ANALYSIS OF FISH FRIENDLY KAPLAN TURBINE FOR SHP

A DISSERTATION

Submitted in partial fulfillment of the
requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
ALTERNATE HYDRO ENERGY SYSTEMS

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CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in this dissertation, entitled **"ANALYSIS OF FISH FRIENDLY KAPLAN TURBINE FOR SHP"** submitted in partial fulfillment of the requirements for the award of degree of **Master of Technology** in **"Alternate Hydro Energy Systems"** in **Alternate Hydro Energy Centre, Indian Institute of Technology Roorkee,** is an authentic record of my own work carried out during the period from July 2010 to June 2011 under the guidance and supervision of **Dr. S. K. Singal,** Senior Scientific Officer and **Dr. M. P. Sharma,** Associate Professor, Alternate Hydro Energy Centre, Indian Institute of Technology Roorkee.

I also declare that I have not submitted the matter embodied in the report for award of any other degree or diploma.

Date: June 29, 2011

Place: Roorkee

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CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

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ABSTRACT

Small hydro power project development has been, for the last decade, one of the sectors in the energy field that has been very active. Where the preceding decades saw a fair number of large hydroelectric developments. One of the main environmental challenges of small hydropower development is related to fish passage both upstream and downstream. These migrations are ecological imperatives for populations of anadromous fish. Technologies for upstream passage are more advanced than for downstream passage but both need more work and evaluation. Upstream passage failure tends to result from less than optimal design criteria based on physical, hydrologic, and behavioural information, or lack of adequate attention to operation and maintenance of facilities. Downstream fish passage technology is complicated by the limited swimming ability of many down migrating juvenile species and unfavourable hydrologic conditions. There is no single solution for designing up and downstream passageways. Downstream passage of fish and protective measures to reduce turbine mortality are the areas most in need of research.

Recent developments in the design of advanced, environmentally friendly turbines indicated that there is a real potential for reducing some of the most common adverse impacts of hydropower. In the present study an attempt has been made to design and analysis a low head fish friendly turbine. In this the mortality rate of fishes after design modification were also studied. The modification of design was done on the runner diameter of the Kaplan turbine and its effect was analyzed on the Hub and tip ratio, Flow velocity, Efficiency, Peripheral velocity at hub and tip, twist angle and mortality rate of the aquatic species. The cost of the modified fish friendly Kaplan turbine was also estimated. The comparative study of per unit generation cost of plant using conventional and modified fish friendly Kaplan turbine was carried out. With the modification in conventional Kaplan turbine the efficiency of the system decreases due to which the project cost increase. With the increase in project cost generation cost also increases. With the modification in the conventional Kaplan turbine the mortality rate decreases by an amount of 50%.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

V_{axial} : Axial velocity

n : Number of blades

N : Runner speed

t_{cr} : critical passage time

MR : Mutilation Ratio

Ln : Natural logarithm

l : Fish length

A_{wgc} : Surface area of the imaginary cylinder

h_{wg} : Height of wicket gate

V_t : Tangential velocity

V_1 : Absolute velocity

u_1 : Blade peripheral velocity

v : Relative velocity

α : Angle between tangential and absolute velocity vectors

θ : Angle between axial and absolute velocity vectors

P : Power

ρ : Density of water

Q : Discharge

H : Net Head

η_h : hydraulic efficiency of the turbine

LIST OF ACRONYMS

CEA	:	Central Electricity Authority
SHP	:	Small Hydro Power
MNRE	:	Ministry of New and Renewable Energy
MGR	:	Minimum Gap Runner
WGA	:	Wicket Gate angle
WGO	:	Wicket Gate Opening
FWS	:	Fish and Wildlife Service
STSs	:	Submersible travelling screens
MIS	:	Modular Inclined Screen
ARL	:	Alden Research Laboratory
HMD	:	Hydro Median Depth
PUD	:	Public Utility District
AHT	:	Advanced Hydropower Turbines
SV	:	Stay Vane

LIST OF UNITS

kW	:	Kilowatt
MW	:	Megawatt
rpm	:	Revolutions per Minute
cm	:	centimetre
g	:	gram
m	:	meter
mm	:	millimetre
m^3/s	:	cubic meters per second
kPa	:	kilo pascal
m/s	:	meter per second
fps	:	feet per second
cfs	:	cubic feet per second
MU	:	Million Unit

INTRODUCTION

1.1 GENERAL

Power is very important infrastructure in overall development of any nation in the world. It is the tool to forge the economic growth of the country. There has been therefore an ever-increasing need for more and more power generation recently in all countries of the world. In the true global perspective of the power demand it can be laid with certainty that many of the developing countries of the world are now a day's experiencing the "energy crises" and busy in formulating methods and devices to explore the various possibilities of energy generation for satisfying the growing demand. As such it there has to be a fresh appraisal of energy producing resources and formulation of program for the implementation of plans with maximum efficiency.

The spurt in energy crisis, due to the oil embargo of the seventies, has led nations to take serious measures with regard to the energy consumption patterns. The problem is further aggravated by the fact that the available fossil fuels are exhaustible and are depleting with successive years of the utilization. By contrast, the renewable energy sources especially, small hydro power have an inexhaustible supply and if used, may help in alleviating the burden of fossil fuels besides bridging the yawning gap between the demand and the supply with economical benefits to the country. The renewable energy resources being harnessed at present include solar, biomass, wind and small hydro. The centralized electric power generating system is undoubtedly the most versatile in nature but is ill suited when it comes to satisfying energy needs at the village level.

India with population more than one billion is the second most populous country in the world after china. With respect to energy, India is the net importer of the energy and consumes roughly 3% of the world's total energy. The total installed capacity in India as on April 2011 was 1, 74,361.40 MW, out of which 1, 13,559.48 MW (65.12%) from Thermal, 37,567.40 MW (21.54%) from Hydro, 4,780.00 MW (2.74%) from Nuclear and 18,454.52 (10.58 %) from Renewable Energy Sources. [1]

It is being realized that renewable energy sources can argument the availability of energy and provide a viable option in wide range of applications and can play an increasing important role in solving the twin problem of energy supply in the decentralized applications. Nowadays, small hydropower is considered to be the promising source among Renewable Energy. Fig.1.1 presents contribution of various energy sources in Indian power sector in percentage. Fig 1.2 shows all India generating capacity in MW.

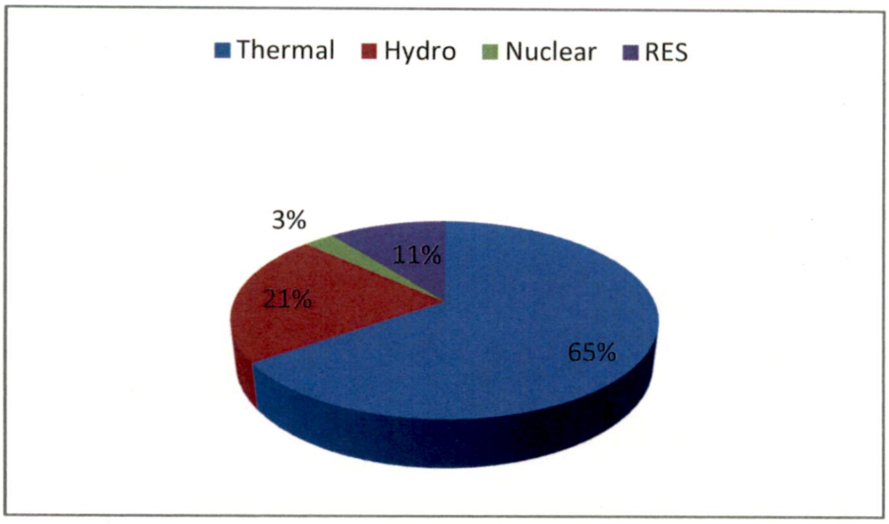


Fig.: 1.1 Contribution of energy sources in Indian power sector as on April 2011
Sources: CEA

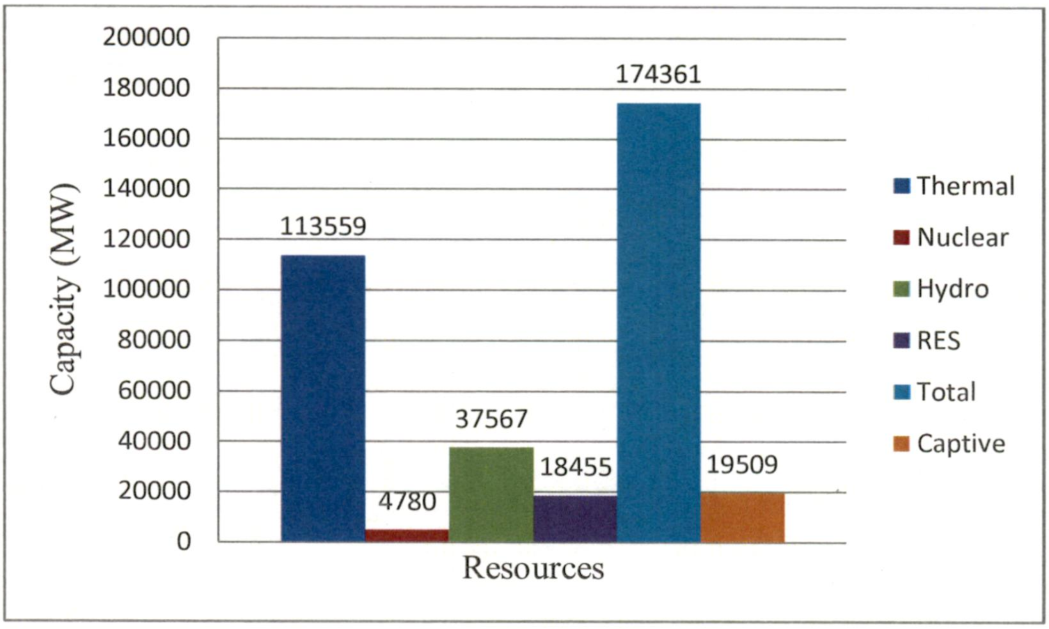


Fig.: 1.2 All India generating capacity (MW) as on April 2011
Sources: CEA

1.2 HYDROPOWER

Hydropower is considered to be an attractive source as it avoids the pollution associated with burning of fuels; however most of the large hydro scheme involves massive dams' impounding enormous volume of water in manmade lakes. In order to provide year round power by smoothing out fluctuations in the river flow. In many cases, such schemes are far from in exhaustible because the lakes gradually silt up and will function effectively. There are also numerous environment problems that can result from interference with river flows. Many of larger schemes have had adverse effect on the local environment and gestation period is quite long. On the other hand small hydro is one of the most environmentally benign energy conservative option enhance the main advantages comparing with electricity sources, namely saving consumption of fossil fuels or fire wood, being self sufficient without the need of important component. The term hydropower refers to generation of shaft power from falling water. The power could then be used for direct mechanical purposes or, more frequently, for generating electricity. Hydropower is the most established renewable resource for electricity generation in commercial investments. Although, hydroelectric generation is regarded as a mature technology, there are still possibilities for improvement. [2]

Small scale hydropower constitutes a cost effective technology for rural regions in developing countries and, on the other hand, is a still growing sector in India. Most of the small hydropower (SHP) plants are of the run-of-river type, which is much different in design, appearance and impact from conventional large hydroelectric projects. There is no water storage reservoir except the small head pond capacity and all diverted water returns to the stream below the power house, whereas the environmental impact is minor. The problem of optimum design of a SHP plant is very critical for the cost effectiveness of the investment. The difficulty in sizing the components of the plant and mainly in determining its installed capacity arises from the non-uniformity and seasonal variation of the natural flow rate combined with the lack of an upstream reservoir of important volume.

A SHP plant requires a sizable flow and an adequate head of water, which is available without building elaborate and expensive facilities. SHPs can be developed at existing dams and can be constructed in connection with water level control of rivers, lakes and irrigation schemes. By using existing structures, only minor new civil engineering work is required; therefore, the initial investment costs are considerably reduced. In addition, they do not have negative effects to the environment such as replacement of settlements, loss of historical sites and agricultural fields, destruction of ecological life.

There is a general tendency all over the world to define Small Hydropower by the power output. Different countries follow different norms, the upper limit ranges between 5 to 50 MW. In India, hydro projects up to 25 MW station capacities have been categorized as Small Hydro Power (SHP) projects. Table 1.1 shows the classification of hydro schemes in India. [4]

Table 1.1 Classification of hydro schemes in India. [4]

Type	Station capacity
Micro	Up to 100 kW
Mini	101 to 2000 kW
Small	2001 to 25000 kW

1.2.1 Small Hydro Power in India

India is blessed with great rivers, mighty mountains and long sea coast offering conventional and non-conventional field. Hydropower represents use of water resources towards inflation free energy due to absence of fuel cost with mature technology characterized by highest prime moving efficiency and spectacular operational flexibility. Out of the total power generation installed capacity of 1, 74,361.40 MW (April, 2011) in the country, hydro power contributes about 21.54% i.e. 37,567.40 MW. The Ministry's (MNRE) aim is that the SHP installed capacity should be about 6000 MW by the end of 12th Plan. The focus of the SHP program is to lower the cost of equipment, increase its reliability and set up projects in areas which give the maximum advantage in terms of capacity utilization. An estimated potential of about 15,000 MW of small hydro power projects exists in India.

MNRE is now responsible for promoting development of entire SHP sector for projects up to 25 MW capacities. MNRE is providing fiscal and financial incentives to encourage implementation of SHP projects by the private developers and state governments. These include financial support for undertaking surveys and investigations and also for preparation of Detailed Project Reports (DPRs) for the identified sites. While capital subsidy is being given to the government funded projects, interest subsidy is being offered to private developers.

Table 1.2 Small Hydro (Up to 25 MW) Scenarios [3]

Overall Potential	15,000 MW
Identified Potential	15384 MW (5718 Sites)
Installed Capacity	2953 MW (801 Projects)
Under Construction (as on 31. 01.2011)	914 MW (271 Projects)
Target Capacity Addition- 11th Plan (2007-2012)	1400 MW

1.2.2 Types of SHP Schemes

1.2.2.1 Run-Off River Scheme

Run-of-River hydroelectric schemes are those, in which water is diverted towards power house, as it comes in the stream. Practically, water is not stored during flood periods as well as during low electricity demand periods, hence water is wasted. Seasonal changes in river flow and weather conditions affect the plant's output. After power generation water is again discharged back to the stream. Generally, these are high head and low discharge schemes.

1.2.2.2 Canal Based Scheme

Canal based small hydropower scheme is planned to generate power by utilizing the fall in the canal. These schemes may be planned in the canal itself or in the bye pass channel. These are low head and high discharge schemes. These schemes are associated with advantages such as low gestation period, simple layout, no submergence and rehabilitation problems and practically no environmental problems.

1.2.2.3 Dam Toe Based Scheme

In this case, head is created by raising the water level behind the dam by storing natural flow and the power house is placed at the toe of the dam or along the axis of the dam on either sides. The water is carried to the powerhouse through penstock. Such schemes utilize the head created by the dam and the natural drop in the valley. [5]

1.2.3 Basic Components of SHP

The various components of SHP can be categorized in two parts.

i. Civil works components

ii. Electro- mechanical equipments

(i) Civil Works Components

The components which are contact with water and do not have any rotating parts are called as civil works components, examples: Intake weir, Desilting tank, Forebay, Power Channel, Penstock, Power House and Tailrace etc. The purpose of civil work components is to divert the water from stream and convey towards the power house. In selecting the layout and types of civil components, due consideration should be given to the requirement for reliability.

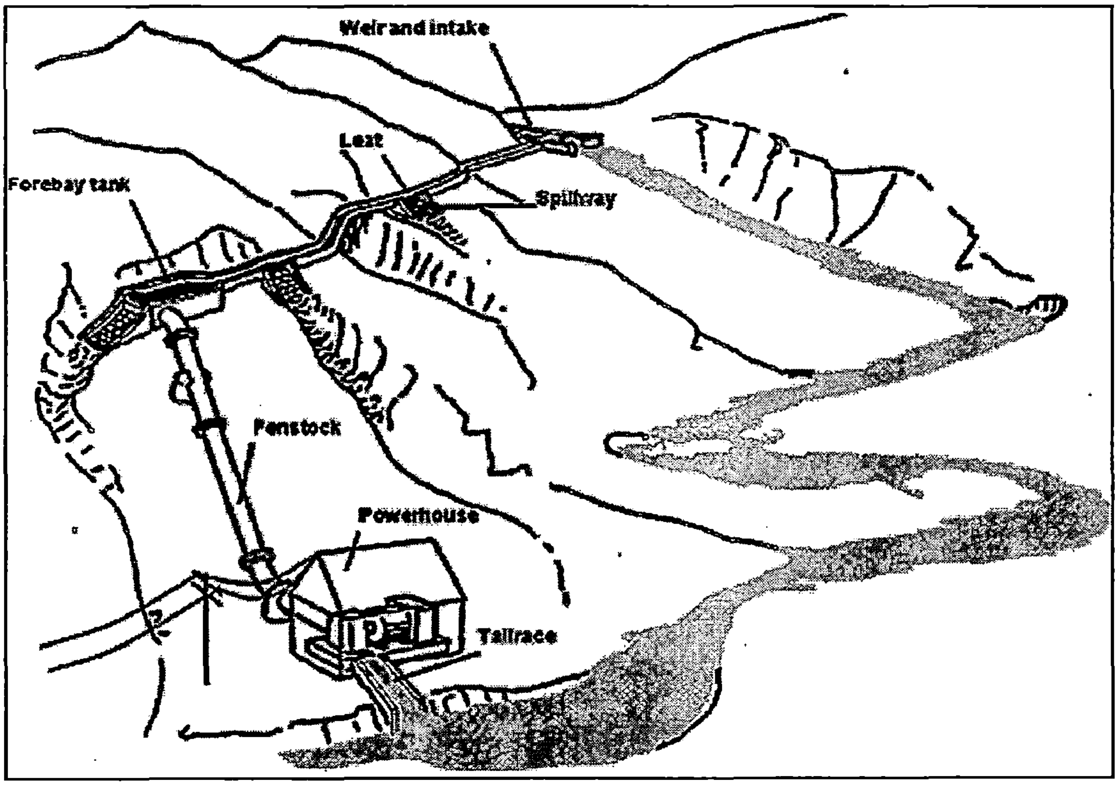


Figure 1.3 Basic Components of SHP [6]

(ii) Electro Mechanical Equipments

Electro-Mechanical equipments mainly include hydrogenating unit, speed increaser, governor, gates and valves and other auxiliaries. The parts which are contact with water and having rotating parts are called mechanical equipment. The parts which are not contact with water and having rotating parts are called as electrical equipment as a rule of thumb.

1.3 HYDROPOWER GENATING EQUIPMENT

Hydro Generating unit mainly consist Hydro-turbine and Generator which are coupled directly or with speed increaser. The hydrogenating unit converts the potential energy of water into mechanical energy in the form of rotation of shaft with the help of turbine and this rotation of shaft is converted to electrical energy with the help of generator. Hydro-Turbine can be broadly classified into two categories according to action of water on moving blades.

- Impulse turbine
- Reaction turbine

1.3.1 Impulse Turbines

In case of impulse turbines the penstock is connected with the nozzle and hence the whole pressure energy of water is transformed into kinetic energy in nozzle only. The water coming out of the nozzle is in the form of a free jet, which strikes with a series of buckets mounted on the periphery of the runner. The water comes in contact with only few of the buckets at a time. Once the water comes out of the nozzle then the pressure is atmospheric throughout, hence in case of impulse turbine the casing do not have any hydraulic function to perform but it is necessary only to prevent splashing and to lead the water to the tail race, and also act as a safeguard against accidents. Examples of impulse turbines are Pelton turbine, Turgo- Impulse turbine, Cross flow turbine.

1.3.2 Reaction Turbines

The water pressure can apply a force on the face of the runner blades, which decreases as it proceeds through the turbine. Turbines that operate in this way are called reaction turbines. It operates with its runner submerged in water. The water before entering the turbine has pressure as well as kinetic energy. All pressure energy is not transformed into kinetic energy as in case of impulse turbine. The moment on the runner is produced by both kinetic and pressure energies. The water leaving the turbine has still some of the pressure as well as the kinetic energy. The pressure at the inlet to the turbine is much higher than the pressure at the outlet. Thus, there is a possibility of water flowing through some passage other than the runner and escape without doing any work. Hence a casing is absolutely essential due to the difference of pressure in reaction turbine. The reaction turbines can be further classified into mixed and axial flow turbines. Mixed flow turbine water enters from outer periphery of the runner, moves inwards in radial direction and comes out from center in axial direction. Example of mixed flow turbine is Francis turbine. Axial flow turbines water enters from the wicket gates to the runner in the axial direction, moves along the axial direction and comes out in axial direction. Examples of axial flow turbines are: Propeller turbine, Kaplan turbine, Bulb turbine, Star flow turbine.

1.4 CLASSIFICATION OF HYDRO TURBINES

(i) Depending upon head and discharge

- High head and low discharge turbines
- Low head and high discharge turbines

(ii) According to action of water over the moving blades

- Impulse turbine
- Reaction turbine

(iii) According to the direction of flow of water over runner

- Tangential flow (Pelton, Turgo, Cross flow)
- Radial flow (old Francis)
- Mixed flow (modern Francis)
- Axial flow (Propeller, Kaplan)

(iv) According to the position of shaft

- Horizontal
- Vertical

(v) Based on specific speed

- High specific speed turbines
- Medium specific speed turbines
- Low specific speed turbines

In this present dissertation, the work is focused on the new concept i.e. analysis of fish friendly Kaplan turbine design, which is basically low head turbine. So the Kaplan turbine and why need it to make a new fish friendly turbine runner is discussed here. [5]

1.5 WHAT IS ENVIRONMENT FRIENDLY HYDROTURBINE

The development of an environmentally friendly hydropower turbine stems from the need to continue using a reliable source of renewable energy along with maintaining a healthy environment and a sustainable ecosystem. The program was created in 1994 with the objective of developing new hydropower turbine designs that minimize fish injury and mortality are environmentally friendly (i.e., maintain adequate water quality), and produce hydroelectricity efficiently. [7]

1.5.1 Fish-Friendly Hydroturbine

The issue of safe fish passage dominated the decision of whether a new turbine design concept was environmentally friendly. Fish passage is an important issue to many hydroelectric plants' operators. However, improving water quality of turbine discharge, such as increasing low dissolved oxygen content, and plant operating conditions were also considered priorities. The survival of a turbine-passed fish is highly dependent on the path that the fish takes through the turbine system. Once a fish departs the forebay and enters a turbine system it must contend with changes in physical geometry and flow characteristics that are very rapid and believed to be injurious in certain zones along the path. There are certain points due to which we have to need to make a new hydro turbine runner. i.e. [7]

- Injury and mortality mechanisms are dependent on the zone which the fish takes to pass through the turbine system.
- Fish encountering the zone surrounding the blade sustain injury due to blade strike, blade end gaps, and local fluid flow effects.
- Injuries caused by pressure appear to be related to the difference between the acclimation pressure upstream of the turbine and the exit pressure within the draft tube zone.
- Turbines can be designed to operate cavitation free while increasing power production. Proper turbine operation at cavitation-free conditions will reduce maintenance costs and fish mortality that is believed to be related to cavitation.
- Turbine operating point has significant effect on fish survival.

1.6 OBJECTIVES OF STUDY

The objectives of the study are given below:

- The least fish damaging turbine system design is one that directs the majority of the migratory fish away from turbine intakes and towards their natural surface oriented migration route. i.e. to decrease the fish mortality rate.
- Review the upstream fish passage technologies.
- Review the downstream fish passage technologies.
- Study the behaviour of fish in the fish friendly turbine.
- Analysis of fish friendly Kaplan turbine and comparison with conventional Kaplan turbine.

1.7 ORGANIZATION OF DISSERTATION WORK

Chapter 1 gives the detail introduction about the power scenario, various renewable energy sources, importance of the small hydropower technology in the present energy context. It also gives the requirement and objective of the fish friendly turbine.

Chapter2 explain the different type of fish passage technologies i.e. upstream and downstream or, turbine passage. Here gives the detail review of all fish friendly devices and there efficiency towards the decrease in mortality rate of fishes.

Chapter 3 consists of brief discussion about Kaplan turbine and its various components. Here also explained the how the injury occur in the Kaplan turbine and its design modifications concept. Study the numerical model for fish passage and fish behaviour towards the fish friendly turbine.

Chapter 4 details the analysis of fish friendly Kaplan turbine by using the basic data of Mainmatti Small Hydropower Project. Here changing the turbine parameter and find out there relation on the mortality rate of the fishes.

Chapter 5 represents the conclusion of present work and scope of future work.

LITERATURE REVIEW

During the review it is found that the mortality induced during the migration of fish at hydroelectric generating stations can occur at three locations.

(i) Upstream migration

(ii) Turbine passage

(iii) Downstream migration

Therefore the detailed literatures review on recent developments in fish passage technologies is given below:-

2.1 UPSTREAM FISH PASSAGE TECHNOLOGIES

Upstream fish migration systems have historically been observed for several centuries, mainly in Europe, although systems used in the past were fairly primitive. At the turn of the century, Denil (1909) was the first to propose a system based on more scientific principles of hydraulic energy dissipation within a fishway. During the first part of the 20th century, the hydraulic aspects of fishways were studied, as well as swimming abilities of main migratory species such as salmonids. Construction of the Bonneville dam on the Columbia River in the late 1930's and work done by Nemenyi and McLoead in the early 1940's on performance of fish in relation to a number of types of fishways brought a giant step forward in the understanding of upstream fish passage (Clay, 1995). The construction of the Hells Gate vertical slot fishway in the late 1940's was also a milestone in the development of this type of fishway. Nowadays, fishways are fairly well standardised and much experience has been gained on efficiency of various types of fishways and the general fish performance using these installations, especially for migratory species such as salmonids and alosids. However, migration characteristics of resident species are less well known, and it's only recently that habitat fragmentation concerns and specific research on these species have been carried out. [8]

A **fishway** can be defined as any artificial flow passage that fish negotiate by swimming or leaping (i.e., fish ladders) [9]. In an engineering context, it is a waterway specifically designed to afford fish passage around a particular obstruction [10]. It may be any structure, or modification to a natural or artificial structure, for the purpose of fish passage. Fishway systems often include attraction features, entrances, auxiliary water systems, collection and transport channels, exits, and operating/maintenance standards [11]. A fishway can be a simple culvert under a country road or a complex bypass system at a huge hydropower facility.

2.1.1 UPSTREAM FISH PASSAGE DESIGN

The success of a fish passage system (i.e., ladders, lifts, and trap and truck) at a hydropower facility is dependent on many factors. Effectiveness is directly related to biology and behaviour of the target species, as well as hydrologic conditions both up- and downstream of the project. Ultimately, a fishway must be designed to be "fish friendly" by taking into consideration all of the above. At some sites, two types of upstream mitigation may be required to provide effective fish passage. The hydrologic conditions of the waterway above and below the project will influence the location of the fishway exit and entrance, and influence conditions within the fishway itself. The fishway should be designed to be effective under a range of conditions while accommodating the swimming ability and behaviour of the target species and the targeted run size. In addition, physical and environmental conditions will influence location and effectiveness of the fishway, especially under changing flow conditions [12]. An understanding of fish swimming performance and behaviour is also essential to fish passage success. It is difficult to determine the exact performance of fish under natural conditions. However, significant knowledge exists in this area for some species, which can be applied to design. Species of fish and individuals within species behave and respond differently, requiring various types of flows and conditions in waterways and subsequently in fishways. Fishway design should consider and accommodate the life stages and unique characteristics of the target fish. Fish passage structures can be designed to accommodate fishes that are bottom swimmers, surface swimmers, or orifice swimmers; fishes that prefer plunging or streaming flow; and weak or strong swimmers [13]. Advances in fish passage will depend on fish behaviourists and biologists working cooperatively with hydraulic engineers to design appropriate fishway environments. [12]

2.1.2 TYPES OF DEVICES

This section describes the various types of fishways that can be usually found at hydroelectric sites. Although other types of fish migration devices exist such as passage through culverts, or small dams (i.e. < 2.0 m) these configurations are not typical of hydroelectric installations and won't be discussed further.

2.1.2.1 Pool and Weir Fishway

The pool and weir ladder has the longest history of use. Pool and weir fish ladders are designed primarily to provide plunging flow and ample resting areas that provide leaping fish with hydraulic assistance in moving upstream (see fig.: 2.1.1). In these fishways, pools are arranged in a stepped pattern and are separated by overflow weirs [10]. Ladders of the pool and weir type can be applied on any scale; they generally require a great deal of space, but little water [11].

