GUIDELINES FOR MAINTAINING LONGITUDINAL CONNECTIVITY THROUGH DAMS

CENTRAL WATER COMMISSION

SEPTEMBER 2017

Government of India

Central Water Commission

Guidelines for Maintaining Longitudinal Connectivity through Dams

September 2017

New Delhi

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PREFACE

The purpose of these guidelines is to provide guidance for maintaining longitudinal connectivity through dams pertaining to water (e-flow), sediment and fish. This manual is addressed to the water user community involved in assessing, recommending, and designing water diversion structures so that longitudinal connectivity can be ensured. The issue of longitudinal connectivity pertaining to water i.e. e-flow is dealt by MoEF and is not covered in this document and as such the document primarily focuses on longitudinal connectivity through dams pertaining to sediment and fish.

The document captures various reservoir sediment management strategies to prolong reservoir life and benefit downstream reaches by mitigating the sediment starvation that results from sediment trapping.

Longitudinal connectivity in the stream/river is regarded as the most important connectivity dimension for fish species representing from cold water, warm water, freshwater, brackish water and marine water for their migration. Although water resource planners, fishery biologists, and engineers have been aware of the need for fish protection, there has been inconsistent application of criteria and technology, or more importantly, a lack of consensus among fishery resource agencies and the water resource development community as to the scientific basis of past and present criteria. These guidelines include recent advancements in fish passes concept, knowledge, and application to both warm and cold water fish species.

These guidelines are prepared by the Central Water Commission (CWC), New Delhi with invaluable assistance and inputs from Central Electricity Authority (CEA), New Delhi, ICAR- Central Inland Fisheries Research Institute, Kolkata, NHPC Limited, Faridabad and AHEC, IIT Roorkee. The Central Water Commission expresses grateful appreciation to those organizations that have permitted the use of material from their publications, especially ICAR- Central Inland Fisheries Research Institute, Kolkata.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

GUIDELINES FOR MAINTAINING LONGITUDINAL CONNECTIVITY THROUGH DAMS

1. INTRODUCTION

Connectivity can be defined as a functional exchange pathway of matter, energy and organisms. Within the stream/river system, longitudinal connectivity refers to the flow or water regime that brings exchange of materials (physical, biological or chemical) along the entire pathways of a stream/river, specifically referring to longitudinal dimension, without disturbing the river/stream continuum (RC). River continuum has been considered as a central organizing paradigm in running water ecology and applicable to many streams and rivers even through physical modifiers such as impoundments require special consideration.

The longitudinal connectivity patterns starts in headwater areas where streams are shaded by riparian vegetation with less aquatic biodiversity and ends at the estuary where river meets to sea with characteristics of heavy siltation and more aquatic biodiversity with varied salinity regime.

A string of physical barriers such as dams/barrages that alter the free flow of water, sediment and movement of biotic organisms including fish, benthic communities and plankton is only the most obvious example of the loss of longitudinal connectivity.

2. PURPOSE

Longitudinal connectivity is regarded as the most important connectivity dimension for silt transportation and fresh-water fish species, because it allows upstream and downstream fish migration cycles to occur. To obtain this, sufficient water should be released downstream of the dam/barrage. The flow patterns needed to maintain important aquatic ecosystem services are known as environmental flows. If longitudinal connectivity is lost, the aquatic ecosystem will be disturbed.

3. SCOPE

As far as water resources sector is concerned, longitudinal connectivity will include passage of the following across the dam or barrage:

1. Longitudinal Connectivity Pertaining to Water
2. Longitudinal Connectivity Pertaining to Sediment
3. Longitudinal Connectivity Pertaining to Fish

3.1 Longitudinal Connectivity Pertaining to Water

Longitudinal Connectivity of water through a dam can be maintained by guaranteeing required Environmental flow. Environmental flows describe the quantity, timing, and quality of water flows required to sustain freshwater and riverine/estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems. If the flow is less, it may result in reduced connectivity and limited species migration.

This issue is under study by a committee which is looking after the e-flow issue.

3.2 Longitudinal Connectivity Pertaining to Sediment

By trapping sediment in reservoirs, dams may interrupt the continuity of sediment transport through rivers, resulting in loss of reservoir storage and reduced usable life, and depriving downstream reaches of sediments essential for channel form and aquatic habitats. With the acceleration of new dam construction globally, various sediment management strategies have been evolved for maintaining longitudinal connectivity. Generally, during monsoon, most of the sediments (75-80%) flow through flood waters. If a dam is constructed with low level sluices to pass flood water, sediments are also transported to the downstream along with flood waters. However, in cases where sluices are not provided, there are various methods by which sediment management can be achieved.

3.2.1 Reservoir sediment management strategies

This section reviews reservoir sediment management strategies that both prolong reservoir life and benefit downstream reaches by mitigating the sediment starvation that results from sediment trapping:

1) Sediment by passing and off-channel reservoir storage: Sediment bypassing diverts part of the incoming sediment laden waters around the reservoir, so that they never enter the reservoir at all. Typically, the sediment-laden waters are diverted at a weir upstream of the reservoir into a high-capacity tunnel or diversion channel, which conveys the sediment-laden waters downstream of the dam, where they rejoin the river. Normally, the weir diverts during high flows, when sediment loads are high, but once sediment concentrations fall, water is allowed into the reservoir.

   The ideal geometry for sediment bypass is one where the river makes a sharp turn between the point of sediment collection and the point of sediment reintroduction to minimize the length of the conveyance device and take advantage of the relatively steeper gradient for gravity flow. Where that ideal condition does not exist, the technique is most practical where the reservoir is relatively short, as there must be sufficient gradient to drive the transport of sediment through the diversion tunnel or diversion channel.

In recent time, dams are being design with bypass tunnels controlled with gates for bypassing the sediment during flood not only to minimize the reduction in reservoir storage capacity but also to maintain the longitudinal sediment movement. The tunnels constructed for diverting the water during the construction may also be used for diverting the sediment movement.

