bremwar SHP	2.47	0.02	0.03	0.05	3.41	8.41
6	Pareng SHP	1.45	0.05	0.08	0.13	29.53	42.82
7	Rangbang SHP	4.04	0.03	0.04	0.07	5.53	22.36
8	Rangit and Balwavyas SHP	4.00	0.04	0.05	0.08	24.45	97.80
9	Singrauli SHP	1.01	0.06	0.08	0.14	221.24	223.45
10	Rangit SHP	3.08	0.02	0.03	0.05	5.32	16.38
11	Luni II SHP	1.29	0.02	0.03	0.05	1.39	1.80
12	Luni III SHP	1.39	0.02	0.03	0.05	1.58	2.19
13	Upper Joiner SHP	2.27	0.04	0.06	0.11	8.93	20.28
14	Upper Nanti SHP	2.99	0.06	0.08	0.14	13.85	41.41

Table 5.5: Cost calculation of suction pump arrangement

S.NO.	Project Name	Volume of Siphon barrel (m3)	Suction Pump Capacity (m3/h)	Corresponding Cost of Suction Pump (INR)	Suction Time Required (Minutes)	Suction Pump Power Rating in kW	Units Used in operation of pump	Units Lost in during priming	Cost of Units Lost in priming (INR)	Cost of Units Lost in operation of pump (INR)	Total Cost for priming arrangement
3	Barun MHP	696.49	76	119750	549.86	2.4	21.99	30242	11945	72.58	131768
9	Singrauli SHP	115.40	76	119750	91.10	2.4	3.64	12146	12268	29.15	132047

Table 5.6: Total Cost of Siphon Penstock/ Turbine Intake

S.N.	Project	Construction Cost (Lakh INR)	O & M Cost (Lakh INR)	Working Capital Cost (Lakh INR)	Suction Arrangement Cost (Lakh INR)	Cost of Units Lost (Lakh INR)	Total Cost (Lakh INR)
1	Suringad SHP- II	7.96	2.28	0.19	Not Applicable	3.617	14.04
2	Balsun River SHP	12.18	3.19	0.27	Not Applicable	34.231	49.87
3	Barun MHP	293.93	73.42	6.12	1.32	17.15	391.94
4	Yettinahole MHP	49.16	13.45	1.12	Not Applicable	19.185	82.92
5	Bremwar SHP	19.09	4.89	0.41	Not Applicable	8.649	33.04
6	Pareng SHP	54.26	14.10	1.17	Not Applicable	69.633	139.16
7	Rangbang SHP	27.52	7.05	0.59	Not Applicable	32.968	68.13
8	Rangit and Balwavyas SHP	45.68	11.70	0.97	Not Applicable	84.628	142.98
9	Singrauli SHP	94.27	30.25	2.52	1.32	208.791	337.15
10	Rangit SHP	47.26	12.10	1.01	Not Applicable	13.938	74.31
11	Luni II SHP	8.02	2.34	0.19	Not Applicable	1.65	12.20
12	Luni III SHP	8.20	2.39	0.20	Not Applicable	2.01	12.80
13	Upper Joiner SHP	22.37	5.81	0.48	Not Applicable	18.84	47.50
14	Upper Nanti SHP	21.73	5.56	0.46	Not Applicable	48.69	76.44

Table 5.7: Total Cost of Existing Intake

S.N.	Project	Construction Cost (Lakh INR)	O & M Cost (Lakh INR)	Working Capital Cost (Lakh INR)	Cost of Units Lost (Lakh INR)	Total Cost (Lakh INR)
1	Suringad SHP- II	6.20	1.78	0.15	2.97	11.11
2	Balsun River SHP	28.41	7.45	0.62	35.25	71.73
3	Barun MHP	308.41	77.04	6.42	18.52	410.39
4	Yettinahole MHP	15.32	4.19	0.35	34.01	53.87
5	Bremwar SHP	19.51	5.00	0.42	8.41	33.34
6	Pareng SHP	19.44	5.05	0.42	42.82	67.73
7	Rangbang SHP	9.24	2.37	0.20	22.36	34.17
8	Rangit and Balwavyas SHP	76.92	19.70	1.64	97.80	196.06
9	Singrauli SHP	111.45	35.77	2.98	223.45	373.65
10	Rangit SHP	30.98	7.93	0.66	16.38	55.95
11	Luni II SHP	12.29	3.58	0.30	1.80	17.97
12	Luni III SHP	12.79	3.73	0.31	2.19	19.02
13	Upper Joiner SHP	19.30	5.02	0.42	20.28	45.02
14	Upper Nanti SHP	20.88	5.35	0.45	41.41	68.09

Table 5.8: Total cost comparison of Existing and Siphon Intake

S.N.	Project	Total cost of existing intake in (Lakh INR) (1)	Total cost of siphon intake in (Lakh INR) (2)	Difference (1)-(2)	Percentage
1	Suringad SHP- II	10.86	13.73	-2.87	-26.43
2	Balsun River SHP	71.73	49.87	21.86	30.48
3	Barun MHP	410.39	391.94	18.44	4.49
4	Yettinahole MHP	53.87	82.92	-29.05	-53.93
5	Bremwar SHP	33.34	33.04	0.3	0.90
6	Pareng SHP	67.73	139.16	-71.43	-105.46
7	Rangbang SHP	34.17	68.13	-33.96	-99.39
8	Rangit and Balwavyas SHP	196.06	142.98	53.08	27.07
9	Singrauli SHP	373.65	337.15	36.5	9.77
10	Rangit SHP	55.95	74.31	-18.36	-32.82
11	Luni II SHP	17.97	12.20	5.77	32.11
12	Luni III SHP	19.02	12.80	6.22	32.70
13	Upper Joiner SHP	45.02	47.50	-2.48	-5.51
14	Upper Nanti SHP	68.09	76.44	-8.35	-12.26