Pool and weir ladders can operate under two hydraulic regimes. The normal flow regime in fish ladders is plunging flow; however, at higher velocities plunging flow converts to streaming flow at the water surface. In this instance, a continuous surface jet passes over the weir crests, skimming the pool surfaces. Streaming flows are difficult to manage and should be used with caution. Moreover, the transition between plunging and streaming flow creates a hydraulic instability that may delay some fish species [11]. Streaming flow does not provide the hydraulic boost needed by jumping fish to successfully negotiate the ladder; however, streaming flow is often required because some species cannot or refuse to leap [14]. Auxiliary water, beyond what flows down the ladder itself, is almost always needed to attract fish to the entranceway.

Design parameters for pool and weir ladders include receiving pool volume, head differential between pools, water depth in pools, and slope. Values can be calculated for different fish, different sized runs, and different project scales. For example, the recommended head differential between pools is one foot for most salmon and trout, which can leap from pool to pool and three-fourths of a foot for chum salmon and American shad. Most pool and weir ladders have a slope of 10 percent and are sensitiveto changing water levels (headwater variations) with a narrow range of operation if no other flow control is provided. An upper flow limit for effective passage is that at which energy cannot be dissipated from pool to pool. Some pool and weir fishways have submerged orifices that allow fish to pass upstream without cresting each weir. Weir and orifice/weir fishways have been used successfully by anadromous salmonids, but not readily by alewife, shad and other fish that rarely leap over obstacles or swim through submerged orifices. [10]

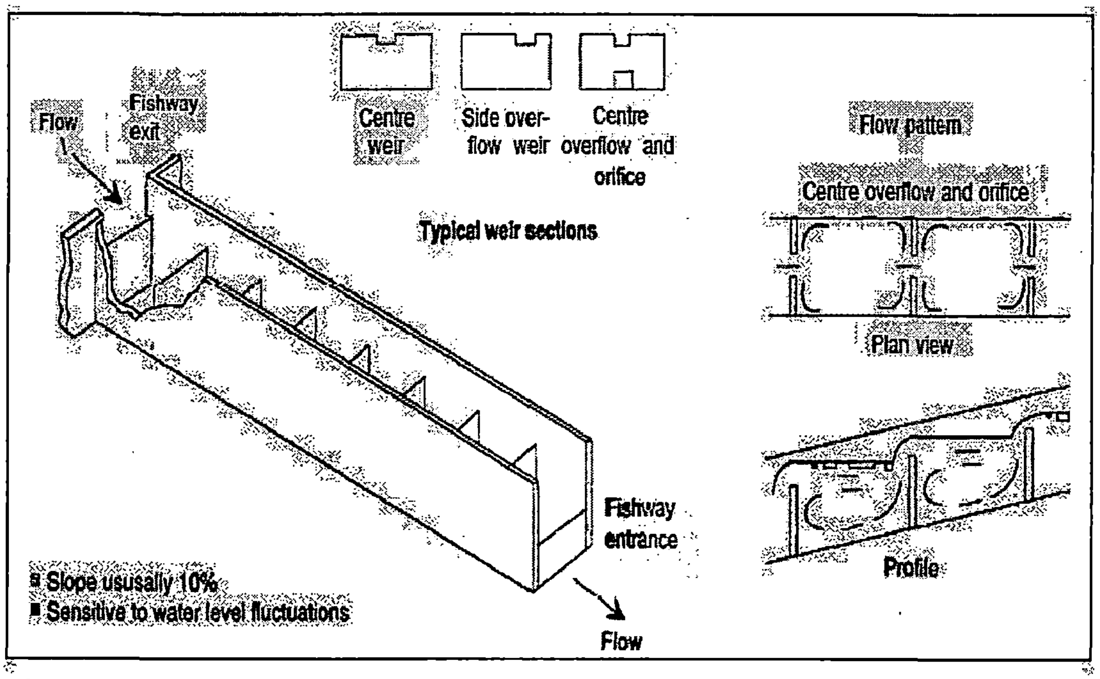


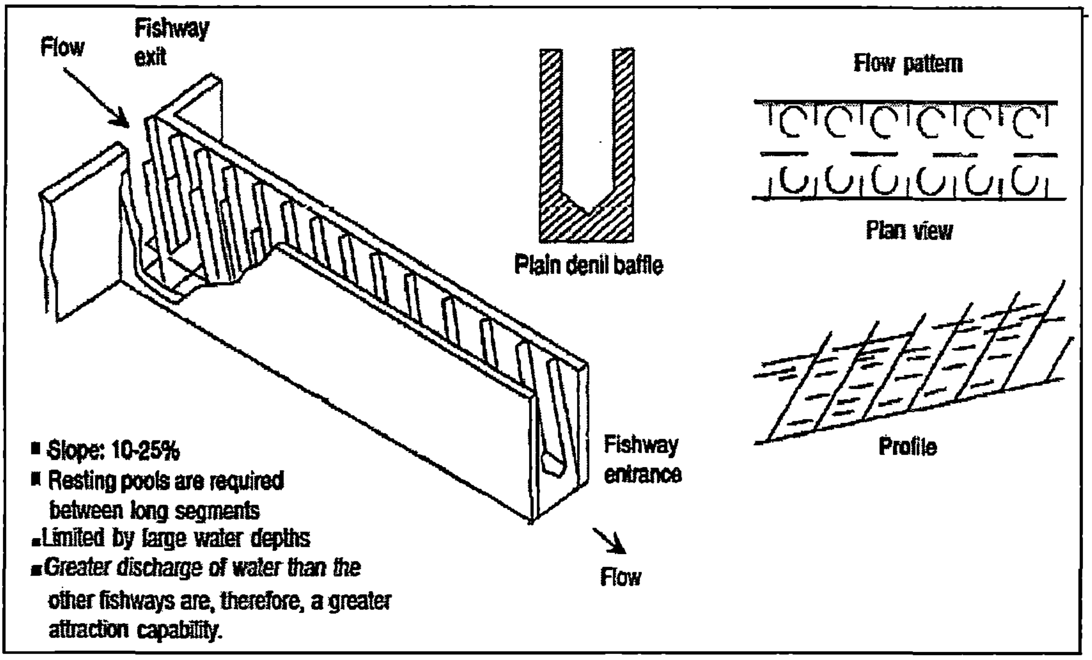
Fig.: 2.1.1 Pool and Weir Fishway Source: C. Katopodis, 1992. [10]

2.1.2.2 Denil Fishway

Denil fish ladders are rectangular chutes or flumes. These relatively narrow chutes have baffles extending from the sides and bottoms which point upstream (see fig.: 2.1.2). The internal roughness created by the baffling controls flow for fish passage. The Denil concept originated in the 1920s and was tested in Iowa in the 1940s. Denil fishways accommodate more different species of fish than other fishways and have been successfully used with a wide variety of anadromous and riverine fish. In the East, Denil fishways are most commonly deployed in small streams. The U.S. Fish and Wildlife Service (FWS) have very specific design parameters relating to slope, water depth and volume of flow to control turbulence and velocity for different species. [15]

Flow through Denil fishways is very turbulent, with large momentum exchange and high energy dissipation. Fish must swim constantly in the Denil chute so resting pools must be provided in higher head situations. Pools are recommended at 10 to 15 meter intervals for adult salmon and at 5 to 10 m intervals for adult riverine species [13]. The U.S. Fish and Wildlife Service, Region 5, suggests a resting pool for every six to nine feet of vertical lift in Denil fishways. The large, turbulent flows associated with the Denil decrease fishway sedimentation and provide good attraction capability [16]. However, auxiliary attraction flows are often needed since flows are generally lower near the bottom and faster at the top depending on the specific fishway design and depth of the water. [13]

Denil fishways are typically two to four feet wide and four to eight feet deep. Fish can ascend the fishway at their preferred depth. Fish ascending a Denil face varying water velocities depending on their preferred swimming depth. Fish generally move more quickly through Denil fishways than through pool and weir fishways, and the former can be more effective at steeper slopes than most other fishways. Operable slopes range up to 25 degrees for adult salmon; lesser slopes of 10 to 15 percent are more appropriate for adult freshwater fish. Denil fishways also accommodate a wider range of flow conditions than pool and weir ladders; thus, flow control to maintain operable depths is not as critical. However, forebay elevations generally must be maintained within several feet to maintain good passage conditions. For greater headwater variations, a stacked Denil with an intermediate bottom can be used to increase the range of flows over which the fishway can operate [10]. Finally, debris blockage is a common problem associated with Denil fishways.



- Slope: 10-25%
- Resting pools are required between long segments
- Limited by large water depths
- Greater discharge of water than the other fishways are, therefore, a greater attraction capability.

Fig.: 2.1.2 Denil Fishway Source: C. Katopodis, 1992. [10]

2.1.2.3 Steeppass Denil Fishway

The Alaska steeppass is a prefabricated, modular style of Denil fish ladder originally developed for use in remote locales (see fig.: 2.1.3). The steeppass is a relatively economical, lightweight fishway, where one 10-foot aluminium unit weighs only about 1,500 pounds. The steeppass has a more complex configuration of baffles than the standard Denil, is more efficient in controlling water velocity, and is operable at steeper slopes (up to about 33 percent for salmon and steelhead). The maximum slope, and therefore the water velocity within the fishway, is a design criterion dependent on species and size of fish to be passed [14]. Less flow is required for successful passage. However, due to its smaller open dimensions, the steeppass has a more limited operating range and is more susceptible to debris problems than the plain Denil. Flow control is critical to successful operation of the steeppass. Forebay water surfaces cannot vary more than a foot without passage difficulties. Similarly, tailwater levels cannot fluctuate significantly without problems either with plunging flow or backwatering. As is true of the plain Denil, water velocities vary with depth within the steeppass. At low depths, velocity tends to be higher near the bottom and to decrease toward the surface. At higher depths, flow divides into upper and lower layers with maximum velocities at mid-depth. The U.S. Fish and Wildlife Service Region 5, however, do not allow the use of the steeppass design at hydropower facilities because it cannot function under a range of flows. [16]

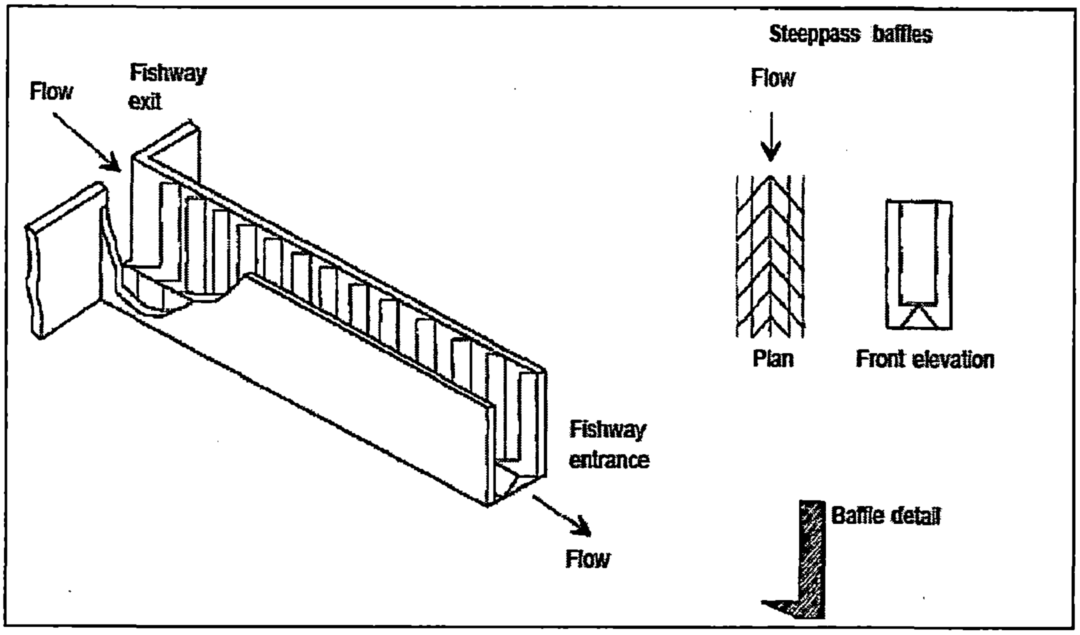


Fig.: 2.1.3 Steeppass Denil Fishway Source: C. Katopodis, 1992. [10]

2.1.2.4 Vertical Slot

Like pool and weir ladders, vertical slot designs have distinct steps. The basic design is a rectangular channel portioned by baffles into resting pools (see fig.: 2.1.4).

Water flows and fish swim from pool to pool through slots oriented vertically. The vertical slot fishway was first developed for application at Hell's Gate, a barrier created by highvelocity flow through a narrow gorge of the Fraser River in Western Canada . The design has been used successfully in many locales for a wide variety of anadromous and riverine fish. Fish are assumed to move from slot to slot in a nearly direct path (this has not, however, been verified) while swimming at their preferred depth. Fish use a "burst-rest" pattern to move up the fishway from pool to pool [10]. Pools provide an opportunity to rest, but fish must exert a burst of speed to move upstream through the slots.

The dimensions of slots and pools are critical to the stability of flow in vertical slot ladders. Flow is a function of slot width and depth, water depth and the head differential across slots. Sill blocks can be installed in the bottom of the slot to reduce turbulence by reducing slot depth [11]. Usually, a 300-mm and 200-mm water level differential between pools is appropriate for passage of adult salmon and riverine species, respectively. Slot width generally is based on the maximum size fish that is expected to use the fishway. However, many variations in design are possible by varying the slot arrangement, spacing, positions, width and materials, without significantly affecting flow patterns in the fishway. [16]

Vertical slot fishways typically have a slope of 10 percent. The change in elevation from ladder top (exit) to bottom (entrance) is nearly equally divided among all the fishway steps; the number of steps is determined by the maximum forebay to tailwater head differential; whether this maximum differential is a feature of low or high flow conditions. [11]

The greatest advantage of the vertical slot design is that it is hydraulically self-regulating through a large range of tailwater and forebay water surface elevations. Hydraulic control is provided by the slots, which are the zones of highest water velocity. Energy, in the form of water jets at each slot, is dissipated as the jet is cushioned and mixes with the pool water between baffles. The jet discharge pattern and drop between pools can be adjusted for a particular target species. Water velocities are almost constant along the entire 'slot height, and velocities are maintained for very large water depths. As flows increase, pools deepen and the appropriate level of energy dissipation is maintained. As a result, these fishways can be built to accommodate a large range of water levels [10]. The only constraint to operable range is the depth of the slots. Within this constraint, any change in forebay or tailwater surface is automatically compensated for and distributed throughout the fishway [11]. Thus, vertical slot fishways may be the most effective design for localities where water levels are expected to vary significantly during periods of fish migration. Additional water generally is needed for attraction flow at the entrance of vertical slot fishways. Vertical slot fishways have had considerable application across the country with wide success. These fishways seem to work well for a variety of species. In the Pacific Northwest, vertical slot fishways were constructed at 21 tributary sites in the 1980s. Radio telemetry studies showed that fish moved past these facilities in less than a day. [17]

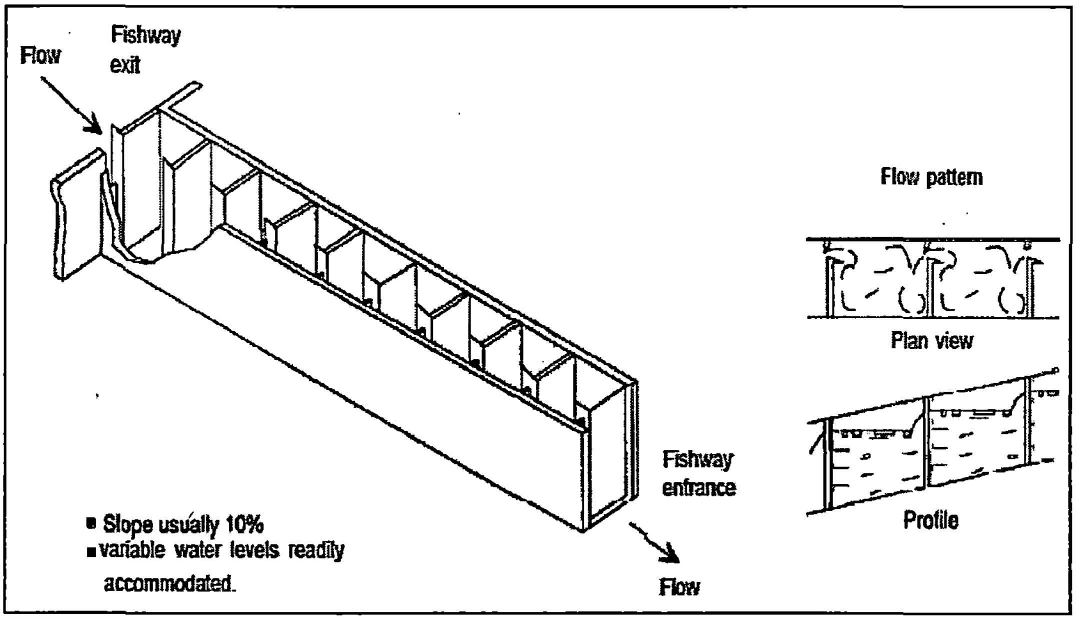


Fig.: 2.1.4 Vertical Slot Source: C. Katopodis, 1992. [10]

2.1.2.5 FISH LOCKS, ELEVATORS, AND TRAPS

2.1.2.5.1 Fish Lock

The first of modern fish locks was built in Ireland in 1949 based on a design by J.H.T. Borland. Since that time, more than a dozen have been built in Scotland and reland surmounting dams of up to 60 m. In France, locks have been used on a few occasions but they have not proven to be very effective, as it has been observed that some fish remain in the lock chamber instead of passing into the forebay. Similarly, on the Connecticut River near Holyoke, MA a fish lock was installed to pass American shad but was found to be unsatisfactory and has since been replaced by a fish elevator. However, a lock was built on the Haines River in Ontario and is reported to pass large numbers of rainbow trout and Chinook salmon over a 7.3 m dam. [18]

The principle behind the fish lock is that fish enter the lock at the tailwater level. A downstream gate closes, and at the same time, an upstream gate allows water to fill the lock. Once the water level has reached the head pond level, fish can leave the lock into the forebay (see fig.: 2.1.5a).One of the limiting factors for the use of the fish lock is the fish passage capacity, because of the size of the lock chamber, and the duration of a complete lock cycle. For this reason, this system is not practical for the Pacific Coast of North America, where large salmon runs are frequently encountered.

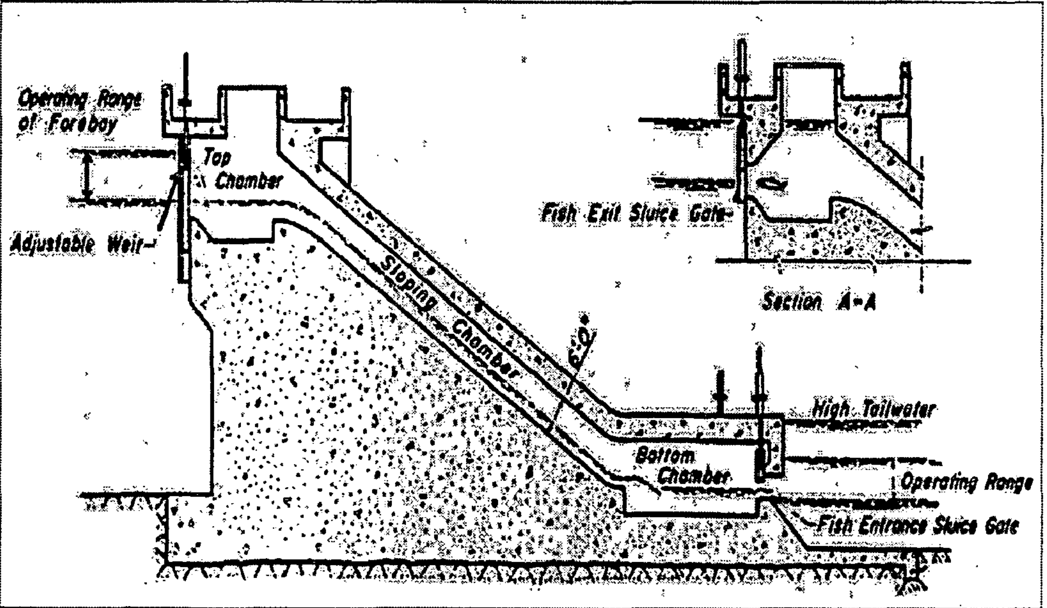


Fig.: 2.1.5a Fish Lock Sources: clay 1995. [18]

2.1.2.5.2 Fish Elevators, and Traps

Fish elevators are also used to pass fish over high-head dams (Fig.: 2.1.5b), where conventional fishways would be too expensive. Fish enter a holding chamber where they are lifted with a hopper directly to the forebay level. In France two such fish elevators are in place and convey shad upstream of the Golfech and Tuiliere hydropower dams. The main advantages of such systems are initial costs which are independent of the height of dams, and tolerance to upstream water levels. They are also considered more efficient for species such as shad that have difficulties in more traditional fishways. A modification to the fish elevator is the trapping system where instead of lifting the fish with a hopper to the head pond elevation, fish are simply dumped from the hopper into a truck and then transported upstream to a release point.

This system is fairly frequent on salmon rivers in Quebec as it gives river managers flexibility for optimal distribution of the salmon resource on the river reach. In rivers where multiple barriers are present on the main river channel, trapping at the first downstream obstacle and transporting upstream of the last one can prove to be an interesting alternative as this would avoid having to build fishways at all obstacles, and would reduce delays of fish migration through all these fishways. However, trucking costs can be substantial depending on the distance that needs to be travelled from the trapping point to the release point. Moreover, care must be taken during the fish manipulation so not to induce undue stress. [19]

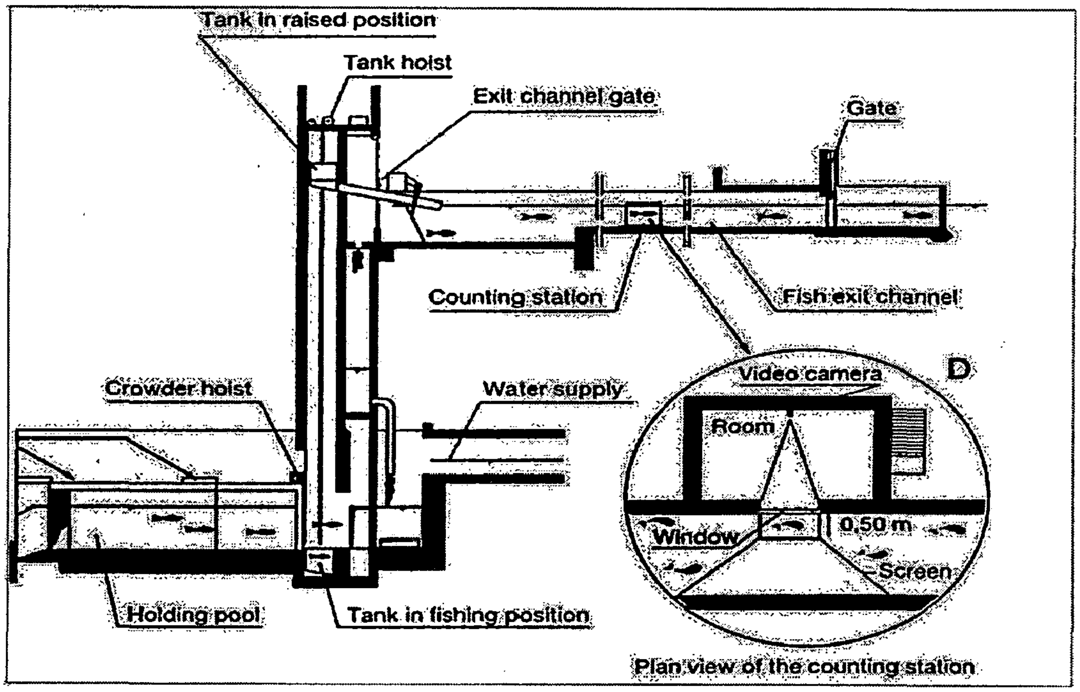


Fig.: 2.1.5b Fish Elevator Sources: Travade et al, 1998. [21]

2.1.2.6 Eel Fishway

Eel fishway are fairly different from standard fishways described above. Eels are catadromous fish meaning that the juveniles (elvers) migrate up river to their habitat and pass many years in freshwater until they reach their adult size. Once they have reached their adult size, they migrate downstream to the sea to spawn. At their juvenile stage, eels are like snakes in that they can slither out of the water to pass obstacles, in as much as there is a minimal amount of water (i.e. even on wet grass, elvers can migrate upstream). A typical eel fishway is illustrated in Fig.: 2.1.6. It is generally composed of a steep channel with bristles installed at the bottom. A minimal amount of water is used for this type of fishway. [20]

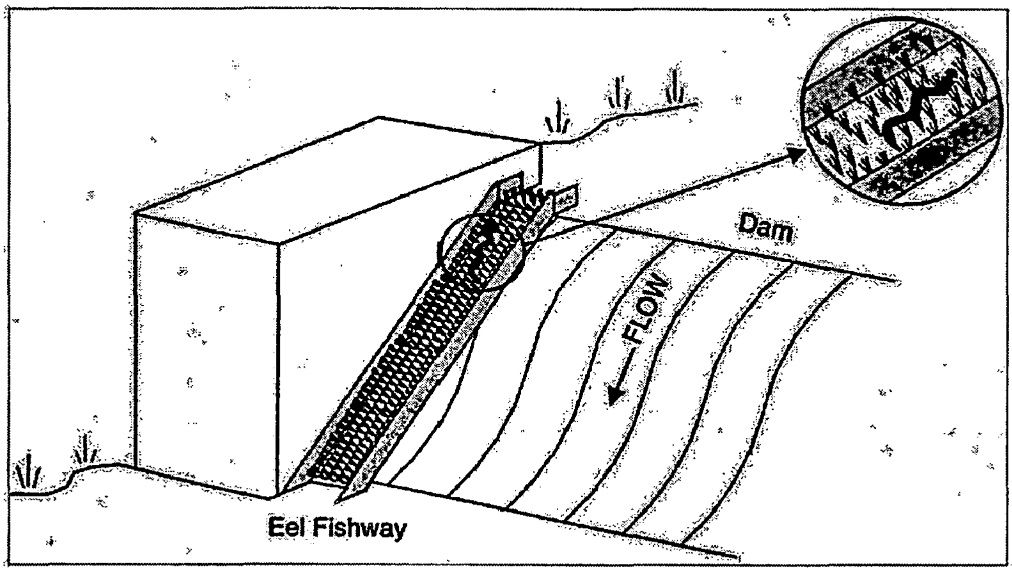


Fig.:2.1.6 Eel Fishway Sources: Odeh, 1999 [20]

2.1.2.7 Artificial Channels

An alternative to fishways discussed earlier is to put in place an artificial channel (see fig.: 2.1.7). The use of this type of environmentally friendly design allows not only for fish passage both upstream and downstream, it also creates fish habitat. However, their low gradient from less than 2% to a maximum of 5% to surmount a given dam height means that they will be very long compared to other systems mentioned earlier. Furthermore, artificial channels require more space than other fishway, so they would not be appropriate if space is limited, unless an in-channel configuration is possible. [20]

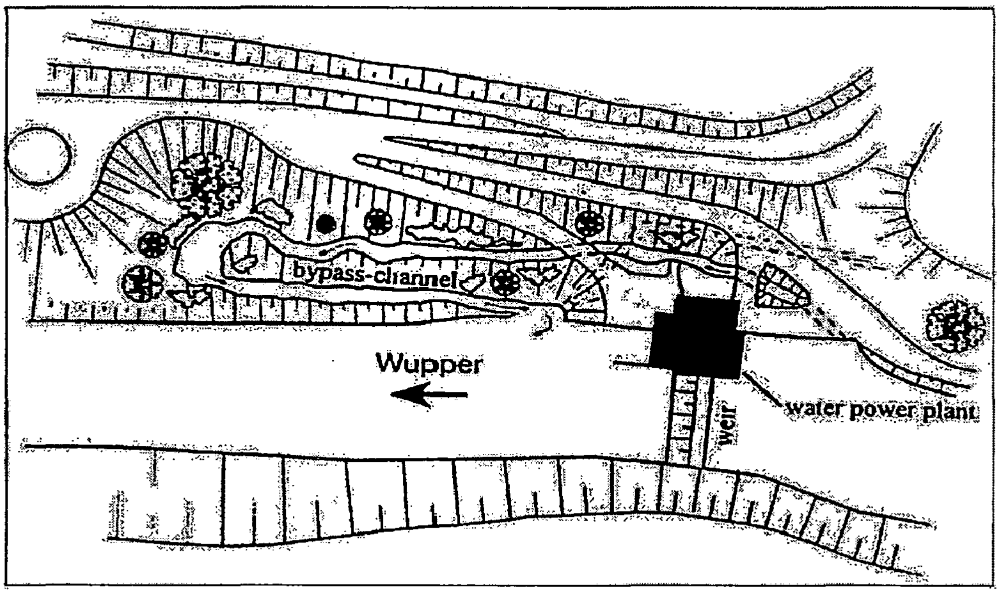


Fig.: 2.1.7 Artificial Channels Sources: Odeh, 1999. [20]

2.1.2.8 Hybrid Fishway

The design features of several types of ladders may also be combined in a single fishway design to accommodate variations in flows or multiple target fish. Features of pool and weir, vertical slot and roughened channel (Denil) designs can be brought together (see fig.: 2.1.8). For example, a "pool and chute" fishway may be constructed to accommodate a wider range of stream flows than pool and weir ladders without additional flow controls. The fishway essentially operates as a pool and weir facility at low flow and as a Denil-type chute at higher flow. Combination designs such as this have not yet been thoroughly tested and therefore have not been evaluated as to effectiveness in passing target fish. [11]

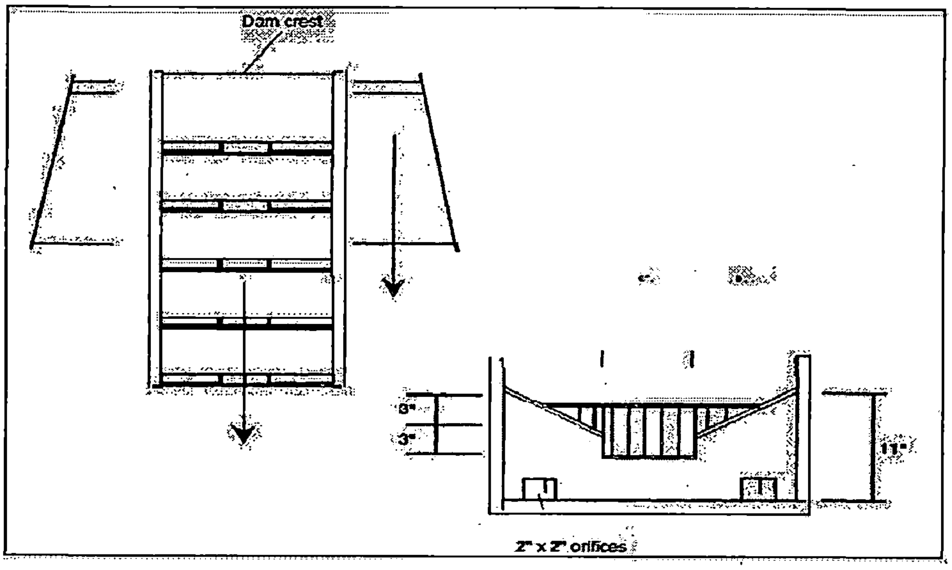


Fig.: 2.1.8 Hybrid Fishway Source: C. Katopodis, 1992. [10]

2.1.3 OTHERS

2.1.3.1 Fish Pumps

The use of fish pumps to move adult fish upstream of hydropower projects is not widely accepted or used. The FWS Region 5 generally does not support the use of fish pumps due to the nature of the passage method which is completely facilitated and subjects fish to an artificial environment. Fish are pumped to a bypass conduit which releases them upstream of the project. Pumping fish has the potential to lead to injury and de-scaling as a result of crowding in the bypass pipe. This means of passage may also result in disorientation upon release which could potentially lead to problems with predation.