2) Sediment sluicing: Sluicing involves discharging high flows through the dam during periods of high inflows to the reservoir, with the objective of permitting sediment to be transported through the reservoir as rapidly as possible while minimizing sedimentation. Some previously deposited sediment may be scoured and transported, but the principal objective is to reduce trapping of incoming sediment rather than to remove previously deposited sediment. One advantage of this approach is that deposition in the reservoir is minimized and the sediment continues to be transported downstream during the flood season when sediment is naturally discharged by the river. Finer sediments are more effectively transported through the reservoir than coarse sediments. Sluicing is performed by lowering the reservoir pool prior to high-discharge sediment-laden floods. This approach requires relatively large capacity outlets on the dam to discharge large flows while maintaining low water levels and the required velocities and transport capacity. These outlets need not be at the very bottom of the dam, and at some sites with smaller storage volumes, tall crest gates can be used for this purpose.

A drawdown and sluicing strategy may be employed at reservoirs of all sizes, but the duration of sluicing depends on the watershed size and the time scale of floods events. At dams on small watersheds with rapidly rising floods, the reservoir may be drawn down only for a period of hours. In other cases, such as dams sites with small storage volumes for daily regulation (pondage), the reservoir may be held at a low level during the entire flood season to maximize sediment pass-through while continuing to produce power and using a desander to protect hydro-mechanical equipment from the abrasive sediment that is mobilized by sediment sluicing. In storage reservoirs on large rivers the reservoir may be held at a low level for a period of many weeks at the beginning of the flood season and filled with late-season flows

3) Drawdown flushing: In contrast to sluicing, whose aim is to pass sediment without allowing it to deposit, drawdown flushing focuses on scouring and re-suspending deposited sediment and transporting it downstream. It involves the complete emptying of the reservoir through low-level gates that are large enough to freely pass the flushing discharge through the dam without upstream impounding, so that the free surface of the water is at or below the gate soffit. While flushing can be undertaken in reservoirs having any configuration, because the flushing channel will typically not be wider than the original streambed, flushing will recover and maintain a substantial fraction of the original reservoir storage only in reservoirs that are long and narrow.

   The best scenario for flushing is to establish river-like flow conditions through the reservoir upstream of the dam, which is favored by the following conditions: narrow valleys with steep sides; steep longitudinal slopes; river discharge maintained above the threshold to mobilize and transport sediment; and low-level gates installed in the dam. Flushing is best adapted to small reservoirs, and on rivers with strongly seasonal flow patterns.

4) Flushing sediment for dams in series: In flushing sediment through a series of dams(located in near vicinity of each other), simultaneous flushing can be accomplished by releasing the flushing pulse first from the upstream or downstream reservoir depending upon the reservoir capacities of individual reservoirs and total discharge released in the downstream of last dam in series. Depending upon whether the most downstream or upstream reservoir starts depleting first, the other remaining dams in series should start depletion in such a manner that no incoming sediment from other dams is allowed to settle in their reservoirs. Just before that pulse reaches the next downstream reservoir, its lower level gates are also opened to pass the sediment. After finishing the sediment flush, the reservoirs are refilled and clear water released from upper level gates to flush the downstream channel of deposited sediment.

5) Pressure flushing: This technique is a variant on drawdown flushing; rather than drawing the reservoir down so that it is acting like a river in

carrying its sediment load, pressure flushing works only to remove sediment directly upstream of the dam to keep intakes operational. The reservoir level is not lowered, but outlets are opened to remove sediments a short distance upstream of the outlet, creating a cone-shaped area of scour just upstream of the outlet, the scour hole being created in a fraction of the time it would take to refill. However, the scale of sediment removal by this technique is much smaller than with drawdown flushing. Rather, pressure flushing serves to reduce sediment concentrations to the intake and thereby reduce abrasion of hydraulic structures by sediment. To maintain or restore reservoir capacity, pressure flushing is not an effective technique.

6) Turbidity current venting: Turbidity (or “density”) currents are important in the transport and deposition of sediment in reservoirs worldwide. Turbidity currents form when inflowing water with high sediment concentrations forms a distinct, higher density current that flows along the bottom of the reservoir toward the dam without mixing with the overlying, lower density waters. If the bed of the reservoir is highly irregular, with protruding features that would break up the flows and cause turbulence, turbidity currents may not sustain themselves. However, turbidity currents occur in many reservoirs, and it is often possible to allow this dense, sediment-laden water to pass through outlets in the dam, a practice referred to as “venting” of turbidity currents. This can be undertaken as a sediment management technique, even at large reservoirs where other techniques, such as reservoir drawdown, are not feasible. Some dams have been able to pass half of the inflowing sediment load by venting turbidity currents, but the technique is possible only in cases where the turbidity current has sufficient velocity and turbulence to maintain particles in suspension and the current can travel all the way to the dam as a distinct flow, where it can then be passed downstream.

7) Dredging and mechanical removal of accumulated sediments: Accumulated sediments can be removed by suction using hydraulic pumps on barges with intakes. If cohesive sediments have “set up,” cutter heads may be required to break up the cohesive sediments. Dredging is expensive, so is most often used to remove sediment from specific areas near dam intakes. If there is sufficient hydrostatic head over the dam, it can create suction at the upstream end of the discharge pipe to remove sediment and carry it over the dam as a siphon.

8) Sediment traps: Low dams located just upstream of reservoirs can function as traps for (mostly coarse) sediment. These should be designed for easy access by heavy equipment, so the trapped material can be easily excavated and trucked to the downstream river channel for sediment augmentation.

Nowadays in the designs of dam, sluices are provided at the lower level near to river bed level to manage the sediment in the reservoir. Flushing and/or sluicing operation during the monsoon ensures the longitudinal connectivity pertaining to sediment in the river, as most of the sediment is carried by the water in monsoon season.

In un-gated spillway sediment usually gets deposited up to crest level, therefore in monsoon season the sediment connectivity is maintained automatically.

As Himalayan Rivers carry about 75% - 80% of average annual sediment during the monsoon season, the longitudinal connectivity pertaining to sediment is usually maintained by combination of drawdown sluicing and reservoir flushing. ICOLD Bulletin 115 "Dealing with Reservoir Sedimentation" also states that sediment management through drawdown sluicing and reservoir flushing are practiced internationally and various case studies are given in the Bulletin pertaining to these methods. Drawdown sluicing is almost a continuous process during monsoon period and as such majority of incoming sediment is passed in the downstream through the spillway. Reservoir flushing is carried out in small sized reservoirs (run-of-the-river projects) once in a month during monsoon period which re-mobilizes the deposited sediment and releases the same through the spillway. Thus both drawdowns sluice and reservoir flushing operations during monsoon being followed for sediment management, ensures the longitudinal connectivity with respect to sediment in the river, as most of the sediment is carried by the rivers during monsoon.

