DESIGN ANALYSIS OF FUSEGATE APPLICATION FOR DAM SAFETY AND STORAGE ENHANCEMENT

A DISSERTATION

Submitted in partial fulfillment of the
requirements for the award of the degree
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by

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in this thesis, entitled **"DESIGN ANALYSIS OF FUSEGATE APPLICATION FOR DAM SAFETY AND STORAGE ENHANCEMENT"** in partial fulfillment of the requirements for the award of degree of Master of Technology in Water Resources Development, submitted in the Department of Water Resources Development and Management of the Indian Institute of Technology Roorkee, India, is an authentic record of my work carried out during the period from June, 2014 to May, 2016 under the supervision of Dr. Ashish Pandey and Dr. Nayan Sharma.

The matter embodied in this has not been submitted by me for the award of any other degree.

Date: 27th April, 2016

Place: Roorkee MUKTI NARAYAN

CERTIFICATE

This is certifying that the above statement made by the candidate is correct to the best of my knowledge.

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ABSTRACT

For the purpose of controlled release of water from the dams spillway is provided. Spillway releases floods so that the water does not overtop and damage the dam. Except during the flood periods water generally does not flow over the crest of the spillway. Devices such as Floodgates and Fuseplugs are constructed along with the spillways to regulate the flow of water and dam height.

A controlled spillway is the one which is provided with mechanical structures such as gates in order to regulate the flow. On the other hand, uncontrolled spillways does not possess any gates, when the level of water rises above the crest level of the spillway it begins to be released from the reservoir of the dam. The nappe depth above the dam’s crest governs the rate of discharge.

It’s a well known fact that about 20 to 30 % of dam failures are attributed to the failure of spillway gates, which confirms the urgent need of improvement in gate operations in order to enhance dam safety. In some cases due to the failure of the controlling systems, interrupted power supply or some manual mistakes by the operators result in the failure of dams.

Fuseplugs and fusegates are collapsible devices which are by nature collapsible devices. Under normal operations they behave as conventional spillways but when catastrophic floods occur, these devices get collapsed or they get toppled about their downstream abutments and give additional space to water to pass through and thus ensuring the safety of dam under catastrophic floods and freak hydrological events.

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1. INTRODUCTION

Once the great American president John F. Kennedy stated, “Anyone who can solve the problems of water will be worthy of two Nobel Prizes - one for Peace and one for Science”.

Ever since the evolution of mankind, water has been the most important resource. It is evident by the fact that every ancient civilization has flourished near the banks of rivers.

With the changing climatic conditions and owing to the freak hydrological events, a more dynamic behavior of hydraulic structure is desired. Artificial changes in rivers cause change in their flow behavior in terms of their quantity, quality and many other aspects.

Dams possess enormous amount of energy. If this energy is liberated all of a sudden, disaster is imminent. In the year 1952, Andre Coyne the designer of the Malpasset Dam said:” Among all the creations of mankind, dams are the deadliest” [1].

In the year 1959, this huge dam in France failed resulting in the loss of a very large number of lives. Mostly large dams bank upon spillway gates in order to pass floods. If the gates fail to operate properly during the time of floods the dams are likely to fail.

It’s a well known fact that about 20 to 30 % of dam failures are attributed to the failure of spillway gates, which confirms the urgent need of improvement in gate operations in order to enhance dam safety. In some cases due to the failure of the controlling systems, interrupted power supply or some manual mistakes by the operators result in the failure of dams.

1.1 TRADITIONAL DEVICES

Conventionally Sand bags & Flash boards have been widely used as collapsible devices.

- The main advantage of using such devices is their low cost and little or no maintenance requirements.

BUT, the main disadvantage is that,

- These conventional devices do not always collapse corresponding to a precise amount of discharge value and moreover their collapse mechanism is by and large unpredictable.

Therefore, an urgent need of such collapsible devices was felt which would collapse for a precise discharge and thus will give way to water to pass through in case of catastrophic floods and thus ensuring dam safety.

1.2 PRINCIPLE OF COLLAPSIBLE DEVICES

Usually the device should be readily overtopped by the normal flows without any damage but they should collapse in case of catastrophic floods during freak hydrological events.

1.3 PREDICAMENT OF DESIGNERS

- **PROFITABILITY CONSIDERATIONS**
- **SAFETY REQUIREMENTS**

In case a free sill is preferred, it offers total safety but it results in an appreciable loss in the operational capacity. On the other hand a Gated sill provides full operational capacity but is susceptible to system malfunctions that may occur as a consequence of human or technical glitches or due to problems with power source**.**

For the purpose of controlled release of water from the dams, spillway is provided. Spillway releases floods so that the water does not overtop and damage the dam. Except during the flood periods, water generally does not flow over the crest of the spillway. Devices such as Floodgates and Fuseplugs are constructed along with the spillways to regulate the flow of water and dam height.

A controlled spillway is the one which is provided with mechanical structures such as gates in order to regulate the flow. On the other hand, uncontrolled spillways does not possess any gates, when the level of water rises above the crest level of the spillway it begins to be released from the reservoir of the dam. The nappe depth above the dam's crest governs the rate of discharge.

Fuseplugs and fusegates are collapsible devices which are by nature collapsible devices. Under normal operations they behave as conventional spillways but when catastrophic floods occur, these devices get collapsed or they get toppled about their downstream abutments and give additional space to water to pass through and thus ensuring the safety of dam under catastrophic floods and freak hydrological events.

2. LITERATURE REVIEW

The Otter Brook dam comprises of a 40 metre high embankment which was constructed in the year 1958 as one of the units among the network of flood control dams which were built on the tributaries of the Connecticut River which is located in New Hampshire in the United States of America[2]. It was owned and operated by the US Army Corps of Engineers in New England District. Even after the original construction, the dam had a constriction of discharge which was equivalent to $37m^3/s$. The dam also consisted of a 48 metre long free overflow spillway for the discharge of large flows, but this was inadequate.

After the initial assessment of the economical benefits, a comprehensive review of all the remediation options were undertaken including spillway control systems and conventional methods.

Finally, it was concluded to install Fusegates on the dam. The French company Hydroplus constructed Fusegate on the Otter Brook dam. Total number of six fusegates was to be constructed. Each of the Fusegate was of 2.75 metre height and 8 metre width and was installed during the year 2005.The first Fusegate was designed to tip off when the head of water reached 1.82 metre above its crest. All the Fusegate were designed to tip of corresponding to a discharge of 1650 m^3/s. The project undertook the advantage of the capability of the Fusegates to withstand large amount of water above its crest before it tilts.

The Canton Dam located in the USA in the western province of Oklahoma[3]. It was owned and managed by the US Army Corps of Engineers. The main aim of the dam was to protect the Oklahoma city from the flooding by the North Canadian River. A comprehensive review of all the remediation options were undertaken including spillway control systems and conventional methods.

Finally, it was concluded to install Fusegates on the dam. The French company Hydroplus constructed Fusegate on the Canton dam. Nine numbers of fusegates were built each having height of 9.14 metre and width of 16.25 metre, each of them were made of reinforced concrete, cast in situ and weighed 530 tons.

Jindabyne dam[4] constructed across the Snowy river near Cooma in New South Wales, Australia and was owned by the Snowy Hydro Limited [5]and had primary aim of power generation and for the purpose of sustaining environmental flow in Snowy river. The spillway was originally designed to pass the PMF with a free board of 1.2 metre.

The actual discharge was much more than the estimated discharge. Various alternatives were studied including the overtopping protection of dams, raising the dam crest, drop inlet, labyrinth spillway and at last fusegates were installed because of its benefit in terms of less capital costs, maintenance costs, reliability and environmental aspects. It was decided to equip this dam with Fusegates having height of 7.6 metre height.

Fusegates were installed on the Kamuzu dam in Malawi [6]. This dam was owned by Lilongwe Water Board. It was completed in the year 1999. Later on, it was decided to increase the water level by 5 metres. Hydroplus completed the design, construction and installation of 14 concrete fusegates in less than a year's time.

Labyrinth type fusegate were provided each with a height of 5 metres and width of 7.5 metres. This system made it feasible to double the reservoir storage capacity from 8.9 million m^3 to 19.8 million m^3.

Dartmouth dam in Australia was provided with Labyrinth type fusegate[7, 8]. Ten numbers of fusegates were installed. The fusegates provided were 3.30 metres high and width of 5.80 metres.

The Franca dam in Brazil were installed with fusegate[9]. These fusegates increased the storage capacity by 30%. Straight type fusegates were provided. Nine numbers of fusegates were provided with height of 1.5 metre and 6.11 metres width.

3. FUSEGATES

3.1. CONCEPT

Fusegates are an inventive and veracious spillway system. **Fusegates** are the mechanical equivalent of a fuse plug[10]. This system which is patented by the Hydroplus presents itself as a indubitable alternative to the traditional systems like gates, inflatable tubes or flaps. Fusegates have been implemented successfully on more than 50 dams throughout the world illustrating undeniable evidence of its importance and effectiveness. Fusegates can be viewed as a system of freestanding units which can be installed on the sill of a spillway, side by side. The Fusegate comprises of three main components:

1. A Bucket
2. A Base
3. Intake well, joined to the chamber situated at the bottom of the fusegate apparatus.

If the Fusegate has to be placed on an already existing spillway then the sill has to be leveled before installing fusegates so that adequate flat profile for proper placing of fusegates is achieved. If it is desired to achieve an enhancement in the spillway capacity only then the fusegate's crest elevation is maintained at the same level as it was of the already existing spillway.