At the Edwards Dam (hydropower project) on the Kennebec River in Augusta, Maine, negotiations between the project owner and the resource agencies over how best to provide an economic means of safely passing American shad, alewife, and Atlantic salmon have been underway for some time. The intent was to use a pump to transport fish (mainly adult alewives) to a sorting and holding facility for trucking upstream. A fish pump is being used as an interim measure, though it has not been as effective as hoped in passing fish upstream. In addition, there were initial difficulties with injury and mortality. The State of Maine favors removal of the Edwards Dam in an effort to restore the river above the project as a spawning and rearing area for a variety of anadromous species which are not known to utilize conventional fish passage technologies. [22]

2.1.3.2 Transportation

Trapping and then trucking adult migrants to move them upstream has become highly controversial. The lack of a conventional fishway and the cost of installing one are typical reasons for using this alternative means of fish transport. Some practitioners have concerns regarding the effect that handling and transport have on fish behavior and health. On the other hand, trap and truck operations have been successfully used in some cases to move adults upstream of long reservoirs, or multiple projects; fish can then be released close to spawning grounds. Transportation operations should be executed under conservative conditions to minimize stress. Possible adverse impacts of trapping and trucking fish include disorientation, disease and mortality, delay in migration, and interruption of the homing instinct, which can lead to straying. Additionally, in the case of a proposed trap and truck system for a proposed project on the Penobscot River in Maine, transport of fish would bypass traditional fishing grounds of the Penobscot Indian Nation. Additional adverse impacts include low capacity to move the peak of the run without delay and injury, and the cost of operation, leading to a reduction of the operating season or overloading of hauling trucks. [23]

However, moving fish by truck can be a sound method of transport. On the Susquehanna River in Pennsylvania, fish lifts are in operation at the downstream-most hydropower project. They assist a trap and truck operation which supports the restoration of American shad, blueback herring, and alewives. The fish are transported upstream of the four projects on the river and released in the highest headpond near to spawning grounds. There are two lifts in operation at the Conowingo project, one on the west side of the dam and one on the east. Several improvements were made to trap and transfer operations in 1993, including development of new holding facilities at the east lift.

The 10-year-old Conowingo program, supported by state and federal resource agencies, has been quite a success. The transport survival of American shad ranged from 65 to 100 percent from the east lift, while the west lift transport survival ranged from 94.9 to 100 percent in 1993 [24].Holding facilities at both lifts were utilized to reduce stress, maximize transport operations, and release larger schools of fish. In addition, load size of fish transported was reduced to prevent undue stress due to crowding. A monitoring program was instituted to determine delayed mortality rates at the release sites. The evaluation of the program at Conowingo has led the agencies to investigate the installation of fish lifts at three upstream projects and once built, trapping and trucking will be used at a minimum to move fish around the Conowingo hydropower facility. [25]

2.2 TURBINE PASSAGE

Generally turbine passage is thought to be the most likely of all of the downstream passage routes to harm or kill fish. A good deal of work has gone and is going into improving turbines to reduce damage and increase survival of fish when going to pass turbine. Water speeds are often very high and cause of injury.

Here I review many literature related to turbine passage and find some specific observations that cause of fish mortality and injury rate for many fish species i.e. due to

(i) Pressure
(ii) Turbine zone
(iii) Runner peripheral velocity
(iv) Abrasion, strike and grinding

Name of Hydroelectric Project	SPECIFIC OBSERVATIONS								Ref. no.
2.2.1 **Wanapum Dam (US)**	Fish Species / Observation		Riverine and anadromous fishes (1997)	Juvenile clupeid species (1987)	Rainbow trout	Sockeye salmon	Whitefish fry	Alewives	7
	Turbine Mortality rate	Francis turbine	20 %	16%	-----	-----	-----	-----	
		Kaplan turbine	12%	4%					
		Bulb turbne	9%	-----					
	Pressure range no mortality occur		-----	-----	241 kPa to 1,275 kPa	2064 kPa	4997 kPa	350 kPa	
	Head	Francis turbine							
		Kaplan turbine							
	Turbine zone								
	Runner peripheral velocity	Water body							
		Solid							

	object
Pressure change felt by the fish	Low head plant
	High head plants
	Kaplan turbine

Criteria for the Design and Evaluation of the New ARL/NREC Fish-Friendly Turbine Runner

Criteria Description	Value Chosen	Reasoning
Fish-friendly turbine runner	A new runner design	Project's objective
Hydraulic design parameters	Flow 28.3 m^3/sec Head (23 – 30 m)	-----
Turbine operating efficiency	85% minimum (3-D calculations included scroll case and draft tube)	Efficiency for most turbines peaks at 90% to 93%. 85% was chosen so the new runner can be competitive with existing designs.
Peripheral runner speed	Less than 12.292 m/sec (preferably 6.096 m/sec	Reduces strike injury
Minimum pressure	68.8 kPa	206 kPa, and mortality occurs when pressure drop is more than 30% of acclimation pressure.

Rate of change of pressure	Less than 550.3 kPa/sec	Assuming fish injury occurs at a pressure rate of 1101.88 kPa in Kaplan turbines.
Shear stress indicator (Rate of Strain, du/dy)	Less than 4.572 m/sec	Tests of alewives, a fragile fish, at ARL with 4.572 m/sec did not cause injury.
Clearance between runner and fixed turbine housing components	2 mm or less	Small clearances reduce possibility of mechanical injury. 2 -3mm gap chosen by the USACE for testing in a Kaplan turbine.
Flow passage Sizes	Maximize	Large amounts of water between blades should reduce abrasion injury by keeping fish away from the blades.
Flow control and plant Configuration	Maximize distance between runner and wicket gates and minimize travel time from intake to runner	Kaplan turbines are more fish-friendly than Francis turbines. A small distance between wicket gates and the runner in Francis turbines may increase the chance for abrasion and grinding injury.

Preliminary Design of the New ARL/NREC Runner

During the preliminary design stage, the pump impeller performance in the turbine mode was analyzed. Peak electrical efficiency reached 79% at 28.3 m^3/s, 29.26 m of head, and the rotor diameter was about 6.76 m. A new design was needed because this efficiency was well below the desired value of 85%, and the efficiency was reduced drastically when the unusually large rotor diameter was made smaller. This meant a new runner design had to be developed, and two- and three-bladed runners were compared with the large pump impeller operated as a turbine, see Table below. Here, although Case 3 was chosen for further analysis because of the lower number of blades, Case 2 may be used if a smaller diameter runner is desired.

Case	**Design Description**	**Basic design**	**Number of Blades**	**Runner Diameter (m)**	**Runner Length (m**	**Rotational Speed (rpm)**	**Head (m)**	**Overall Efficiency (%)**
1	Scaled up Impeller as Turbine	pump impeller	1	6.76	3.29	61.2	29.26	79
2	New Turbine Design	pump impeller	3	4.93	3.75	73	25.60	90
3	New Turbine Design	pump impeller	2	5.33	4.05	68	25.90	89

Sources: cook et al. 1997

Satisfying the Design Criteria

The new runner had to meet the engineering and biological design criteria in order to be considered a viable new concept for further development as a fish-friendly hydropower turbine. Preliminary two-dimensional and advanced three-dimensional CFD analyses were performed to determine overall performance and flow characteristics, respectively. Important findings that resulted from this conceptual design phase of the new runner included:

Case	Design Description	Basic design	Number of Blades	Discharge (m^3/s)	Min. flow passage (m)	Runner Diameter (m)	Runner Length (m)	Rotational Speed (rpm)	Head (m)	Overall Efficiency (%)

1	New Turbine Design	pump impeller	2	28.3	0.9144 m	5.33	4.05	70.1	25.60	90

2.2.2

Bonneville first power house (US)

Turbines / Observation	MGR	Conventional Kaplan runner
Injury rate	1.5%	2.5%
Survivals of fish passed near the hub	97% or greater	97% or greater
Survivals of fish passed middle blade region	95 – 97 %	95 – 97 %
Survivals for blade tip-released fish	93.8 – 97.5 %	90.8 -95.6 %

26

2.2.3

Laboratory Studies

Published Estimates of Shear Stress (N/M^2) in Natural and Man-Altered Aquatic Environments.

Environment	Shear stress (N/m^2)	Literature Cited
Water column in a trout stream, average flow	<1.0	Fausch and White (1981)
Small streams, near bed	<1-7	Lancaster and Hildrew (1993)
Medium-size streams, near bed (90 measurements)	<30, but some >200	Statzner and Müller (1989)
Flash floods, small basins	61-2600	Costa (1987)
Floods, large rivers	6-10	Costa (1987)
Bulb turbine draft tube	500-5421	McEwen and Scobie (1992)
Near ship hulls and wakes	7.6-40.4	Morgan et al. (1976

27

Near barge propeller	>5000	Killgore et al. (1987)

Description of Turbine Environment and Expected Shear and Turbulence Strains to be Encountered by a Fish Passing Through a Turbine

Turbine Zone	Description	Environmental Conditions
1	Turbine intake (trash rack) to the stay vanes, including the scroll case.	Velocities increase from ~1 m/s at the entrance to 2+ m/s at the scroll case.
2	The area above and upstream of the turbine blades, including around the stay vanes and wicket gates.	Velocities increase from 2+ m/s to >6 m/s just above the turbine blades..
3	Downstream of the turbine blades and near the turbine hub.	Velocity is highest here and acceleration is rapid, increasing from >6 to >15 m/s over a relatively short distance. There is also a pressure drop from 2 to near 0 atmospheres.
4	The vertical portion of the draft tube	Velocities decrease from >15 m/s to ~5 m/s. Shear condition are expected, but undefined.
5	The horizontal portions of the draft tube parallel to the river bottom	Velocities decrease from ~5 m/s to ~3 m/s as the flow enters the tailrace.

2.2.4
Alden/NRE

Scroll Case Design

design discharge	Head	Runner	Flow passage within	Minimum clearance in a

28

C fish friendly turbine

(m^3/s)	(m)	diameter (m)	scroll and runner (m)	pilot scale runner diameter (m)
28.3	25.90	3.962	0.1524 - 0.1524	1.2192

scroll case design parameters:

- Geometric scaling is 3.25 to 1 m
- Pilot scale flow is 2.690 m^3/s
- Number of wicket gates is 11

2.2.5 McNary Dam

Turbines	High pressure	Pressure at Turbine blade near the hub	Pressure at blade near the tip	Low pressure
Bulb turbine	210 kPa	-----	------	80 kPa
Kaplan turbine	460 kPa	>=115 kPa	Pressure drop from 340 to 2 kPa	2 kPa

Test Species

Species name	Length	Obtained/purchased
Rainbow trout	13 cm	Troutlodge, Inc. in Soap Lake, Washington
Bluegills	7 to 10 cm	Osage Catfisheries
juvenile fall chinook salmon	10 cm	Eggs, from the Washington Department of Fish

29

2.2.6

Wanapum dam, CFD Calculations

The Wanapum CFD Calculations

flow rates (m^3/s)	**Head (m)**	**Shear stress/ shear**
254.85	22	High shear stress at inlet and draft tube.
311.48	22	-----
424.75	22	-----

The main area where shear above the threshold valve (1600 pa) which cause the fish injury. i.e. are

1. Boundary layer on the blade surface
2. Near the periphery gap
3. Near the hub gap
4. Under the blade

30

2.3 DOWNSTREAM FISH PASSAGE TECHNOLOGIES

2.3.1 INTRODUCTION

The implementation of downstream mitigation for fish passage at hydropower facilities has three distinct goals: to transport fish downstream; to prevent fish from entrainment in turbine intakes; and to move fish, in a timely and safe manner, through a reservoir. A range of mitigation methods for downstream passage and for prevention of turbine entrainment exist, and some have been applied with more success than others. The so-called "standard" or "conventional" technologies are mainly structures meant to physically exclude or "guide" fish to a sluiceway or bypass around the project and away from turbine intakes by means of manipulating hydraulic conditions. Other "alternative" technologies attempt to "guide" fish by either attracting or repelling them by means of applying a stimulus (i.e., light, sound, electric current). Many theories have been applied to the design of downstream passage systems and further experimentation is underway in some cases. For downstream migrating species, including the juveniles of anadromous upstream spawners, it is important that a safe route past hydropower facilities be made available. For these fish, a means of preventing turbine entrainment, via a diversion and bypass system, is often needed. For some resident fish, downstream movement may not be critical or desirable. Philosophies of protection vary across the country depending on target fish, magnitude of the river system, and complexity of the hydropower facility. For example, practitioners in the Northwest tend to prefer exclusion devices that physically prevent entrainment, while those in the Northeast tend to recommend structural devices that may alter flow and rely on fish behavior for exclusion. Much of the variance in protection philosophy may be linked to differences in target fish in these regions. The Northwest hosts a number of endangered or threatened species (mainly salmonids), while the Northeast does not have quite the same history of concern. In the Northwest, fish protection is mainly focused on salmonids. Downstream migrants tend to be small and have limited swimming ability. In the Northeast, fish protection is focused on a variety of species. In some cases downstream migrants are of fairly good size and possess fairly good swimming ability (e.g., American shad).

Physical barriers are the most widely used technology for fish protection. These technologies include many kinds of screens (positioned across entrances to power canals or turbine intakes) providing physical exclusion and protection from entrainment. In some parts of the country, *behavioral guidance devices* such as angled bar racks (modified versions of conventional trashracks) are used to protect fish from turbine entrainment. For both categories of downstream passage technologies, careful attention to dimensions, configurations and orientations relative to flow are required to optimize fish guidance.

In most cases, structural measures to exclude or guide fish are preferred by resource agencies. Screens and angled bar racks providing structural measures for physical guidance are preferred by resource agencies, however, the screens can be expensive to construct and maintain. As a result, the development of alternatives to these technologies, such as *alternative behavioral guidance devices* (e.g., light, sound), continues to be explored. These devices have not been proven to perform successfully under a wide range of conditions as well as properly designed and maintained structural barriers. Thus, the resource agencies consider them to be less reliable in the field than physical barriers. In addition, other methods for downstream passage are also being explored. New turbine designs that will be not only more efficient but more "friendly" to fish are under proposal. And in the Columbia River Basin, a surface collector system which intends to guide fish past hydropower facilities by better accommodating natural behavior is being experimented with at a number of sites. [9]

2.3.2 DOWNSTREAM PASSAGE TECHNOLOGIES

There are regional differences in the recommendations of resource agencies for downstream passage. Variations relate to differences in target fish, including differences in swimming ability of down-migrating juveniles, susceptibility to injury, and the history of concern for endangered and threatened species. Structural methods, including screens that physically exclude fish from turbine entrainment and angled bar racks and louvers that may alter flow patterns and rely on fish behavior for exclusion, are the most widely accepted technologies for downstream passage. Downstream technologies that are accepted by resource agencies in different regions of the country, and those that are considered experimental, are summarized in table 2.3.1. Resource agencies generally prefer physical barrier screening techniques with associated bypasses for downstream passage (e.g., drum, travelling, and fixed screens). This type of technology is well understood. Physical barrier and bypass systems can prevent entrainment in turbines and water intake structures. Design criteria incorporate hydraulic characteristics and take into account the swimming ability and size of fish present to avoid impingement problems. A commonly cited advantage of these systems is that they are effective for any species of the size and swimming ability for which the system is designed. This type of downstream passage technology is usually recommended in the Pacific Northwest and California. Acceptance is based on experience at many sites and non-peer reviewed (i.e., gray literature) evaluations of performance. Design criteria are mandated for some species by some state and federal agencies. Criteria vary among the agencies but generally address approach velocities and flow-through velocities, size of mesh, and materials, for different sizes and species of fish. Designs generally must be tailored to the individual site and target fish.

Table: 2.3.1 Statuses and Use of Downstream Fish-Passage Technologies.

Downstream passage technology	**Accepted in the Northwest and California**	**Accepted in the Northeast and Midwest**	**In use**	**Considered experimental**
Physical Barrier Devices				
Drum screen	✓		✓	
Travelling screen (submersible; vertical)	✓		✓	
Fixed screen (simple; inclined)	✓		✓	
Eicher screen			✓	✓
Modular inclined screen				✓
Barrier net		✓	✓	✓
Coanda screen		✓		✓
Structural Guidance Devices				
Angled bar/trash rack		✓	✓	
Louver array		✓	✓	
Surface collector			✓	✓
Complements To Technologies				
Bypass chute or conduit	✓	✓	✓	
Sluiceway		✓	✓	
Alternative behavioural Guidance devices				
Acoustic array			✓	✓
Strobe and mercury lights			✓	✓

Electric field			✓	✓
Other Methods				
Trapping and trucking	✓	✓	✓	✓
Pumping			✓	✓
Spilling	✓		✓	✓
Barging	✓		✓	✓
Turbine passage	✓	✓	✓	

Sources: Office of Technology Assessment, 1995.

In the Northeast, resource agencies more frequently recommend the use of angled bar racks with relatively close spacing and an associated bypass for down-migrating anadromous juveniles. This approach is also supported by favourable evaluations in one peer reviewed study [31] and a small number of gray literature studies, although the mechanism that leads to successful performance is not understood. A similar approach is louvers, a behavioral system that alters the flow characteristics of the water that fish are able to respond to. Louvers are viewed favourably by some, but have been criticized by the NMFS NW region as having unacceptably high entrainment rates for small fish, even with favourable hydraulic systems. In the Northwest, many poorly performing louvers have been replaced by physical barrier screens and bypass systems. Screens built prior to the mid-1980s sometimes experienced poor performance in guiding juvenile fish. Since then, new screen designs in the Pacific Northwest and California have achieved nearly 100 percent guidance efficiency [32]. However, these screens can be expensive. A significant portion of costs are due to structural measures required for proper anchoring and installation and there are frequently operation and maintenance deficiencies. Incompatible operation of hydropower facilities or water diversions may also reduce the effectiveness of the technology. These accepted technologies are usually designed to withstand normal variations in flow; however, flow conditions can be highly variable. In some cases, changes in the river itself can cause problems; the position of the river can actually change over time, resulting in screen failure. This is more likely to be a problem at water diversions where there are no dams controlling water flow. Adequate operation and maintenance is required to optimize the performance of these accepted technologies. Preventive maintenance can minimize failure. Manual methods of cleaning are generally favoured to reduce capital costs, but few resources are devoted to ensuring that manual cleaning occurs. Frequent cleaning may be needed where there is a lot of debris. Some of the more sophisticated and expensive designs provide automated cleaning, but these are rarely installed due to the high capital costs. [33]

2.3.3 PHYSICAL BARRIER DEVICES

Physical barrier screens can be made of various materials based on the application and type of screen (i.e., perforated plate, metal bars, wedge wire, or plastic mesh). Screens are designed to slow velocities and reduce entrainment and impingement [34]. Smooth flow transitions, uniform velocities, and eddy-free currents just upstream of screens are desirable. Adequate screen area must be provided to create a low flow velocity that enables fish to swim away from the screen. The positioning of the screening device is critical. It must be in appropriate relationship to the powerhouse to guide fish to the bypass by creating the appropriate hydraulic conditions. Fish then enter a bypass which either deposits them in a canal that eventually rejoins the main channel, releases them into the main flow downstream of the project via an outfall pipe or sluiceway, or leads them to a holding facility for later transport. Outfall pipes typically release fish above the water's surface to avoid creation of a hydraulic jump or debris trap within the closed pipe. Releasing fish above the water may also alleviate disorientation and help to prevent schooling. However, predation at the outfall can be a problem and there is no consensus on how to avoid this, though multiple outfalls might alleviate the situation in some cases. [35]

The screen must be kept clean and clear of debris or it will not function properly. Debris is commonly the biggest problem at any screen and bypass facility. Debris loading can disrupt flow and create high-velocity hot spots, or cause injury to fish. In addition, a partially blocked bypass entrance can reduce the efficiency of fish passage and cause injury or mortality .Installation and operation of a screen cleaning system and regular inspections to ensure proper operation of screens may be the most important activities to increase effectiveness. Mechanical cleaning systems are preferable over manual ones and often more reliable, provided they are functioning properly. Very frequent cleaning may be needed where there is a lot of debris. California screen criteria require cleaning every five minutes. Ideally, screens should be cleaned while in place, and temporary removal of a screen for cleaning is usually not acceptable. A variety of physical barrier screens has been developed to divert downstream migrants away from turbine intakes. Years of design, experimentation, evaluation, and improvement have alleviated some problems but others still remain, and no physical barrier is 100 percent effective in protecting juveniles. Few studies have been able to demonstrate conclusively a guidance efficiency exceeding 90 percent; and although the effectiveness of these facilities is probably close to 100 percent at many sites, losses of fish may occur due to predation or leakage of fish past faulty or worn screen seals [32]. Some specifics of design and function of a variety of low-velocity physical barrier screens are highlighted below.

2.3.3.1 The Drum Screen

The *drum screen* is often found to provide the best fish protection at sites with high debris loads. Comprehensive evaluation of large drum screen facilities has demonstrated nearly 100 percent overall efficiency and survival. The drum rotates within a frame and is operated continuously for cleaning. Debris is carried over the drum and passed down a channel or into a bypass. Drum screens can be expensive to construct and install, but relatively economical to operate; however, application criteria are site specific. These screens have been proven to be reliable at sites in California and the Pacific Northwest. Relatively constant water levels in the forebay are necessary for operation and maintenance and repairs to seals can be problematic and costly [36]. The rotation of the revolving drum screen induces a current perpendicular to the rotation axis which entrains fish to a waste way (Fig.: 2.3.1).

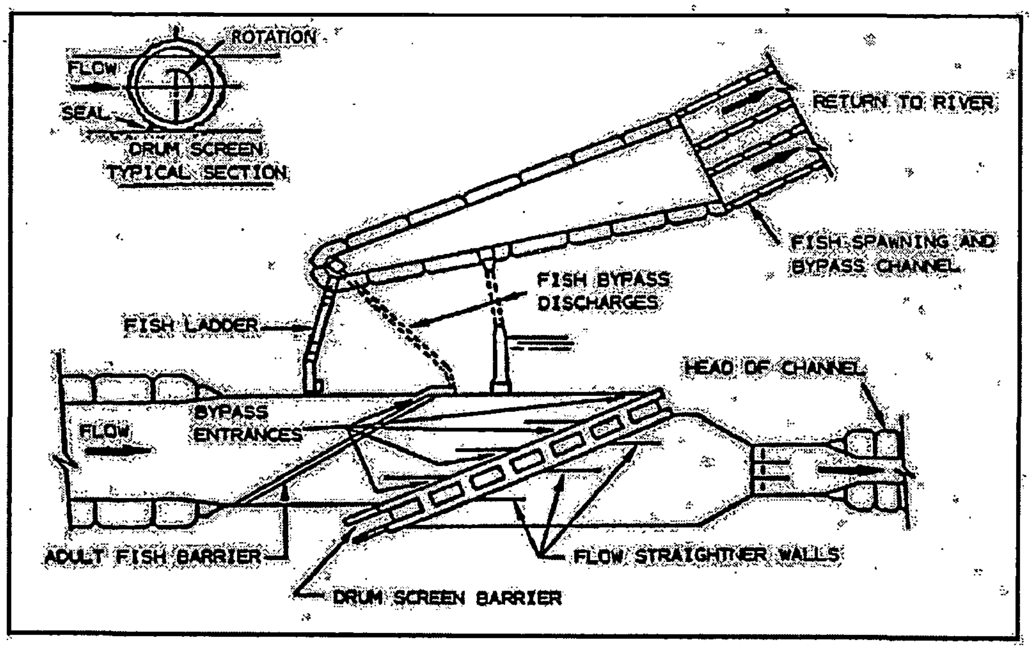


Fig.: 2.3.1 Schematic cross-sectional view of a drum screen perpendicular to flow.

Sources: from EPA, 1976

This type of screen is efficient in channels where depth is less than 2 m and for a maximum approach velocity of about 0.15 m/s for screens installed perpendicular to the current. Screens that have an angle with the current are clearly more efficient and cover a broader range of velocity. The maximum perpendicular velocities tolerated are the same as for deflector screens. The screen mesh size could also be around 1 cm, for certain species such as juvenile salmon. This system, initially design for irrigation ditches, was adapted to hydropower projects, but mostly on large ones. [18]

2.3.3.2 Travelling Screen (Submersible; Vertical)

2.3.3.2.1 Submersible travelling screens

Submersible travelling screens (STSs) are expensive to construct and install, and subject to mechanical failures, although in some cases they have been considered by the U.S. Army Corps of Engineers to be the best available technology for diverting downstream migrating fish in the Columbia River Basin. STS configurations operate continuously during the four- to nine month salmonid migration period in the Columbia River; they are capable of screening extremely large flows in confined intakes but do not screen the entire powerhouse flow. At hydropower facilities where the fish are concentrated in the upper levels of the water column, good recoveries have been achieved .However, intakes at projects in the Basin tend to be very deep (i.e., greater than 90 feet) and flows are high. Under these conditions, fish have been seen to try to move away from STSs, especially if they are deeper in the intake. Also, the potential for impingement is greater due to high through-screen flow velocities. [36] These screens seem to work better for some species than others.