3.3 Longitudinal Connectivity Pertaining to Fish

Longitudinal connectivity in the stream/river is regarded as the most important connectivity dimension for fish species representing from cold water, warm water, and freshwater, brackish water and marine water for their migration. Fish migrations are grouped into different categories such as anadromous, catadromous, oceanodromous, and potamodromous etc., based on their relationship to the seawater /freshwater boundary.

Anadromous fishes

Anadromy occurs when most feeding and growth occurs in saltwater and fully grown adults move back into freshwater to spawn. One of the most important and well-studied migratory species is Tenualosa ilisha, commonly called as hilsa shad. Belonging to family Clupeidae, the species inhabits rivers, estuaries and coastal waters.

Catadromous fishes

Catadromous fishes are ones that migrate from fresh water into the sea to spawn; or, ones that stay entirely in fresh water and migrate downstream to spawn. The species Anguilla bengalensis, commonly called as Indian mottled eel, is a semelparous, catadromous species.

Amphidromous and potamodromous fishes

There are many amphidromous species among the ichthyofauna, which move from coastal to freshwater habitat and vice versa for feeding and other (not breeding) purposes. Amphidromous fishes that are spawned in freshwater migrate downstream to the sea and then go upstream at a juvenile stage for further growth and reproduction.

When fishes migrate from one freshwater habitat to another in search of food or for spawning, it is called potamodromous migration. There are about 8,000 known species that migrate within rivers, generally for food on daily basis as the availability of food differs from place to place and from season to season. Many species of fishes are potamodromous, which migrate within the river system. Potamodromous fish species such as carps, and catfishes are mostly dependent upon good flow and water availability throughout the year in the entire stretch.

In the light of rapid development of enormous physical barriers such as dams and barrages, the longitudinal connectivity of most of the rivers is at stake. Riverine flow is a major determinant of physical habitat in rivers, which in turn influences biotic composition. Change in flow regime leads to habitat alterations, shifting in species composition, loss of biodiversity and failure in migration and breeding of residential fishes. In this regard, longitudinal connectivity of entire river plays a significant role for maintaining river flow and fish migration. Longitudinal connectivity in the stream and river can be maintained through the prescribed ecological flows or environmental flows taking into consideration of optimum water requirement of ecological functions.

Therefore, the concept of Environmental flow came into existence, which mainly refers to the water considered sufficient for protecting the structure and function of an ecosystem and its dependent species. Ecological/Environmental flows are required to be maintained through a river reach for sustaining its ecosystem and dependent species. It means enough water is to be released in the downstream of the river system after utilizing the water for the development projects in order to ensure downstream environmental, social and economic benefits.

Though longitudinal connectivity can be achieved through ecological /environmental flows, additional support for the fish migration in the up/down stream could be achieved through providing suitable fish pass for successful recruitment through breeding and feeding.

Establishment of fish bypass/pass depends upon the 1) topography of the river 2) hydrological regime of the river 3) targeted fish species and their behavior and 4) type and height of structure.

3.3.1 Fish Passes

Fish passes are engineering structures that facilitate the natural upstream or downstream movement of aquatic organisms especially fish stocks across these structures placed besides dam, barrages and weirs.

General requirements of a fish pass

The general criteria that fish passes should meet include the biological requirements and the behavior of migrating aquatic fish.
The working principle of a fishway is attraction of the migrating species to a particular location in the river which is on the downstream side of the obstruction and then enables them to pass upstream. For planning fish passes, following principals are to be followed:

Safe passage: Facilitating upstream and downstream passage of migrating fish with minimal injury or mortality resulting from the project barrier or impediment.

Timely passage: Minimal delay of migration movements past the barrier to the extent needed to achieve restoration goals which otherwise can result in adverse effects on reproductive potential through many factors.

Effective passage: is achieved when most if not all fish arriving at the barrier successfully pass to upstream/downstream habitats without impact on their natural biological functions.

Thus while designing fish passes, following criteria are of paramount importance:

(a) Optimal position of fish pass

In rivers fish utilize the whole width for migration. Fish passes in dams provide the migrating fishes a small part of the dam for their migration. Thus positioning of the pass is extremely important. Fish usually migrate upstream in or along the main current. For the entrance of a fish way to be detected by majority of upstream migrating organisms, it must be positioned at the bank of the river where the current is highest. Entrance of the fish way should be located where fish will have good access. Therefore, for the entrance of a fish way to be detected by majority of upstream migrating fishes, it must be positioned at the location of the river where there is optimum/ adequate attraction flow or current.

(b) Fish pass entrance

The perception of current by fishes plays a decisive role in their orientation in rivers. Fish that migrate upstream as adults usually swim against the current (positive rheotaxis). If migration is blocked by an obstruction, the fish seek onward passage by trying to escape laterally at one of the dam's side. In doing so they continue to react with positive rheotaxis and in perceiving the current coming out of a fish way, are guided into the fish pass. The optimum range of velocity at which the attracting current exits the fish pass should be within the range of 0.8 to 2.0 m/s.

Since diurnal fish avoid swimming into dark channels, the fish pass should be in daylight and thus not covered over. If a small portion of the fish way is not exposed to sunlight, the fish way should be lit artificially in such a way that lighting is as close as possible to natural light.

(c) Fish pass exit and exit condition

In general, if the headwater level of the impoundment is constant, the design of the water inlet does not present a problem. However, special provisions have to be made at dams where the headwater level varies, where variations in level exceed one meter, several exits must be constructed at different levels for the fish way to remain functional.

Upstream fish exit at different levels: Strong turbulence and current velocities over 2.0

m/s must be avoided at the exit area of the fish pass so that the fish leaves the pass for headwater more easily. The water intake of the fish way should be protected from debris by a floating beam.