On the other hand if an increase in the storage capacity of the reservoir is desired then the elevation of the fusegate's crest is maintained higher than the original elevation of the Ogee spillway. Across the entire width, the fusegate is placed side by side.

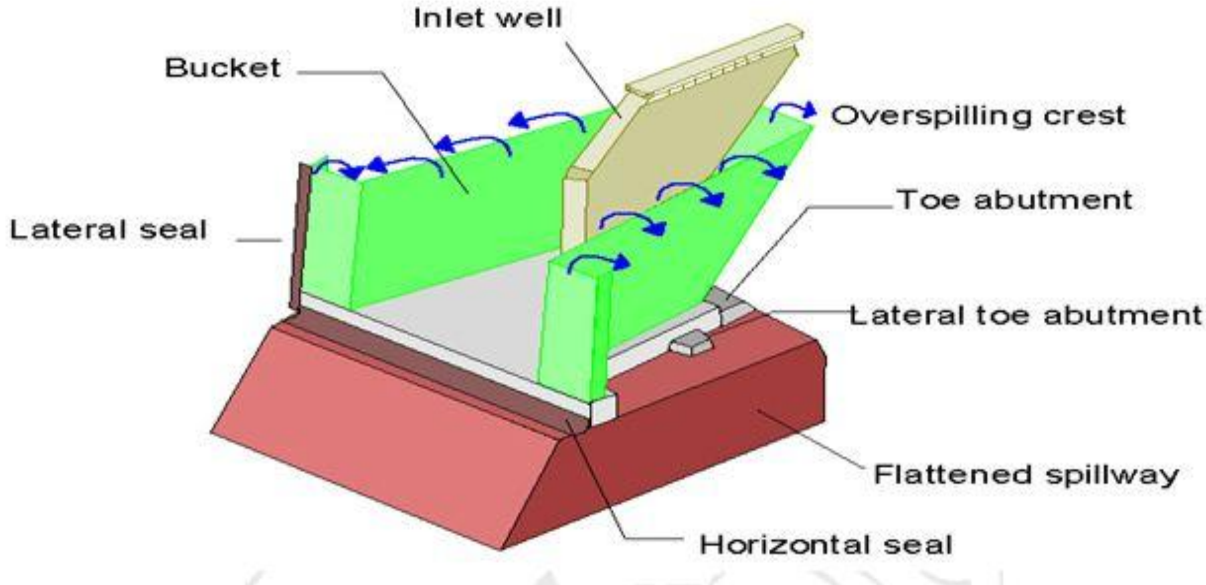


Figure 3.1 3D View of a Fusegate

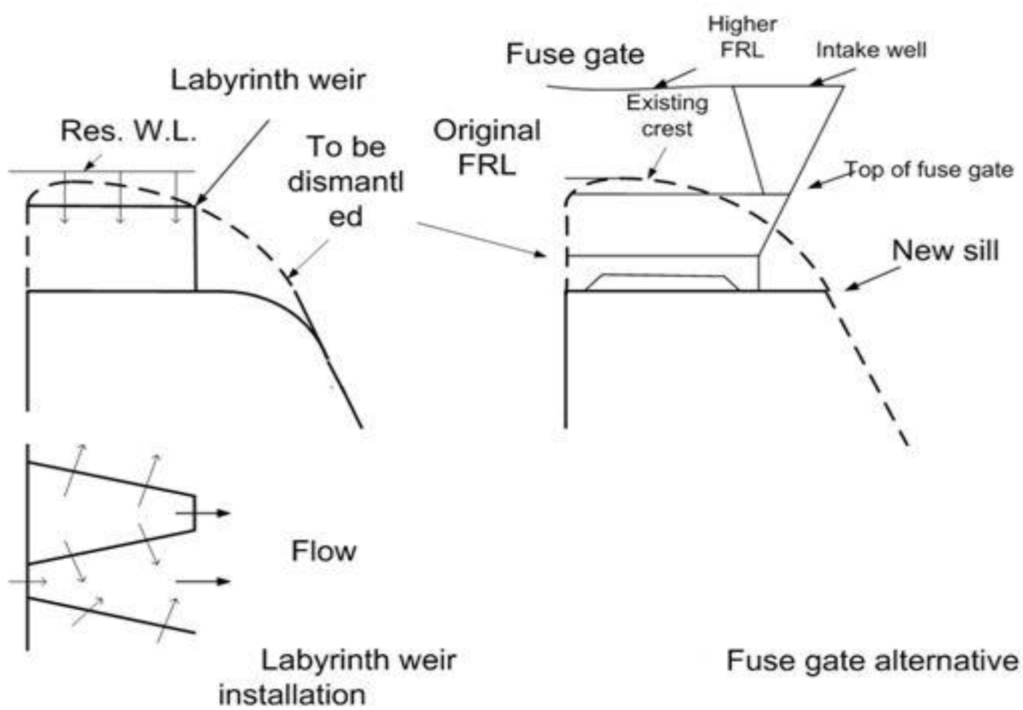


Figure 3.2 Retrofitting on an already existing dam.

3.2 BASIC OPERATION

Fusegates operate in the same manner as an aerated labyrinth for the discharges up to the design discharge value. For the value of the discharges which is greater than the value of design discharge, water enters the chamber situated at the base of the Fusegate through the intake wells. Generally, the intake well is placed directly above the base of the fusegate. But in some cases the intake well can also be placed remotely and can be linked to the chamber located at the base through conduits. Every individual bottom chamber is provided with two drains which prevents the seepage water from accumulating inside it. The joint between any two adjoining fusegates is properly fixed with the help of rubber gasket generally[11].

With the increment in flow and the amount of water entering the chamber through the intake well also increases and if it supercedes the quantity of flow which is leaking out from drains, water in the intake well increases leading to an increase in the pressure in the chamber and an uplift force is exerted on the fusegate. As a consequence of generation of this uplift force, the gates become unstable and for a predetermined level of water in the well, tilting of the Fusegate takes place by rotation about its downstream edge. At the downstream end, abutment is so made that failure occurs by rotation and not by sliding.

The elevation of the crest of the fusegates is maintained differently. Each Fusegate is designed to overturn for a progressively higher elevation of the reservoir.

When a fusegate tips off it provides additional space for the passage of flood water and the number of Fusegates falling off depend on the amount of the flood water that has to be passed. For the value of the maximum design discharge, generally equivalent to PMF, all Fusegates get tipped off and complete length of the crest is made available for the passage of the flow.

Instead of main dam being damaged or breached, the Fusegates are washed away by the rising floodwaters. Once all the Fusegates are washed away, the floodwater is easily passed through and the safety of the dam is ensured even for the catastrophic floods.