Table 5.9: Cost calculation of Siphon Spillway Construction

S.N.	Project	Thickness of barrel (m)	Volume of steel(m^3)	Weight of steel (MT)	Cost per MT of steel (Lakh INR)	Cost of Barrel (Lakh INR)	Area of trash rack (m^2)	Weight of trash rack (MT)	Cost of trash rack (Lakh INR)
1	Suringad SHP - II	0.005	0.02	0.18	1.60	0.29	1.30	0.26	0.23
2	Bremwar SHP	0.010	0.09	0.73	1.60	1.17	3.05	0.61	0.55
3	Pareng SHP	0.010	0.23	1.79	1.60	2.87	4.47	0.89	0.80
4	Luni II SHP	0.005	0.02	0.19	1.60	0.31	1.16	0.23	0.21
5	Luni III SHP	0.005	0.02	0.19	1.60	0.31	1.16	0.23	0.21
6	Upper Joiner SHP	0.010	0.09	0.71	1.60	1.13	3.46	0.69	0.62
7	Upper Nanti SHP	0.010	0.11	0.84	1.60	1.34	4.00	0.80	0.72

Table 5.10: Cost calculation of Siphon Spillway Construction (continued)

S.N.	Project	Siphon Spillway Cost (Lakh INR)	Interest rate (%)	Interest during construction (Lakh INR)	Total Cost (Lakh INR)	Interest Repayment (Lakh INR)	Total Cost (Lakh INR)	O & M Cost (Lakh INR)	Working capital cost (Lakh INR)	Final Cost (Lakh INR)
1	Suringad SHP - II	0.52	12.00	0.06	0.59	0.16	0.75	0.24	0.02	1.01
2	Bremwar SHP	1.72	12.50	0.21	1.93	0.86	2.79	0.77	0.06	3.63
3	Pareng SHP	4.48	12.00	0.54	5.02	2.46	7.48	2.02	0.17	9.66
4	Luni II SHP	0.85	10.00	0.08	0.93	0.39	1.32	0.38	0.03	1.73
5	Luni III SHP	1.36	10.00	0.14	1.50	0.72	2.21	0.61	0.05	2.88
6	Upper Joiner SHP	4.63	12.00	0.56	5.18	2.42	7.61	2.08	0.17	9.86
7	Upper Nanti SHP	1.76	12.50	0.22	1.98	0.95	2.93	0.79	0.07	3.78

5.3. ANALYSIS

Using Figure 5.1 based on Table 5.8 of life cycle cost analysis, the result of cost comparison of existing and siphon intake is shown in form of bar chart..