(d) Discharge and current conditions

The discharge required to ensure optimum hydraulic conditions for fish within the pass is generally less than needed to form an attracting current. However, the total discharge available should be put through the fish pass to allow unhindered passage of migrants especially during periods of low flow. The turbulence of the flow through the fish way should be as low as possible so that all fishes can migrate through the pass independent of their swimming ability. In general the current velocity in fish way should not exceed 2.0 m/s at any narrow point such as orifices or slots. The flow through the fish way is very important and should be well within the sustained swimming capabilities of the fishes concerned to make the passage efficient and effective.

(e) Lengths, slopes of a fish pass

The body length of the biggest fish species that occurs or could be expected to occur in a particular river is an important consideration in determining the dimensions of fish pass.

The average body length of the longest fish species expected in the river as well as the permissible difference in water level must be considered in defining the dimension of a fish pass. The maximum permissible slope of the fish passes normally is less than 1:15. For length & slope of fish pass, IS: 13877 can also be referred.

(f) Design of bottom

The bottom of a fish pass should be covered along its whole length with a layer at least 0.2 m thick of coarse substrate. Ideally the substrate should be typical for the river. The rough bottom must be continuous up to end including the exit area of the fish pass as well as at the orifices.

3.3.2 Different Kinds of Fish Passes

There are various kinds of fish passes currently being used in different parts of the world. Provisions of a particular type of fish pass depends upon various factors such as site topography, height of structure (dam/barrages), hydrological regime, fish species behavior etc. in this section, a general overview of various types of prevalent fish passes has been described.

(a) Pool pass

It is generally a concrete channel from the head water to the tail water. This channel is divided into a succession of stepped pools from the headwater to the tail water by cross walls of wood or concrete. This cross walls are fitted with submerged orifices and top notches on alternate sides. Fish migrate from one pool to the next through openings in the cross-walls. During migration the pools with their low flow velocities provide shelter to the fishes.

Design: The pool passes may be straight from headwater to tailwater. It may be curved or folded resulting in a shorter structure. The entrance to the fish pass downstream must be located in such a way that dead angles or dead-ends are not formed

Pool dimensions: The pool dimensions must be selected in such a way that the ascending fish have adequate space to move and that the energy contained in the water is dissipated with low turbulence. On the other hand, the flow velocity must not be reduced to the extent that the pools silt up. A volumetric dissipated power of 150 W/m^3 should not be exceeded to ensure that pool flows are not turbulent. The pool size must be chosen as to suit the behavioral characteristics of the potential natural fish fauna and should match the size and expected number of migrating fish. The bottom of the pools must always have a rough surface in order to reduce the flow velocity in the vicinity of the bottom and make it easier for the benthic fauna and small fish to ascend. A rough surface can be produced by embedding stones.

Application: Pool passes are suitable for maintaining the possibility of migration at dams for both strongly swimming fish, and for bottom oriented and small fish. In pool passes, a continuous rough bottom can be constructed whose spaces offer opportunities for ascent to the benthic fauna.

The relatively low water requirements of between 0.05 and 0.5 m^3/s for normal orifice dimensions and differences in water level are an advantage.

On the other hand, the high maintenance requirements of pool passes are disadvantageous, as there is a high risk of the orifices being obstructed by debris. Experience has shown that many pool passes are not functional during most of the time simply because the orifices are clogged by debris. Pool passes, therefore, require regular, maintenance and cleaning.

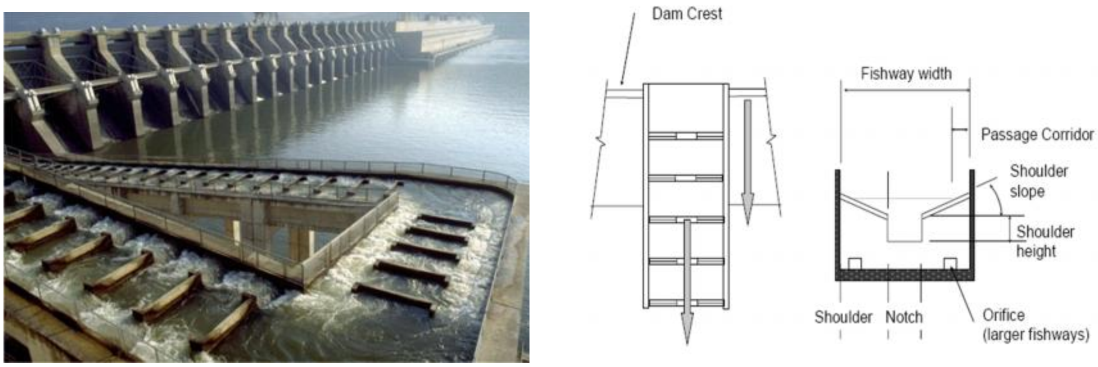

Figure 1: Pool Pass

(b) Slot passes

It is generally a concrete channel from the head water to the tail water. This channel is divided into a succession of stepped pools from the headwater to the tailwater by cross-walls of wood or concrete. The cross-walls may have one or two slots depending on the size of the watercourse and the discharge available. In the one-slot design, the slots are always on the same side. The slot pass was developed in North America and has been widely used there since the middle of the twentieth century.

Application: Slot passes (vertical slot passes) are well suited to guarantee ascent of all types of fish species especially that are weak swimmers and small fishes.

Other advantages are:

- Column and bottom-living fish can easily swim through the vertical apertures that stretch over the whole height of the cross-walls.
- The reduced flow velocities existing near the bottom of the slots allow low performance fish to ascend.
- Not sensitive to varying tailwater levels.