2.3.3.2.2 Vertical travelling screens

Vertical travelling screens were originally designed to exclude debris from water intakes but were found to be effective at guiding or lifting fish past turbine intakes. The screen may consist of a continuous belt of flexible screen mesh or separate framed screen panels (baskets). Vertical travelling screens are most effective for sites where the intake channel is relatively deep. If approach velocities are kept within the cruising speed of the target fish, impingement can be screens that lift fish are not recommended for fish that are easily injured, such as smelting salmonids.

2.3.3.3 Fixed Screen (Simple; Inclined)

2.3.3.3.1 Simple fixed screens

Simple fixed screens can be an economical method of preventing fish entry into water intakes at sites where suspended debris is minimal; however, costs are site specific. Though fixed panel screens can and have been built in areas with substantial debris, automatic screen cleaners are required. These screens have demonstrated greater than 95 percent overall efficiency and survival at sites in the Columbia River Basin. Several types of simple fixed screen are available. The stationary panel screen is a vertical or nearly vertical wall of mesh panels installed in a straight line or "V" configuration. Fish-tight seals are easily maintained around this fixed screen, and the design accommodates a range of flows and forebay water elevations.

2.3.3.3.2 Inclined plane screens

Inclined plane screens are also stationary, but are tilted from the vertical to divert fish up or down in the water column to a bypass. A conceivable problem with this design is the potential for dewatering of the fish and debris bypass route if water levels should fall below either end of the tilted screen. Also, cleaning is a primary concern for both stationary panel and inclined plane screens. Manual brushing is usually required to keep surfaces debris-free. The design is practical for water intakes drawing up to 38 cubic meters per second; however, application depends more on the site than on the flow. [36]

2.3.3.4 Eicher Screen

The Eicher Screen was developed in the late 1970s by biologist George Eicher in an effort to develop a better means of bypassing fish safely around a turbine. The elliptical screen design fits inside the penstock at an angle and can function in flow velocities up to 8 feet per second (fps) Non-penstock designs are also possible. The screen's ability to function at relatively high velocities is what distinguishes it from conventional screens, which tend to operate at channel velocities of about 1-2 fps. Eicher Screens are relatively less expensive and have smaller space requirements than most barrier screens. The system is about 50 percent cheaper to install than conventional, low velocity screening systems, and involves a screened area about one-tenth that of conventional systems.

The other benefits of employing this screen are that it takes up no space in the forebay area, has low operating costs, no risk of icing, and is not dependent on forebay water levels. In addition, because the screen operates at high velocities, there is less chance that it will harbour predators. [37]

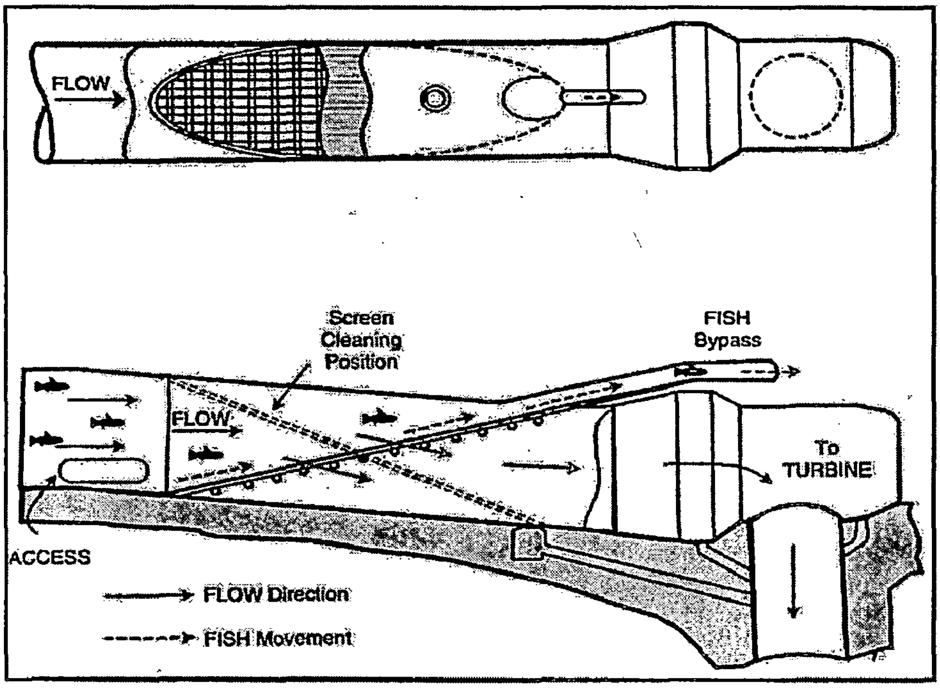


Fig.: 2.3.2 Schematic cross-sectional view of an Eicher screen in a penstock. [38]

The Eicher screen is made of a series of parallel bars spaced by about 2 to 3 mm. The screen has a 15° to 20° incline and allows average perpendicular velocities up to 1 m/s, the effective velocity increasing from upstream to downstream of the screen. Beyond this velocity, the risks of injuries and scaling increase. To remain below this perpendicular velocity threshold, the maximum velocity suggested in the penstock must be less than 2.4 m/s. On the other hand, current velocity at the entrance to the bypass must be fairly high, at least 90% of the velocity in the penstock. It can also be slightly superior to the latter. The efficiency obtained is above 98% for smolts and above 91% for alevins of various salmonids. Scaling, in the order of 2% at velocity less than 1.5 m/s and up to 40% at 2.4 m/s, occurred during the tests and was a major cause of injuries. A device with variable screen porosity has been designed and it allows an increase in current velocity of 10% in the penstock, without a significant impact on efficiency. [38]

2.3.3.5 Modular Inclined Screen (MIS)

EPRI has developed and completed a biological (laboratory) evaluation of a type of high velocity fish diversion screen known as the Modular Inclined Screen (MIS). This screen is designed to operate at any type of water intake with water velocities up to 10 fps. The MIS consists of an entrance with trash rack, stop log slots, an inclined wedgewire screen set at a 10 to 20 degree angle to flow, and a bypass for directing diverted fish to a transport pipe. This modular screening device is intended to provide flexibility of application at any type of water intake and under any type of flow conditions. Installation of multiple units at a specific site should provide fish protection at any flow rate. Currently, no fish protection technology has proven to be highly effective at all types of water intakes, for all species, and at all times (i.e., seasonal variability. [39]

A full scale testing in an intake still needs to be done. The screen was installed in a water intake at an angle ranging from 10° to 20°. The average size of fish tested ranged from 47 to 170 mm for the following species : bluegill (laboratory and field), rainbow trout (l&f), Coho salmon (l), Chinook salmon (l), brown trout (l), blueback herring (f), yellow perch (f), clupeids (l), smallmouth bass (f), largemouth bass (f), golden shiner (l&f), walleye (l), channel catfish (l) and Atlantic salmon (l). Efficiency levels varied depending on species and current velocities (ranging from 0.23 to 3.05 m/s). Laboratory tests showed efficiency above 98% for salmonids at all current velocities, except for Chinook salmon at 3 m/s (94%). Rainbow trout had survival rates over 99% at velocities up to 2.4 m/s on the field. For other species, efficiency was generally above 92% in laboratory or field for current velocities up to 2.4 m/s, except for clupeids, including blueback herring, where the efficency was generally low: under 86% at 0.6 m/s and below 35% at 1.8 m/s in the field (75% in laboratory). Scaling seems to be the major cause of injury, particularly for clupeids (87% of diverted fish at 1.2 m/s) and for bluegill (49% at 1.8 m/s). For this screen, the maximum velocity suggested in the penstock is also 2.4 m/s, to avoid risks of scaling and injuries, except if the target species are clupeids. [38]

The prototype MIS test is important in the development and acceptance of the technology. However, resource agencies will be unlikely to approve full-scale applications of the MIS without additional testing. Resource agencies are particularly troubled by operational aspects of high-velocity turbine screening. These screens only collect fish when water is flowing over them. Hydropower operational changes may be necessary to ensure adequate flow to the screens, especially during periods when many hydropower projects are filling reservoirs and not producing much power. [39]

2.3.3.6 Barrier Net

Most technologies proven to be effective in downstream mitigation at hydropower intakes rely on large screening structures designed to provide a very low approach velocity. For many projects, such technologies are not financially other reasons. In these cases, the use of barrier nets may provide a cost-effective means of protecting fish from entrainment. In general, barrier nets have not been utilized in situations where both downstream passage and protection from entrainment are desirable. Barrier nets of nylon mesh can provide fish protection at various types of water intake, including hydropower facilities and pumped storage projects. Nets generally provide protection at a tenth the cost of most alternatives; however, they are not suitable for many sites. Their success in excluding fish from water intakes depends on local hydraulic conditions, fish size and the type of mesh used. Barrier nets are not considered to be appropriate at sites where the concern is for entrainment of very small fish, where passage is considered necessary, and/or where there are problems with keeping the net clear of ice and debris. It may not be practical to operate nets in winter due to icing and other maintenance problems. Thus nets may not offer entrainment protection in winter at some sites.

Nets tend to be most effective in areas with low approach velocities, minimal wave action and light debris loads. Bio fouling can reduce performance, but manual brushing and special coatings can help alleviate this problem. An evaluation was underway during the spring of 1995 at the Northfield Pump Storage Project on the Connecticut River in Massachusetts. The study has yet to be completed. There have been problems with debris loading and net at the project. The Ludington Pumped Storage Plant, one of the world's largest pumped storage facilities, located on the eastern shore of Lake Michigan, has had a 13,000-foot-long barrier net installed around the intake since 1989. Barrier net effectiveness, described as the percentage of fish prohibited from entering the barrier net enclosure, substantially increased to about 84 percent in 1994 after significant improvements were made. This seasonal barrier appears to be effective for target fish. [40]

2.3.3.7 Coanda Screen

Coanda/inclined screens, the Coanda screen design uses a concave arc or flat plate panel consisting of wedge wire. Coanda screens are installed on downstream faces of overflow weirs. Flow passes over the crest of the weir, across a solid acceleration plate, and across and through the screen panel. Flow passing through the screen is collected in a conveyance channel below the screen, while the overflow containing fish and debris passes off the downstream end of the screen.

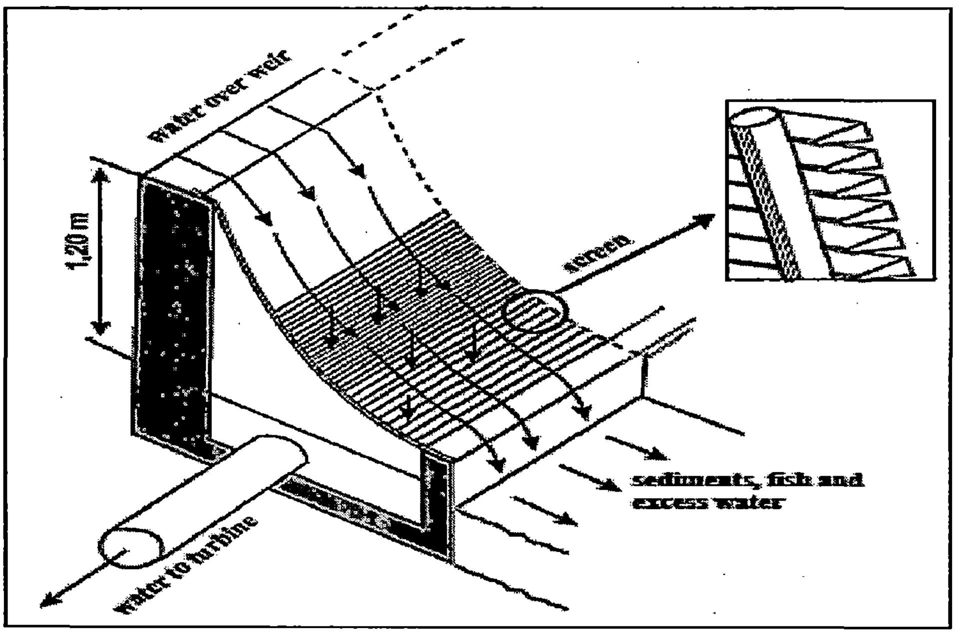


Fig.: 2.3.3 Coanda Screen. [5]

Flow velocities across the face of the screen are highly variable, and are a function of the drop height from the upstream pool to the start of the screen. Sufficient flow depths must be maintained over the end of the screen to prevent excessive fish contact with the screen surface. Flow depths across the screen are shallow, which increases fish exposure to the screen surface. These screens typically require a head drop of several feet. Coanda screens have high flow-handling capacities for their size, are essentially self-cleaning, and have the ability to exclude very fine debris and small aquatic organisms. Fish impingement on Coanda/inclined screens appears to be a minor concern, compared to impacts from traditional screens, because the sweeping velocity carries fish off the screen immediately. However, because of the high velocities across the screen surface and shallow flow, fish injury and mortality is a concern. Installations of this screen in California are likely limited to small hydropower facilities. Coanda screens are used in California at the Panther Ranch Hydroelectric Project in Shasta County (maximum flow rate 4 cfs); Bear Creek

Hydroelectric Project in Shasta County (maximum flow rate 70 cfs); Montgomery Creek Project in Shasta County (maximum flow rate 120 cfs); and Bluford Creek Hydroelectric Project in Trinity County (maximum flow rate 30 cfs). Limited biological evaluations have been conducted on the Coanda screen and it is not yet considered acceptable for anadromous fisheries in California. [41]

2.3.4 STRUCTURAL GUIDANCE DEVICES

2.3.4.1 Angled Bar/Trash Rack

Angled bar and trash racks have become one of the most frequently prescribed fish protection systems for hydropower projects, particularly in the north eastern United States to prevent turbine entrainment of down-migrating juvenile anadromous species (e.g., alosids and salmonids). Most of the angled bar racks installed to date consist of a single bank of racks placed in front of the turbine intake at a 45- degree angle to flow. Although design can vary from site to site, most racks consist of 1-inch spaced metal bars with a maximum approach velocity of two feet per second. The angled bar rack is set at an acute angle to flow and with more closely spaced bars than conventional trash racks. It can divert small downstream migrating fish, and larger fish cannot typically pass through the bars. However, the use of close-spaced bar racks creates the potential for impingement of fish. This is of greatest concern for species with weak swimming ability and/or compressed body shapes. [32] Most of the angled bar racks have been installed at small hydropower projects, the majority of which have not been evaluated for their performance in effectively diverting fish. Proper cleaning and maintenance of the bar and trash rack systems on a regular basis is a critical element of operational success. Racks can be equipped with mechanical cleaning systems or can be pulled out of the water for manual cleaning; trash booms can also be helpful in mitigating debris loading. The ideal trash boom is designed to carry debris past the fishway exit to the spillway or falls and out of the forebay area. [11]

2.3.4.2 Louver Array

A louver system consists of an array of evenly spaced, vertical (hard plastic) slats aligned across a channel at a specified angle and leading to a bypass. The louver system, like the angled bar rack, attempts to take advantage of the fact that fish rely mainly on senses other than sight to guide them around obstacles. Theoretically, as fish approach louvers, the turbulence that is created by the system causes them to move laterally away from it toward a bypass. [32]

Louvers are made of a curtain of rigid plastic blades directing fish toward a bypass Fig.: 2.3.4. They can be fixed or floating. In the latter case, louvers cannot exceed 2 m in height if the design of the bypass prevents current returns.

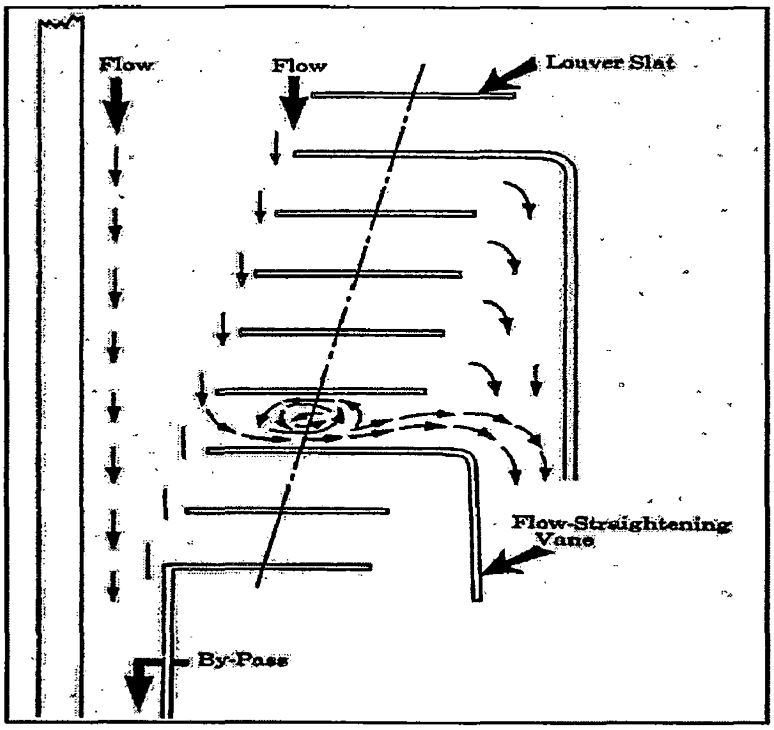


Fig.: 2.3.4 Schematic overview of louvers [42]

Ideally, louvers must be set at a certain angle (11° to 40°) in relation to the river current and the efficiency decreases when the angle increases. Each louver blade must be almost perpendicular to the current. The average spacing between louvers varies in relation with species and regulatory requirements. Fish tend to face the current and, usually, they do not make sudden changes of direction. When nearing the louvers, they perceive certain turbulence and a decrease of current velocity, and they tend to swim away laterally. However, velocity alongside the louvers can be greater than swimming speed to transport fish toward the bypass. In order to minimise head loss, louvers are generally equipped with deflectors or current rectifiers distributed at regular intervals along the louvers line. The deflectors are made of the prolongation of a blade and its branching along the louvers line (Fig.: 2.3.4). Where head loss is not a great concern, the flow deflectors are often omitted. The water velocity in the bypass must be approximately 1.4 times the velocity near the louvers. The best efficiency is obtained when the device is installed in the head race of a powerhouse or in an intake canal. Louvers have proven to be the best behavioural device, especially in streams where current velocity is high and where site configuration is optimal. [42]

2.3.4.3 Surface Collector

Surface-oriented bypasses could prove to be effective in improving juvenile salmon survival in the Columbia River Basin. There is a major effort underway in the Pacific Northwest spearheaded by the COE to develop a surface collector design. The thrust of the research is to better understand the biological and physical principles that are at work at the Wells Dam, where a hydro combine design is in use, and apply them to the surface collector design to provide a safer means of passage for juveniles. This "attraction flow" concept may provide downstream- migrating juveniles with an alternate, more passive route through hydropower facilities than is possible with other methods. Surface collector prototypes are being evaluated at The Dalles and Ice Harbor Dams by the Portland and Walla Walla Districts of the COE, respectively. Various configurations of the design are being tested. The attraction flow prototype consists of a 12-foot-wide by 60-foot-high steel channel attached to the forebay face of the powerhouse perpendicular to flow in the forebay. The goal is to guide fish hydraulically directly into the collectors, and then pump them to a bypass which moves them around the dam. Hydro acoustics will be used to monitor fish movement and behavior in and near the collector. An adaptation of the new surface collector design is in operation at Bangor Hydro's West Enfield project on the Penobscot River and Ellsworth project on the Union River, although debris blockage has been a problem at both sites. The results of the 1995 testing at Wanapum Dam could potentially add much to what is known about downstream fish passage and design at hydropower facilities. Also, results of the prototype tests would hopefully be transferable to other powerhouses at projects on the Columbia and Snake Rivers. [43]

2.3.5 COMPLEMENTS TO TECHNOLOGIES

2.3.5.1 Bypass Chute or Conduit

Engineered bypass conduits are needed for downstream-migrating fish at hydropower facilities and are the key to transporting fish from above to below a hydropower project. Most early downstream mitigation efforts only marginally improved juvenile fish survival. Today, juvenile bypass structures are more efficient due to lessons learned and a better understanding of the interaction of hydraulics and fish behaviour. In some instances bypasses must provide efficient and safe passage for both juvenile and adult life stages. [36]

2.3.5.1.1 Spillway

In this type of device, fish leave the head race with surface flows (Fig.: 2.3.5), through debris gates or spillway gates, or by any other opening implemented for surface spills. In some cases, surface collectors are added to lead the fish through the spillway. Subsurface flow from a notch between 0.4 and 4.7 m of depth has also been tested and it showed better results than surface spilling (2.1 and 3 m of depth) for salmonids. Spills originating at great depth are generally ineffective but it may be efficient in some cases where the flow and depth are high, a deep slot of 24.4 m.

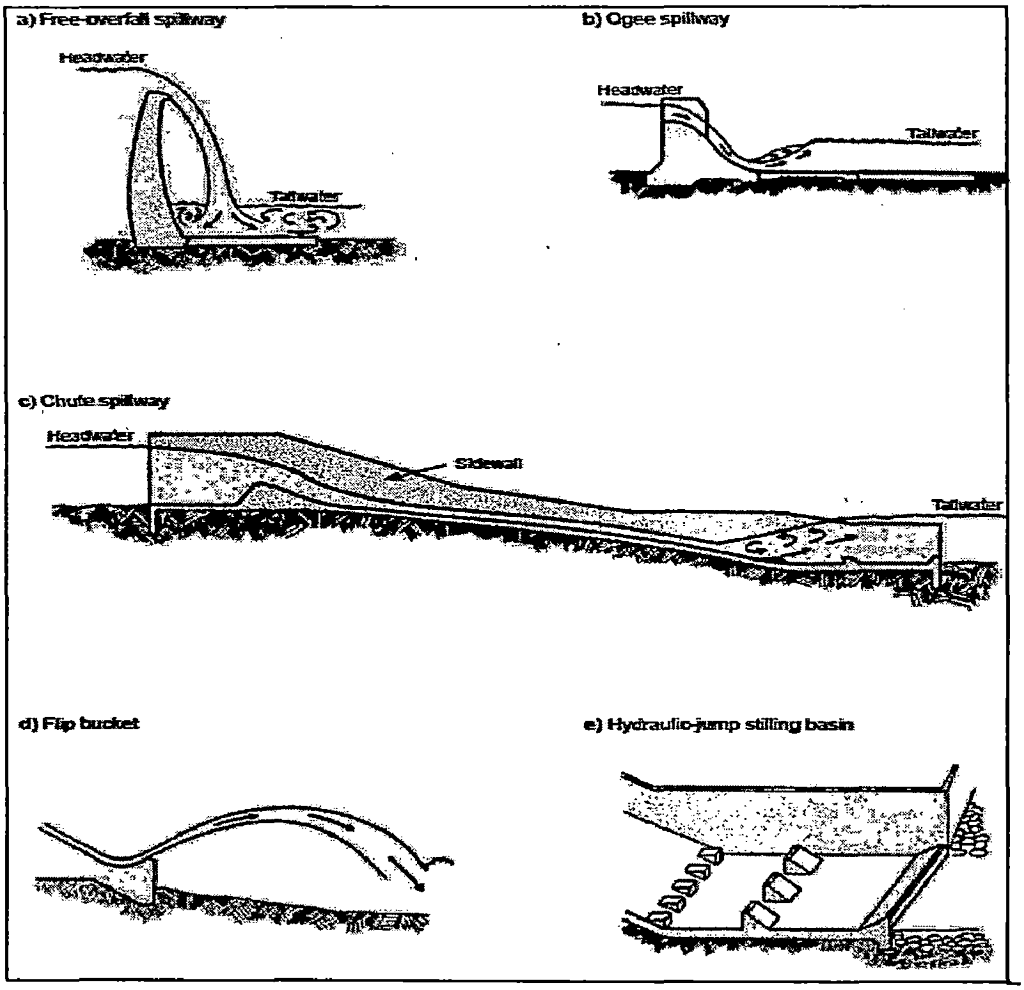


Fig.: 2.3.5 Several Spillway Types [44]

The discharge must be designed to avoid any contact with fish and to ensure that, at mortality induced by nitrogen super saturation. For example S-shaped or "skijump" structures can reduce contacts at the base of the dam (Fig.: 2.3.5b and 2.3.5d). The digging of a basin below the dam also reduces the risks of contacts, but it increases the risks of nitrogen supersaturation. The use of deflectors is also recommended to reduce nitrogen supersaturation, but, depending on site configuration and water depth at the base of the dam, they may become a constraint if they induce collisions with fish (Fig.: 2.3.5e). The head must not exceed 30 to 40 m for fish 150 to 180 mm in length, and 12 m for fish larger than 60 cm at facilities where a free fall occurs (Fig.: 2.3.5a). Apparently, the net head is not limiting for fish smaller than 130 mm. In general, these constraints are likely to be more limiting at structures higher than 30 m, although excellent results (98% survival) had been obtain with a free fall of 90 m. Injuries may also occur by abrasion on the structure if it is not smooth, or by sudden pressure changes. The general shape of the upstream end of spillways should be broad-crested to prevent avoidance reactions by fish. [44]

2.3.5.2 Sluiceway

Sluiceways are typically used to bypass ice and debris at hydropower projects, but they can also provide an adequate and generally successful means of downstream passage provided fish are able to locate them. Small hydropower projects often rely on sluiceways for passage. This type of passage may work well for surface or near-surface oriented fish (i.e., clupeids, salmonids, and some riverine species) but may not work as well for fish distributed elsewhere in the water column. Entrance location, adequate flow, and thorough maintenance and debris removal are critical factors to sluiceway success. The sluiceway should be located to one side of the powerhouse, generally at the most downstream end, with its outfall located so as not to interfere with the attraction flow of the upstream fishway. The greatest problem associated with sluiceways is the potential for predation at the entrance or exit.

2.3.6 ALTERNATIVE BEHAVIOURAL GUIDANCE DEVICES

The various methods that employ sensory stimuli to elicit behaviours that will result in down migrating fish avoiding, or moving away from, areas that potentially impair fish survival. In all cases, the purpose is to get fish to leave a particular area (e.g., a turbine intake) and move somewhere else. The nature of the response may be long-term swimming in response to a continuous stimulus where the fish has to move some distance (e.g., a sound that is detected for an extended period of time and from which the fish continues to swim), or it may be a "startle response" that gets a fish to turn away and then continue in a different direction without further stimulation. Any stimulus that produces a startle response or frightens a fish from a particular place (essentially exclusion) is not a suitable deterrent unless there is a component to the response that moves the fish in a specific direction that leads to safety as opposed to swimming away from the stimulus in a random direction Behavior-based technologies are touted as being less expensive than physical screening devices and easier to install than more conventional methods. Another presumed benefit is that these technologies can be used to the physical plant or project operation. Lastly, developers of these technologies claim that although they have not yet achieved 100 percent effectiveness, they have shown that various behavioural methods do guide fish, and that guidance can be improved upon with research and experimental application. [45]

2.3.6.1 Acoustic Array

Sound has many characteristics that make it suitable for use in the possible modification of fish movement, especially over longer distances or when visibility is marginal. Sound travels at a high rate of speed in water, attenuates slowly, is highly directional, and is not impeded by low light levels or water turbidity. Moreover, many species of fish are able to detect sounds. From the standpoint of directionality, attenuation characteristics (especially with depth), the lack of effect of turbidity, and suitability during the day and night, other potential signals are not as versatile as sound. At the same time, high noise levels, such as at turbine intakes, may prevent fish from hearing artificially generated sounds in such environments, while high-intensity sounds (produced by any source) might have deleterious effects on fish. [46]

2.3.6.2 Strobe and Mercury Lights

Many species of fish have well-developed visual systems. Light has a high rate of transmission in water and is not masked by noise. At the same time, the usefulness of light depends upon the clarity of the water as well as upon the contrast between the artificial and ambient light. Two types of lighting are the most widely used in experiments—mercury and strobe. Of the two, experimental results suggest that strobe lights (pulsing light) are the more successful in affecting fish movements, although mercury illumination was useful in a number of instances, including attracting and holding blueback herring at the Richard B. Russell Dam to keep them from entering undesirable areas. At the same time, light may attract some species and repel others living in the same habitat.