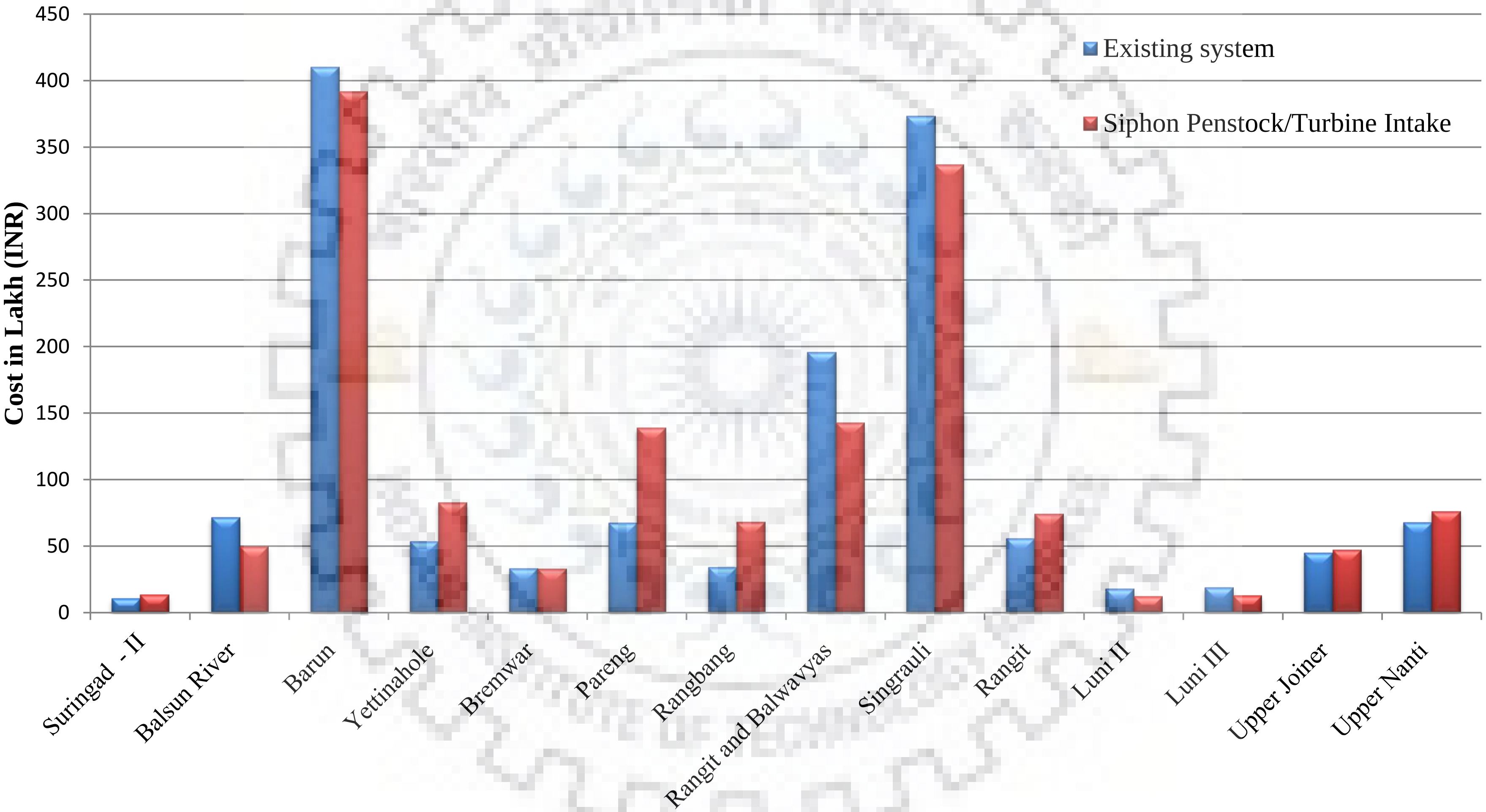


Figure 5.1: Total cost comparison of existing and siphon penstock/turbine intake

Using Figure 5.2 based on Table 5.10 of life cycle cost analysis, the total cost of siphon spillway is shown in form of bar chart.

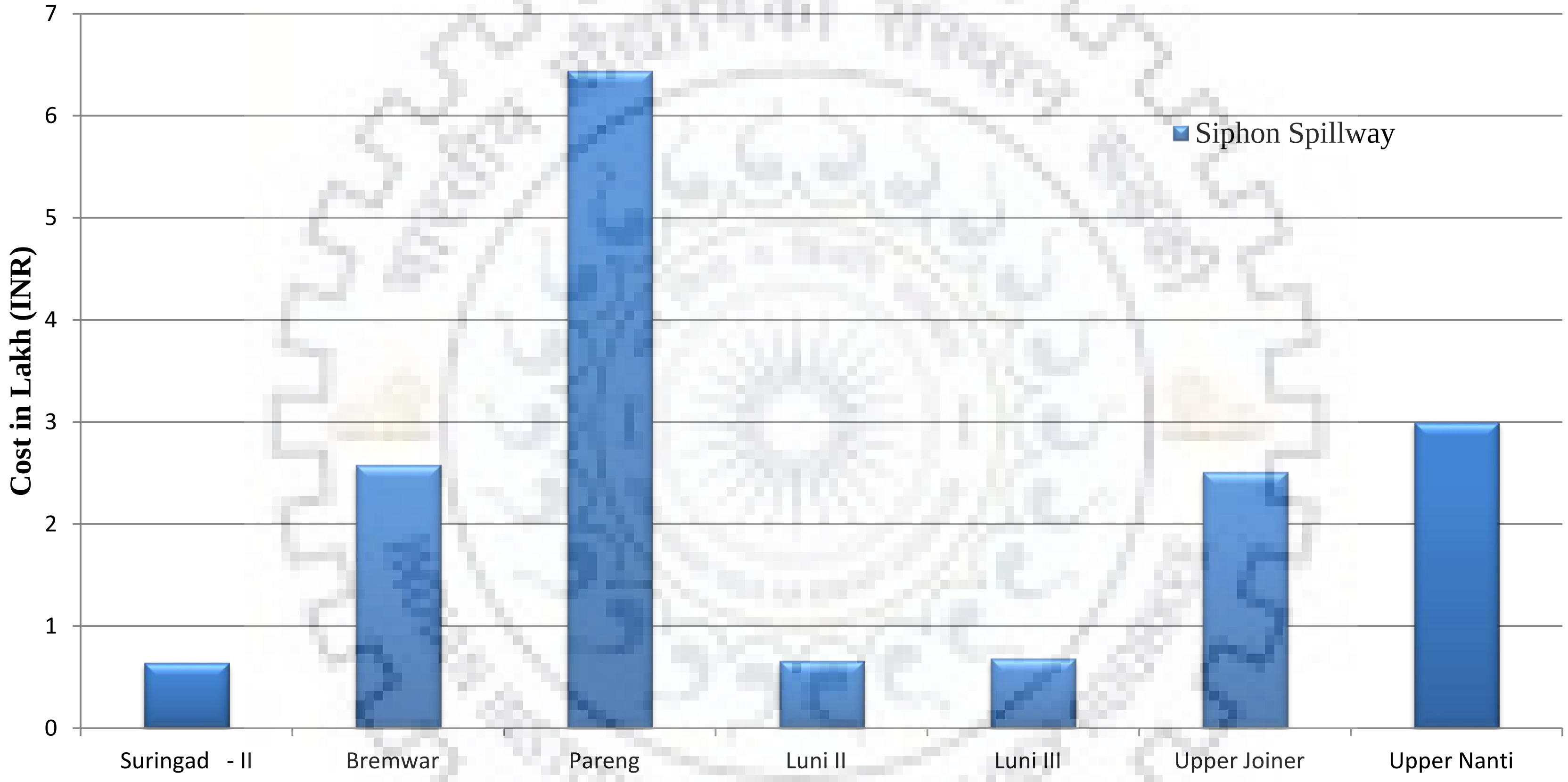


Figure 5.2: Total cost of Siphon Spillway

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1. CONCLUSIONS:

Based on the literature survey, design, cost calculation and life cycle cost analysis of siphon penstock/ turbine intake and spillway, following conclusions are drawn:

a. Out of fourteen siphon penstock/ turbine intake, seven SHP projects worked out to be cheaper. Use of siphon as penstock intake Siphon as penstcok intake in Luni III SHP Project was found 32.7% and Bremwar SHP project as found 0.9% cheaper than conventional intake. Hence, the selection of siphon penstock/turbine intake is case specific.
b. Siphon as penstock/turbine intake should be selected based on economic and other reasons.
c. The siphon spillways are found expensive as compared to the existing spillways and hence should only be used in special cases of space constraints.
d. Siphon is more viable as penstock/turbine intake compared to spillways.
e. There are no fixed criteria for selection of siphon penstock/turbine intake and siphon spillway in SHP Projects.

6.2. RECOMMENDATIONS:

Based on the study performed on siphon as penstock/turbine intake and spillways for SHP projects, following are the recommendations:

a. Model studies should be conducted before installation of siphon as penstock/turbine intake or as spillway so as to determine the appropriate size of baby siphon for priming of siphon, check steady operation of siphon as penstock/turbine intake or spillway and determine any further requirement in design to control hunting.
b. Site visit should be conducted for more details regarding design and performance of conventional intakes and spillways and for comparison with the siphon penstock/turbine intake.
c. Due to unavailability of design data of most of the SHP projects, main dimensions of the forebay tanks are taken from the existing drawings are used as the reference for calculations.
d. Cost estimates of existing intake were not available. Hence the costs of existing intakes are calculated according to present conditions.

[1] "Renewable & Non-Renewable Resources: Definition & Differences" [Online]. Available on: https://study.com/academy/lesson/renewable-non-renewable-resources-definition-differences.html

[2] "FAQs on Hydropower, Ministry of Power, Government of India"[Online]. Available on: https://powermin.nic.in/en/content/faqs-hydropower

[3] "Country Rankings, Featured Dashboard- Capacity Generation"[Online]. Available on: http://resourceirena.irena.org/gateway/dashboard/?topic=4&subTopic=18

[4] "Small Hydro Power Programme, Ministry of New and Renewable Energy, Government of India"[Online]. Available on: https://mnre.gov.in/small-hydro

[5] AHEC-IITR, "1.2 and 2.1 General/ Civil Works – Planning and Layouts", standard/manual/guideline with support from Ministry of New and Renewable Energy, Roorkee, June 2013.

[6] "How to Plan a Mini Hydropower Project"[Online]. Available on: https://energypedia.info/wiki/How_to_Plan_a_Mini_Hydro_Power_Project

[7] AHEC-IITR, "2.5- Civil Works: Technical Specifications for Hydro Mechanical Works", standard/manual/guideline with support from Ministry of New and Renewable Energy, Roorkee, September 2013.

[8] AHEC-IITR, "3.4 E&M Works – Selection of Control, Automation, Protection and Monitoring System", standard/manual/guideline with support from Ministry of New and Renewable Energy, Roorkee, July 2012.

[9] Khatsuria, R.M., 2004. Hydraulics of spillways and energy dissipators. CRC Press.

[10] Brown, G.J., 1965. Hydro-electric engineering practice (No. BOOK). Blackie.

[11] Ervine, D.A., Elsawy, E.M., 1975. Siphons in river engineering. In Proceedings Symposium on Design and Operation of Siphons & Siphon Spillways, London.

[12] Blaisdell, F. W., Hebaus, G. G., 1975.the two way drop inlet self-regulating siphon spillway. In Proceedings Symposium on Design and Operation of Siphons & Siphon Spillways, London.

[13] Blaisdell, F.W.,Yalamanshili, K. 1975.The hood drop inlet self-regulating siphon spillway. In Proceedings Symposium on Design and Operation of Siphons & Siphon Spillways, London.

[14] Bonvissutio, G.,1975.A simple criteria for deign of self levelling siphon to satisfy specific operation needs.. In Proceedings Symposium on Design and Operation of Siphons & Siphon Spillways, London.

[15] Blaisedell, F.W., Donnelly, C.A.,1975.The hood inlet self-regulating siphon spillway. In Proceedings Symposium on Design and Operation of Siphons & Siphon Spillways, London.

[16] Blaisdell, F.W.,1975.Theory of flow in long siphons. In Proceedings Symposium on Design and Operation of Siphons & Siphon Spillways, London.

[17] Ackers, P. and Thomas, A.R., 1975. Design and operation of air-regulated siphons for reservoir and head-water control. In Proceedings of the Symposium on Design and Operation of Siphons and Siphon Spillways.

[18] Kenyon, W. J.,1975. The use of low head siphons in land drainage. In Proceedings Symposium on Design and Operation of Siphons & Siphon Spillways, London.

[19] Kelly, A. G., 1975.Effect of tube material on siphon performance. In Proceedings Symposium on Design and Operation of Siphons & Siphon Spillways, London.

[20] Charlton, F.G. and Perkins, J.A., 1975. The behaviour and design of air regulated siphon spillways. In Proceedings Symposium on Design and Operation of Siphons & Siphon Spillways, London.

[21] Renner, J., 1975. Air entrainment in surface rollers. In Proceedings Symposium on Design and Operation of Siphons & Siphon Spillways, London.

