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Study, Design, Fabrication and Testing of Perforated Pipes for Desilting Basin

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Abstract

A desilting basin is a critical component of hydropower systems designed to remove sediment from the water flow before it enters the turbines. Over time, sedimentation can lead to various problems, including reduced water storage capacity followed by decreased turbine efficiency. The project focuses on the utilization of perforated pipes within desilting basins to address the sedimentation challenges. By tracing the historical evolution and diverse applications of perforated pipes in sediment control, the study explores their potential as a cost-effective and efficient solution for enhancing sediment removal in desilting basins. The theoretical framework, rooted in fluid mechanics, guides the design considerations, emphasizing factors such as flow distribution, velocity, perforation size and spacing. The objectives include designing and testing a functional perforated pipe system to visualize its effectiveness in maintaining optimal hydropower plant operations. While acknowledging limitations such as potential inefficiency for larger particles, it showcases promising results with a commendable 65% sediment removal efficiency in practical demonstrations, underscoring the viability of perforated pipes as a valuable tool in sediment control for sustainable hydropower systems.

Keywords: Perforations, Desilting Basin, Sediment Removal, Bernoulli's Principle, CAD Model

1. Introduction

Sedimentation is a persistent operational challenge in hydropower plants, particularly those located in regions with high sediment loads such as Nepal. When suspended particles such as sand and silt enter the water conveyance system, they accelerate wear on turbine components, reduce overall generation efficiency, and lead to increased maintenance requirements. To mitigate these issues, desilting basins are installed upstream of the turbines to facilitate the removal of heavier particles through sedimentation, thereby protecting downstream equipment.

Despite their importance, conventional desilting basins are often limited by uneven sediment deposition, accumulation in low-flow zones, and the frequent need for manual or mechanical cleaning. These drawbacks not only increase maintenance frequency but can also interrupt plant operation. Therefore, there is a need for more efficient and low-maintenance sediment management techniques within desilting basins.

This study investigates the integration of perforated pipes as a supplementary sediment removal mechanism within desilting basins. Perforated pipes, which feature regularly spaced openings along their length, are installed near the basin floor to assist in the continuous evacuation of settled sediments through controlled flushing.

1.1 Problem Statement

To address the issue of sedimentation, various techniques are employed to flush out accumulated sediments from the desilting basin. These techniques include sluice gates, flushing tunnels and mechanical equipment such as excavators or dredgers. Perforated pipes offer a potential solution to mitigate the problem of sedimentation in desilting basins. Enhanced sediment removal efficiency helps maintain optimal water flow and reduces the risk of sediment deposition in critical hydropower system components.

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2. Literature Review on Perforated Pipe Design and Applications

Several studies have investigated the design and application of perforated pipe systems in various fields, focusing on factors like perforation size, spacing, and materials, all of which significantly influence system performance.

El-Zein et al. (2020) showed that perforation size and spacing significantly impact hydraulic conductivity. Larger perforations increased water flow, while smaller gaps enhanced uniform distribution. Optimizing these factors can improve sediment removal efficiency in desilting basins.

Rahimi et al. (2019) examined how material choice affects pipe strength and durability. They found that materials like PVC and stainless-steel resist corrosion better, which extends pipe lifespan. Their findings suggest material selection is crucial for maintaining performance in aquatic environments.

Wang et al. (2021) focused on the role of perforated pipes in agricultural drainage systems. They concluded that larger diameters and wider spacing improve flow rates, reduce soil waterlogging, and boost crop yield. This insight is applicable to improving sediment removal efficiency in desilting systems.

Smith et al. (2020) investigated perforated pipes in urban stormwater systems. They found that correct pipe placement and installation can reduce surface water pooling and flooding. Proper design maximizes drainage efficiency and minimizes clogging.

In geotechnical engineering, Johnson et al. (2018) studied perforated pipes to enhance soil stability and prevent liquefaction in high groundwater areas. Their findings demonstrate that a well-designed system can prevent soil failure during seismic events by ensuring proper drainage.

3. Methodology

3.1. Design Approach

Theoretical framework of perforated pipes in desilting basins is based on the principles of fluid mechanics and sediment transport. The main objective of a desilting basin is to remove sediment from the water flow by allowing the water to slow down and allowing the sediment to settle out of the water. The perforated pipes are an important component of this process, as they help to distribute the water evenly across the basin and promote sediment settlement.

From a fluid mechanics perspective, the perforations in the pipes create localized pressure drops and velocity variations, which help to reduce the flow rate in different sections of the basin. This distribution of flow is essential for creating areas of low velocity where sediment can settle effectively. Additionally, the design and placement of the perforated pipes are optimized to balance the flow rate and sedimentation efficiency, ensuring that the sediment is captured efficiently without disrupting the overall water flow dynamics. In the experimental setup (Figure 1), these pipes are used within the desilting basin.