2.3.6.2.1 Strobe Lights

Strobe light has been extensively evaluated as a fish deterrent in both laboratory and field situations. Deterrence has been shown with a number of species, but the lights have worked most extensively and effectively with American shad juveniles. Successful fish deterrence with strobe lights has often been site specific, which indicates that hydraulic and environmental conditions and project design and operation have influence on the effect the lights have on species. The lack of conclusive results may also be attributed to inadequate sampling methodology and design

This type of lighting has a repulsive effect on fish (300 to 600 flash/min for salmon). Water turbidity, concentration of suspended sediments and current velocity can influence the efficiency. When currents are weak, strobe lights have had 90% success for shad, smelt and alewife. For salmon, the efficiency of this device ranges from 20 to 93%, and is related to current velocity, and time of day (day/night). Variable results were also obtained for eels (65 92%). The device is also considered efficient for largemouth bass, catfish and walleye. In general, the efficiency ranges from 65% to 99%. However, it seems to be low at velocities above 1 m/s for all the species tested. Strobe lights are significantly more efficient when used in combination with other devices. [47]

2.3.6.2.2 Mercury Lights

The use of mercury lights to attract or repel various species including salmonids and clupeids is reviewed by EPRI. The results suggest that such illumination can be used with a number of species to move fish away from intakes, although the results are quite variable between sites and species. Such illumination may be more effective at night than during the day (not an unreasonable situation considering the contrast between the stimulus and ambient illumination differs greatly at night). Incandescent illumination has been tried as a method to modify behaviour, but with no clear success. Studies conducted at the York Haven project on the Susquehanna River indicate that mercury lights can be highly effective in attracting gizzard shad, and several studies have successfully improved bypass rates of salmonid species using mercury or incandescent lighting. The relatively inexpensive nature of mercury lights is a driving force of research. However, additional research is necessary to determine the feasibility of using sound as part of a directional bypass system. [48]

2.3.6.3 Electric Field

The occurrence of an electric field in the vicinity of hydropower facilities tends to repulse fish and direct them toward artificial or natural bypasses (Fig.: 2.3.6). The frequency and intensity of the current, as well as water quality and temperature affect its efficiency. Experiments made with three species of salmonids in downstream migration (Chinook salmon, Coho salmon and rainbow trout), at varying current velocities, have demonstrated an efficiency ranging from 40 to 84%. An efficiency of 84% was also recorded for rainbow trout, brown trout, largemouth bass, gizzard shad and golden shiner.

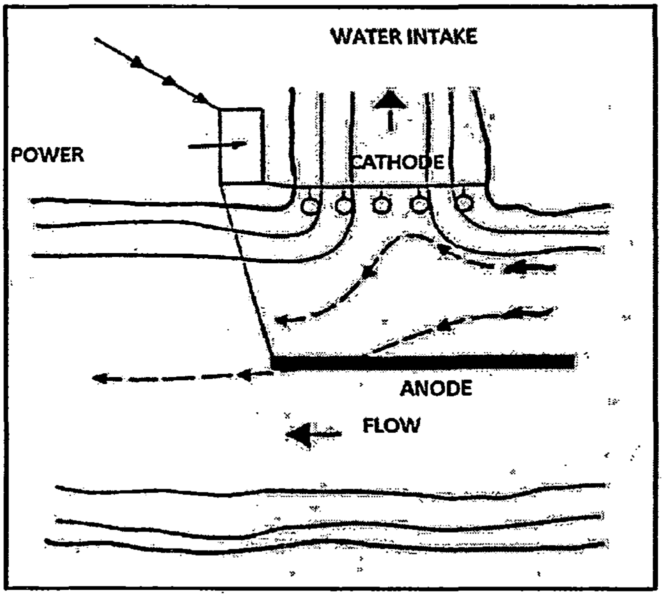


Fig.: 2.3.6. Schematic view of an electric field [49]

This method has better results in preventing upstream migration than in preventing downstream migration or guiding fish in a desired direction. In the latter case, fish that do not respond quickly to the stimulus can become shocked when entering in the stronger portion of the electric field, and then be entrained by the turbine intake flow without any possibility of avoidance. A new device using a gradual electric field has been developed, but it has only been tested on upstream migrations to prevent access to potentially hazardous zones. [49]

2.3.7 OTHER METHODS

2.3.7.1 Trapping and Trucking

Transportation as a means of providing downstream passage of juvenile fish encompasses both trap and truck operations and barging. Transporting fish around hydropower facilities is used for a variety of reasons: to mitigate the loss of fish in long reservoirs behind dams; to avoid the impacts of nitrogen supersaturation that may be associated with spilling water; to decrease the possibility of turbine entrainment; and to help avoid predation problems associated with locating bypass entrances to downstream fish passageways and diversion systems. The use of transportation to move juvenile salmonids downstream in the Columbia River Basin is to decrease the time it takes for out migrants to move through the system. However, transportation in the Basin is controversial. During high flow periods, the need for transport is diminished, while during low flows the need for transportation is favoured, in part due to the length of time required for the juveniles to move through reservoirs. During high flows juveniles may be bypassed by spilling and may be able to pass relatively quickly through reservoirs. However, during times when flows range somewhere in the middle, the use of transportation becomes controversial.

Fish may be captured above the dam(s) and powerhouse(s), and transported downstream by truck. Trapping of fish usually requires deviation structures to lead fish to the traps. Powerhouse with a head race may be advantageous since the trap system can be installed directly in this channel. However, in the case where there are several dams on the same water course, this option is only practical if a single device is used at the most upstream dam, and if fish production is low between dams. This system can also be used in combination with one of the previous devices, when neither a bypass nor troughs are used to allow downstream passage of fish. [50]

2.3.7.2 Pumping

The hydropower industry is currently examining the application of fish collection systems, or *pumps,* to collect and divert fish at intakes. There are air-lift, screw impeller, jet, and volute pumping systems. These pumps could be used to force fish into bypass pipes for downstream passage at hydropower projects. Pump size and speed, however, may affect fish survival. Fish pumps are not widely used because they can lead to injury and de-scaling as a result of crowding in the bypass pipe and to disorientation once released back into the river environment, and do not allow the fish to move on their own. Historically, the conventional wisdom of the resource agencies is to use bypass methods which allow fish to move of their own volition. However, a major research effort spearheaded by the Bureau of Reclamation is underway at Red Bluff Diversion Dam on the Sacramento River. Tests are being done to evaluate the usefulness of pumps to pass juvenile salmonids. Both the Archimedes screw and the Hydrostal-Volutepumps are being tested for the effective and safe passage of fish. [51]

2.3.7.3 Spilling

Spill flows, or water releases independent of power generation, are the simplest means of transporting juvenile fish past (over) a hydropower project and away from turbines. Increased spill to flush fish over a dam can be especially cost-effective when the downstream migration period of the target species is short, when migration occurs during high river flows, or where spill flows are needed for other reasons (e.g., to increase dissolved oxygen levels to maintain minimal instream flows). Care should be taken to ensure that spillway mortality does not exceed turbine passage mortality [9].

2.3.7.4 Turbine Passage

An explicit assumption behind the design of downstream bypass systems at hydropower facilities is that fish mortality associated with the bypass will be significantly less than turbine mortality. This assumption is reasonable for many small-scale facilities, but is not always borne out at hydropower plants with large, efficient turbines [9]. Turbine- induced fish mortality may be greatly overestimated or underestimated, and can vary considerably from site to site. Turbine passage exposes out migrating juveniles to blades, which can either de-scale or kill them, and distinct pressure changes, which can cause physical injury and/or death. Turbine mortality increases with fish size, suggesting that physical impact is also important. At the edge of the turbine blade are areas of negative pressure that can be strong enough to pull molecules of metal from the turbine blades and likewise can cause damage to fish in the same vicinity. Various turbine designs have been found to be linked to varying mortality rates for naturally and experimentally entrained fish. Francis turbines are designed with "fixed" blades to accommodate a given head, flow, and speed. Kaplan turbines have "adjustable" blades which are better for low-head operations and seem to be better for fish survivability (i.e., are more "fish friendly"). To evaluate turbine mortality, fish must be tagged and released in the intake and then captured in the tailrace. The mark, release, and recapture technique has been found to be the most effective method of evaluating resultant turbine mortality for salmonid species; however, it has not been proven to be as useful for alosids. Operational factors can also affect turbine mortality rates. Running turbines at maximum overload during high power demands can result in higher losses of juveniles. The new turbine design is based on a number of concepts: it allows for shallow intakes, and a smaller number of blades; it is capable of increasing dissolved oxygen in the tailwater; it has a wide flow range and is non-cavitations; it also is greaseless and oil-free. These design considerations aim to increase survivability. Other factors are equally important to successful passage, such as where the fish exist in the turbine, what the blade strike range is, and what affect the pressure gradient that occurs in the vortexes between blades (gap flows) has on the juveniles. Principals in the turbine industry predict that technology is moving toward the use of these variable speed units. [52]

In this chapter we discussed the success of a fish passage technologies at a hydropower facility is dependent on many factors. Effectiveness is directly related to biology and behaviour of the target species, as well as hydrologic conditions both up- and downstream of the project. Here a detailed review is done on the upstream, downstream and turbine passage technology and find out how they efficient to reduce the fish mortality in these region. By explain all the up and down stream devices the turbine passage is the most fish effected region.

CHAPTER 3

LOW HEAD KAPLAN TURBINE AND FISH BEHAVIOUR

Kaplan and propeller turbines are axial-flow reaction turbines; generally used for low head from 2 to 40 m. The Kaplan turbine has adjustable runner blades and may or may not have adjustable guide- vanes. If both blades and guide-vanes are adjustable it is described as "double-regulated". If the guide-vanes are fixed it is "single-regulated". Fixed runner blade Kaplan turbines are called propeller turbines. They are used when both flow and head remain practically constant, which is a characteristic that makes them unusual in small hydropower schemes. The double regulation allows, at any time, for the adaptation of the runner and guide vanes coupling to any head or discharge variation. It is the most flexible Kaplan turbine that can work between 15% and 100% of the maximum design discharge. Single regulated Kaplan allows a good adaptation to varying available flow but is less flexible in the case of important head variation. They can work between 30% and 100% of the maximum design discharge. [5]

In the low head turbines, we found that the maximum mortality rate of fish occur in the Kaplan turbine because of its maximum flexibility. In the Kaplan turbine wicket gate and runner blade both are adjustable so due to any adjustment there is many changing occur which not suitable for fish passage. For Kaplan turbines, fish that pass higher through the wicket gate openings will pass nearer the runner hub, while those passing lower through the wicket gate openings will pass nearer to the tips of the runner blades. Therefore finding the maximum fish mortality rate in this we are going to study about it than going to other hydroturbines.

3.1 KAPLAN TURBINE

Kaplan turbines have been developed to be the most employed type of turbines for low heads and comparatively large discharges. The Kaplan turbines are fairly suitable due to the following three main reasons:

- Relatively small dimensions combined with high rotational speed
- A favourable progress of the efficiency curve
- Large overloading capacity

The runner has only a few blades radial oriented on the hub and without an outer rim. The water flows axially through. The runner blades have a slight curvature and cause relatively low flow losses. This allows for higher flow velocities without great loss of efficiency. Accordingly the runner diameter becomes relatively small and the rotational speed more than two times higher than for a Francis turbine for the corresponding head and discharge. In this way the generator dimensions as well become comparatively smaller and cheaper. The comparatively high efficiencies at partial loads and the ability of overloading are obtained by a co-ordinated regulation of the guide vanes and the runner blades to obtain optimal efficiency for all operations. [53]

Kaplan turbines are certainly the machines that allow the most number of possible configurations. The selection is particularly critical in low-head schemes where, in order to be profitable, large discharges must be handled. The hydraulic conduits in general and water intakes in particular, are very large and require very large civil works with a cost that generally exceeds the cost of the electromechanical equipment.

Table: 3.1 All possible configurations of Kaplan turbine. [5]

Configuration	Flow	Closing system
Vertical Kaplan	Radial	Guide-vanes
Vertical semi-Kaplan siphon	Radial	Siphon
Inverse semi-Kaplan siphon	Radial	Siphon
Inclined semi-Kaplan siphon	Axial	Siphon
Kaplan S	Axial	Gate valve
Kaplan inclined right angle	Axial	Gate valve
Semi-Kaplan in pit	Axial	Gate valve

3.2 SCHEMATIC ARRANGEMENT OF KAPLAN TURBINE

A vertical section through a Kaplan unit is shown on Fig.3.1. From the upstream basin the water flows into the scroll casing. The water flows from the scroll casing through the stay ring, the guide apparatus, the runner and the draft tube into the tail water basin. The generator is arranged above the turbine, and in most cases above the highest level of the tail water. The axial thrust bearing is loaded with axial forces from all the rotating parts. In many cases this bearing is arranged upon the upper turbine cover, which then has to carry all the axial forces. [7]

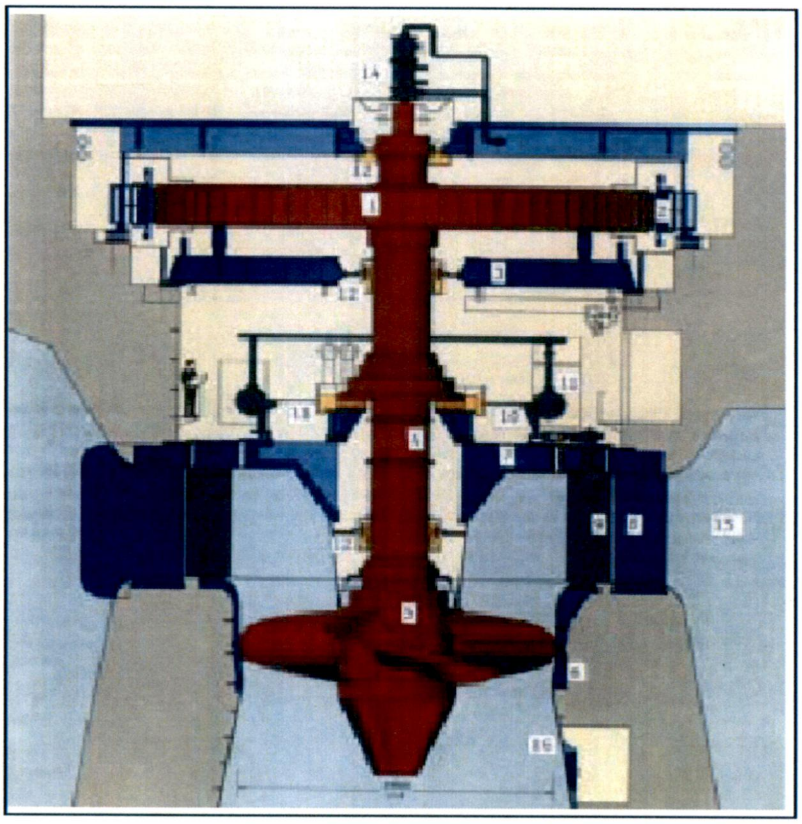


Fig.: 3.1. Schematic diagram of Kaplan turbine [7]

3.2.1 Main Components and Their Functions [53]

The Kaplan turbines have the following main components:-

a. Scroll casing and stay ring
b. Guide apparatus
c. Covers
d. Runner
e. Runner blade servomotor
f. Regulating mechanism of the runner blades
g. Co-operation of regulating the runner blades and guide vanes
h. Turbine shaft
i. Turbine bearing
j. Shaft sleeve and seal box
k. Runner chamber
l. Draft tube

3.2.1.1 Scroll Casing and Stay Ring

The scroll casings for lower heads 25 - 30 meters are made of concrete. To make these types of scroll casings with the required accuracy, wooden models are used against which the concrete is poured. The manufacturer of the turbine determines the shape and makes the drawings of these models. The quality of a water tight and even surfaces of the scroll casings is required to be the same as for draft tube bends of concrete. For higher heads the hydraulic pressure may be too high for the concrete to withstand the load. In such cases scroll casings of steel plates are designed in a way analogous to that of Francis turbines as shown on. The cross sections of the scroll casing are normally of circular shape, and the steel plate shells are welded to the stay ring. The vanes in the stay ring conduct the water towards the guide vanes. In addition the hydraulic forces are transferred through the stay ring and the stay vanes which are anchored to the concrete with large pre-stressed stay bolts. The stay vanes are normally made of welded steel plates and filled with concrete.

3.2.1.2 Guide Apparatus

The guide vane cascade of Kaplan turbines are constructed in the same way as for Francis turbines. In the sense of operation a regulating ring rotates the guide vanes through the same angles simultaneously when adjustments follow changes of the turbine load. The vanes are manufactured of steel plate material and the trunnions are welded to them. The vane design is purposely to obtain optimal hydraulic flow conditions, and they are given a smooth surface finish

3.2.1.3 Covers

The Kaplan turbines are usually provided with an inner cover in addition to an upper and a lower cover. The inner cover is bolted to the upper cover and forms a shield from upper flow conducting surface and downwards to the runner. Furthermore this serves as a support for the guide vane mechanism with the regulating ring, the turbine bearing and the shaft seal box with standstill seal. The lower turbine cover is combined with the runner chamber by a flanged connection

3.2.1.4 Runner

The runner in a Kaplan turbine is a very challenging part to design. The details for adjusting the blades can be designed in different ways. Increasing blade number for increasing head may create problems because of lack of space and consequently high stresses in some details of the construction. It is not however, only the head that determines the number of blades. The blade length and shape as well as the specific blade loading and location in relation to the downstream water level, are factors which must be considered. As a general guideline four blades can be used up to heads of 25 - 30 meters, five blades up to 40 meters, six blades up to 50 meters and seven blades up to heads of 60 - 70 meters. Kaplan turbines have also been designed with 8 blades for heads even higher than 70 meters. This increases the hub diameter and the shape of the hub becomes more complicated, and the efficiency may suffer. The outside of the hub is spherically shaped as shown on Fig. 3.2.

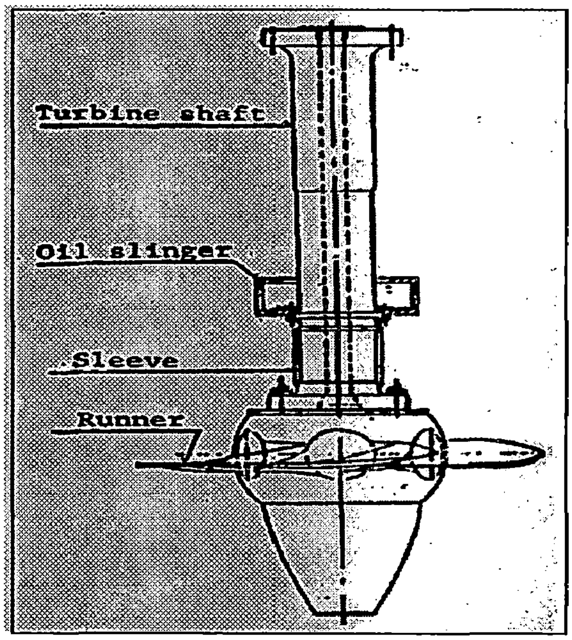


Fig.: 3.2 Runner of Kaplan turbine

This is done to keep a small clearance gap between the adjustable blade ends and the hub for all operating conditions. With increasing head the hub diameter is increasing from approximately 40% to 65 - 70 % of the runner diameter. The torque of the runner is transferred to the turbine shaft through either a pure friction joint connection or through a combined shear bolt and friction joint. The bolts joining the turbine shaft flange and the runner are pre-stressed by means of heat for the largest bolt dimensions. [53]

3.2.1.5 Runner Blade Servomotor

The servomotor for the rotary motion of the runner blades is either a construction part of the turbine shaft or located inside the hub. There are however, good reasons for localising the servomotor inside the hub, and the details of a construction are dealt with in the chapter of bulb turbines. This servomotor may consist of a moving cylinder and a fixed piston integrated with the hub. The conversion from axial piston movement to rotating blade movement is carried out by a link and lever construction. The hub is completely filled with oil to provide reliable lubrication of moving parts. The oil pressure inside the hub is kept higher than the outside water pressure to prevent water penetration into the oil.

3.2.1.6 Regulating Mechanism of the Runner Blades

The oil supply to the servomotor is entered at the upper end of the generator shaft. The oil is conveyed to the respective sides of the servomotor through two coaxial pipes and inside the hollow generator shaft. The inner tube conveys oil to and from the lower side of the piston whereas the annular opening between the pipes and conveys oil to and from the chambers and at the top of the unit.

3.2.1.7 Cooperation of Regulating the Guide Vanes and the Runner Blades

The turbine governor operates directly on servomotor which executes the movement of the guide vanes. The movement of the servomotor thriggs and controls the slope adjustment of the runner vanes. This is carried out by a rod and lever transfer from the servomotor to the cam which is turned according to the movement of the servomotor piston. In this way the spool valve is moved out of the neutral position and the servomotor piston is then put to movement by the oil pressure supply. The spool valve receives pressure oil either directly from the oil pump or from the accumulator which is energised by an oil pump.

3.2.1.8 Runner Chamber

The clearance gap between the outer blade ends and the chamber wall is essential to keep as small as possible for all blade inclinations. Therefore the runner chamber is made spherical below the rotation centre line of the blade trunnions. Ideally the spherical shape should have been maintained above the blade rotation centre as well however, on account of installation and dismantling aspects, this part is being made cylindrical as shown on fig.3, which is a concept of Escher Wyss. The gap between the runner blade ends and the runner chamber wall is approximately 0.1% of the runner diameter. On fig. 3.3, the length of the runner chamber is indicated by H. The runner chamber is normally completely or partly embedded in concrete. The turbine shown on fig. 3.3 has an access tunnel around the complete circumference, providing access to the lower guide vane bearings. In combination with this tunnel there is a manhole access to the runner chamber for inspection of the runner blades. In the lower part of the runner chamber there is a tap for connection of a vacuum meter. In the lower part holes are plugged by means of removable stainless steel plugs.

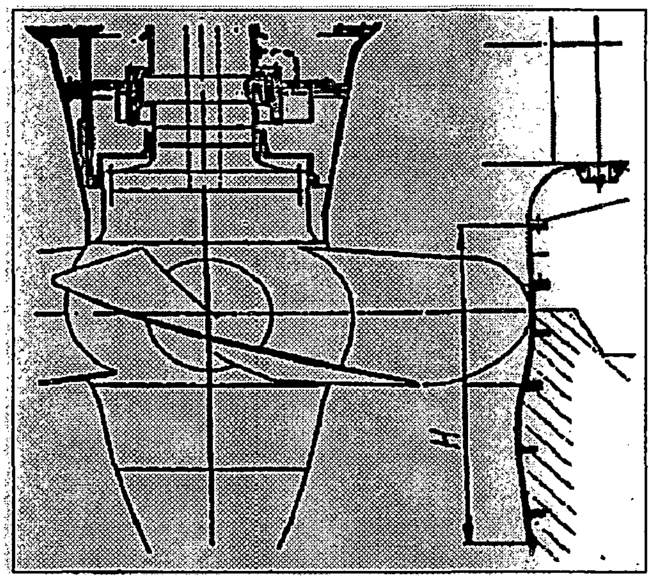


Fig.: 3.3. Runner Chamber

3.2.1.9 Turbine Shaft

The turbine shaft is made of Siemens Martin steel and is provided with integrally forged flanges in both ends. In the area of the shaft seal box, a wear sleeve made of stainless material is clamped around the shaft. The rotating oil reservoir is bolted to the turbine shaft.

3.2.1.10 Turbine Bearing

This bearing is a rather simple and commonly used design and has a simple way of working and a minimal requirement of maintenance. The bearing house is split in two halves and mounted on the upper flange of the upper cover. The bearing pad support ring consists of two segments bolted together and mounted to the underside of the bearing house. The pad support ring has four babbit metal bearing surfaces with correctly shaped leading ramps ensuring stable centring of the turbine shaft. In the pad support ring there are also four oil pockets. The upper part of the housing has a cover split in two halves with inspection openings. By load rejections the turbine is subject to a vertical force acting upwards and this may cause a lifting of the unit. The back thrust ring then hit the underside of the bearing pads which transfer the vertical force to the base of the bearing. The back thrust ring is made of bronze and is provided with lubrication grooves ensuring a good distribution of oil, and a load carrying oil film is then attained.

3.2.1.11 Shaft Seal Box

A commonly applied seal box for Kaplan turbines is the carbon ring box. The seal elements against the turbine shaft consist of specially made split carbon rings which are pressed against the shaft by means of spiral springs. The seal box is exposed to a fluctuating pressure from the turbine waterside and the rings must be located with this in mind. The turbine shaft is exposed to certain wear by the seal rings. The shaft which is passing through the seal box is therefore provided with a wear sleeve of stainless steel.

3.2.1.12 Draft Tube

The draft tube consists of a draft tube cone and a draft tube plate lining through the bend. The water has a relatively large velocity when it leaves the runner. This kinetic energy must be converted to pressure energy in the draft tube. To obtain this with a minimum of losses, the outlet velocity at the draft tube outlet should be as uniform as possible. Because the kinetic energy represents a high fraction of the total energy, the shape of the draft tube is of great importance for the hydraulic efficiency. The draft tube of a Kaplan turbine has a somewhat special shape. The units have comparatively large dimensions and the civil works are expensive. It is therefore a requirement to make the draft tube as shallow as possible. The cone, the upper part and the inner curve surface are always lined with steel plates. The rest is normally made of unlined concrete. The formwork and the pouring of concrete are made as simple as possible by making the walls straight with single curved surface only. [5]

3.3 MECHANISMS OF FISH INJURY THROUGH THE TURBINE

The survival of a turbine-passed fish is highly dependent on the path that the fish takes through the turbine system. Once a fish departs the forebay and enters a turbine system it must contend with changes in physical geometry and flow characteristics that are very rapid and believed to be injurious in certain zones along the path. An illustration of the damaging zones within a turbine system is shown in Fig. 3.4. [7]

Potential damage mechanisms were identified and loosely grouped into four categories; mechanical, pressure, shear, and cavitation. Mechanical causes include strike, abrasion, and grinding. Pressure fluctuations, shear stress, turbulence, and cavitation are related to flow characteristics. After identifying the damage mechanisms, the next logical step would be to determine biological design criteria that, when incorporated in new and rehabilitated turbines, would make them more fish friendly.