[22] Ağiralioğlu, N. and Müftüoğlu, R.F., 1989. Hood characteristics for siphon-shaft spillways. Journal of Hydraulic Engineering, 115(5), pp.636-649.

[23] Charlton, F.G. and Perkins, J.A., 1975. The effect of waves on air regulated siphon. In Proceedings Symposium on Design and Operation of Siphons & Siphon Spillways, London.

[24] Naibo Z, Shingyi S, Zhengli H. Small-scale hydropower in China. Biomass. 1989 Jan 1;20(1-2):77-102.

[25] Sharma, S.K., 1984. Irrigation Engineering and Hydraulic Structures. S. Chand Publishing.

[26] Burogoine, D., Rodrigue, P., Tarebell, J.C., Siphon Installation at Hydroelectric Projects: A survey of Design, Constcuction and Operating Experienec in Waterpwoer, 1989.

[27] Ervine, D.A., Elsawy, E.M., 1975. Some scale effects in modeling of air regulated siphon spillways. In Proceedings Symposium on Design and Operation of Siphons & Siphon Spillways, London.

[28] Unser, K., 1975.Design of Low head siphon spillways. In Proceedings Symposium on Design and Operation of Siphons & Siphon Spillways, London.

[29] Ghafourian, A., Jahromi, H.M. and Bajestan, M.S., 2011. Hydraulic of siphon spillway by physical and computational fluid dynamics.

[30] Jafarinia, R., Jahromi, S.H.M. and Shafai-Bejestan, M. ,2010. Prediction of Scour Dimensions Downstream of Siphon Spillways.World Applied Sciences Journal,9(7)

[31] Musavi-Jahromi, S.H. ,2011. Simulation of Pizometric Pressure in Dam Siphon Spillways.World Applied Sciences Journal,12(7)

[32] Aydin, M.C., Öztürk, M. and Yücel, A. ,2015. Experimental and Numerical Investigation of Self-Priming Siphon Side Weir on a Straight Open Channel.Flow Measurement and Instrumentation,45, pp.140-150.

[33] Ghafourian, A. and Adlan, M.N. ,2012. Discharge Coefficient in Siphon Spillway with Different Cross Sections.World Applied Sciences Journal,17(2)

[34] Manley, G. D., Markland, E., 1975. A partial siphon of compact design. In Proceedings Symposium on Design and Operation of Siphons & Siphon Spillways, London.

[35] Thatcher, E. F., Battson, A. K.,1975.Delivery siphons on the pumping plants for docks. In Proceedings Symposium on Design and Operation of Siphons & Siphon Spillways, London.

[36] Petaccia, G. and Fenocchi, A., 2015. Experimental assessment of the stage–discharge relationship of the Heyn siphons of Bric Zerbino dam. Flow Measurement and Instrumentation, 41, pp.36-40.

[37] HEC, March 30, 1987. Black Bear Lake Hydroelectric Project- Penstock Siphon Study Report, HEC Chicago, pp.7.

[38] FitzPatrick, J.B., 1993. Investigating syphon hydro intake installations. Hydro Review Worldwide, 1(2).

[39] Konviz, V.S., Chibisov, I.T. and Shavarin, V.N., 1974. Siphon intakes at hydroelectric plants. Power Technology and Engineering (formerly Hydrotechnical Construction), 8(4), pp.321-324.

[40] AHEC, April 1993. Detailed Project Report, Devarabelkare Mini Hydro Electric Project, Karnataka. AHEC-IITR, Roorkee. pp.151.

[41] Wang XH. Siphon intakes for small hydro plants in China. International Water Power and Dam Construction IWPCDM. 1989;41(8).

[42] FitzPatrick JB. Investigating syphon hydro intake installations. Hydro Review Worldwide. 1993 Dec 31;1(2).

[43] Chaudhary S., Analysis and Optimum Design of Forebay Tank. Dissertation. May 2015.

[44] AHEC, August 2008. Detailed Project Report, Suringad Small Hydropower Project Stage- II, Uttarakhand. AHEC-IITR, Roorkee. pp.169.

[45] M/s AEC, Spetember 2012. Detailed Project Report, Balsun Small Hydro Electric Project, West Bengal. M/s AEC, Kullu.pp.232.

[46] AHEC, March 2002. Detailed Project Report for Renovation and Modernization, Barun Mini Hydro Electric Project, Bihar. AHEC-IITR, Roorkee. pp.144.

[47] M/s MM Co. Ltd, April 2008. A Detailed Project Report for Yettinahole MHS, Karnataka. M/s MM Co. Ltd., Banglore.pp.284.

[48] P&RES P. Ltd., January 2008. Detailed Project Report, Brenwar H.E. Project, Jammu and Kashmir. P&RES P. Ltd., Chandigarh.pp.320.

[49] AHEC, November 2007. Detailed Project Report, Pareng Small Hydro Power Project, Arunachal Pradesh. AHEC-IITR, Roorkee. pp.167.

[50] M/s AEC, Spetember 2012. Detailed Project Report, Ranbang Small Hydro Electric Project, West Bengal. M/s AEC, Kullu.pp.272.

[51] M/s AEC, Spetember 2012. Detailed Project Report, Rangit and Balwavas Small Hydro Electric Project, West Bengal. M/s AEC, Kullu.pp.265.

[52] AHEC, December 2007. Detailed Project Report, Singrauli Small Hydro Power Project, Uttar Pradesh. AHEC-IITR, Roorkee. pp.139.