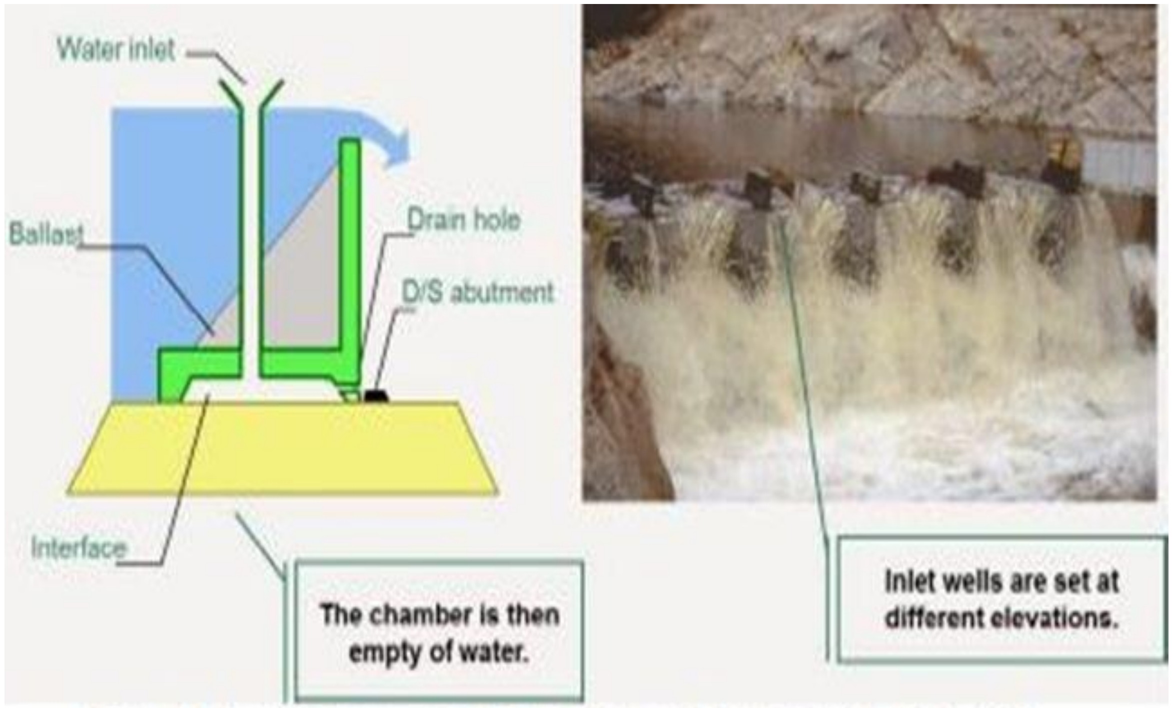


Figure 3.3 C/S through a fusegate with moderate overspill

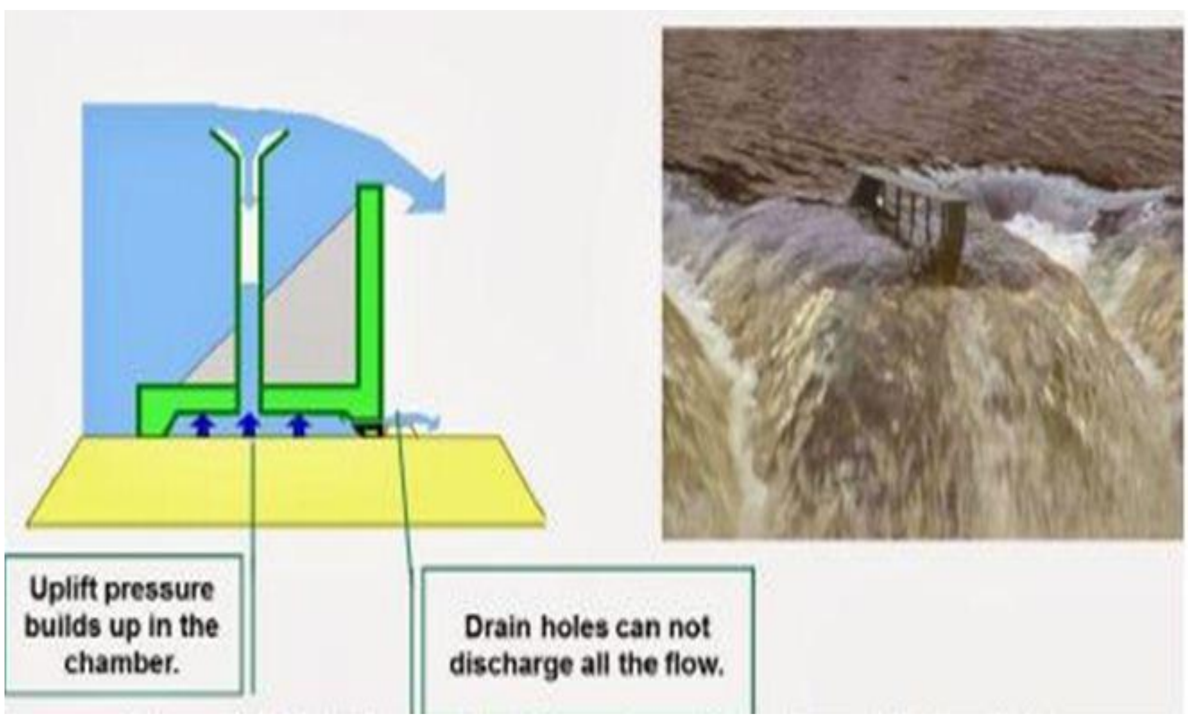


Figure 3.4 C/S through a fusegate with inlet well being fed.

When the discharge is increased, the water level in the channel is increased and the inlet well starts being fed by the water. When the water entering the chamber is more than the discharge capacity of the drain holes, the chamber gets filled completely with water and an uplift thrust is generated which renders instability to the fusegate.

Due to the lateral water pressure acting in the horizontal direction and the uplift pressure acting in the vertical direction, a resultant force acts in the downstream direction and the fusegates tips off due to rotation about the downstream abutment.

This abutment ensures that the failure takes place by rotation and not due to sliding. Thus this downstream abutment prevents sliding.

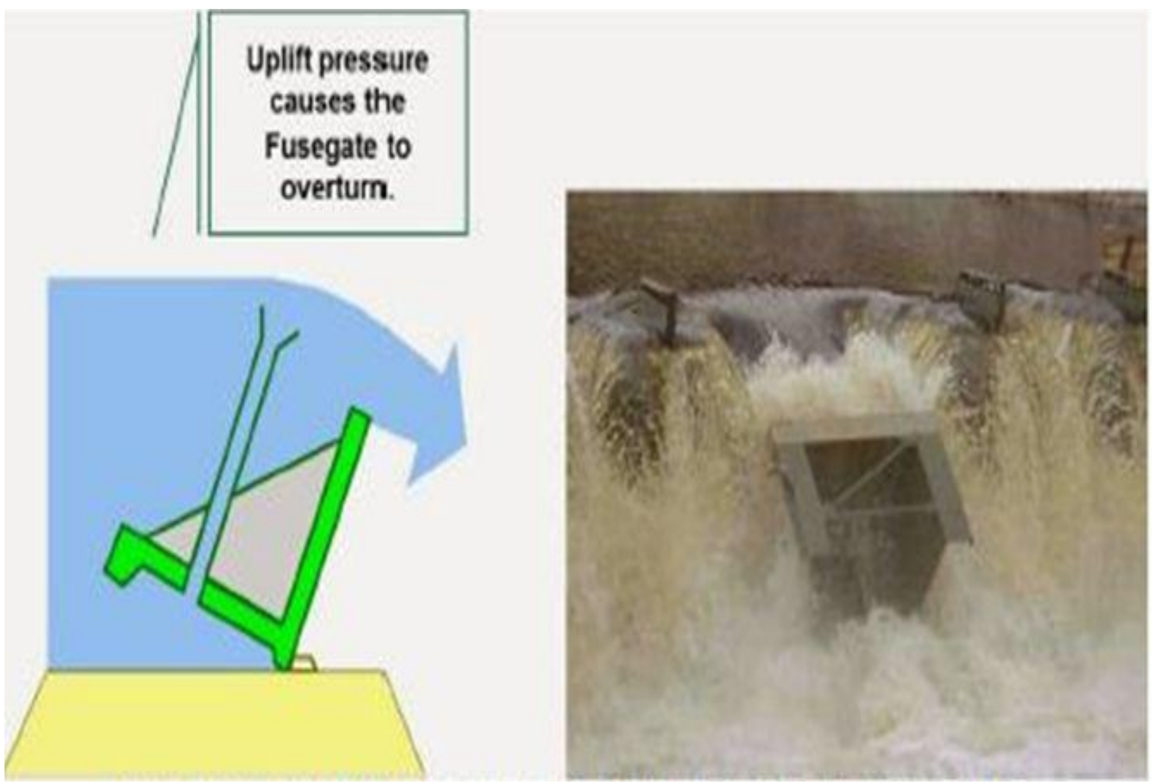


Figure 3.5: Uplift pressure causes the Fusegate to overturn

3.3 ADVANTAGES OF FUSEGATES

1. **Flexible and versatile.**
2. **Cost Effective.**
3. **Rapid installation.**
4. **Minimum long term maintenance.**
5. **Dependable, reliable and safe.**
6. **Achieves no net loss in environmental values.**

The fusegate enhances the performance of the spillway. The fusegate can be constructed in the newly dam being constructed and it can also be incorporated in the pre-existing dams[11].

The applications of Fusegate can be broadly divided into four broad categories: Firstly, Fusegate can be installed on the spillway sill which increases the normal reservoir level whilst maintaining the safety level of the dam. Secondly, Fusegates can be installed after lowering the spillway sill.

As a result, the initial storage capacity is still maintained while ensuring discharge of revised design flood. Thirdly, fusegates can be used to secure a gated system. When Fusegates are installed as a supplement to gated system, Fusegates make the dam safer by increasing its capacity so that it can discharge major floods and also ensures safety in case of human or technical failures which can result in gate malfunction. Fourthly, In cases of incidents of major flooding, the Fusegate system which are installed on the river spillways can provide protection to populated areas by diverting floodwaters into temporary holding basins.

Figure 3.6 Increment in storage capacity

Figure 3.7 Enhancing safety of dams

Some references of increased storage capacity:

Table 3.1 Some instances of increased storage

Name of Dam	Country	Increase in storage (%)
KAMUZU DAM	MALAWI	120
DARTMOUTH DAM	AUSTRALIA	62
FRANCA DAM	BRAZIL	30

3.4 FOLDING FUSEGATES

This fusegate device is based on the same triggering principles as the Classical Fusegate but it is not dragged by the flood water rather it disappears downwards like a valve. It can be set back in place manually by the operator after the flood has passed.

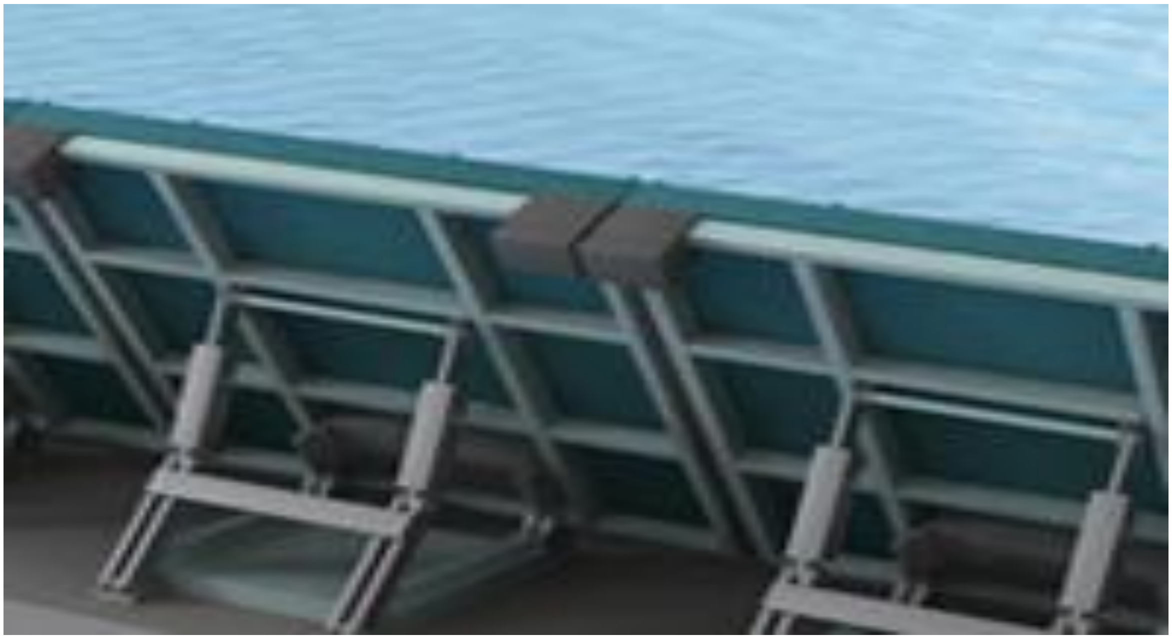


Figure 3.8 Folding Fusegate in operation

An inclined and mobile panel is supported by a set of hinged arms. It allows moderate floods to be discharged over its crest. A negative pressure chamber is mounted in the base of each module. It is equipped with drainage purges at the interface with the threshold. The storage level of the retention is raised to the level of the panel discharge crest. When the reservoir is full, the flood flows over the crest of the folding fusegate, which acts as a free threshold .During major floods, the upstream water level reaches the crest of the supply well the negative pressure chamber is supplied.