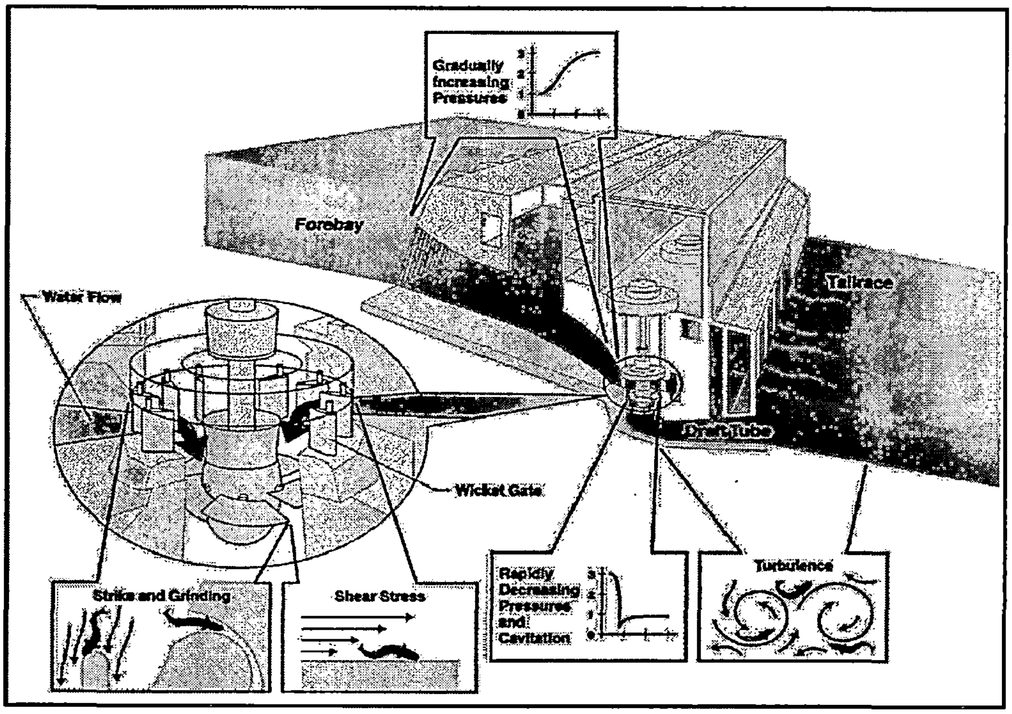


Fig.: 3.4 Locations within a hydroelectric turbine at which particular injury mechanisms to turbine passed fish tend to be most severe. [54]

3.3.1 Mechanical Injury Like Abrasion, Grinding, and Strike

The rubbing action of a fish against a turbine system component or objects in the flow field is referred to as abrasion, and can cause damage to the fish. Abrasion damage is dependent on flow discharge and velocity, number of turbine blades and spacing between them, and the geometry of flow passages. Data are not available to identify the amount of or to distinguish injury due to abrasion. Grinding injury can occur when a fish is drawn into small clearances (gaps of sizes close to that of the fish) within the turbine system. Gaps with high velocity zones that may cause grinding injury are present between the turbine blade leading edge and the hub, the blades and the throat ring, the wicket gates and stay vanes, and between the wicket gates and the distributor ring. [10] Grinding injury can be documented by examining the fish's body for localized bruises, deep cuts, and even decapitation. However, precise prediction of injury due to abrasion and grinding is not possible, and some of the fundamental symptoms of grinding may also be caused by other fish injury mechanisms. [56]

A fish may be injured when it collides with (strikes) a turbine system component. The probability of a fish striking parts of the turbine system depends on several factors which include the size of the fish, number of blades and their spacing, turbine speed, flow velocity and discharge, among others. Several equations have been developed to calculate the probability of strike in Francis and Kaplan type turbines. These probability equations make the assumption that a strike means serious injury or death, which may not always be true. The probability of a fish dying from striking an object within the turbine system is variable. A blade and a fish striking each other (colliding) may cause scale and mucous loss, eye injury, and internal bleeding depending on the velocities involved and the shape of the blade's leading edge. Direct visual observations are not available to correlate mortality to strike and to verify the strike probability models. Data on specific causes of mechanical injury to fish passing through turbines are very limited and when compared to the field results, probability models yield varying results. [57]

3.3.2 Pressure

Fish are subjected to rapid pressure changes throughout the turbine system. Damage due to pressure is dependent on the amount and rate of change of pressure experienced by the fish as well as the type of the fish. Physostomous fish, such as salmon and trout, have a pneumatic duct 10 that connects the swim bladder to the esophagus, which is used, along with the mouth, to rapidly take in or vent gas. [56]

Physoclistous fish, such as perch and bass, do not have a pneumatic duct and must adjust their body's gas content by diffusion into the blood. Because this diffusion process may take hours, these fish are more susceptible to damage due to rapid pressure decrease. Pressure changes felt by a fish are relative to its acclimation pressure prior to entering the turbine system. These typically range from low-head plants to high-head plants. [55]

3.3.3 Cavitation

The presence of voids in the liquid has a damaging effect on marine and hydraulic turbine propellers. Cavitation is the rapid vaporization and condensation process of liquid. It normally occurs when the local pressure in the liquid drops to or below vapor pressure, and with nuclei present in the liquid vapor cavities (bubbles) are formed. These bubbles grow within the vapor pressure region and then become unstable and collapse as they travel to areas with higher pressures. The collapse of bubbles can sometimes be violent and cause noise, vibrations, pressure fluctuations, erosion damage to solid surfaces, and loss of efficiency or flow capacity. Cavitation damage can occur as a result of high-pressure shock or high-velocity micro jets shooting through the centre of the bubble creating a local pit to the bubble's adjacent solid boundary Mortality in fingerling salmon was 50% when they were subjected to vapor pressure followed by instantaneous return up to atmospheric pressure; the damage was attributed to the high-pressure shock waves as vapor pockets in the test chamber collapsed. Cavitation can also reduce turbine efficiency, which in some cases indicates an increase in fish mortality. [58]

3.3.4 Turbulent Shear Stress

Shear stresses in the flow field are a result of the change of velocity with respect to distance, or the rate of deformation of the fluid. Shear stress is expressed as the force acting on an area parallel to its direction. The spatial change of velocity can be attributed to both viscous forces and fluid flow properties, or fluid-induced forces due to its acceleration and local turbulence. The highest values of shear stress are found close to the interface between the flow and solid objects it speeds by, such as the blade leading edges, vanes, and gates. Fish are believed to sustain injuries, sometimes lethal, when they encounter zones of 'damaging' shear stress within the turbine system; injuries are dependent on fish species, size, and the manner they enter the shear zone. [59]

Typical velocity changes across shear zones are on the order of 30 ft/sec, which is higher than velocity gradients inside Kaplan turbines. Shear stress zones are also associated with vortices within the flow field. Most Kaplan turbines have gaps near wicket gates and runner blades, and leakage from these and non-optimal turbine operation produce flow separation which create vortices with high shear stress zones.

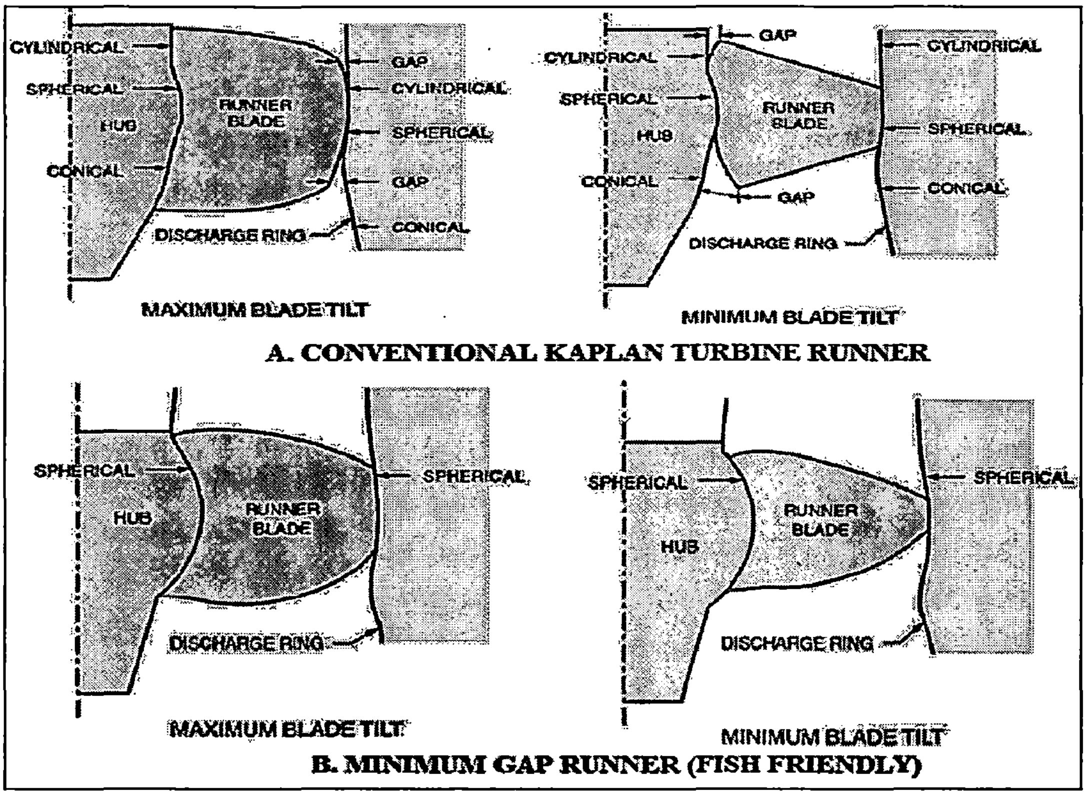
Quantifying these high shear stress zones can assist in designing and operating a turbine so that shear stress zones are minimized and fish survivability is enhanced. For example, maximizing the blade tilt and matching its leading edge angle to the incoming velocity vector minimizes vortices in a Kaplan turbine, which reduces shear stress zones. Vortices in the draft tube swirl also have associated shear stresses and may be a primary source of shear stress damage to fish in Francis turbines. [55]

3.4 DESIGN CONCEPTS

The design concepts provided here can be used for both rehabilitating existing turbines as well as new turbines in order to improve their compliance with the new age of environmental awareness and safe fish passage. These new concepts would also benefit the hydropower plant in more ways. The design modifications would result in a more efficient operation; more generated power, and reduced operation and maintenance costs. An environmentally friendly Kaplan turbine is one that generates power efficiently, passes fish safely, and costs less to operate and maintain. Following is a list of design concepts that make existing and new turbine designs more fish and environmentally friendly.

1. A turbine should be operated at high efficiency with no cavitation and reduced back roll; reducing the probability for fish injury and decreasing runner replacement costs.
2. Removing the gaps within a turbine system eliminates the added probability of fish injury and enhances the turbine efficiency. Eliminating gaps at the wicket gates or between the blades and the hub and discharge ring is believed to minimize fish injury due to grinding. Side by side comparison of a typical Kaplan runner and a fish friendly Kaplan runner are shown on Fig. 3.5. The gaps were removed by changing the shape of the hub and discharge ring from the cylindrical-spherical-conical shape to one that is all spherical, and recessing the blades into the discharge ring.

The fig. 3.5 as shows the maximum and minimum tilt angles. Unlike fixed blade, propeller-type runners, blades on Kaplan and MGR runners are pivoted on the hub to maintain efficiency under different flow rates. Gaps on a conventional Kaplan turbine between the blade tip and discharge ring and between the blade and the hub are reduced in the MGR by changing the shape to a more spherical profile.



A. CONVENTIONAL KAPLAN TURBINE RUNNER

B. MINIMUM GAP RUNNER (FISH FRIENDLY)

Fig.: 3.5 Comparison of conventional Kaplan turbine runner and a Minimum Gap Runner (MGR) [59]

3. Eliminate the wicket gate overhang. Eliminating the overhang of wicket gates by changing the shape of the discharge ring from cylindrical to spherical results in eliminating the gaps between the wicket gates and the discharge ring. Leakage through gaps causes strong vortices with high shear stress that can potentially injure fish. Reducing the wicket gate overhang will also increase the efficiency of the power plant by reducing losses caused by the leakage at the wicket gate see Fig. 3.6.

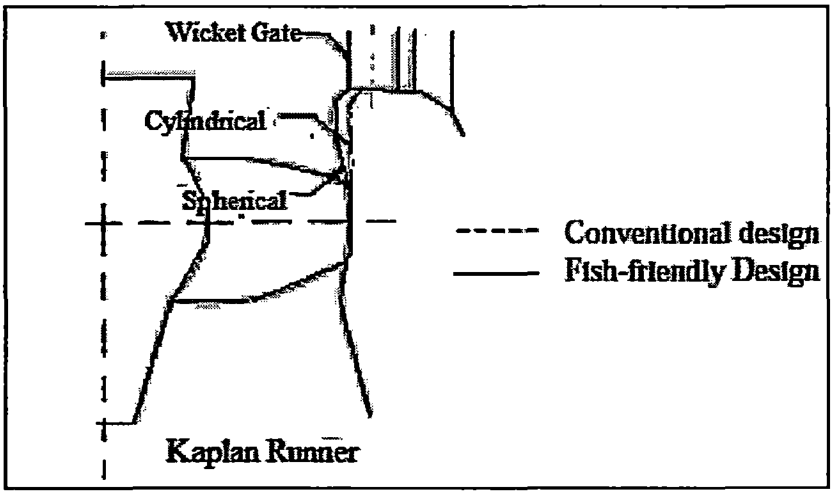


Fig.: 3.6 Elimination of wicket gate overhang in Kaplan Turbines. [59]

4. Properly place the wicket gates and stay vanes to minimize the potential for fish injury due to strike and flow behaviour induced stresses. Use a hydraulically smooth stay vane and place it relative to the gates in such a way as to provide efficient operation of the turbine and decrease fish injury. Fig. 3.7.

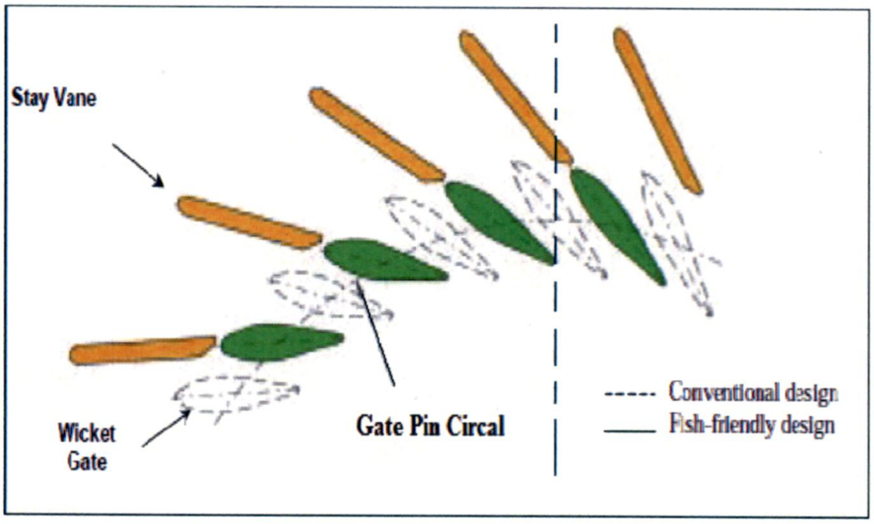


Fig.: 3.7 Locating wicket gates properly behind stay vanes to maximize efficiency and minimize probability of strike. [59]

5. Use environmentally friendly lubricating fluids and greases. Use a biodegradable fluid in the hub and greaseless wicket gates bushings. This prevents pollutants from being discharged into the water, enhancing water quality for the aquatic habitat downstream of the power plant.
6. Polish the surfaces. Keep surfaces smooth on the turbine's stay vanes, wicket gates and draft tube cone. Welds on the various parts of a turbine system can be made smoother to reduce abrasion injury to fish, Fig. 3.8. In certain areas where the velocity is low smoothing the surfaces and weld may not be a necessity and could be costly.

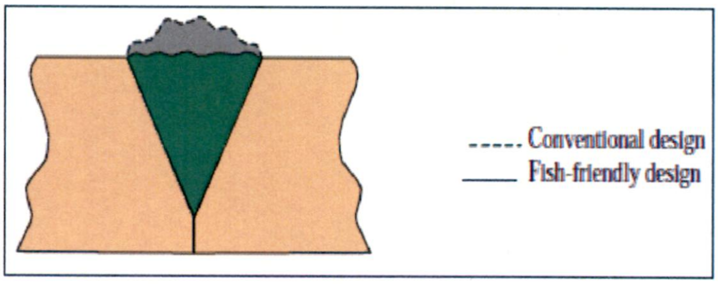


Fig.: 3.8 Schematic of a rough weld joint smoothed over for fish safety. [59]

7. Use of advanced control system to operate the hydropower plant electrical components efficiently, which is also believed to be more fish friendly.
    - Runner rotational speed and generator speed can be adjusted to maintain turbine operation at the "fish friendly" point at any required discharge. It is recommended that the addition of this type of equipment be accompanied with new runner upgrade at the same time.
    - Ensure cam optimization to provide maximum efficiency operation and minimize flow stresses by maintaining turbine blade and wicket gates positions for maximum efficiency, and perhaps minimal fish injury.
    - Install sounding devices to give warning when the trash racks need cleaning. Clean trash racks minimize flow disturbance and allow surface oriented fish to enter the intake from its upper portion, therefore minimizing blade tip strike that may occur when fish are forced to enter at the bottom of the intake.
8. Draft tube piers. Total removal of draft tube piers may not be a possibility due to structural reasons. However, design the draft tube piers to be hydraulically smooth (round nose) to reduce flow separation and possibility of strike.

3.5 NUMERICAL MODEL FOR FISH PASSAGE

Recent investigations of turbine passage survival suggest that fish are most vulnerable to injury during turbine passage in the immediate vicinity of the turbine runner. Here they can be injured by direct contact with turbine runner blades or exposure to the hydraulic environment where hazardous conditions may exist. Improvement in the survival and the injury rates for fish passing through turbines is being sought by hydropower owners and operators through changes in hydro turbine design and operation. *Blade strike* has traditionally been thought of as the direct contact between a fish and the leading edge of a turbine blade. Von Raben (1957) first identified the variables that could affect the probability of strike and developed one of the first models for predicting probability of strike.

Physical variables identified by researchers as important in estimating the rate of runner blade strike were the number and length of blades in a turbine runner, the rotational speed of the runner, discharge through the runner, and the velocity of impact, which is related to the velocity of the turbine runner blade relative to that of a fish. Important biological variables identified include fish length, mass, stiffness, and the probability of tissue trauma from a strike of a given force, which is specific to fish species and age. Also identified as important was the vertical distribution of fish as they pass through the turbine wicket gates and behaviour that might influence the aspect a fish presents to an approaching runner blade. For Kaplan turbines, fish that pass higher through the wicket gate openings will pass nearer the runner hub, while those passing lower through the wicket gate openings will pass nearer to the tips of the runner blades (assuming fish follow the flow streamlines).

3.5.1 Blade-Strike Model

The theory behind the model is that the fish must pass through the plane of the leading edges of the blades in a turbine runner after the sweep of one blade and before the sweep of the next to avoid strike by a runner blade. The "water length" between two successive blades as

$$Water\ Length = \frac{V_{Axial}}{\cos\theta \bullet n \bullet \frac{N}{60}} \qquad (3.1)$$

where V_{axial} is axial velocity, θ is the angle between V_{axial} vector and the absolute water velocity vector, n is the number of blades, and N is the runner speed in revolutions per minute (RPM). They stated that any fish longer than the water length would be struck by a blade, and the probability of strike was then given by

$$P = \frac{fish\,length}{water\,length} = \frac{l \bullet \cos\theta \bullet n \bullet \frac{N}{60}}{V_{axial}} \qquad (3.2)$$

Where l is the fish length.

In our model, we use another construct as a factor affecting the probability that a fish will be struck during runner passage. We define "critical passage time" t_{cr} as the time between sweeps of two successive blades as

$$t_{cr} = \frac{l}{n \bullet \frac{N}{60}} \qquad (3.3)$$

And the time a fish needs to pass safely through the plane of the leading edges of the runner blades is

$$t = \frac{l \bullet \cos\theta}{V_{axial}} \tag{3.4}$$

A fish will experience a blade strike if it does not pass through this plane within t_{cr} and the probability of strike is then expressed as

$$p = \frac{t}{t_{cr}} = \frac{l \bullet \cos\theta \bullet n \bullet \frac{N}{60}}{V_{axial}} \tag{3.5}$$

This is the same as Equation (3.2).

Von Raben (1957) observed that his blade-strike model always produced an estimate of blade strike that was higher than the proportion of live fish he observed to be injured during passage through the turbine he was modelling. To account for the obvious fact that not all fish struck by a turbine blade were injured, Von Raben introduced the idea of a *mutilation ratio* (MR). The mutilation ratio was simply the ratio between the proportion of fish he estimated to be struck by a turbine blade and the proportion he observed to be injured. To deal with the same issue in his experiments, empirically developed a regression equation of MR for different fish lengths: [60]

$$MR = 0.15533\text{Ln}\,(l) + 0.0125 \tag{3.6}$$

Where MR is mutilation ratio, Ln is natural logarithm, and l is fish length.

3.5.2 Velocity and Geometry Relationship

Of the five variables in the model, n, N, and l are usually known, and V_{axial} is estimated by dividing the turbine discharge Q by the turbine blade-swept area A_{tip}:

$$V_{axial} = \frac{Q}{A_{tip}} = \frac{Q}{\pi(R_{tip}^2 - R_{hub}^2)} \tag{3.7}$$

Where R_{tip} and R_{hub} are the radii of circles formed by the runner blade tip and runner hub, respectively. An estimate of the fifth variable θ in the model requires several steps to calculate, beginning at the turbine wicket gates and ending at entry to the turbine runner.

Picture an imaginary vertical cylinder, where the cylinder side touches the downstream tips of all wicket gates (Fig. 3.9). The radius of this cylinder R_{wgc} is a function of the wicket gate opening angle in degrees (WGA, degrees) or wicket gate opening in inches (WGO, inches). Sometimes WGA and WGO are measured in terms of servomotor stroke (inches) or percentage servomotor stroke (%). A servomotor is a hydraulic ram that controls the opening and closing of a turbine wicket gates. Here we assert that R_{wgc} can be obtained from the wicket gate operation parameters. Then the axial velocity of water at the wicket gate is

$$V_{axia\_wg} = \frac{Q}{A_{wgc}} \tag{3.8}$$

Where A_{wgc} is the surface area of the imaginary cylinder and is calculated by

$$A_{wgc} = 2\pi \bullet R_{wgc} \bullet h_{wg} \tag{3.9}$$

Where h_{wg} is the height of wicket gate.

The tangential velocity at the wicket gate is given by

$$V_{t\_wg} = \frac{V_{axial\_wg}}{Tan\,(\theta_{wgt})} \tag{3.10}$$

where θ_{wgt} is the angle between the absolute velocity and tangential velocity at the downstream tip of wicket gate. θ_{wgt} can be obtained from the WGA or WGO.

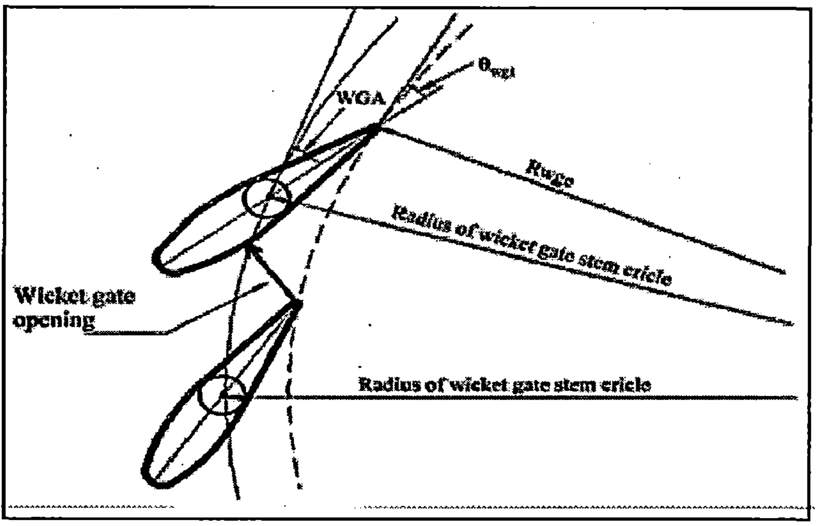


Fig.: 3.9 Wicket Gate Angle, Wicket Gate Opening R_{wgc}, and θ_{wgt}, the Angle between the Absolute Velocity and Tangential Velocity at the Downstream Tip of Wicket Gate.

According to the principle of conservation of angular momentum, the tangential velocity at the runner entrance (V_t) is equal to the tangential velocity at the wicket gate (V_{t_wg}) multiplied by the ratio of radial distances out from the centre of the runner at the two respective elevations:

$$V_t = \frac{V_{t\_wg} \bullet R_{wgc}}{R_1} \qquad (3.11)$$

Where R_1 is the fish-passage radius, that is, the radius of a circle extending out along the blade from the runner hub to where fish enter the runner. From neutrally buoyant bead experiments in physical models, the beads released near the top of wicket gate openings pass near the runner hub, those released mid-gate pass mid-blade, and those released near the bottom of the wicket gate openings pass near the tips of the runner blades. Here, we divided the area swept by runner blades (A_{tip}) into three equal doughnut-shaped (concentric) areas and calculated the average radius for hub, mid, and tip releases ($R1 = R_{hub}$, R_{mid}, or R_{tip}) from the radii bounding each successive area:

$$\begin{aligned} R_1 &= \overline{R}_{hub} = \sqrt{\frac{A_{tip}}{6\pi} + R_{hub}^2} \\ R_1 &= \overline{R}_{mid} = \sqrt{R_{hub}^2 + \frac{A_{tip}}{2\pi}} \\ R_1 &= \overline{R}_{tip} = \sqrt{R_{tip}^2 - \frac{A_{tip}}{6\pi}} \end{aligned} \qquad (3.12)$$

For a given fish passage location, the absolute velocity is estimated by

$$|V_1| = \sqrt{V_{axial}^2 + V_t^2} \qquad (3.13)$$

And the angle between axial and absolute velocity vectors (θ) is given by

$$\theta = 90 - \alpha = 90 - \sin^{-1}\left(\frac{V_{axial}}{V_1}\right) \qquad (3.14)$$

Where α is the angle between tangential and absolute velocity vectors.

These relationships are diagrammed in Fig. 3.10.

The diagram shows a fish of length l in flow approaching the leading edge of a runner blade in a Kaplan turbine, velocity vectors, and associated angles. Velocity vectors include V_t = tangential velocity; V_1 = absolute velocity; V_{axial} = axial velocity; u_1 = blade peripheral velocity, and v = velocity relative to the blade. Angles are as follows: α = the angle between tangential and absolute velocity vectors; θ = the angle between axial (parallel to the runner axis) and absolute velocity vectors (θ = 90° – α); and β = the angle between the horizontal plane and the velocity relative to the blade (v) and is called the "angle of attack." [60]

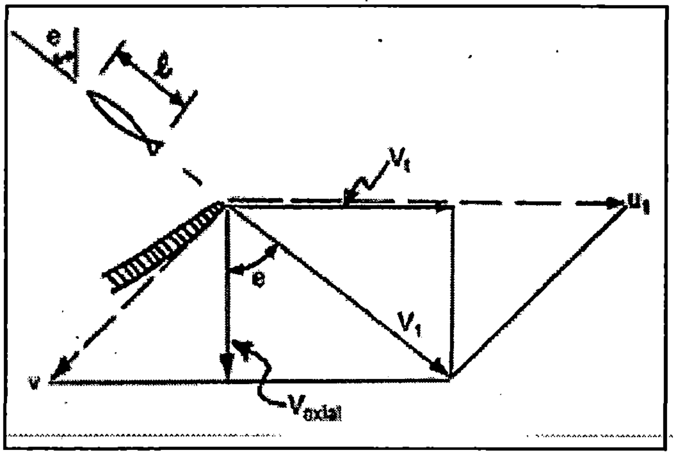


Fig.: 3.10 Water Velocity Vectors at the Runner Blade

3.6 FISH BEHAVIOUR

There are various approaches for classifying the rivers on the basis of biotic communities or various basin ecological indicators. Table 3.2 classifies the different stretches rivers.

Table: 3.2 Environmental management rivers and there tributaries. [61, 62]

S.No.	Class based on the ecological indicators	lilies and Botosaneanu (1963)	Class based on fishes	Holmes *et al.* (1998)	Trophic status class
1.	B	Epirhithron	No Fish Zone	D2	Ultra-oligotrophic
2.	C	Metarhithron	Trout Zone	Dl	Oligotrophic
3.	D	Hyporhithron	Mahseer Zone	C2	Oligo-mesotrophic

3.6.1 Illies and Botossaneanu (1963) Classification

According to the classification of lilies and Botossaneanu (1963), river basin can be classified into a rithronic stretch which has mean monthly temperature up to 20°C with high dissolved Oxygen, fast and turbulent water velocity and the river bed is composed of rocks, stones with occasional sandy/silty patches. This rithronic stretch is again divided into three sub-types- Epirithron (dominated by rapids, waterfalls and cascades), Meta-rithron (alternation of riffles and pools) and hyporhithron (relatively less riffles). [61]

3.6.1.1 Classification Based on the Presence of Fish Communities

The classification of the river water bodies based on the presence of fish communities was initially devised into 8 major types. The entire river stretches can be divided into three types - No fish zone, Trout zone and Mahseer zone. 'No fish zone' is the epirhithronic, while the trout zone is metarhithronic. The Mahseer zone is hyporhithronic stretch.