[53] M/s AEC, February 2014. Detailed Project Report, Rangit Small Hydro Electric Project, West Bengal. M/s AEC, Kullu.pp.98.

[54] NHPC P.Ltd., November 2004. Detailed Project Report, Luni II Small HEP, Himachal Pradesh. NHPC P.Ltd.,Shimla.pp178.

[55] NHPC P.Ltd., November 2004. Detailed Project Report, Luni III Small HEP, Himachal Pradesh. NHPC P.Ltd.,Shimla.pp188.

[56] NHPC P.Ltd., March 2007. Detailed Project Report, Upper Joiner Small HEP, Himachal Pradesh. NHPC P.Ltd.,Shimla.pp124.

[57] NHPC P.Ltd., September 2007. Detailed Project Report, Upper Nanti Small HEP, Himachal Pradesh. NHPC P.Ltd.,Shimla.pp224.

[58] Cengel YA. Fluid mechanics. Tata McGraw-Hill Education; 2010.

[59] “How To: Calculate The Minimum Required Wall Thickness For Tubing”[Online]. Available on: https://www.powerengineering101.com/calculate-minimum-required-wall-thickness-tubing/

ANNEXURE A

EXAMPLE DESIGN OF SIPHON PENSTOCK/TURBINE INTAKE

DESIGN OF SIPHON PENSTOCK INTAKE FOR SURINGAD SHP-II

Given Details:

Installed Capacity		=	5 MW
Head		=	360m
Discharge		=	$1.82 m^3/s$
Available Suction Head		=	8.41m
Forebay Details			
	FSL	=	1703.62
	Length	=	16.5m
	Width	=	5m
	Depth	=	4m
Penstock Details			
	Diameter	=	1m
	Number of Intakes	=	1

1. **Diameter of Intake:**

   As according to IS 11625-1986: Criteria for Hydraulic Design of Penstock,

$$D_{intake} = 1.4286 D_{penstock}$$

   Therefore, Diameter of Intake = 1.43m

2. **Velocity through siphon inlet:**

$$v_i = \frac{Discharge\ through\ intake}{Area\ of\ intake}$$

$$v_i = \frac{1.82}{\left(\frac{\pi * 1.43^2}{4}\right)}$$

   Therefore, velocity through intake = 1.14m/s

3. **Velocity through penstock:**

$$v_p = \frac{Discharge\ through\ penstock}{Area\ of\ penstock}$$

$$v_i = \frac{1.82}{\left(\frac{\pi * 1^2}{4}\right)}$$

Therefore, velocity through intake = 2.318m/s

4. Froude's Number at Intake:

$$F_r = \frac{v_i}{\sqrt{gd}}$$

Froude's Number = 0.30

5. Submergence:

$$\frac{h_s}{D_{intake}} = 1.5\, F_r + 0.2\ to\ 0.3\ \ for\ circular\ inlets$$

Submergence = 0.94m

6. Depth including submergence:

Centre line of penstock is 3m below the wall top. Hence, the depth is 3m. Further the length of siphon becomes 6m.

7. Velocity head:

$$\mathrm{v_h} = \frac{v_i^2}{2\mathrm{g}}$$

velocity head = 0.066

8. Losses:

a. Entry Loss

$$= 0.05\mathrm{v_h}$$

=0.0026m

b. Trash Rack Loss

$$= \mathrm{k_t v_h}$$

Using kt=0.35

=0.023m

c. Bend Loss

$$= k_b v_h$$

Using kb=.21 for 90 degree bend and .14 for 45 degree bend

= 0.003m

d. Friction Loss

$$= \frac{f l v_p^2}{2 g D_{penstock}}$$

Using, f=0.012 and g=9.81,

=0.020m

e. Total Losses = 0.048m

9. Check for available suction:

Required Suction= Length required +Diameter of Penstock + Losses

= 3 + 1 + 0.048

= 4.048m

And Available Suction =8.41m

Since Required Suction< Available Suction, Hence the design is acceptable

DESIGN OF SIPHON SPILLWAY FOR SURINGAD SHP-II

Given Details:

Installed Capacity		=	5 MW
Head		=	360m
Discharge		=	1.82m^3/s
Available Suction Head		=	8.41m
Forebay Details			
	FSL	=	1703.62
	Length	=	16.5m
	Width	=	5m
	Depth	=	4m
Penstock Details			
	Diameter	=	1m
	Number of Intakes	=	1