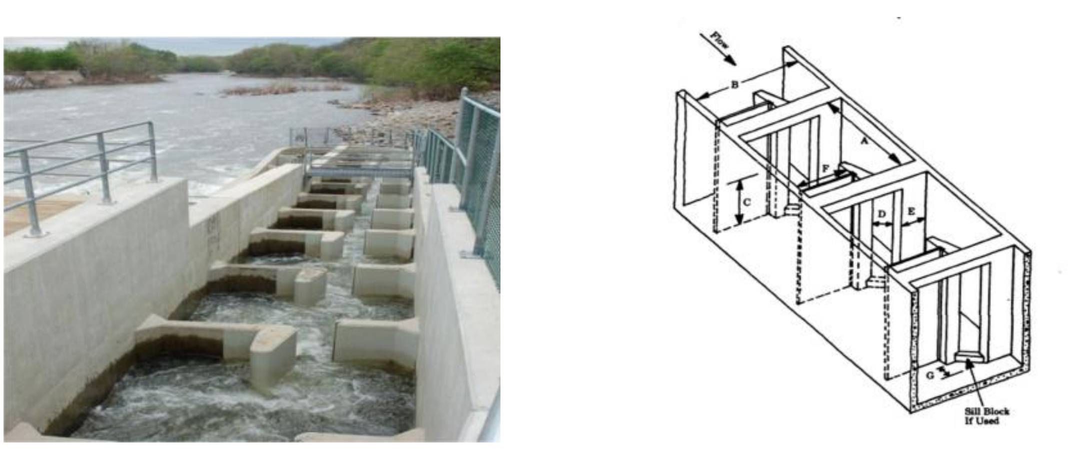

Figure 2: Slot Pass

(c) Denil pass

"Denil pass" is named after its designer (Denil, 1909). The fish pass consists of a linear channel, in which baffles usually of wood are arranged at regular and relatively short intervals, angled at 45° against the direction of flow. The backflows formed between these baffles dissipate considerable amounts of energy and, because of their interaction, allow a relatively low flow velocity in the lower part of the baffle cutouts. This allows the Denil pass to have a steep slope, relative to other types of fish passes, and to overcome small to medium height differences over relatively short distances.

Application: The Denil pass is characterized by the following advantages:

- It can have steep slopes with resulting low space requirements;
- It is not susceptible to variations in tailwater level;
- It usually forms a good attraction current in the tailwater.

The disadvantages of this type of construction are:

- High susceptibility to variations in the headwater levels. In practice, only variations of a few centimeters, with a maximum of about 20 cm, are permitted;
- Relatively high discharges needed compared to other construction types;
- Clogging with debris can easily upset its functioning. Denil passes require regular inspection and maintenance.

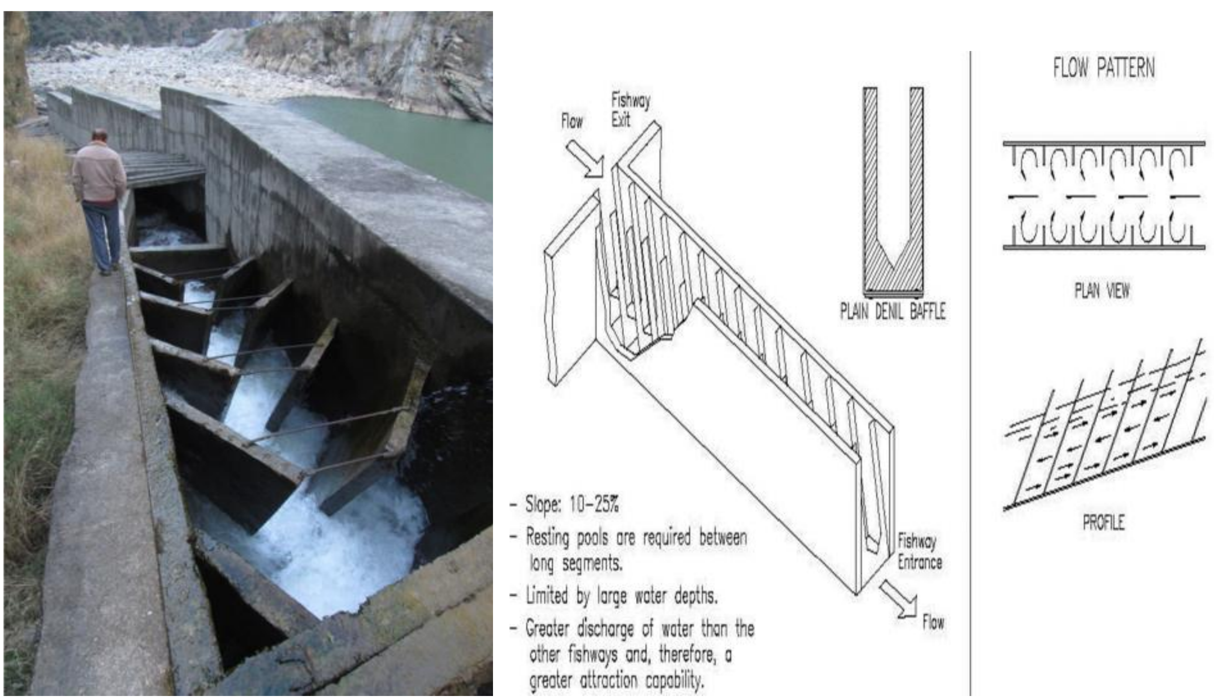

Figure 3: Denil Pass

(d) Fish lock

It is a pit shaped chamber with controllable closures at head water and tailwater openings. The attraction current is formed by controlling the sluice gate openings or by sending water through a bypass.

The use of fish locks as mitigation devices has been known for quite some time now and has been applied especially in the Netherlands, Scotland, Ireland and Russia.

Design: The design of the chambers and closing devices is variable and largely depends on the specific local conditions. When designing the chamber bottom there should be measures to prevent fish being left in areas that become dry.

Application: It is used for high heads, and where space or available water discharge is limited. Planning and construction is often technically demanding. Fish locks require high efforts in maintenance and operation, high construction and service cost, low water consumption. Useful where very large fish e.g. hilsa are to be taken into consideration.