The negative pressure force generated in this chamber actuates the tilting mechanism of the folding fusegate. The panel folds in order to discharge the flood.

The tilting rate of each panel is precisely adjusted by the admission well height setting. After a major flood has passed, the panel set back into its original configuration.

Fusegate technology brings together the benefits associated with free (ungated) sills and gated systems. This is a completely reliable and standalone system, whose operation is triggered solely by water pressure.

4. PIANO KEY WEIR

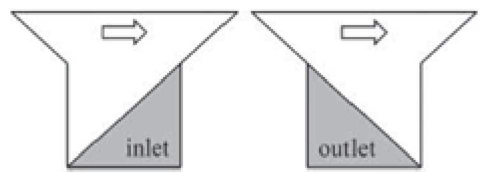
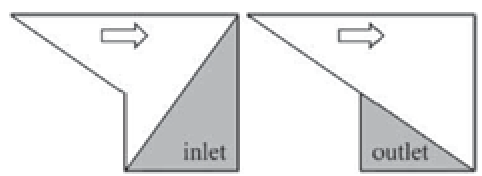
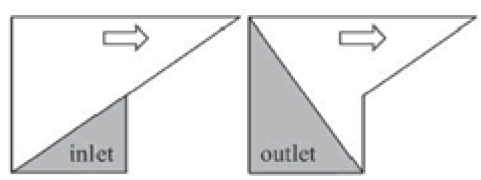
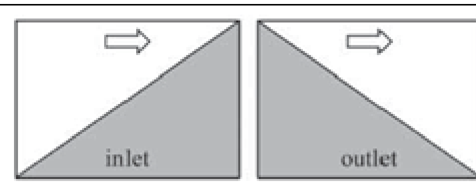
4.1. GENERAL OVERVIEW

A piano key weir is a kind of labyrinth hydraulic structure, in general, placed transversely to rivers that causes flow discontinuity and affects the hydraulics of rivers ([12-14]). General transverse structures like weir (triangular or rectangular) have a significant function in maintaining the upstream depth of water and securing water resources for optimum use ([15-17].

Figure 4.1: Piano Key Weir in operation

Piano key weir is in general a sort of a labyrinth shaped hydraulic structures which are installed transverse to the direction to the river flows and it results in the discontinuity of flow and also affects considerably the hydraulics of stream. Transverse spillway structures play a very significant role in maintaining the aspired upstream level of water and in securing water resources by storing or diverting it for optimal use. But these structures intermeddle with the sediment continuity of flows, since the flow velocity is considerably reduced due to the enhancement of water depth. As a consequence of inhibiting the propagation of sediment load passing to the downstream, the sediment gets deposited directly at the upstream of the weir. Piano Key Weir has been classified into four types on the basis of inlet and outlet keys .Among these four types, Type A of Piano Key Weir is the most commonly used PKW across the globe[18].

Table 4.1 Various types of Piano Key Weir

Piano Key Weir type	Structure Configuration	Depiction
Type A	Overhang on both sides	
Type B	Overhang on inlet side.	
Type C	Overhang on outlet side.	
Type D	No overhangs.	

The PK-Weir comprises of a rectangular non-linear weir crest set up (in plan form), different from traditional labyrinth weirs, the inclined bottom in the inlet and outlet-cycles, cited to as keys, overhangs the apexes allowing for a longer crest length than a traditional rectangular labyrinth weir, and several times to the transverse weir width.

The hydraulic conducts of PKW and the conventional labyrinth weirs are very different[19]. In the PKW, the stream may be separated into two components. The first part comprises of the inlet key region, the flows occur over the inlet key and it appears as a thin sheet of overflowing liquid, and the other part gets inside from the region of outlet key, flowing like a jet towards the bottom portion of the outlet keys.

The inclined bottom of the keys alleviates the transition of sediment over the structure, reducing upstream sedimentation and minimizing the morphological change impact on the regime of the alluvial river. Since the structure is un-gated, there is very significant reduction in the costs of construction and no operation or maintenance is required. The structure is a viable option for the water resources development, with a developing cost between 30% and 50% of the conventional barrage and spillways.

The Piano Key Weir is more efficient hydraulically than the traditional Labyrinth weirs and the conventional spillways. Piano Key Weir is an innovative, cost effective solution to increase the active storage capacity of the reservoirs and also for improving the safety of dam in case of erratic catastrophic flood events in the backdrop of climate change uncertainties[20].

Apart from Straight PKW (as mentioned above), circular and fractal type of PKW have been used across the globe to alter the hydraulic characteristics according to the local requirement.

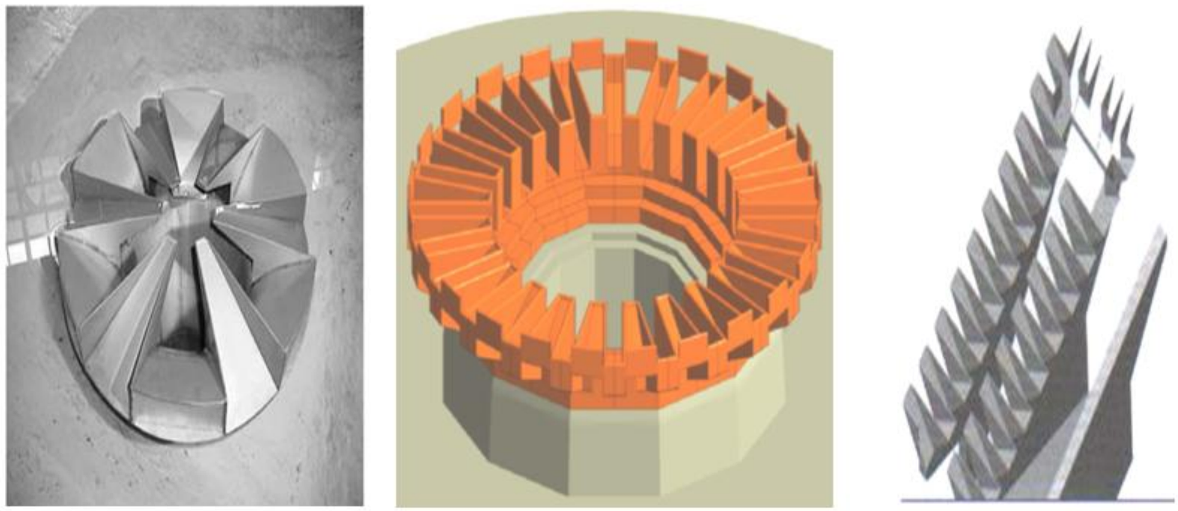


Figure 4.2 Alternatives of the straight PKW as per the local requirements

4.2 PKW as free flow Spillways at the Dam Top

Since the base footprint of the Piano Key Weir is much lesser it can be provided at the top of the dam and it can result in highly hydraulically efficient free flow spillways. In many countries they are installed at the top of the dam, list of some instances are given below in Table.

Table 4.2 List and technical details of PKW on Dam Top across the world

Name	Country	Q_{design}	P	H_{design}
		m^3/s	m	m
Campauleil	France	120	5.35	0.9
Charmines	France	300	4.38	1
Dak Mi 4B	Vietnam	500	3.75	2
Dak Mi 4C	Vietnam	200	2.5	1
Dak Rong 3	Vietnam	6550	5	3.5
Etroit	France	82	5.3	0.95
Hazelmere	South Africa	4300	9	3.23
Malarce	France	570	4.4	1.5
Raviege	France	300	4.67	1.4
Saint Marc	France	138	4.2	1.35

Since PKW seems to be very promising in the context of new dams as well as rehabilitation of the existing dams, many research and development program is being carried out around the world.

5. FUSEPLUG:

The HYDROCOOP organisation developed the device named Fuseplug and named it 'Concrete Fuseplug'**.**

5.1 MERITS OF FUSEPLUGS

Fuseplugs are a very simple and economical system for floods upto few hundred cumecs, and are considerably efficient to enhance the storage or spillage capacity of the already existing dams.

5.2 PRINCIPLE

Concrete fuseplugs consists of massive blocks made of concrete which are placed adjacently to each other on the sill of the spillway. Fuseplugs consists of freely standing units. They are self stable till the level of water in the reservoir reaches a particular elevation, and it starts to tilt when this level is superceded. Fuseplugs are designed so that they are overtopped by normal flows but they tilt for higher flows than the design discharge[21].