1. **Adopting number of barrels = 1**
2. **Discharge Per barrel**

$$= \frac{Design\ Discharge}{Number\ of\ barrels}$$

= 1.82m^3/s

3. **Diameter of barrel:**

Adopting maximum allowable velocity of 3m/s through barrel

$$Area = \frac{Discharge\ through\ barrel}{3m/s}$$

Area = 0.61m^2

Hence Diameter = 0.88m

Adopting =0.90m

4. Diameter of Intake:

As according to IS 11625-1986: Criteria for Hydraulic Design of Penstock,

$$D_{intake} = 1.4286 D_{penstock}$$

Therefore, Diameter of spillway Intake = 1.29m

5. Velocity at spillway intake:

$$v_i = \frac{Discharge\ through\ intake}{Area\ of\ intake}$$

$$v_i = \frac{1.82}{\left(\frac{\pi * 1.29^2}{4}\right)}$$

Therefore, velocity through intake = 1.4m/s

6. Froude's Number at Intake:

$$F_r = \frac{v_i}{\sqrt{gd}}$$

Froude's Number = 0.47m

7. Submergence:

$$\frac{h_s}{D_{intake}} = 1.5\ F_r + 0.2\ to\ 0.3\ \ for\ circular\ inlets$$

Submergence = 1.17m

8. Velocity head:

$$v_h = \frac{v_i^2}{2g}$$

velocity head = 0.107m

9. Losses:

a. Entry Loss

$$= 0.05 v_h$$

=0. 0.0017m

b. Trash Rack Loss

$$= k_t v_h$$

Using kt=0.35

=0. 0118m

c. Bend Loss

$$= k_b v_h$$

Using kb=.21 for 90 degree bend and .14 for 45 degree bend

= 0.003m

d. Friction Loss

$$= \frac{flv_p^2}{2gD_{penstock}}$$

Using, f=0.012 and g=9.81,

=0. 002m

e. Total Losses = 0. 0375m

10. Check for available suction:

Required Suction= (Difference in Wall top and FSL) +Diameter of Barrel + Losses + submergence

= 0.63 + 0.9 + 0.0375+1.17

= 2.73

And Available Suction =8.41m

Since Required Suction< Available Suction, Hence the design is acceptable

ANNEXURE C

LIFE CYCLE COST ANALYSIS OF EXISTING PENSTOCK INTAKE

LCCA OF EXISTING INTAKE FOR SURINGAD SHP-II:

1. Given Details

Dimensions of gate	=	1.3 X 1.3 m^2
Dimensions of trash rack	=	4 X 1.3 m^2
Interest rate	=	12.00%
PLF	=	73%
Efficiency	=	88%
Cost per unit	=	INR 2.50/kWh

2. Calculation of gate and trash rack cost

Area of gate	=	1.69 m^2
Weight of gate	=	1.0 X Area of gate MT
	=	1.69 MT
Cost of gate	=	1.6 X Weight of gate Lakhs
	=	2.70 Lakh
Area of trash rack	=	5.2 m^2
Weight of trash rack	=	0.2 X Area of trash rack MT
	=	1.04 MT
Cost of trash rack	=	1.2 X Weight of trash rack Lakhs
	=	1.24 Lakh
Total cost of gate and trash rack=		3.94 Lakh

3. Working parameters

Interest During Construction = 0.47 Lakh

Total Cost of intake = 4.43 Lakh

O & M cost per year = 1.5% of capital cost

= 0.06 Lakh

O & M Cost for 30 years = 1.78 lakh

Working Capital for 30 years = 1/12 of O &M Cost

= 0.15 lakh

4. Debt Repayment Calculation:

Total cost = 4.43 Lakh

Debt (70%) = 3.10 Lakh

Equity (30%) = 1.33 Lakh

Taking 10 years payback period

Year	Loan(Lakh)	Repay(Lakh)	Quarterly Interest (Lakh)
IV	3.10	0.00	0.09
	3.10	0.00	0.09
	3.10	0.00	0.09
	3.10	0.00	0.09
V	3.10	0.13	0.09
	2.97	0.13	0.09
	2.84	0.13	0.09
	2.71	0.13	0.08
VI	2.58	0.13	0.08
	2.45	0.13	0.07
	2.33	0.13	0.07
	2.20	0.13	0.07
VII	2.07	0.13	0.06
	1.94	0.13	0.06
	1.81	0.13	0.05
	1.68	0.13	0.05
VIII	1.55	0.13	0.05
	1.42	0.13	0.04
	1.29	0.13	0.04
	1.16	0.13	0.03
IX	1.03	0.13	0.03
	0.90	0.13	0.03
	0.77	0.13	0.02
	0.65	0.13	0.02
X	0.52	0.13	0.02
	0.39	0.13	0.01
	0.26	0.13	0.01
	0.13	0.13	0.00

Hence total interest repayment = 1.53 Lakh

5. Cost of units lost due to head loss:

Head Losses due to gate = 0.25 X $\frac{v_i^2}{2g}$

= 0.25 X$\frac{1.14^2}{2\ X\ 9.81}$

= 0.0165m

Head Losses due to trash rack= 0.35 X $\frac{v_i^2}{2g}$

= 0.25 X$\frac{1.14^2}{2\ X\ 9.81}$

= 0.023m

Total Head Loss (Δh) = .0395m

Units lost due to head loss in 30 years = 9.81 X Q X Δh X η X PLF X 30 X 365 X 24 X 10^{-5} MUnits

= 1.19 Million Units

Cost of units lost in 30 years = 2.97 Lakh

6. Final Cost

Final Cost = Cost of Gates + Cost of Trash Rack + IDC + O & M Cost + Working Principle Cost + Debt Interest Repayment + Cost of units lost

= INR 10.86 Lakhs

ANNEXURE D

LIFE CYCLE COST ANALYSIS OF SIPHON PENSTOCK INTAKE

LCCA OF SIPHON PENSTOCK INTAKE FOR SURINGAD SHP-II:

1. Given Details

Diameter of Penstock	=	1.00m
Diameter of Intake	=	1.43m
Thickness of penstock	=	0.01m
Interest rate	=	12.00%
PLF	=	73%
Efficiency	=	88%
Cost per unit	=	INR 2.50/kWh