3.6.2 Classification by Holmes et al (1998)

On the basis of the classification given by Holmes *et al.* (1998), the study area can be divided in the three categories: High altitude (D2), high altitude (Dl) and middle altitude (C2) category. The high altitude (D2) category is characterized by the presence of hard rocks, steep slopes, presence of cobble, boulder bed rock with 'torrential water current and ultra-oligotrohic status of ecosystem with high gradient. This stretch is part of the epirhithron. High altitude Dl category is of moderate gradient of altitude with oligotrophic status of ecosystem which can be categorized under meta-rhithron. The third category is Medium Altitude (C2 category), which is characterized by presence of pebbles, cobble, boulder bed with smooth flow with abundant riffles and the trophic status of the ecosystem is oligo-mesotrophic which can be designated under hyporhithronic stretch. [62]

3.7 AQUATIC ECOSYSTEM

Endemic riverine species possesses life history traits that enable individuals to survive and reproduce within a certain range of environmental variation. A myriad of environmental attributes are known to shape the habitat templates that control aquatic and riparian species distributions including flow depth and velocity, temperature, bottom substrate size distributions, Oxygen content, turbidity soil moisture/ saturation, and other physical and chemical conditions and biotic influences. Hydrological variation plays a major part in structuring the biotic diversity within river ecosystems as it controls key habitat conditions within the river channel, the flood plain, and hyporheic (stream-influenced groundwater) zones. The often strong connections between stream flow, floodplain inundation, alluvial groundwater movement, and water table fluctuation mediate the exchange of organisms, particulate matter, energy, and dissolved substances along the upstream- downstream, river floodplain river —hyporheic, and temporal dimensions of riverine ecosystems. An in-depth study on the relationship between hydrological variability and river ecosystem integrity overwhelmingly suggests a natural flow paradigm, states: the full range of natural intra- and inter annual variation of hydrological regimes, and associated characteristics of timing, duration, frequency and rate of change are critical in sustaining the full native biodiversity and integrity of aquatic ecosystems. [63]

3.8 MAJOR ECOSYSTEM BIOTIC RESPONSE COMPONENTS AND THEIR HYDROLOGICAL REQUIREMENTS

Internationally, there already exist a wide range of different methods that can be used to assess the effects of various ecosystem drivers (water quantity and quality) on different response components. The most important biotic response components as Valued Ecosystem Components (VECs) in the rivers are macro-invertebrates, fish and fish otter. The species of these biotic response components dwelling the various sites of hydropower projects and their flow groups and hydrological requirements (water depth; water velocity. Many freshwater organisms have precise requirements for particular current velocities or flow ranges and certain taxa may be ideal indicators for prevailing flow conditions. On the basis of primary and secondary information, an overview on the hydrological requirements of important biotic valued ecosystem components (macro invertebrates, fish and fish otter) is given in Table 3.3.

Table: 3.3 Freshwater macro-invertebrate and fish flow group, ecological flow associations and hydrological requirements (water depth and water velocity) [63] [69]

Flow Group	Ecological Flow Association	HMD (cm)	Water velocity (cm/sec)
I	Taxa associated with rapid flows	15-20cm	>100
II	Taxa associated with moderate to fast flows	20-30 cm	20-100
III	Taxa associated with slow to moderate flows	30-50cm	<20

Explicit attempt to connect macro-invertebrate populations with flow conditions are less prevalent, although two decades ago Jones and Peters (1977) made some headway in linking flows in unpolluted British rivers to invertebrate community structure. Armitage (1995) has associated community response with variable current velocities in experimental situations. Petts and Bickerson (1997) provided a summary of detailed investigations into invertebrate/flow relationships in the River Wissey, Norfolk. Despite these advances, there is still a need for straightforward and reliable ecological assessment method which is sensitive and responsive to varying flow patterns and that can be used with existing data. [63, 64, 65]

3.9 MACRO-INVERTEBRATES

Many freshwater invertebrates have precise hydrological requirements (water depth and water velocity). Quantitative responses to flow changes, site specific studies also show that most taxa associated with slow flow lead to increase in abundance as flow decline, whereas most species associated with faster flows exhibit the opposite response. Alterations in community structure may occur as a direct consequence of varying flow patterns or indirectly through associated habitat change. Benthic macro-invertebrates will be adversely impacted due to change in environmental flow regimes on riverbed and river bank ecology. However, phytoplankton, zooplankton and macrophysics will not be adversely affected.

In case of uncertainty or ambiguity on ecological assessment and the lack of straightforward data on the hydrological requirements of macro-invertebrates, most of the flow group associations have been derived from published work from the professional experience of freshwater biologists and the personal experience working on these organisms during the last three decades. Typical mean current velocities associated with various benthic freshwater macro-invertebrates flow groups and ecological associated have been outlined. Many invertebrates have an inherent need for current either because they rely on it for feeding purpose or because their respiratory requirements demand it. These are typical rheostenic species and many workers have found that particular species have been confined to fairly definite range of water velocity. [66]

The benthic freshwater macro-invertebrate flow groups and their hydrological requirements dwelling epirhithronic, metarhithronic and hyporhithronic stretches of the Alaknanda-Bhagirathi basin have been presented (Table 3.4, 3.5, 3.6). Where species data are unavailable, it is done at family level. The use of family level data may result in a loss of precision, since a number of families contain species with fairly wide ranging flow requirements. Ubiquitous taxa such as Chironomidae and Oligochaeta are not used, since there appears to be no definitive relationship between the Chironomid/Oligochaete abundance. [67]

Table: 3.4 Diversity of macro-invertebrates and their hydrological requirements for epirhithronic stretch [69]

S. No.	**Macro-invertebrates**			**Flow group**	**Hydrological requirement**	
	Order	**Family**	**Taxon**		**HMD (cm)**	**Water velocity (cm/s)**
1	Ephemeroptera	Baetidae	*Baetis niger*	II	20-30	20-100
			B.muticus	II	20-30	20-100
			B. rhodani	II	20-30	20-100
			Centroptilum lutecium	II	20-30	20-100
		Heptageniidae	*Rhithrogena*	I	15-20	>100
			Heptagenia	I	15-20	>100
		Ephemerellidae	*Ephemerella ignita*	II	20-30	20-100
2	Diptera	Tendipidae	*Tendipes tentans*	II	20-30	20-100
3	Trichoptera	Hydropsychidae	*Hydropsyche*	II	20-30	20-100
4	Plecoptera	Perlidae	*Perla*	I	15-20	>100
		Perlodidae	*Isoperla*	I	15-20	>100

Table: 3.5 Diversity of macro-invertebrates and their hydrological requirements for metarhithronic stretch [69]

Macrozoobenthos			Flow group	Hydrological requirement	
				HMD (cm)	Water Velocity (cm/s)
Order	Family				
Ephemeroptera					
	Heptageniidae	*Heptagenia*	I	15-20	>100
	Baetidae	*Baetis niger*	II	20-30	20-100
	Baetidae	*B. muticus*	II	20-30	20-100
	Baetidae	*B. rhodani*	II	20-30	20-100
	Baetidae	*Cloeon*	II	20-30	20-100
	Caenidae	*Caenis*	III	30-50	<20
	Ephemerellidae	*Ephemerella ignita*	II	20-30	20-100
	Heptageniidae	*Rhithrogena*	I	15-20	>100
Trichoptera					
	Rhyacophilidae	*Rhyacophila*	I	15-20	>100
	Hydropsychidae	*Hydropsyche*	II	20-30	20-100
	Glossosomatidae	*Glossosoma*	II	20-30	20-100
	Hydroptilidae	*Hydroptila*	III	30-50	<20
Diptera					
	Tabanidae	*Tabanus*	II	20-30	20-100
	Tipulidae	*Antocha*	III	30-50	<20
Coleoptera					
	Amphizoidae	*Amphizoa lecontei*	II	20-30	20-100

Table: 3.6 Diversity of macro-invertebrates and their hydrological requirements for hyporhithronic stretch [69]

S. No.	Macroinverebrates			Flow group	Hydrological requirement	
	Order	**Family**			**HMD (cm)**	**Water Velocity (cm/s)**
1.	Ephemeroptera					
		Ephemerellidae	*Ephemerella*	II	20-30	20-100
		Caenidae	Caeww	III	30-50cm	<20
		Heptageniidae	*Heptagenia*	I	15-20	>100
			Rithrogena	I	15-20	>100
		Baetidae	*Baetis*	II	20-30	20-100
			Cloeon	II	20-30	20-100
2.	Trichoptera					
		Hydropsychidae	*Hydropsyche*	II	20-30	20-100
		Psychomyiidae	*Psychomyia*	II	20-30	20-100
			Polycentropus	II	20-30	20-100
		Leptoceridae	*Leptocella*	III	30-50cm	<20
			Mystacides	III	30-50cm	<20
		Glossosomatidae	*Glossosoma*	II	20-30	20-100
		Hydroptilidae	*Hydroptila*	III		
		Rhyacophilidae	*Rhyacophila*	I	15-20	>100
		Limniphilidae	*Limniphilius*	II	20-30	20-100
3.	Diptera					
		Syrphidae	*Chrysogaster*	III	30-50cm	<20

S. No.	**Macroinverebrates**			**Flow group**	**Hydrological requirement**	
	Order	**Family**			**HMD (cm)**	**Water Velocity (cm/s)**
		Blepharoceridae	*Philorus*	III	30-50cra	<20
		Musidae	*Limnophora*	III	30-50cm	<20
		Tabanidae	*Tabanus*	II	20-30	20-100
		Simuliidae	*Simulium*	II	20-30	20-100
		Dixidae	*Dixa (pupa)*	II	20-30	20-100
		Rhagionidae	*Atherix*	III	30-50cm	<20
		Tipulidae	*Antocha*	III	30-50cm	<20
4.	Coleoptera					
		Psephenidae	*Psephanus*	III	30-50cm	<20
		Elmidae	*Heterlimnius*	II	20-30	20-100
		Gyrinidae	*Dineutes*	III	30-50cm	<20
5.	Odonata					
		Lestidae	*Archilestes*	III	30-50cm	<20
		Gomphidae	*Octagomphus*	II	20-30	20-100
		Libelludidae	*Epicordulia*	III	30-50cm	<20
		Libelhididae	*Sympetnan*	III	30-50cm	<20
6.	Plecoptera					
		Perlidae	*Perla*	I	15-20	>100
		Perlodidae	*Isoperla*	I	15-20	>100

3.10 FISHES

Fish is also one of the most valued ecosystem components (VECs) of rivers and there tributaries as a consequence of cascade of hydropower projects in operation, under construction, or under development this valued ecosystem component of fish will be adversely affected. The magnitude, timing and duration of flow events determine *inter alia* the temporal and spatial availability as well as the connectivity of different physical habitats required by riverine fish during their various life history stages. With respect to fish in perennial rivers, there may be several critical habitat conditions including the effects of reducing flow on the availability of marginal habitat caused by a reduction of wetted parameter, a reduction in fast and deep habitats in favour of either slow and deep or fast and shallow habitats, or a reduction in fish mobility due to insufficient depth of water flowing over shallow riffle areas. If these conditions persist for extended lengths of time they may impact on the capacity of a specific species of fish to successfully feeds, spawn or compete with other species and therefore affect abundance and dynamics. Many of these effects will be seasonally dependent and therefore extended periods of high "stress" in some months may be normal; while in the other months may be detrimental to ecological functioning.

Periodic high, flushing flows are desirable to prevent settling of fine, clogging interstitial spaces in the substratum. Upland rivers are more sensitive to change in flow than those in lowland rivers, thus, they need more stringent standards of protection. Spawning fish require a minimum area of suitable habitat and flows sufficient to keep gravel free from fines; thus most of the fish species have threshold levels of depth and velocity. During incubation fish eggs must be submerged and well oxygenated by water percolating through the gravels and pan survival rates are density dependent so sufficient flow is required to maintain adequate habitat. The viability of the spawning habitat is dependent on the magnitude of sand deposition. A change of substrate comparison from a primarily cobble to a sand-cobble bed mixture could result in the elimination of preferred spawning habitat, suffocation of eggs or entrapment of the larvae. A minimum stream flow is required that will sustain all the life stages of fish species. [68]

The effect on fish habitat of the deposition of excessive amounts of sands and fine material on the cobble substrate can be severe, limiting the aquatic insect population, reducing the opportunity for spawning and reducing the channel carrying capacity. Reduced or altered flow patterns and corresponding reductions in sediment transport capacity could threaten the fish population. Entry of mahseer fish into headwater tributaries is particularly flow dependent. The epirhithronic stretch has no fish due to very cold temperature and turbulent water current. However, metarhithroic stretch has a natural favourite habitat for snow trout (Trout zone). The hyporhithronic stretch is a natural habitat for Himalayan Mahseer *(Tor tor* and *Tor putitora*). Thus, this can be aptly called as Mahseer zone. Some of the fishes, especially Barils *(Barilius spp)* and laoches *(Noemacheilus spp)* use to prefer to stay in the small tributaries having fast currents. However, the adult big fishes like snow trout and mahseers use to stay most of the time in the main rivers. The rare cat fishes including *Glyptothorax* sp and *Pseudoecheneis* sp prefer very fast current and are adapted to cling to the stones with their suckers and adhesive pads. Most of the cold water fish species particularly rheophilic cyprinids are very sensitive to modified flows. However, coarse fishes exhibit greater plasticity towards modified flows. The hydrological requirements of the fishes dwelling metarhithronic and hyporhithronic stretches can be met provided a suitably designed environmental flow release programme is implemented.

Table: 3.7 Diversity of fish and their hydrological requirements for metarhithronic stretch (EMC-C) [69]

S. No.	Name of the Fish	Flow group	Hydrological requirement	
			HMD (cm)	Water velocity (cm/s)
	Family Cyprinidae			
1.	*Schizothorax richardsonii* Gray	II	20-30	20-100
2.	*Schizothorax plagiostomus* Heckel	II	20-30	20-100
3.	*Schizothorax sinuatus* Heckel	II	20-30	20-100
4.	*Schizothoraichthys progastus* McClelland	II	20-30	20-100
5.	*Garra lamta* Hamilton	II	20-30	20-100

S. No.	Name of the Fish	Flow group	Hydrological requirement	
			HMD (cm)	Water velocity (cm/s)
6.	*Garra gotyla gotyla* Gray	II	20-30	20-100
7.	*Crossocheilus latius* Hamilton	II	20-30	20-100
8.	*Barilius bola* Hamilton	II	20-30	20-100
9.	*Barilius bendelisis* Hamilton	II	20^30	20-100
10.	*Barilius barna* Hamilton	II	20-30	20-100
11.	*Barilius vagra* Hamilton	II	20-30	20-100
12.	*Barilius barila* Hamilton	II	20-30	20-100
	Family Cobitidae			
13.	*Noemacheilus montanus* McClelland	II	20-30	20-100
14.	*Noemacheilus rupicola* McClelland	II	20-30	20-100
	Family Sisoridae			
15.	*Glyptothorax pectinopterus* McClelland	I	15-20	>100
16.	*Pseudoecheneis sulcatus* McClelland	I	15-20	>100

Table: 3.8 Diversity of fish and their hydrological requirements for hypbrhithronic stretches (EMC-D) [69]

S.No.	Name of Fishes	Flow group	Hydrological requirement	
			HMD (cm)	Water velocity (cm/s)
	Family Cyprinidae			

S.No.	Name of Fishes	Flow group	Hydrological requirement	
			HMD (cm)	Water velocity (cm/s)
1.	*Tor tor* (Ham.-Buch.)	III	30-50cm	<20
2.	*Torputitora* (Ham.-Buch.)	III	30-50cm	<20
3.	*Labeo dero* (Ham.-Buch.)	III	30-50cm	<20
4.	*Labeo dyochelius* (McClleland)	III	30-50cm	<20
5.	*Schizothorax richardsonii* (Gray)	II	20-30	20-100
6.	*Schizothorax sinuatus* (Heckel)	II	20-30	20-100
7.	*Schizothorax niger* (Heckel)	II	20-30	20-100
8.	*Schizothoraichtys progastus* (McClelland)	II	20-30	20-100
9.	*Danio danio* (Ham.-Buch.)	II	20-30	20-100
	Family: Cobitidae			
10.	*Lepidocephalichthys guntea* (Ham-Buch.)	III	30-50cm	<20
11	*Botia geto* (Ham.-Buch)	HI	30-50cm	<20
12.	*Botia dario* (Ham-Buch.)	III	30-50cm	<20
	Family Amblycepidae			
13.	*Amblyceps mangois* (Ham.-Buch.)	III	30-50cm	<20
	Family:Schilbeidae			
14.	*Clupisoma garua* (Ham.-buch.)	II	20-30	20-100

3.11 FISH OTTER

Fish otter is also one of the most important biotic valued ecosystem component and top predator of the Alaknanda-Bhagirathi basin. Fish otter occupies the highest trophic level in the riverine ecosystem. The common otter *(Lutra lutra)* of family Mustelidae and sub-family Lutrinae dwells the hyporhithronic stretch of the study area. The fish otter can be placed under flow group III which requires hydro median depth of 30-50 cm and water velocity <20 cm/s. The data related with the diversity of macroinvertebrates, fish species and fish otter and their hydrological requirements have revealed that some of the species are natural inhabitants of a specific stretch of river and needs specific hydrological requirements. But, they may move into upstream or downstream in search of food or fulfilling the requirements of their life stages. Thus, there is a no demarcation line among the three stretches of epirhithron, metarhithron and hyporhithron. However, the data on hydrological requirements of these biotic valued ecosystem components (VECs) is of paramount importance for determining the environmental flow requirements hydropower. [68]

In view of the above parameter we have chosen only velocity and depth as the only parameterises to study the behaviour of fishes with respect to fish friendly turbines.

In this chapter the discussion is about Kaplan turbine and its various components. Here also explained the how the injury mechanism occur in the Kaplan turbine and its modified design concept. Here the fish is effecting by changing in the pressure, cavitation, and shear stress or the mechanical injury like abrasion, striking, grinding etc. Also study the numerical model for fish passage and fish behaviour towards the fish friendly turbine. Therefore the overall discussion we are going to analysis the fish friendly Kaplan turbine to decrease in mortality rate with the efficient hydraulic efficiency and unit generation cost.

CHAPTER 4

DESIGN ANALYSIS OF FISH FRIENDLY KAPLAN TURBINE

The Mainmatti Small Hydropower Project is envisaged as a canal based scheme. The project site is located on right bank of Augmentation canal off takes from Western Yamuna Canal near Mainmatti village in Karnal district of Haryana. As the canal carries a minimum discharge of 38 cumec throughout the year so it is evident and feasible to develop 2 x 1000 kW installations for power generation at design head 2.37m.

An alternate proposal for above mentioned site may be obtained by clubbing the four falls in the canal, by which there shall be gross head of 4.108m. But for design of 3 x 1000 kW power plant 3.7m head may be considered as net head and design discharge is 105 cumec. Based on the discharge available for power generation, the power potential has been worked out. The power potential is calculated by assuming the efficiency of turbine and generator as 0.95 and 0.94 respectively. Standard turbine runner diameter and generator capacity have been taken into consideration for finding out the power potential and possible energy generation. As the above mentioned site is a low head SHP project, therefore Kaplan turbine has been used.

4.1 BASIC DATA OF KAPLAN TURBINE

The basic data available for the design of conventional Kaplan turbine is given below.

Design discharge	= 105 cumec
Design Head	= 3.7 m
Installed Capacity	= 3000 kW (3 units of 1000 kW provided)
Energy Generation	= 31.72 Million Units
Installation Cost	= Rs. 4400 lacs

4.2 GENERAL LAYOUT OF POWER HOUSE

In Fig. 4.1, the general layout of power house of Mainmatti small hydro power project is shown. The figure shows the layout of the Kaplan turbine with the draft tube and also the over head crane with the trussing.

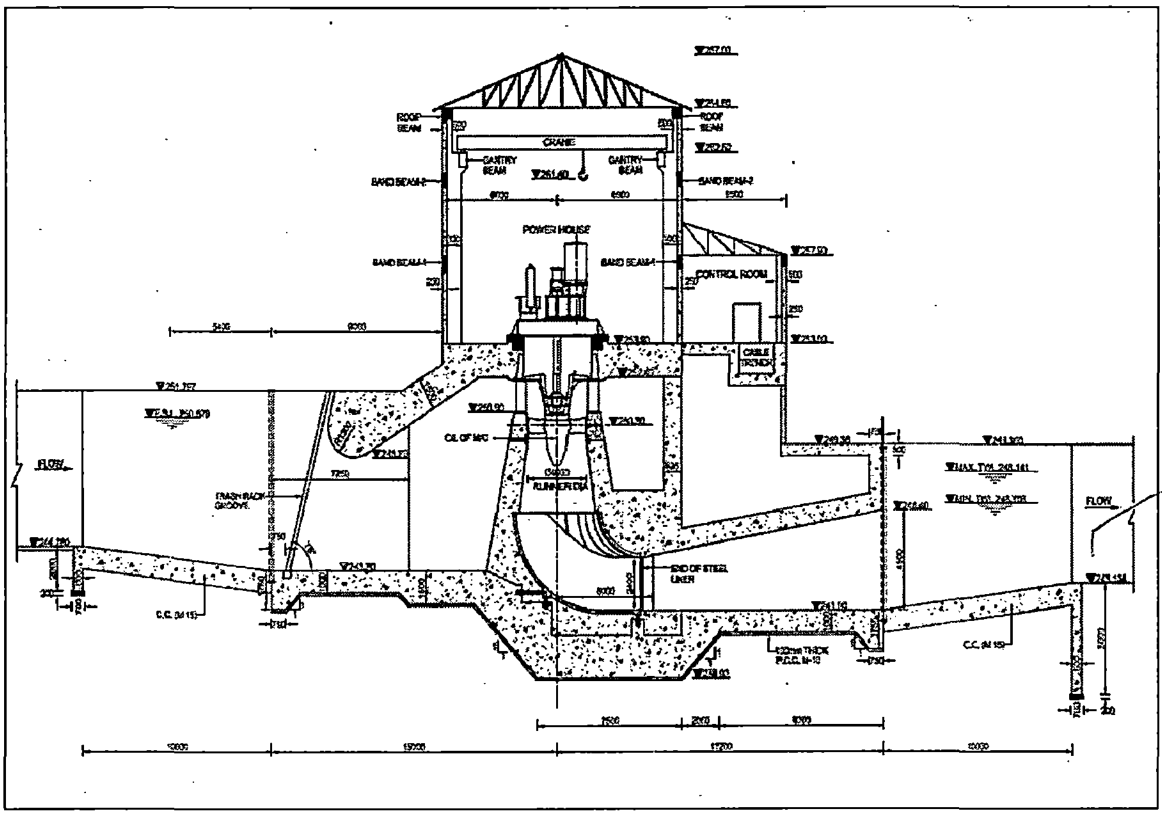


Fig.: 4.1 General Layout of Mainmatti Small Hydropower Project.

4.3 PARAMETERS OF THE TURBINE SELECTION

Parameter of turbine is calculated to facilitate the selection of turbine as shown below:-

4.3.1 Specific Speed

Higher specific speed of turbine results in higher speed of rotation for generator with consequent reduction in cost of generator. This criteria is very important for dictating type turbines from cost consideration in the overlapping head range. The range of ratio of speed and specific speed for various types of commercially available turbines as given by the following equation:

Specific speed

$$n_s = \frac{N\sqrt{P}}{H^{\frac{5}{4}}} \tag{4.1}$$

Where

N = Rotational speed of turbine (rpm)

P = Turbine output in metric HP

H = Head = 3.7 m

$$P_{out} = \frac{p}{0.746 \times 0.9863 \times n_g} \qquad (4.2)$$

Where

P = electric power output per unit

n_g = generator efficiency

Therefore $$P_{out} = \frac{1000}{0.746 \times 0.9863 \times 0.94} = 1445.84 \qquad \cong 1446 \text{ mHP (say)}$$

Putting the value of P_{out} in eqn. 4.1, therefore the value of specific speed is

$$n_S = N \frac{\sqrt{1446}}{3.7^{\frac{5}{4}}} = 7.410N \qquad (4.3)$$

4.3.2 Kaplan Turbine

The specific speed at different turbine speeds shall be as follows:

Table: 4.1 Specific speeds at different turbine speeds

Turbine Speed (N)	**Specific Speed (n_s)**
50	370.5
60	444.6
70	518.7
80	592.8
90	666.9
100	741.0
120	889.2
130	963.3

Specific speed of Kaplan turbine varies between 340 and 1000. Turbine speeds' corresponding to these specific speeds is between 50 and 130 rpm. The specific speed at 130 rpm is 963.3 which is very close to optimum value of 1000. In this problem, the specific speed is taken as 740 as at optimum value. Because the synchronous speed of generator used is about 750 rpm, if the higher specific speed turbine is been selected than, speed reducers like flywheel, gear box etc have to be used which will increase the cost of E&M equipment. Therefore Kaplan turbine of 100 rpm is recommended for the site. The fig. 4.2 shows the conventional Kaplan turbine runner.

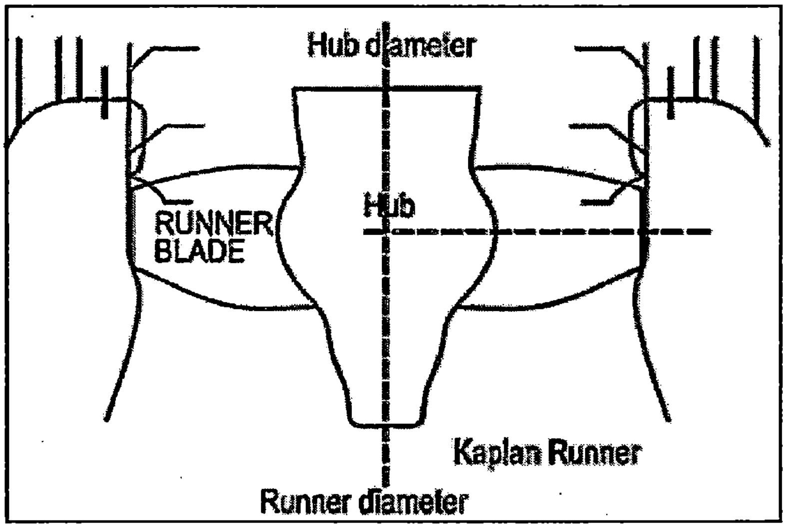


Fig.: 4.2 Conventional Kaplan Turbine Runner

4.3.2.1 Runner Diameter

The actual runner size is determined by the manufacturer in accordance with modal tests and design criteria. For estimating proposes following formula can be used.

$$D = \frac{84.6 \times Q_s \times (H_r)^{\frac{1}{2}}}{N} \quad \text{meters} \qquad (4.4)$$

Where

Q_s = velocity ratio at discharge diameter of runner

$Q_s = 0.0233 \times (n_s)^{\frac{2}{3}}$

H = designed head (m)

N = speed of turbine (rpm)

Therefore

$$D = \frac{84.6 \times 0.0233 \times (740)^{\frac{2}{3}} \times (3.7)^{\frac{1}{2}}}{100} = 3.102 \text{ meters } = 3.2 \text{ m (say)}$$

$D_r = 3.2$ m

4.3.2.2 Hub Diameter

Now we know that

$$\frac{D_h}{D_r}=0.38+\frac{H}{220} \tag{4.5}$$

Putting the value of H, we get,

$$\frac{D_h}{D_r}=0.3968\text{m}$$

$D_h = D_r \times 0.3968$, put the value of D_r from above we get

$D_h = 1.27$ m

4.3.2.3 Flow Velocity

We know the discharge eqn. For Kaplan turbine is

$$Q=\frac{\pi}{4}D_r^2\left[1-\left(\frac{D_h}{D_r}\right)^2\right]\times V_f \tag{4.6}$$

Putting all the values we get

$V_f = 15.49 \cong 15.50$ (say)

4.3.2.4 Numbers of Blades

For the selection of numbers of blade we use the table form IS standard that accordance with IS-12800 for Small Hydro Projects.

Head (m)	Up to 5m	5 - 20 m	20 - 40 m
Numbers of blade	3	4	5

4.3.2.5 Numbers of Wicket Gate

Now select the numbers of wicket gate also from the IS-12800 for Small Hydro Projects.

Runner diameter (D_r) (mm)	Up to 300	300-450	450-750	750-1200	1200-1600	1600-2200	2200-4000	More than 4000
No's of wicket gate (Zo)	8	10	12	14	16	18	20	24

4.3.2.6 Velocity Triangle

The velocity triangle for Kaplan turbine is used to find the inlet and outlet angles.