Fuseplug has quite a significant height compared to its thickness. Usually, the fuse plugs gets overtopped by water nappy of a depth "h" (which may be manifold times of the height of block "H") before it starts to tilt. The Fuseplug has considerable length and its thickness is many times in comparison to its elevation[22].

The height of the fusegates resting on the sill need not be different because by variying their thickness their mass can be varied, and as a result of which they will tilt for different levels of water.The upstream corners are trimmed to ease the flow discharge.

5.3. WATER ELEVATION

The knowledge of magnitude of uplift forces generated in each block enables us to estimate the water level elevation quite accurately. An easy method to get rid of such problems is to construct the blocks in such a manner as to ensure that uplift pressure is acting entirely: this is made possible by designing hollow sections beneath the plug, which are open on the upstream side and is entirely sealed in order to make it absolutely watertight on the downstream end.

5.4. GENERAL ARRANGEMENTS

When big blocks are used in the construction of Fuseplugs, they aregenerally placed adjacent to one another. Otherwise, it is recommended to use intermediate walls between the fuseplugs. These walls, that are usually designed as the integral part of sill of the spillway, helps to maintain the water nappe in the fuse plugs adjacent to that of the tipped one[21].

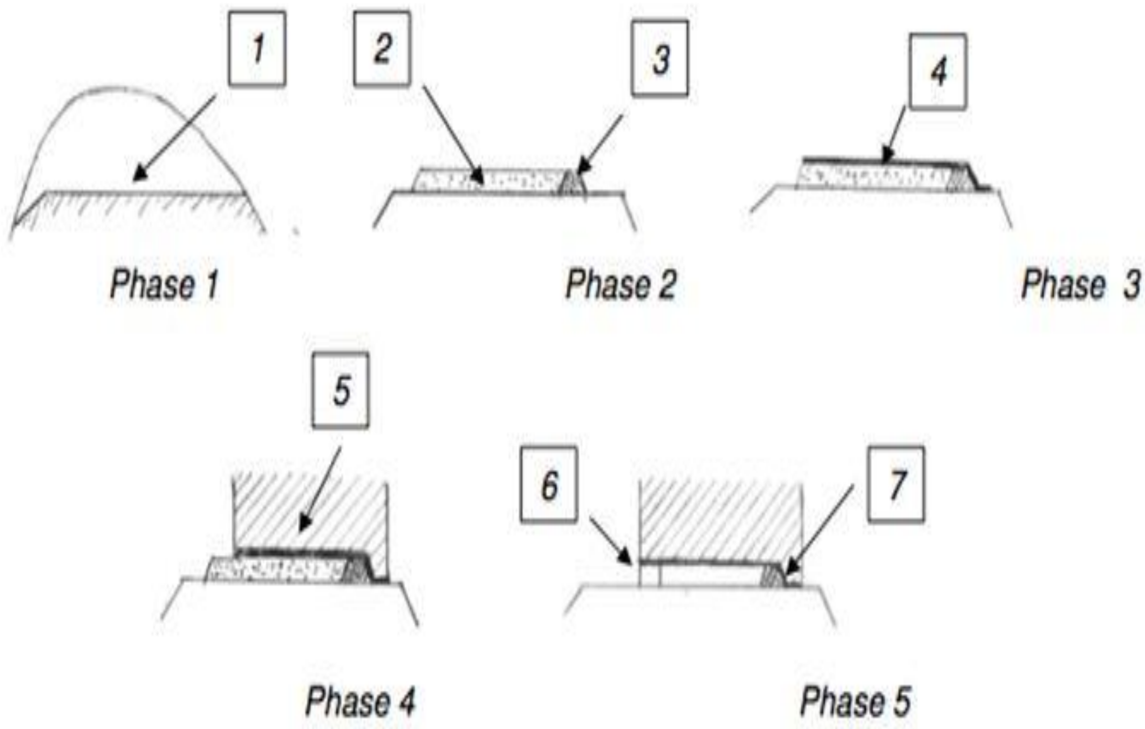
A minimum of 4 to 5 blocks of varying thickness are generally required in order to ensure a progressive tilting of the different blocks used corresponding to different water levels.

Small abutments are placed on the downstream side in order to ensure that the failure takes place due to rotation and not due to sliding.

5.5. CONSTRUCTION

- Blocks may be precast or may be cast in situ. In the cases when the blocks are cast in situ on an already existing spillway sill, they are constructed using the clay plugs for providing water tightness at the downstream end.
- The spillway sill is levelled.
- The materials are laid to form chambers. The materials which are used should be able to be easily removed after the block concreting has been done.

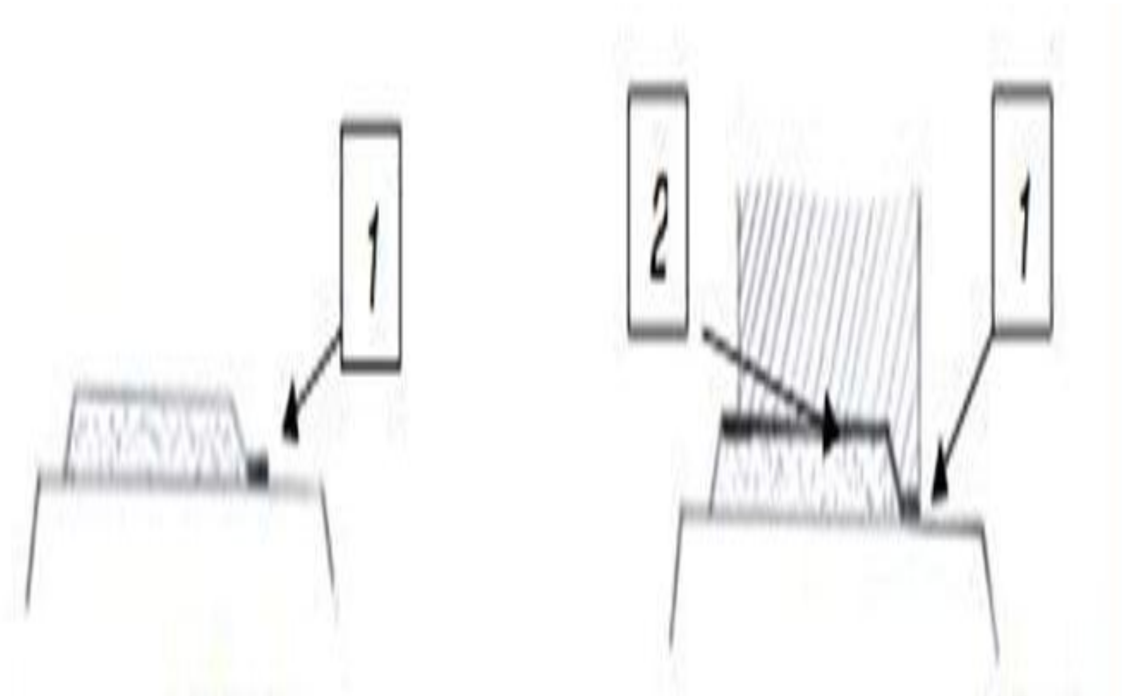
- To prevent the probable leakage at the downstream end clayey sand is used at the location where sealing has been done.
- The materials are overlain by plastic membranes.
- Concreting of the block is done.
- The materials are taken out to empty the chambers (except the downstream plug) using few supports in case side ends are not closed.



1. The sill is leveled. 2. Random materials are used. 3. Clay is placed in plug. 4. Plastic membrane is used. 5. Concrete is poured. 6. Few supports, if required. 7. Seals are placed.

Figure 5.1 Constructing phases with clay plug

5.6: ALTERNATE METHOD



1. Rubber Seal. 2. Plastic Membrane

Figure 5.2 Construction phases with rubber seal

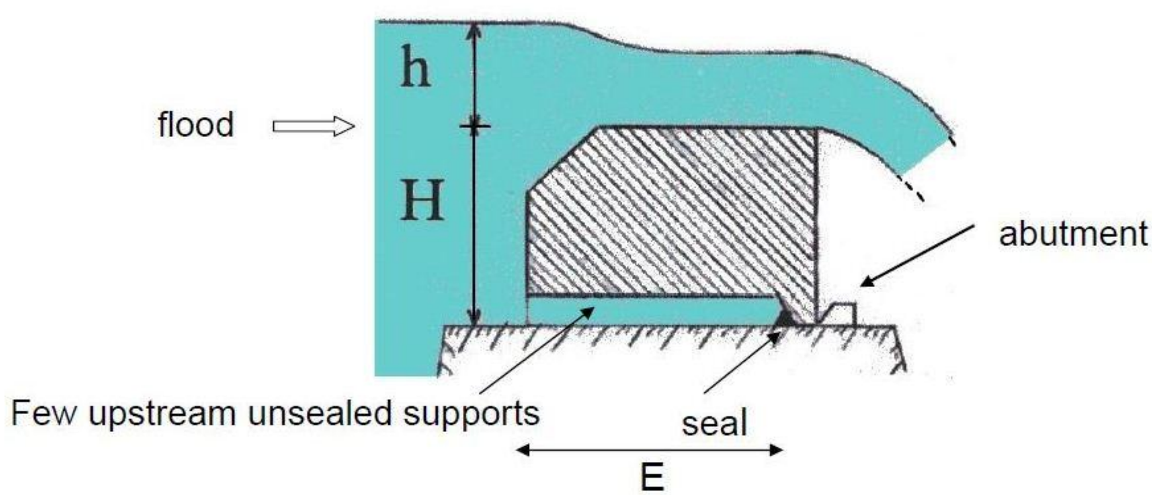


Figure 5.3 Fuseplug in operation

For the shape as shown above, a plug with a height H and a width E is tilting for a nappe depth of $h = E - 0.4\,H$.