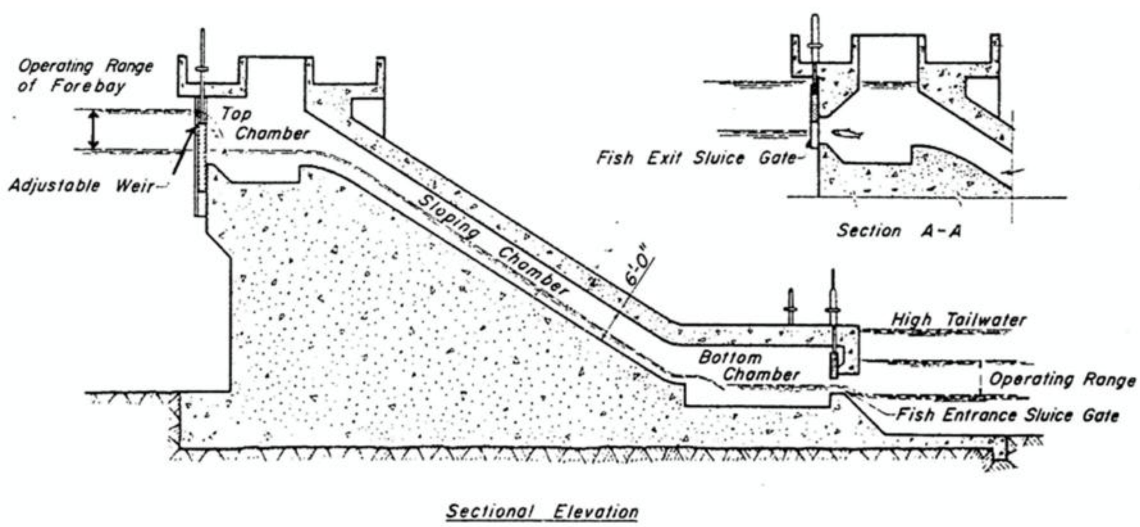

Figure 4: Fish Lock

(e) Fish lift

Fish lifts are used where there are considerable height differences (> 6 to 10m) and little water availability, there are restrictions on the applicability of conventional fish passes, due to the building costs and space requirement. Thus the solutions have been developed to carry fish from the tailwater to the headwater using a lift.

A trough is used as a conveyor and is either equipped with a closable outlet gate or can be tilted. When in the lower position, the trough is sunk into the bottom. Fish have to be attracted towards the fish lift by a guide current. In addition, a sliding and collapsible grid gate located in front of the lift, may serve to push the fish into the lift and thus above the transport trough. The lower gate of the lift closes on a regular cycle. The fish gathered above the trough can no longer escape are "caught" by the rising trough and conveyed to the top. Here a watertight connection may be made to the upper water level or else the trough is simply tipped out above the headwater level into a funnel. Along with the water from the trough the fish reach the upper channel where, once again, there must be a clear attraction current.

The regular cycle is determined according to actual migratory activity. The operation is usually automatic.

The same principles apply to the positioning of a fish lift as for conventional fish passes.

Application:

- Little space is required, and large height differences can be overcome with such fish lifts even at high dams. However, the structural expenditure is considerable.
- Since the fish are conveyed upstream passively, fish lifts are suitable for species with low swimming performance as well as for the transportation of large fishes.
- Fish lifts are not suited for the upstream migration of invertebrates and the downstream migration of fish.
- Large variations in the tailwater always mean design problems in providing an adequate guide current.
- The expenditure on maintenance for fish lifts is higher than for traditional fish passes.

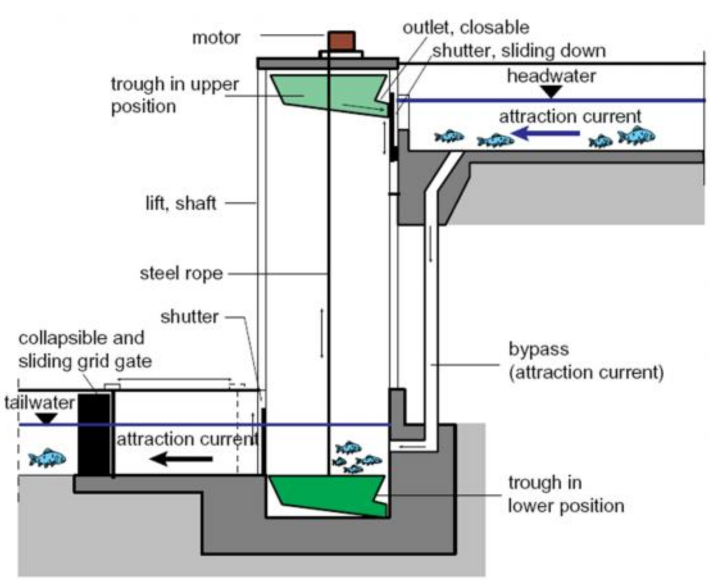

Figure 5: Fish Lift

(f) Fish ramps

It is a construction that is integrated into the weir and covers only a part of the river width; with as gentle a slope as possible to ensure that the fish can ascend. In general the incorporation of perturbation boulders or boulder sills is required to reduce flow velocity in fish ramps.

A. weir can also be converted to a bottom ramp or slide over its whole width if the water levels do not need to be controlled and adequate discharge is available.

The model for designing a fish ramp is again derived from nature. The primary objective of fish ramp design is to mimic the structural variety of natural river rapids or streams with more or less steep slopes.

A fish ramp is normally integrated directly in the weir construction, and concentrates, as far as possible the total discharge available at low and mean water level. At by-pass power stations, for example, the necessary residual discharge can be sent through the fish ramp and water only spills over the weir crest during floods.

Design: As a rule, fish ramps are set by river banks and the bank that receives the greater portion of the current is the most favorable. The upper, acute angle should be selected for the construction of the fish ramp at submerged weirs standing obliquely in the river. An existing empty evacuation channel or abandoned sluiceway can often be used for the construction of a fish ramp.

Fish ramps installed at fixed weirs with very steep slopes, at obstacles with vertical drops or at weirs equipped with movable shutters often have to be confined on one side by a solid wall. Fish ramps at gently sloping weirs can be given an inclined lateral filling, to prevent the formation of dead corners .If the entire discharge passes through the fish ramp, the guide current is always clearly directed. It is therefore possible to place the entrance to the ramp further downstream. Fish ramps usually join the headwater at the weir crest, which has technical advantages, for diverting water during construction for example. The upstream water inlet (i.e. the fish pass exit") may need to be designed with a narrowed cross-section to limit discharges through the ramp, particularly during flooding.

The width of the ramp should be a function of the available discharge, but should not be less than 2.0 m.

The general requirements of fish ramp design can be defined as follows: mean depth of water 30 to 40 cm, slope < 1 :20 to 1 :30, flow velocity1.6 to 2.0 m/s, bottom substrate rough, continuous connection to the bottom of the river bed shelters, deep zones and resting pools to facilitate upstream migration. Longer sections with gentle slopes and with deeper resting pools are recommended, particularly in the case of ramps longer than 30 m.