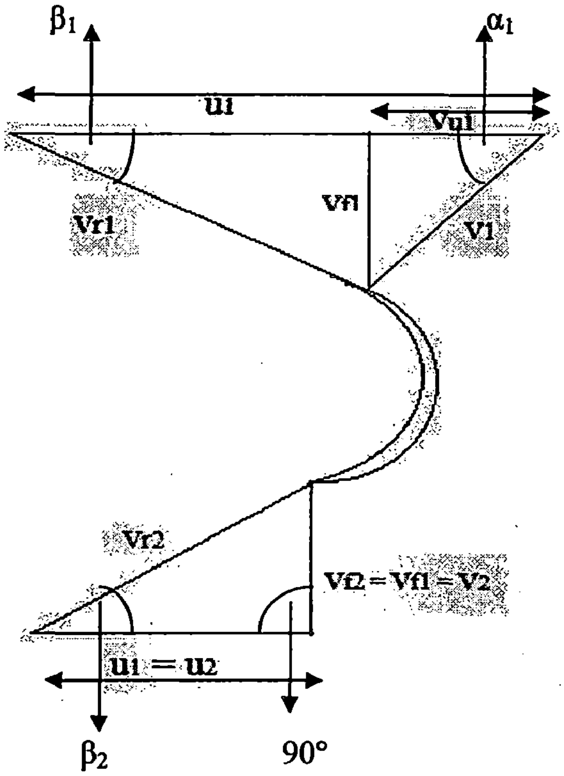


Fig.: 4.3 Velocity triangle of Kaplan turbine.

(i) **Blade angle at hub** (inlet and outlet)

$$u_h = \frac{\pi D_h N}{60} \tag{4.7}$$

$$u_h = 6.65 m/s$$

Now from triangle

$$\beta_{2h} = \tan^{-1}\frac{V_{f2}}{u_2} \tag{4.8}$$

Putting all the values we get

$$\beta_{2h} = 66.78°$$

Assuming the hydraulic efficiency is 0.95.

Therefore $$\eta_h = \frac{V_{uh} u_h}{gH} \tag{4.9}$$

$$V_{uh} = 5.185 \cong 5.2 m/s$$

$$\therefore \tan\alpha_1 = \frac{V_{f1}}{V_{uh}} \qquad (4.10)$$

$$\alpha_{1h} = 71.45°$$

Now $$\tan\beta_1 = \frac{V_{f1}}{u_1 - V_{u2}} \qquad (4.11)$$

$$\beta_{1h} = 84.65°$$

(ii) Blade angle at tip (inlet and outlet)

$$u_{2t} = \frac{\pi D_t N}{60} = 16.75 m/s \qquad (4.12)$$

Similarly from eqn. 4.8 using for tip we get

$$\beta_{2t} = 42.78°$$

Using eqn. 4.9 $V_{ut} = 2.058 m/s$

$$\tan\alpha_{1t} = \frac{V_{f1}}{V_{ut}} \qquad (4.13)$$

$$\alpha_{1t} = 82.43°$$

Now similarly $$\tan\beta_{1t} = \frac{V_{f1}}{u_1 - V_{u1}} \qquad (4.14)$$

$$\beta_{1t} = 46.53°$$

4.4 MODIFIED DESIGN OF FISH FRIENDLY KAPLAN TURBINE

In the modified design, modification is proposed in the runner diameter of conventional turbine and the effect of the modification on various parameters of turbine and its efficiency were analyzed. The cost analyses of the conventional and modified turbine were also determined. For Kaplan turbines, fish that pass higher through the wicket gate openings will pass nearer the runner hub, while those passing lower through the wicket gate openings will pass nearer to the tips of the runner blades. Therefore the modification of the parameter of turbine is calculated as below. The modified fish friendly Kaplan turbine runner is shown in fig. 4.4 as below.

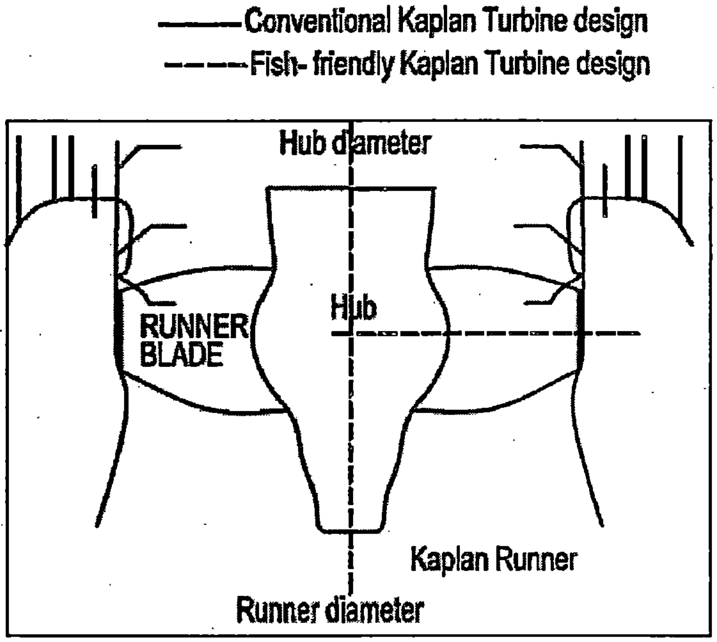


Fig.: 4.4 Modified fish friendly Kaplan turbine runner

4.4.1 Runner Diameter

Take the assumption in case of hub and runner diameter ratio i.e.

Assume $$\frac{D_h}{D_r} = 0.390m$$

The hub diameter (D_h) is taken as similar to conventional turbine i.e.

$$D_h = 1.27m$$

Therefore $$D_r = 3.256m$$

4.4.2 Flow Velocity

Now find out the flow velocity by using all above these values in eqn. 4.6.

Therefore $V_f = 14.87$

4.4.3 Hydraulic Efficiency

We know that

$$\eta_h = \frac{Vu_1 u_1}{gH} \tag{4.15}$$

From velocity triangle

$$Vu_1 = \frac{V_{f1}}{\tan\alpha_1} and$$

$$u_1 = \frac{\pi D_r N}{60}$$

Put all these parameter in eqn. no 6.14, therefore

$$\eta_h = \frac{14.87}{\tan(82.43)} \times \frac{3.1415 \times 3.256 \times 100}{60 \times 9.81 \times 3.7}$$

$$\eta_h = 0.9284 = 92.8\% \cong 93\%$$

4.4.4 Velocity Triangles

Now find out the change in angles due to modification i.e.

(i) Blade angle at hub

Using the eqn. 4.7 and 4.8 respectively than find out

$u_h = 6.649$ *m/s* (say) 6.65*m/s*

$\beta_{2h} = 65.90°$

Now find out the whirl velocity *Vu*, α_{1h} and β_{1h} at hub by using the eqn. 4.9, 4.10, 4.11 respectably

Therefore $Vu_h = \dfrac{0.93 \times 9.81 \times 3.7}{6.65} = 5.076 m/s$

$\alpha_{1h} = 71.15°$ and

$\beta_{1h} = 84°$

(ii) Blade angle at tip

Now using the eqn. 4.12. Than we get

$$u_{2t} = \frac{\pi D_t N}{60} = 17.04 m/s$$

Similarly using the eqn. 4.8 for tip, we get

$\beta_{2t} = 41.11°$

Now find out the whirl velocity V_{ut}, α_{1t} and β_{1t} at tip by using the eqn. 4.9, 4.13, 4.14 respectably

$$V_{ut} = 2.058 m/s$$

Therefore from eqn. 4.13,
$$\tan\alpha_{1t} = \frac{V_{f1}}{V_{ut}}$$
$$\alpha_{1t} = 82.41°$$

Similarly from eqn. 4.14, we get
$$\tan\beta_{1t} = \frac{V_{f1}}{u_1 - V_{u1}}$$
$$\beta_{1t} = 44.63°$$

Therefore find the all blade angles all show the twisting angle in hub and tip of the blade. The fig. 4.5 shows the twist angle of conventional and fish friendly Kaplan turbine runner.

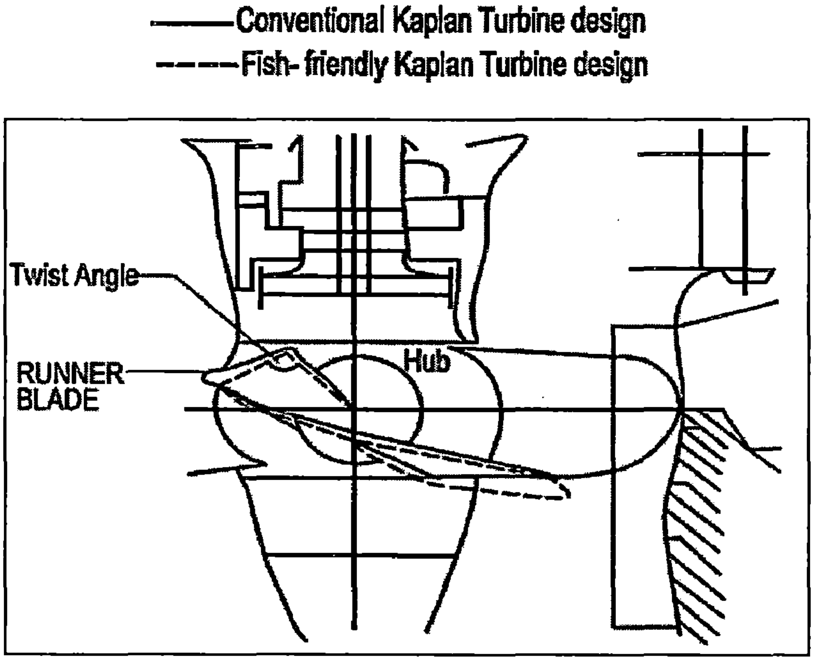


Fig.: 4.5 Change In twist angle of runner blade.

In this report five different case studies depending upon hub and tip diameter ratio of conventional Kaplan turbine have been studied as mentioned below the table 4.2.

Table: 4.2 Case studies

Case	**Hub and tip diameter ratio $\frac{D_h}{D_r}$ (m)**
i	0.390
ii	0.385
iii	0.380
iv	0.375
v	0.370

Therefore all the results of the above case studies are shown in tabular form as below:-

Table: 4.3 Modified result of fish friendly Kaplan turbine

S. No.	**Parameters**	**Modified Fish Friendly Kaplan Turbine**				
		Case				
		i	ii	iii	iv	v
1.	Hub and tip ratio $\frac{D_h}{D_r}$ (m)	0.390	0.385	0.380	0.375	0.370
2.	Runner diameter (m)	3.256	3.298	3.342	3.386	3.432
3.	Flow velocity V_f (m/s)	14.87	14.43	14	13.57	13.15
4.	Efficiency (%)	93	91.2	89.69	88.06	86.51
5.	Peripheral velocity at hub and tip (m/s)	u_h=6.65 u_t=17.04	6.65 17.26	6.65 17.49	6.65 17.72	6.65 17.96
6.	Twist angle At inlet ($\beta_{1h} - \beta_{1t}$) degree At outlet ($\beta_{2h} - \beta_{2t}$) degree	39.37 24.79	40.11 25.36	40.98 25.92	41.81 26.45	42.61 26.96

4.5 COST ANALYSIS

The cost analysis of conventional and modified fish friendly Kaplan turbine and its effect on the unit generation cost were obtained.

4.5.1 Conventional Turbine

As given the basic data i.e.

Project cost = Rs. 4400 lacs
Installed capacity = 3 MW
Annual unit generation =31.72 MU

Now

Take the loan of project cost = 70%
And equity = 30 %
Interest rate = 11%
Construction period = 2 years

Therefore now the amount withdrawal from the bank in instalment = 4

1. During first six month amount is drawn = 20%

   i.e. $= 0.20\times0.11\times3080\times2 = 135.52$ lacs

2. For next six month = 30%

   $= 0.30\times0.11\times3080\times1.5 = 152.46$ lacs

For second year

3. First six month = 35%

   $=0.35\times0.11\times3080\times1 =118.58$ lacs

4. Last six month =15%

   $= 0.15\times0.11\times3080\times0.5 = 25.41$ lacs

Therefore total interest during construction = 135.52+152.46+118.58+25.41
=Rs. 431.97 lacs

Total funding cost = 4400+431.97
= Rs. 4831.97 lacs ≅ Rs. 4832 lacs

Now take loan of total funding cost =70% =Rs. 3382.38 lacs
Equity to be invested = 30% = Rs. 1449.59 lacs

Annual expenditure

(i) O& M cost including insurance = 3% of project cost
$= 0.03\times4832$ = Rs. 145 lacs

(ii) Depreciation = 3% of project cost
$= 0.03\times4832$ = Rs. 145 lacs

(iii) Interest on loan = 11%

=0.11× 3382.38 = Rs. 372.06 lacs

Therefore annual expenditure = 145+145+372.06

= Rs. 662.06 lacs

Now generation cost = $662.06\times10^5/31.72\times10^6$

= Rs. 2.08 per unit

4.5.2 Modified fish friendly Kaplan Turbine

In modified fish friendly turbine following modifications were done in turbine, results in additional cost of about 110 lacs. Therefore generation cost for modified turbine is calculated as below:-

Project cost = Rs. 4510 lacs
Installed capacity = 3 MW
Annual unit generation =31.05 MU

Now

Take the loan of project cost = 70%
And equity = 30 %
Interest rate = 11%
Construction period = 2 years

Therefore now the amount withdrawal from the bank in instalment = 4

1. During first six month amount is drawn = 20%

   i.e. = 0.20×0.11×3157×2 = 138.91 lacs

2. For next six month = 30%

   = 0.30×0.11×3157×1.5 = 156.27 lacs

For second year

3. First six month = 35%

   =0.35×0.11×3157×1 =121.54 lacs

4. Last six month =15%

   = 0.15×0.11×3154×0.5 = 26.04 lacs

Therefore total interest during construction = 138.91+156.27+121.54+26.04

= Rs. 442.76 lacs

Total funding cost = 4510 + 442.76

= Rs. 4952.76 lacs ≅ Rs. 4953 lacs

Now take loan of total funding cost =70% = Rs. 3466.93 lacs

Equity to be invested = 30% = Rs. 1485.82 lacs

Annual expenditure

(i) O& M cost including insurance = 3% of project cost

$= 0.03\times4953$ = Rs. 148.59 lacs

(ii) Depreciation = 3% of project cost

$= 0.03\times4953$ = Rs. 148.59 lacs

(iii) Interest on loan = 11%

$=0.11\times 3466.93$ = Rs. 381.36 lacs

Therefore annual expenditure = 148.59+148.59+381.36

= Rs. 678.54 lacs

Now generation cost $= 678.54\times10^5/31.05\times 10^6$

= Rs. 2.18 per unit

Similarly for the other cases of modified turbine, 121, 132,143,154 lacs more cost was consider compared to conventional turbine project cost. Therefore the generation cost for all cases is calculated in same procedure and result is shown in table 4.4.

Table: 4.4 Cost variations in modified fish friendly Kaplan turbine

S. No.	**Parameters**	**Modified Fish Friendly Kaplan Turbine**				
		Case				
		i	ii	iii	iv	v
1.	Increase in Project cost Rs. (lacs)	110	121	132	143	154
2.	Annual unit generation (MU)	31.05	30.45	29.95	29.41	28.88
3.	Total funding cost Rs. (lacs)	4952.75	4964.83	4976.92	4989	5001.07
4.	Annual expenditure Rs. (lacs)	678.54	680.17	681.82	683.49	685.14
5.	Generation cost per unit (Rs.)	2.18	2.23	2.27	2.32	2.37

4.6 COMPARISON OF CONVENTIONAL AND MODIFIED FISH FRIENDLY KAPLAN TURBINE

After analysed both the turbine various changes were found in the different parameters of turbines and its comparisons will be shown in table 4.5 as below:-

Table: 4.5 Comparison of Conventional and Modified Fish Friendly Kaplan Turbine.

S. No.	Parameters	Conventional Turbine	Modified Fish Friendly Kaplan Turbine				
			Case				
			i	ii	iii	iv	v
1.	Hub and tip ratio $\frac{D_h}{D_r}$ (m)	0.3968	0.390	0.385	0.380	0.375	0.370
2.	Runner diameter (m)	3.2	3.256	3.298	3.342	3.386	3.432
3.	Flow velocity V_f (m/s)	15.50	14.87	14.43	14	13.57	13.15
4.	Efficiency (%)	95	93	91.2	89.69	88.06	86.51
5.	Peripheral velocity at hub and tip (m/s)	$u_h = 6.65$ $u_t = 16.75$	6.65 17.04	6.65 17.26	6.65 17.49	6.65 17.72	6.65 17.96
6.	Twist angle At inlet ($\beta_{1h} - \beta_{1t}$) degree At outlet ($\beta_{2h} - \beta_{2t}$) degree	38.12 24	39.37 24.79	40.11 25.36	40.98 25.92	41.81 26.45	42.61 26.96
7.	Project cost (lacs)	4400	4510	4521	4532	4543	4554
8.	Annual unit generation (MU)	31.72	31.05	30.45	29.95	29.41	28.88
9.	Total funding cost (lacs)	4831.97	4952.75	4964.83	4976.92	4989	5001.07
10.	Annual expenditure (lacs)	662.06	678.54	680.17	681.82	683.49	685.14
11.	Generation cost per unit (Rs.)	2.08	2.18	2.23	2.27	2.32	2.37

4.7 EFFECT OF MODIFIED FISH FRIENDLY KAPLAN TURBINE

The modified Kaplan turbine will have the impact on the following parameters:

4.7.1 Turbine Efficiency

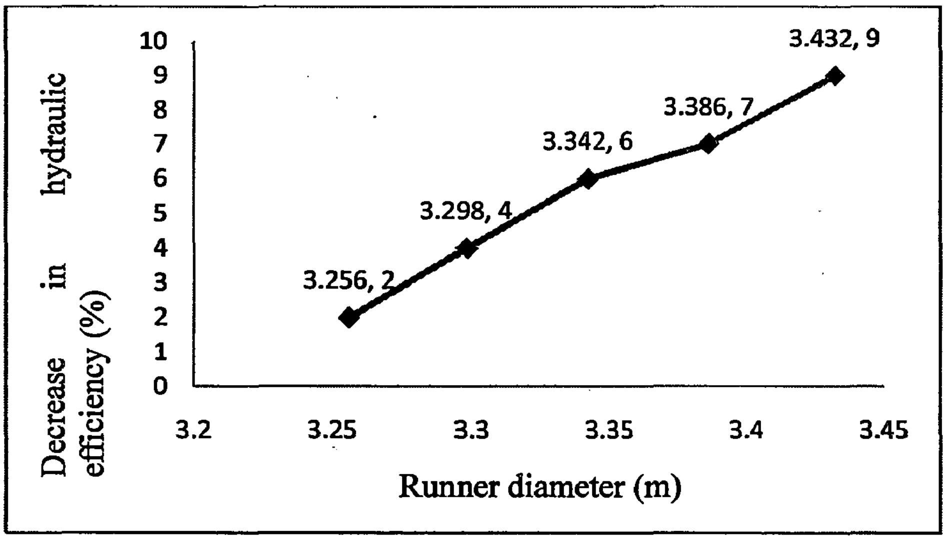


Fig.: 4.6 Percentage decrease in hydraulic efficiency with different runner diameter.

Based upon the modification in the runner diameter with increase in the runner diameter the turbine efficiency is decrease respectively as shown in Fig. 4.6.

4.7.2 Flow Velocity

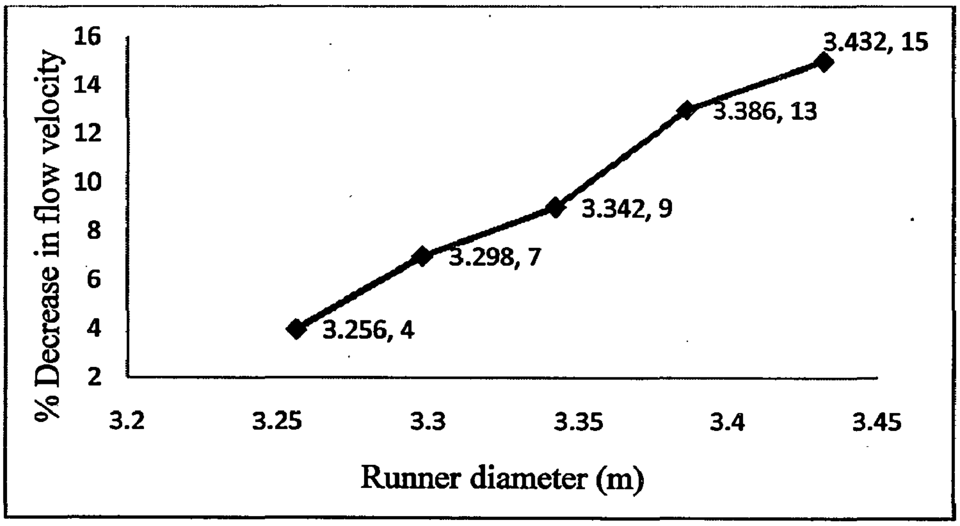


Fig.: 4.7 Percentage decrease in flow velocity with different runner diameter.

With the increase in the runner diameter the flow velocity of water is decrease. Due to this the pressure inside the turbine is also decrease which is helpful to the survival of fishes in the turbine passage and the mortality rate is also goes to decrease. The effect of increase in runner diameter on the flow velocity is shown in percentage wise as shown in Fig. 4.7.

4.7.3 Twist Angle

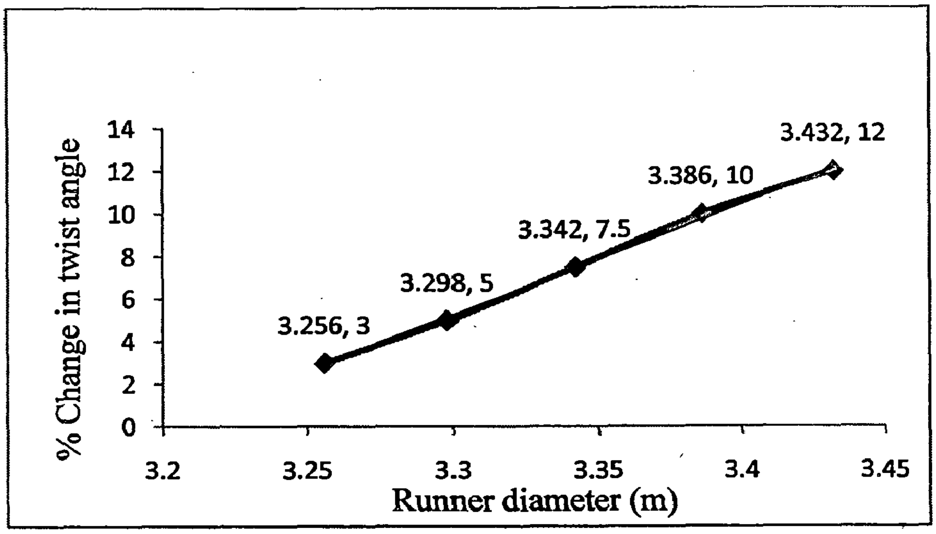


Fig.: 4.8 Percentage change in twist angle with different runner diameter.

Based on the runner diameter with increase in runner diameter the twist angle is also goes to increase as shown in fig. 4.8. Therefore with the increment in the twist angle the passage of fish goes to increase and smoothness of blade profile also occur , which is helpful to the passage of fish the in the turbine.

4.7.4 Unit Generation Cost

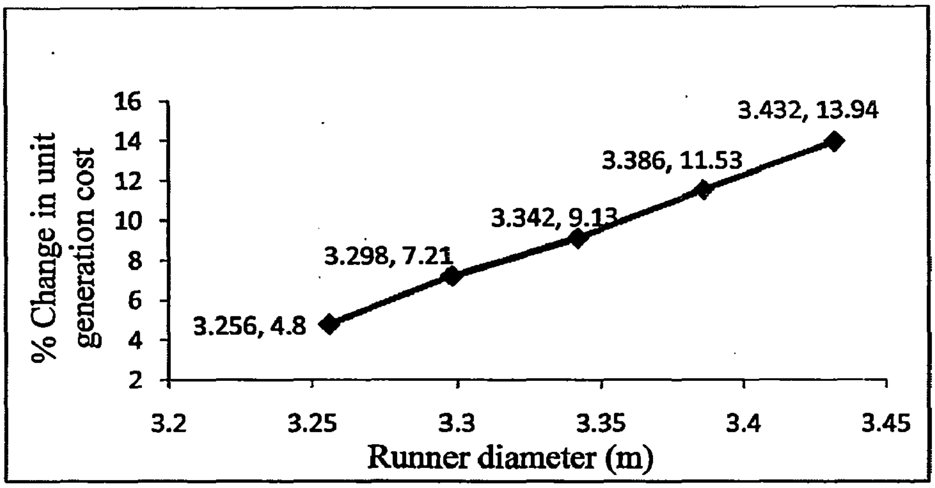


Fig.: 4.9 Percentage change in unit generation cost with different runner diameter.

With respect to runner diameter the project cost is also goes to increase i.e. unit generation cost is increase directly and we see in Fig. 4.3 the efficiency goes to decrease. But the other parameter like flow velocity and twist angle also goes to change which is helpful to the survival of fish in the turbine. Therefore we select the optimum design which is suitable for less mortality rate and high efficient with unit generation cost. The effect of runner diameter on the percentage change in unit generation cost is shown in Fig. 4.9.

4.8 RESULTS AND DISCUSSIONS

In this chapter, attempt are made to analysis the effect of runner diameter on modified turbine efficiency, unit generation cost, twist angle and flow velocity. Percentage change in turbine efficiency, change in flow velocity, change in twist angle and change in unit generation cost with respect to runner diameter are plotted in figures 4.6, 4.7, 4.8, 4.9 respectively. Following are the criteria for optimal selection of runner diameter.

I. Unit generation cost should be low.
II. Flow velocity should be less. So that the pressure injury in turbine passage will be less.
III. Twist angle should be more. So that the passage of the fish will be smooth and mechanical injury will be less.
IV. Efficiency of the modified turbine should be high.

The parameters discussed above are desirable for optimal selection of modified Kaplan turbine. From figures 4.6, 4.7, 4.8, 4.9 it is observed that at 3.34m runner diameter, the percentage change in turbine efficiency is minimum, percentage change in flow velocity is maximum, percentage change in twist angle is maximum and percentage change in unit generation cost is low which is suitable for the optimal selection of runner diameter.

Based on the above study following results were obtained.

1. It has been found that additional cost in Kaplan turbine to make it fish friendly shall be approximately 3 % of the conventional Kaplan turbine.
2. In modification of Kaplan turbine to make it fish friendly, there will be decrease in efficiency by 6%.

3. For a typical project it has been estimated that the unit generation cost increase 9 % for the process of make it fish friendly.
4. Fish mortality can be reduced by the use of modified Kaplan turbine compared to the conventional turbine. More modifications can be done such as:
    I. To increase the number of wicket gates and reduce the spacing between them.
    II. To change the shape and size of wicket gates.
    III. To decrease the clearance between runner and fixed turbine housing components.

CHAPTER 5

CONCLUSIONS AND FUTURE SCOPE

Recent developments in the design of advanced, environmentally friendly turbines indicated that there is a real potential for reducing some of the most common adverse impacts of hydropower. In the present study an attempt has been made to design and analysis a low head fish friendly turbine. The modification of design was done on the runner diameter of the Kaplan turbine and its effect was analyzed on the Hub and tip ratio, Flow velocity, Efficiency, Peripheral velocity at hub and tip twist angle to decrease the mortality rate of the aquatic species. The cost of the modified fish friendly Kaplan turbine was also estimated. The comparative study of per unit generation cost of plant using conventional and modified fish friendly Kaplan turbine was carried out. From the study following conclusions were drawn:

- Based on the velocity triangle analysis optimal runner diameter at which mortality rate of the fish will be minimum is found as 3.34 m. For this runner diameter, twist angle of the blade, flow velocity, efficiency of the turbine and unit generation cost are calculated as 41 $^{\square}$ at inlet, 14m/s, 89.69 % and Rs. 2.27 respectively.
- The additional cost of Kaplan turbine to make it fish friendly shall be approximately 3 % of the conventional Kaplan turbine.
- In modification of Kaplan turbine to make it fish friendly, there will be decrease in efficiency of 6%.
- For a typical project it has been estimated that the unit generation cost increases by 9% for the process of make it fish friendly.
- Fish mortality can be reduced by the use of modified fish friendly Kaplan turbine compared to the conventional turbine.

FUTURE SCOPE

1. Based on the above study the optimum selection of fish friendly turbine for a specific site could be carried out.
2. An analysis on Fish Sensor device can be conducted.

3. CFD analysis of fish friendly turbine for performance analysis can be carried out.
4. To save more fishes and to reduce further mortality of fishes the following modifications are suggested:
    - I. To increase the number of wicket gates and reduce the spacing between them.
    - II. To change the shape and size of wicket gates.
    - III. To decrease the clearance between runner and fixed turbine housing components.

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