Varying E for the different plugs increases the discharge capacity according to the value of the exceptional floods.

- A considerable distance is maintained between the dam crest and the water level at the time when the tilting of the last block takes place in order to ensure safety.
- These criterias are fixed depending on the local data and as per the objectives pursued, but,
- Mostly the fuse plugs are designed to tilt by the floods ranging from 20 years flood to the 100 years flood or even more.
- The height of the concrete blocks should not be more than the ¼ th of minimum distance between the sill of the spillway and the dam crest when the heightening is done.

5.7 ADVANTAGE OF FUSEGATE OVER FUSEPLUG

Fuse gates have been successfully installed on over more than 40 Dams across the world and the results have already displayed their significance and worth in improving the dam safety and enhancing the storage of the dams.

Fusegates are superior to the Fuseplugs due to the following reasons:

1. The Fusegates can easily withstand quite significant discharge above its crest before it gets washed away after tipping off.
2. Fusegates tip off for quite a precise discharge and its failure mechanism is quite predictable and reliable.
3. There is little or no maintenance required.
4. During the instances of catastrophic flooding events, the release of water is more controlled than in Fusegate.
5. The characteristic of the material used is more reliable and does not change with time.
6. Till now there have been no instances where Fusegates behaviour have not been in accordance with their design.
7. Fusegates have a much lesser environmental footprint than the Fuseplug.
8. Fusegates can be easily model tested in the laboratory and their behaviour can be anticipated well in advance.

6: EXPERIMENTAL SETUP

6.1 RECTANGULAR CHANNEL

All the experiments were carried out in the River Engineering Lab, in the department of Water Resources Development and Management, Indian Institute of Technology Roorkee, India.

These experiments were carried out in a rectangular Channel section of 50 cm width and 1.0 m depth. The experimental observations based on localized bed condition were taken at 0.50 m wide section in the middle of the flume. During the experiments, the discharge is maintained between 20 l/sec to 50 l/sec. with constant bed slope. Tailgate was used to maintain the depth of flow.

Figure 6.1 Image of channel in which experiments were conducted

6.2 FLOW REGULATING DEVICE

Figure 6.2 Discharge control mechanism

7 DISCHARGE MEASUREMENT AND CALCULATIONS

Discharge measurement was done with the help of triangular notch pre installed in the flume.

Notch is a device that measures the flow rate of a liquid flowing in a small channel. On the other hand a Weir is defined as masonry or concrete structure, which is installed in an open channel over which the flooding occurs[23]. The notch is of smaller size whereas weir is of larger size.

Classification of Notches and weirs:

1. On the basis of opening.
   a.) Triangular.
   b.) Rectangular.
   c.) Trapezoidal, and
   d.) Stepped.
2. Based on the effect on the sides on the nappe:
   a.) Notches comprising of end contraction.
   b.) Notches without any end contraction or suppressed notch.

Weirs are classified on the basis of their shape of opening, shape of crest, nature of discharge and the effects on the sides of the nappe.

1. According to the shape of the opening.
   a. Rectangular weir
   b. Triangular weir.
   c. Trapezoidal.
2. According to the shape of the crest:
   a.) Sharp crested
   b.) Broad crested
   c.) Narrow crested
   d.) Ogee shaped

Nappe or Vein: Sheet of water flowing through the notch or over the weir is called Nappe.

Crest or sill: Bottom edge of the notch or the top of the weir over which the water flows.

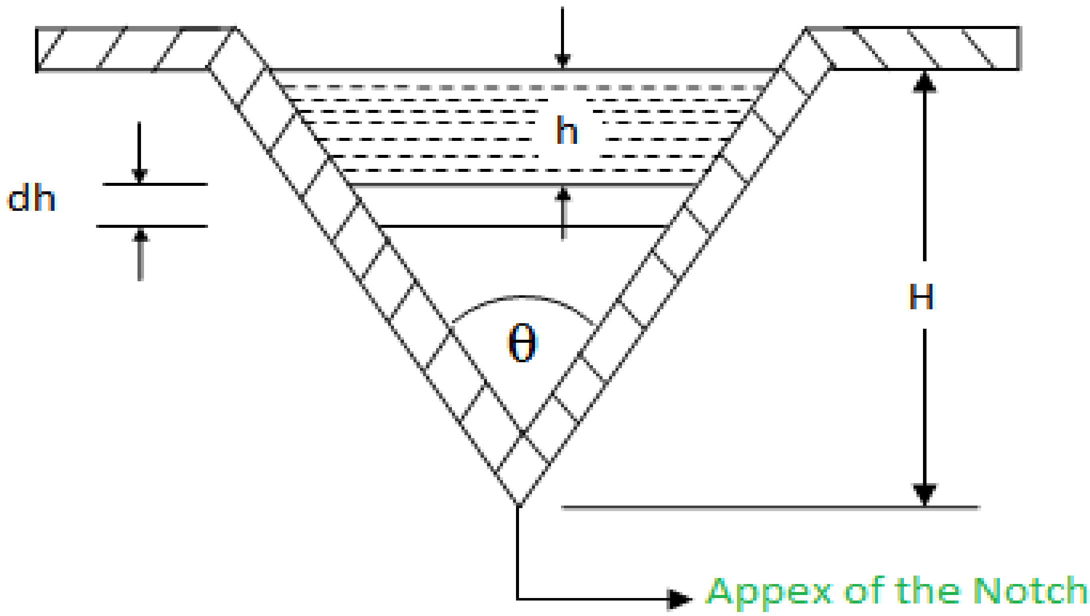


Figure 7.1V –Notch Specifications

Denotations:

- H = Height of water above apex of the notch
- θ = Angle of notch.
- C_d = 0.62, Coefficient of discharge

The top width of the notch at the surface = 2 H tan (θ/2).

Area of the strip =2×(H-h)× tan (θ/2).dh

We know that the theoretical velocity of water flow through the strip = $\sqrt{2gh}$

And discharge through the notch, dq = C_d x Area of strip x Theoretical velocity

=> dq = $C_d \times (2(H-h) \times \tan(\theta/2)\sqrt{2gh}$ [24]

Total discharge above the whole notch is found out only by the integration of the above equation ranging from limits 0 and H.

$$Q = \int_0^H Cd \,.\, (2(H-h)\sqrt{2gh} \qquad \text{...1.}$$

$$\mathbf{Q = \frac{8}{15} . C_d . \sqrt{2g} . \tan\frac{\theta}{2} . H^{2.5}} \qquad \text{...2.}$$