Application:

Fish ramps are "close-to-nature" constructions and characterized by the following features:

- They are suitable for retrofitting of low fixed-weir installations.
- They can be passed even by small fish and fry and by the benthic invertebrates.
- They are also suitable for downstream migration of fish.
- They have a natural-looking, visually attractive design.
- They require little maintenance in comparison with other constructions.
- They are not easily clogged; flood debris do not immediately affect the efficiency of the installation.
- Their guide currents are satisfactory and easily located by fish.
- They offer habitat for rheophilic species.

Their disadvantages are:

- Sensitivity to fluctuating headwater levels.
- The large discharges necessary for their operation.
- The large amount of space they occupy.

A general overview of various types of structures for fish passes is also given in **Annexure - I**.

The fish pass in forms of bypass channel is being observed the most successful than the engineered structure for the fish migration. In the recent times, it has been observed that in the middle and lower stretches of the river fish bypass channel is most suitable for the migration and maintaining the longitudinal connectivity, while in the upper stretch of the river both fish ladder and diversion/bypass channel is recommended. If the height of the proposed barrier /barrage is up to 10m, provision in terms of fish ladder installed in a straight line with gentle slope may be considered for barrages/dam above 10 m, the possibilities of connecting diversion channel to the downstream tributaries or streams with natural slope/gradient, in addition to the suitable fish ladder/lift/lock for maintaining longitudinal connectivity and fish migration shall be explored. For high dam where such provisions cannot be provided due to height of the structure and/or topographical constraint, methods for fish conservation/hatching can be adopted.

3.3.3 Guidelines for maintaining longitudinal connectivity for fish migration

1. **Optimum ecological/environmental flows must be estimated taking into account of fish migration, and recruitment.**

2. **Bypass channel is recommended in the middle and lower stretches of the river for maintaining the fish habitat and migration.**

3. **Detailed behavioral study on fish migration and habitat requirement of the targeted fish species must be carried out before designing of fish pass/bypass.**

4. **Design of fish pass in barrages must be site and species specific and should be installed in a straight way with optimum continuous flows and natural slope of the river.**

5. **In dams with wide gorge or relatively flat topography at abutments, provision of fish passes in the form of fish ladder/ bypass channel should be explored. In other dams, provisions of fish lift shall be explored.**

6. **In dams, where fish ladder/bypass channel/lift etc. is not suitable due to technical constraint of height and site topography, other conservation measures such as creation of fish hatchery/ fish farm may be considered**

7. **For planning and design of fish pass in a particular dam and river reach, CIFRI or any other specialized agency shall be consulted.**

8. **Environmental flow may be used for fish pass water requirement.**

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Annexure - I

Table 1

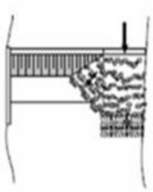
Close-to-nature types of structures						
Type	**Sketch**	**Principle**	**Dimensions* and discharge**	**Range of application**	**Advantages and disadvantages**	**Effectiveness**
Bottom ramps and slopes		Ramps and slopes are structures that have a rough surface and extend over the entire width of the river. Loose rockfill constructions and dispersed constructions are favoured.	The ramps are as wide as the river (b = width of river), their slope normally < 1:15. If the main body of the ramp is steeper, then at least the marginal areas must be less steep. Height h > 0.2 m. Discharge must be q > 100 l/s m. Construction in several layers and with secured downstream bottom.	Recommended where a previous use has been abandoned and where the headwater level needs no longer be regulated. Used for the modification of steep drops and fixed (very steep) weirs, as a protective sill to hinder erosion.	There is a danger of drying out at low discharge, so sealing may be necessary. Relatively low costs. They blend well into the landscape, look natural, require little maintenance. No problems with attraction currents, so can easily be found by fish.	They are passable in both directions by all aquatic fauna. Long term silting of the impoundment restores also upstream the typical flow velocities and substrate conditions.
Bypass channels		Offer an alternative route round a dam with a natural-looking stream bypassing the impoundment.	b > 1.2 m; h > 0.20 m; < 1:20. The bypass should extend up to the upstream limit of the backwater. Discharge must be at least q = 100 l/s m.	Suitable for all barriers and heads if there is sufficient space, particularly useful for retrofitting existing installations. They are not suitable when impounding heads vary; in the latter case, inlet constructions for water regulation might be necessary.	Their financial cost is low, their demand for space high! Deep cuts into the surrounding terrain may be necessary or combination with other technical structures. Bridges or underpasses are often required.	They are passable for all aquatic fauna, provide living space for rheophilic species, are the only fish pass that can bypass the whole area of the dam and the impoundment, blend well into the landscape.
Fish ramps		Ramps with gentle slopes and a rough surface; integrated into the weir structure. Their body may be of rockfill, with perturbation boulders or boulder sills to reduce flow velocities.	b > 2 0 m; h > 0.3 to 0.4 m; = 1:20 or less. Necessary discharge q approximately 100 l/s m.	They can be used to overcome heights not greater than about 3 metres. Used at fixed weir sills, and at multi-bay weirs as a substitute for a weir bay. They are not suitable for variable impounding heads.	Their construction is often technically demanding, with a need for high structural stability. There is a danger of drying out at low water, therefore sealing may be necessary. Require little maintenance; good self-cleaning during floods. Good attraction current.	They are passable for all aquatic fauna in both directions, i.e. upstream and downstream.