2. Calculation of siphon penstock intake and trash rack cost

Length of siphon	=	6m
Volume of barrel material	=	2π X D X t X Length
	=	0.38 m^3
Weight of barrel	=	7.9 MT/ m^3 X Volume of barrel material
	=	2.9 MT
Cost of barrel	=	1.6 X Weight of barrel Lakhs
	=	4.79 Lakh
Area of trash rack	=	π X D^2 X Length
	=	1.6 m^2
Weight of trash rack	=	0.2 X Area of trash rack MT
	=	0.32 MT

Cost of trash rack = 0.75 X Weight of trash rack Lakhs

= 0.29 Lakh

Total cost of barrel and trash rack= 5.07 Lakh

3. Working parameters

Interest During Construction = 0.61 Lakh

Total Cost of intake = 5.68 Lakh

O & M cost per year = 1.5% of capital cost

= .076 Lakh

O & M Cost for 30 years = 2.28 lakh

Working Capital for 30 years = 1/12 of O &M Cost

= 0.19 lakh

4. Debt Repayment Calculation:

Total cost = 5.68 Lakh

Debt (70%) = 3.98 Lakh

Equity (30%) = 1.70 Lakh

Taking 10 years payback period

Year	Loan(Lakh)	Repay(Lakh)	Quarterly Interest (Lakh)
IV	3.98	0.00	0.12
	3.98	0.00	0.12
	3.98	0.00	0.12
	3.98	0.00	0.12
V	3.98	0.17	0.12
	3.81	0.17	0.11
	3.65	0.17	0.11
	3.48	0.17	0.10
VI	3.32	0.17	0.10
	3.15	0.17	0.09
	2.99	0.17	0.09
	2.82	0.17	0.08
VII	2.65	0.17	0.08
	2.49	0.17	0.07
	2.32	0.17	0.07
	2.16	0.17	0.06
VIII	1.99	0.17	0.06

	1.82	0.17	0.05
	1.66	0.17	0.05
	1.49	0.17	0.04
IX	1.33	0.17	0.04
	1.16	0.17	0.03
	0.99	0.17	0.03
	0.83	0.17	0.02
X	0.66	0.17	0.02
	0.50	0.17	0.01
	0.33	0.17	0.01
	0.17	0.17	0.00

Hence total interest repayment = 1.97 Lakh

5. Cost of units lost due to head loss:

Head Losses = 0.048m

Units lost due to head loss in 30 years = $9.81 \times Q \times \Delta h \times \eta \times PLF \times 30 \times 365 \times 24 \times 10^{-5}$ MUnits

= 1.45 Million Units

Cost of units lost in 30 years = 3.61 Lakh

6. Final Cost

Final Cost = Cost of Barrels + Cost of Trash Rack + IDC + O & M Cost+ Working Principle Cost + Debt Interest Repayment + Cost of units lost

= INR 13.73 Lakhs

LCCA OF SIPHON SPILLWAY FOR SURINGAD SHP-II:

1. Given Details

Diameter of Spillway	=	0.90m
Diameter of Intake	=	1.29m
Thickness of Barrel	=	0.005m
Interest rate	=	12.00%
PLF	=	73%
Efficiency	=	88%
Cost per unit	=	INR 2.50/kWh

2. Calculation of siphon spillway and trash rack cost

Length of siphon	=	3.59m
Volume of barrel material	=	2π X D X t X Length
	=	0.02 m^3
Weight of barrel	=	7.9 MT/ m^3 X Volume of barrel material
	=	0.18 MT
Cost of barrel	=	1.6 X Weight of barrel Lakhs
	=	0.29 Lakh
Area of trash rack	=	π X D^2 X Length
	=	1.3 m^2
Weight of trash rack	=	0.2 X Area of trash rack MT
	=	0.26 MT

Cost of trash rack = 0.75 X Weight of trash rack Lakhs

= 0.23 Lakh

Total cost of barrel and trash rack= 0.53 Lakh

3. Working parameters

Interest during Construction = 0.06 Lakh

Total Cost of intake = 0.59 Lakh

O & M cost per year = 1.5% of capital cost

= 0.008 Lakh

O & M Cost for 30 years = 0.24 Lakh

Working Capital for 30 years = 1/12 of O &M Cost

= 0.02 Lakh

4. Debt Repayment Calculation:

Total cost = 0.59 Lakh

Debt (70%) = 0.44 Lakh

Equity (30%) = 0.15 Lakh

Taking 10 years payback period

Year	Loan(Lakh)	Repay(Lakh)	Quarterly Interest (Lakh)
IV	0.44	0.00	0.013
	0.44	0.00	0.013
	0.44	0.00	0.013
	0.44	0.00	0.013
V	0.44	0.02	0.013
	0.42	0.02	0.013
	0.40	0.02	0.012
	0.39	0.02	0.012
VI	0.37	0.02	0.011
	0.35	0.02	0.010
	0.33	0.02	0.010
	0.31	0.02	0.009
VII	0.29	0.02	0.009
	0.28	0.02	0.008
	0.26	0.02	0.008
	0.24	0.02	0.007
VIII	0.22	0.02	0.007
	0.20	0.02	0.006

	0.18	0.02	0.006
	0.17	0.02	0.005
IX	0.15	0.02	0.004
	0.13	0.02	0.004
	0.11	0.02	0.003
	0.09	0.02	0.003
X	0.07	0.02	0.002
	0.06	0.02	0.002
	0.04	0.02	0.001
	0.02	0.02	0.001

Hence total interest repayment = 0.16 Lakh

5. Final Cost

Final Cost = Cost of Barrels + Cost of Trash Rack + IDC + O & M Cost+ Working Principle Cost + Debt Interest Repayment

= INR 1.01 Lakhs