8 LABORATORY SET UP

8.1 DISCHARGE MEASURING DEVICE

Figure 8.1 Discharge measuring device (V-Notch) in laboratory

8.2 Piano Key Weir in operation

Figure 8.2 Piano Key Weir in operation

8.3 EXPERIMENTS ON FUSEGATE

8.3.1 Fusegate before installation

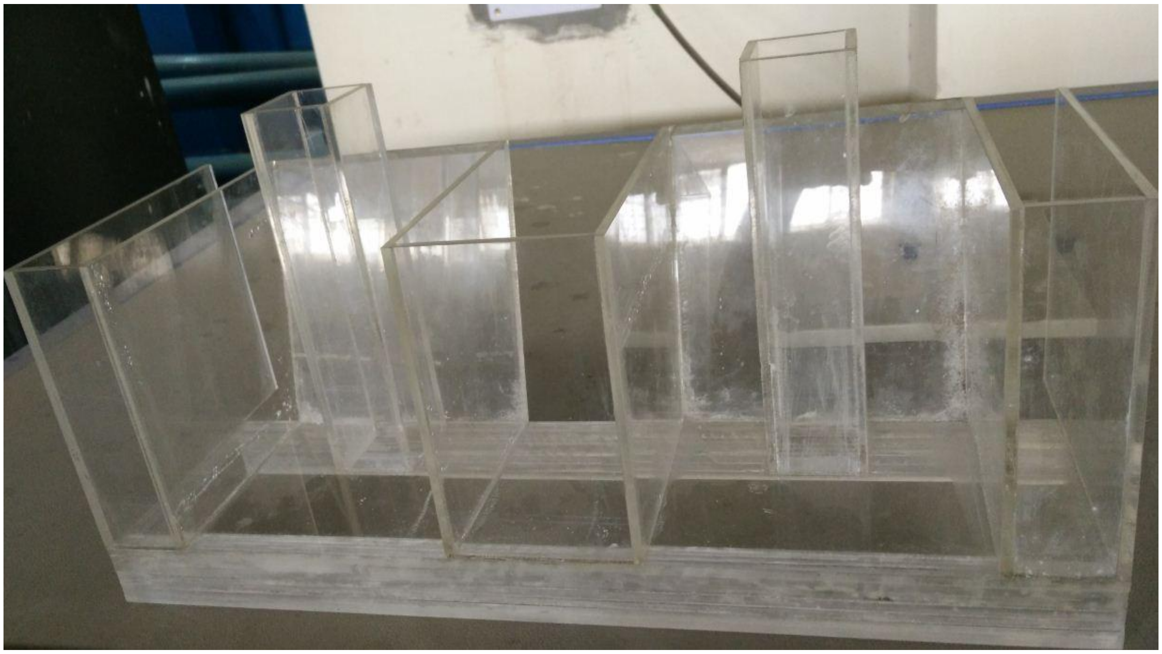


Figure 8.3: Front view of Fusegate

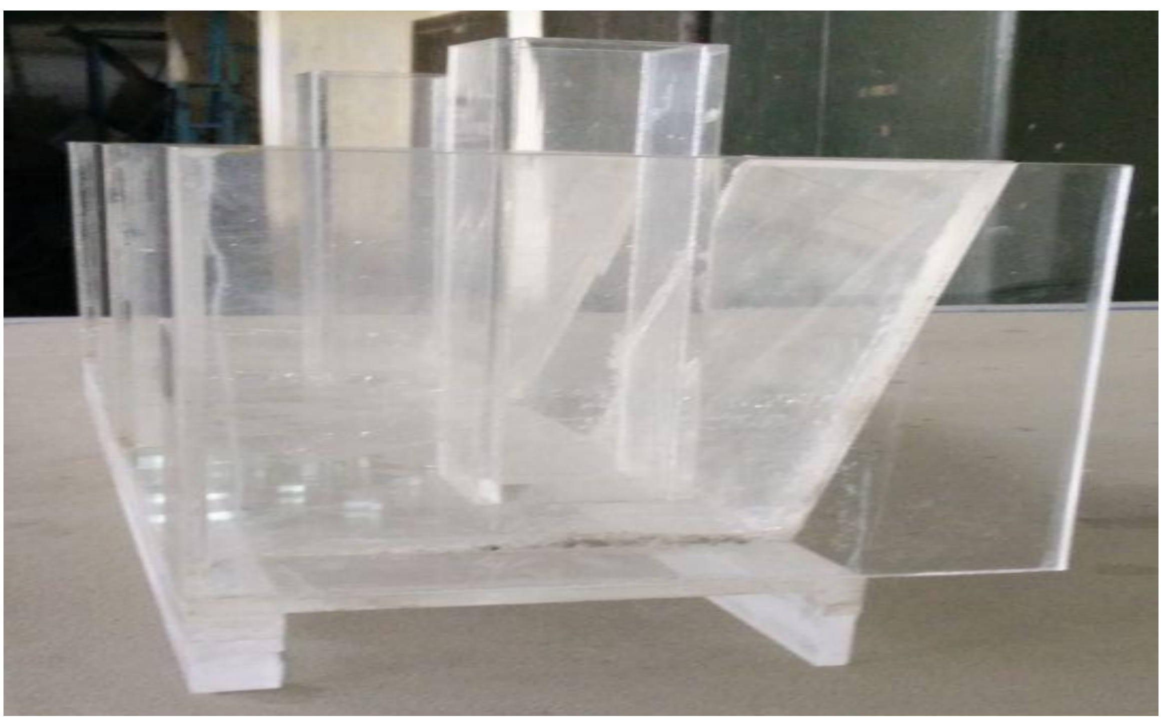


Figure 8.4 Side view of Fusegate

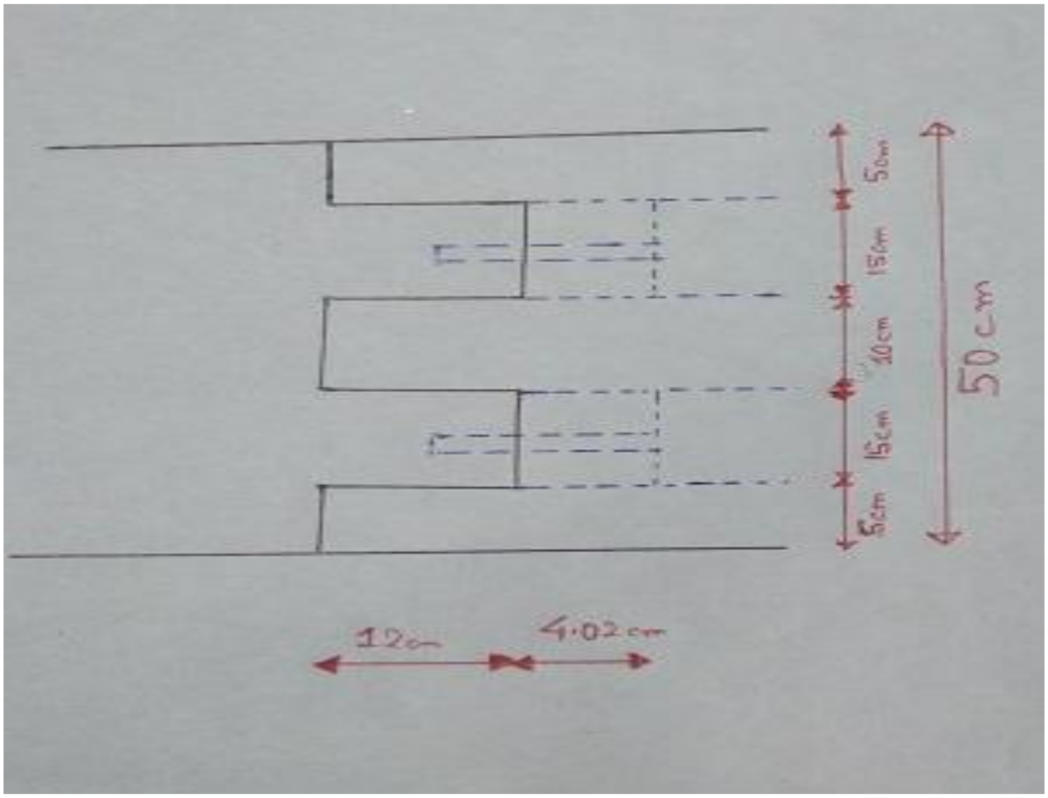


Figure 8.5 Plan view of the fusegate

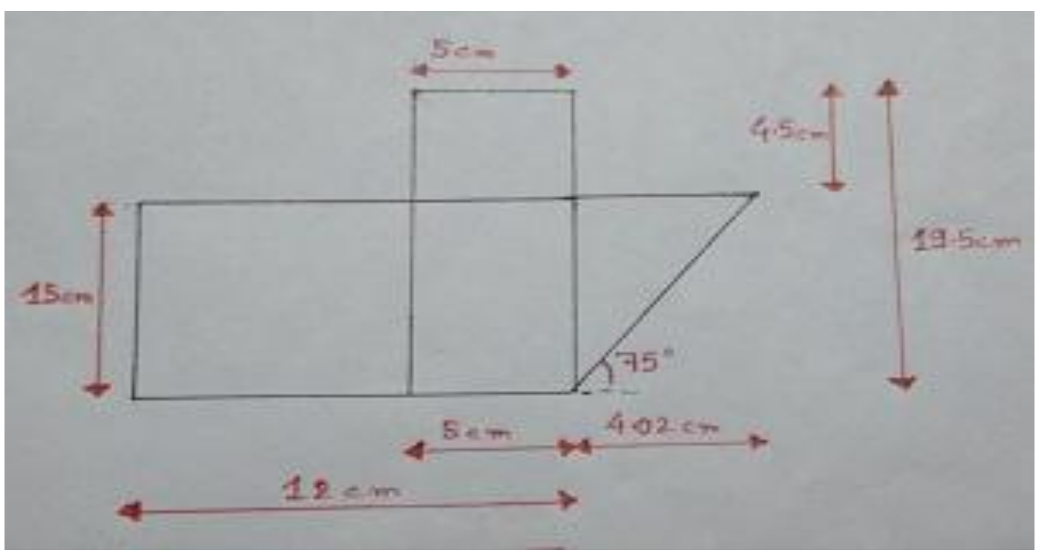


Figure 8.6 Side view of fusegate

8.4 FUSEGATE WORKING UNDER NORMAL CONDITION

Figure 8.7: Fusegate working under Normal Condition

9. FLOW PROFILE AND NAPPE DEPTH MEASUREMENT

9.1 UNDER NORMAL CONDITION

Figure 9.1 Flow profile under normal discharge

9.2 UNDER INCREASED DISCHARGE

As the discharge in the channel is increased, the nappe depth above the fusegate increases. The nappe depth is measured with the help of the verniers. Initially the crest level of the fusegate was measured and later the crest level of nappe was measured. The difference of the two levels is obtained which is known as nappe depth. Corresponding to the increased nappe depth, the increament in discharge was measured from the V-notch apparatus.

The coefficient of discharge was taken as 0.62 for the purpose of discharge calculation. At the v-notch also the discharge was measured with the help of the calculated difference between the notch level and the sill level.

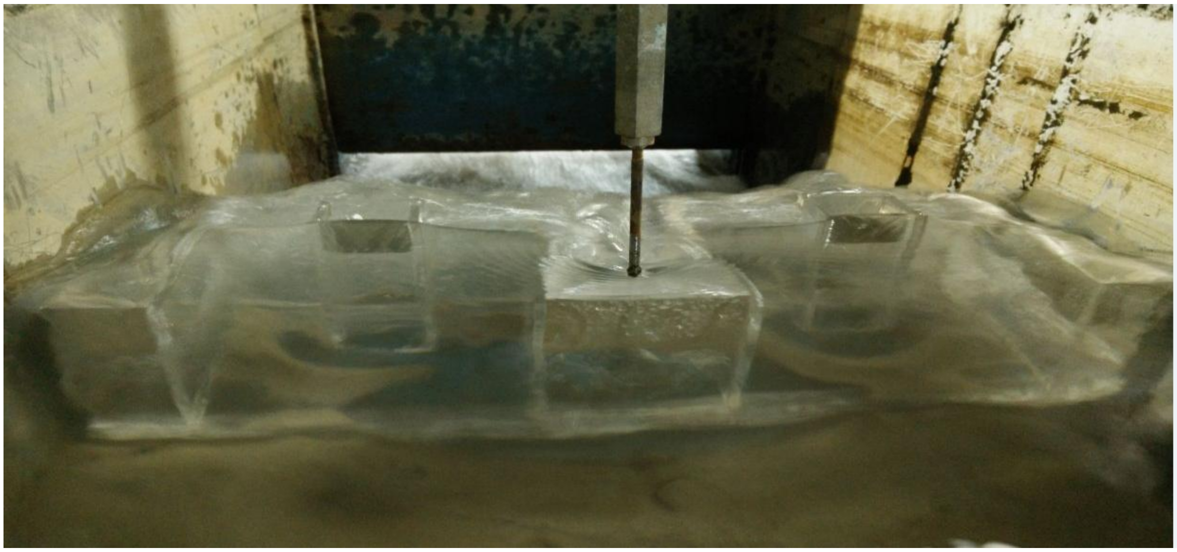


Figure 9.2 Flow profile in case of increased discharge

9.3 When inlet well being fed

Figure 9.3 Inlet well being fed

When the discharge is further increased the water profile starts rising and the water starts to enter inside the inlet wells. When the water entering the inlet wells supercedes the drainage capacity of the drain holes, the chamber at the base gets filled with water and an uplift thrust is generated at the fusegate base. The nappe depth measured is maximum just before the tilting of the fusegate and the corresponding discharge measured in the V-notch is also the maximum at the same time.