Table 2

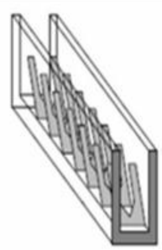
Technical structures						
Type	**Sketch**	**Principle**	**Dimensions* and discharge**	**Range of application**	**Advantages and disadvantages**	**Effectiveness**
Slot passes		Slot passes are generally concrete channels with cross-walls of concrete or wood and with one or two vertical slots that extend over the whole height between the cross-wall and the lateral bounds.	Pool dimensions: l_b > 1.90 m; b > 1.20 m; h > 0.5 m; Slot width: s > 0.17 m. Discharge can be from Q = 140 l/s up to several cubic metres per second.	Used for small and medium heads, suitable for variable impounding heads. Can be used for small streams and large rivers. The minimum tailwater depth must be h > 0.5 m.	Relatively high discharges can be sent through, thus good attraction currents can form. More reliable than conventional pool passes because of the lower risk of clogging of the slots.	They are currently the best type of technical fish pass, being suitable for all species of fish and are passable for invertebrates if a continuous bottom substrate is built in.
Pool passes		Are generally concrete channels with cross-walls of wood or concrete which are fitted with submerged orifices and top notches on alternate sides.	Pool dimensions depend on the river zone; l_b > 1.4 m; b > 1.0 m; h > 0.6 m. Submerged orifices: b_S/h_S > 25 · 25 cm Discharge Q = 80 to 500 l/s.	Used for small and medium heads, at melioration dams and at hydroelectric power stations.	Only relatively low discharges allowed; there is great risk of clogging with debris.	Suitable for all species of fish if the dimensions of the pools and orifices are chosen as a function of the fish size that can be expected to occur. There might not be sufficient attraction current at low discharges.
Denil passes		Wooden or concrete channel with sectioned baffles (usually of wood) that are U-shaped, and are set at an angle of 45° against the flow direction.	Channels: b = 0.6 to 0.9 m; h > 0.5 m; < 1:5; Q > 250 l/s. Channel lengths can be 6 to 8 metres; resting pools are required for heights > 1.5 to 2 m.	Suitable for small heads, particularly for retrofitting of old milldams when there is not much space.	Relatively high discharges; should not be used for variable headwater levels; not sensitive to varying tailwater levels; need little space; cheap; good formation of attraction current.	According to present knowledge, less suitable for weak swimmers or small fish. Selective. Benthic fauna cannot pass.

Table 3

Special constructions						
Type	**Sketch**	**Principle**	**Dimensions* and discharge**	**Range of application**	**Advantages and disadvantages**	**Effectiveness**
Eel ladders		Generally, eel ladders are small channels with brush-type fittings, layers of brushwood or gravel, with water just trickling through them; also "eel pipes" that are led through the weir body and are filled with brushwood or brush-type material.	Channel: b = 30 to 50 cm; h = 15 to 25 cm. Slopes usually 1:5 to 1:10, but can be steeper.	Often used as a bypass in pool passes, but only useful where migration of glass eels and elvers occurs; in general not strictly necessary if there is another fish pass.	Low construction costs, only little space required, only low discharges needed.	Only suitable for glass eels and elvers. Eel pipes are not proven satisfactory because of their tendency to become clogged and the difficulty in maintenance. On their own, they are not sufficient to connect upstream and downstream habitats and cannot guarantee free passage for all fish.
Fish locks		A pit-shaped chamber with controllable closures at headwater and tailwater openings. The attraction current is formed by controlling the sluice gate openings or by sending water through a bypass.	Their dimensions can vary, with minimum chamber width and water depth being similar to those in a pool pass. Water quantity requirements depend on chamber size, cycle intervals for lock operation and required intensity of attraction current.	Used for high heads, and where space or available water discharge is limited.	Planning and construction is often technically demanding. Require high efforts in maintenance and operating, high construction and service costs, low water consumption. Useful where very large fish (e.g. sturgeon) are to be taken into consideration.	According to present knowledge, suitable for salmonids and fish with weak swimming capacities. Less suitable for bottom-living and small fish.
Fish lifts		Lifting device with transport trough and mechanical drive to hoist fish from tailwater to headwater; connection to headwater through a channel; water sent through a bypass creates attraction current.	Dimensions variable, volume of transport trough about 2 to 4 m^3. Continuous flow through a bypass needed to create attraction current.	Used for same situations as fish locks, but often the only type of pass that can be built for heights greater than 10 metres, e.g. at high dams.	Need little space. Planning and construction is often technically demanding. Require high efforts in maintenance and operating, high construction and service costs.	According to present knowledge, suitable for salmonids and fish with weak swimming capacities. Less suitable for bottom-living and small fish. Not suitable for macrozoobenthic fauna or for downstream migration of fish.

Annexure-2

No.6/12-A/2016/CMDD (E&NE)/ 170-178

Government of India

Central Water Commission

CMDD (E&NE) Directorate

2K, 8th Floor (North),
Sewa Bhawan, R.K. Puram,
New Delhi-110066
Date: 13.04.2016

OFFICE ORDER

As per the decision taken in the meeting to discuss and resolve issue of "Longitudinal Connectivity" convened by Chairperson, CEA with Chairman & Member (D&R), CWC on 08.03.2016, following committee is hereby constituted to decide the possible provisions of longitudinal connectivity in the water resources projects :

1. Member (RM),CWC	Chairman
2. Chief Engineer, Designs (E&NE),CWC	Member
3. Chief Engineer, Designs (N&W),CWC	Member
4. Chief Engineer, (HSO) ,CWC	Member
5. Representatives from CEA	Member
6. Representatives from NHPC	Member
7. Representatives from THDC	Member
8. Prof Arun Kumar ,AHEC, IIT Roorkee	Member
9. Director, CMDD,(E&NE),CWC	Member Secretary

The terms of reference (TOR) of the committee will be as follows :

1. To discuss and finalise various aspects of maintaining longitudinal connectivity in water resources projects keeping in view :

   i. Type of the structure (dam/weir/barrage)
   ii. Size of the structure
   iii. Topography of the area
   iv. Hydrology
   v. Any other aspect

2. The committee will evolve its own procedure to achieve TOR.
3. The committee shall finalise its findings within three months.

This issues with the approval of Chairman, CWC.

O/C Sd/-
(Vivek Tripathi)
Director, CMDD(E&NE)

Copy to:

1. PPS to Chairman, CWC
2. Member(RM), CWC
3. Chief Engineer, Designs (E&NE), CWC
4. Chief Engineer, Designs (N&W), CWC
5. Chief Engineer, HSO, CWC
6. Chairman, CEA, It is requested to nominate concerned officials for the above committee.
7. Director (Technical), NHPC. It is requested to nominate concerned officials for the above committee.
8. Director (Technical) THDC. It is requested to nominate concerned officials for the above committee.
9. Prof. Arun Kumar, AHEC, IIT Roorkee.