10 COMBINED INNOVATIVE SPILLWAY

Combining Piano Key Weir and Fuseplugs together allows additional benefits by providing the specific advantages of both these two devices: Piano Key Weirs are useful for usual floods and in the case of exceptional floods the Fuseplugs become operational.

According to the experiments conducted by F. Lemperiere & J.P. Vigny in comparisons to only Piano Key Weir and Combined Innovative Spillway they obtained following results:

- Either to increase the maximum discharge by 60% without modifying the spillway length or the nappe depth.
- It can be used to reduce the length of spillway by 40% without modifying the discharge or nappe depth.
- It can also be used to reduce the nappe depth without altering the spillway length or the discharge.

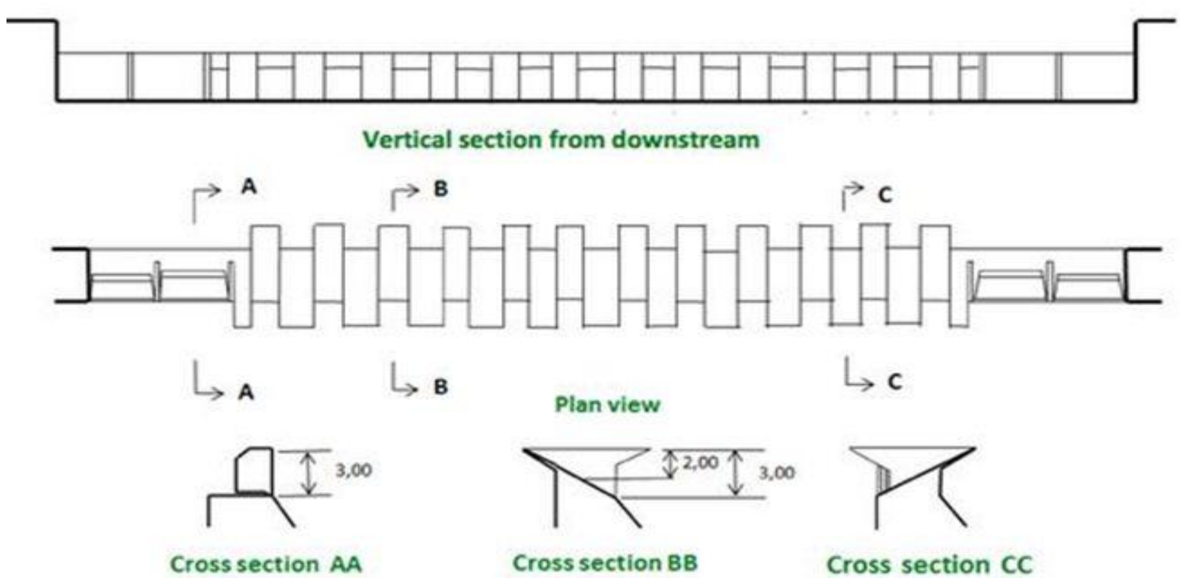


Figure10.1 Vertical section from downstream and various cross-section

Discharge for a 50 m length and 1 m nappe depth

2/3 PKW and 1/3 Plugs	490 m^3/sec
100 % PKW	300 m^3/sec
Creager	100 m^3/sec

The second one includes 1/3 of the length of PK Weirs for 2/3 for fuse plugs which have all tilted for a nappe depth h = 2 m. The corresponding discharges are indicated in the table here below.

Before tilting of the first plug, a nappe 1.70 m depth allows to discharge about 330 m^3/sec., i.e. 1/3 of the maximum discharge.

Discharge for a 50 m length and 2 m nappe depth

1/3 PKW and 2/3 Plugs	1000 m^3/sec
100 % PKW	610 m^3/sec
Creager	300 m^3/sec

It appears that **the increase versus a solution 100% Piano Key Weir is about 60%.**

11 DISCHARGE CALCULATION AND TABULATION

11.1 EXPERIMENTS ON FUSEGATES

Table11.1 Discharge calculation for Fusegate

S.No.→ Specification↓	1	2	3	4	5	6
Top level	62.67	64.56	65.40	66.07	66.25	66.7
Notch level	54.1	54.1	54.1	54.1	54.1	54.1
H(cm)	8.57	10.46	11.3	11.97	12.15	12.6
H(m)	.0857	.1046	.1130	.1197	.1215	.1260
$H^{2.5}$	.00215	.003538	.00429	.004957	.005145	.00563
ϴ/2	45	45	45	45	45	45
$\tan(\theta/2)$	1	1	1	1	1	1
Constant	1.46467	1.46467	1.46467	1.46467	1.46467	1.46467
Discharge (cumecs)	.003149	.005182	.006286	.007260	.007537	.008254
Discharge (lps)	3.149	5.18285	6.2869	7.2606	7.537	8.254

Table11.1: Discharge calculation for Fusegate……..(continued…)

S.No.→ Specification (↓)	7	8	9	10	11
Top level	67.16	67.56	68.1	68.75	69.4
Notch level	54.1	54.1	54.1	54.1	54.1
H(cm)	13.06	13.46	14	14.65	15.3
H(m)	.1306	.1346	.14	.1465	.1530
$H^{2.5}$	.006164	.0066468	.007334	.0082147	.009156
ϴ/2	45	45	45	45	45
$\tan(\theta/2)$	1	1	1	1	1
C_d	.62	.62	.62	.62	.62
Constant	1.46467	1.46467	1.46467	1.46467	1.46467
Discharge (cumecs)	.009028	.009735	.01074	.01203	.01341
Discharge (lps)	9.028	9.735	10.74	12.03	13.41

Table 11.2: Relation between Nappe depth and Discharge

FUSEGATE			NOTCH DISCHARGE	$\frac{\Delta Discharge}{\Delta Nappy\ depth}\%$
R.L. of sill level	R.L. of Water surface	Nappy Depth		
65.69	66.91	1.22	3.149	-
65.69	67.46	1.77	5.18285	369.71
65.69	67.77	2.08	6.18689	323.88
65.69	68.03	2.34	7.2606	412.96
65.69	68.11	2.42	7.537	345.50
65.69	68.27	2.58	8.254	448.12
65.69	68.44	2.75	9.028	455.29
65.69	68.59	2.90	9.731	468.67
65.69	68.8	3.11	10.79	504.28
65.69	69.34	3.65	12.03	229.63
65.69	69.55	3.86	13.41	657.14

11.3 EXPERIMENTS ON PIANO KEY WEIR

Table11.3 Discharge Calculation for PKW

S.No.→ Specification(↓)	1	2	3
Top level	53.84	53.84	53.84
Notch level	65.92	68.17	68.4
H(cm)	12.08	14.33	14.56
H(m)	.1208	.1433	.1456
$H^{2.5}$	.005072	.0077734	.008089
Ɵ/2	45	45	45
$\tan(\theta/2)$	1	1	1
C_d	.62	.62	.62
Constant	1.46467	1.46467	1.46467
Discharge (cumecs)	.010895	.011385	.011847
Discharge (lps)	10.895	11.385	11.847

Table 11.4 Ratio of Discharge to nappe depth

PIANO KEY WEIR			NOTCH DISCHARGE	$\frac{\Delta Discharge}{\Delta Napy\ depth}\%$
R.L. of sill level	R.L. of Water surface	Nappy Depth		
64.20	65.4	1.20	10.895	-
64.20	65.6	1.40	11.385	245.00
64.20	65.78	1.58	11.847	256.70

12. CONCLUSION AND FUTURE SCOPE

Experiments were done on Piano Key Weir and Fusegate. Discharges were varied and the change in discharge values with respect to the change in nappe depth was calculated. These variations have been shown in details in table number 4 to 7.

On an average in Piano Key Weir, the ratio of change in discharge obtained with respect to the change in nappe depth was 2.5 times whereas in case of Fusegates, the ratio of change in discharge obtained with respect to the change in nappe depth was 4 times. Hence, it can be concluded that the specific discharge per unit length of sill in case of Fusegates is much higher than that of Piano Key Weir.

The Fusegate have huge prospects particularly in the context of Indian conditions. In India there is total crop area of 159.6 million hectares. Out of which, irrigation water is available to only 58.13 million hectares of land. In India, there are about 3200 big and small dams. If the height of these dams is increased by even one metre using the Fusegate technique, this shortage of water can be eliminated. Fusegates will be cost effective as compared to conventional spillways by nearly 40% and the water storage capacity can be enhanced by as much as 200%.

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