Figure 1. Perforated Pipes in Desilting Basin

The key principles that govern the operation of perforated pipes in desilting basins include:

- Flow distribution: Perforated pipes are used to distribute the water flow evenly across the basin, which helps to promote uniform sediment settlement. The design of the perforated pipe system must take into account the size of the basin, the flow rate of the water, and the type and size of the sediment being removed.
- Flow velocity: The flow velocity of the water in the perforated pipes is an important factor in promoting sediment settlement and preventing clogging. The velocity should be designed to be low enough to allow sediment to settle out of the water, but high enough to prevent clogging.
- Perforation size and spacing: The size and spacing of the perforations in the pipes help in promoting sediment settlement and preventing clogging. The size of the perforations should be designed to allow the desired flow rate while preventing the entry of sediment particles that could clog the pipes. The spacing of the perforations should be designed to promote uniform flow across the basin.
- Porosity: The porosity of the perforated pipe is an important factor in determining the flow rate and the size of sediment that can be removed. The porosity should be designed to optimize the removal of sediment while preventing clogging.

3.1.1. Components

Perforated pipes are drainage pipes that have small holes or slots cut into them to allow water to enter the pipe and be carried away. Perforated pipes are commonly made of materials such as PVC, HDPE and are available in a variety of sizes and configurations to suit different drainage needs.

Pipe: The perforated pipe is the main component and can be made of materials such as PVC, HDPE. The holes or slots in the pipe allow water to enter and be carried away. The project includes PVC with 50mm diameter of 50cm length, alternatively fitted inside the basin with a joint on the lateral side.

Desilting Basin: The core of the project lies in the design and functionality of the desilting basin, a pivotal element in the sediment removal system. This basin is filled with a water-sand mixture and subjected to rigorous testing procedures. The basin's effectiveness is demonstrated through manual stirring and lid manipulation, simulating real-world conditions to optimize sediment removal.

Desilting Basin Stand: The project includes a strong stand made to support the weight of the water-filled desilting basin. This stand is designed to be stable and sturdy, ensuring it can handle the heaviness of the water and sand mixture in the basin. The stand's job is to provide a reliable structure, helping the basin work well during testing and operation.

Gravel or aggregate: In some cases, gravel or aggregate is placed around the perforated pipe to provide additional drainage capacity and support. This material allows water to flow into the pipe more easily and provides structural support to prevent the pipe from collapsing under heavy loads.

End caps: End caps are used to seal off the ends of the perforated pipe and prevent soil or foreign particles from entering the pipe. They can be made of materials such as PVC or metal and are typically attached to the pipe with glue or adhesive.

Joint (Connector): Connector is used to join two or more sections of perforated pipe together. They can be made of the same material as the pipe or a different material, such as rubber or plastic, and are typically attached with adhesive or a mechanical connection.

3.2. Working Principle

The working principle of a perforated pipe is relatively simple. When the pipe is buried underground and surrounded by gravel, water enters the pipe through the pipe. Once inside the pipe, the water is carried away by the slope of the pipe and the force of gravity. The CAD model of the perforated pipe provides a detailed view of the pipe’s structure as shown in Figure 2.

Figure 2. CAD Model of Perforated Pipe

As the water enters the pipe, it also brings with it any soil or sand that is present in the surrounding soil. It works on the Bernoulli's principle, as the valve is opened, the water enters the pipe vigorously with a high velocity. As the water enters, the pressure inside the pipe goes down. This pressure difference within and outside of the pipe, causes suctions that pulls off the sand and soil and deposits it through the valve. To prevent this material from clogging the holes and reducing the effectiveness of the drainage system, these pipes are often used. The end caps act as a barrier, allowing water to flow through while keeping out unwanted materials. The perforations in the pipe are typically spaced at regular intervals to ensure even water distribution and optimal drainage capacity. The size and spacing of the perforations can be customized based on the specific needs of the drainage system.

3.3. Calculations

Two pipes of same dimensions with 35 perforations each are fitted inside the desilting basin. The pipes are connected with T-shaped joints on a regular PVC pipe that outflows the maximum sand with the water.

Length of pipe = 50 cm

Diameter of pipe = 50mm

Perforations interval = 6.25 cm

Perforations gap = 3.14 cm

Diameter of perforations = 7mm

Total Volume of the desilting basin = 393.6 litre

Area of perforations = Number of Radial Perforations × Number of Longitudinal Perforations × π × (radius)^2

i.e = $7 \times 5 \times \pi \times (0.35)^2 = 13.46\ cm^2$ (Equation 1)

$v = \sqrt{(2gh)} = \sqrt{(2 \times 9.8 \times 0.5)} = 3.13 m/s$ (Equation 2)

where v is the velocity of the fluid, g is the acceleration due to gravity, and h is the height of water above the hole.

Bernoulli's principle states that $p + \rho v^2 + \rho g h = constant$ (Equation 3) where p is the pressure exerted by the fluid, v is the velocity of the fluid, ρ is the density of the fluid and h is the height of the container.

As Continuity equation states that $AV = constant$ (Equation 4)

Area of perforations = $\frac{Flow\ rate}{Velocity\ (input)}$ (Equation 5)

i.e Flow rate. = 6.5 litre per second

Where A is the cross-sectional area of the pipe and V is the flow velocity.

Adding 20 kilograms of sediments into the desilting basin led to 13 kilograms of sediments being accumulated out the basin that gave us around 65% efficiency due to perforations on the pipe.

3.4. CAD Modeling

The CAD models, Figure 3 and Figure 4 were prepared as per the fabrication plan. Each component of the model was made separately and then combined together at the end. It was done so that we could visualize our desilting basin and perforated pipes project idea.

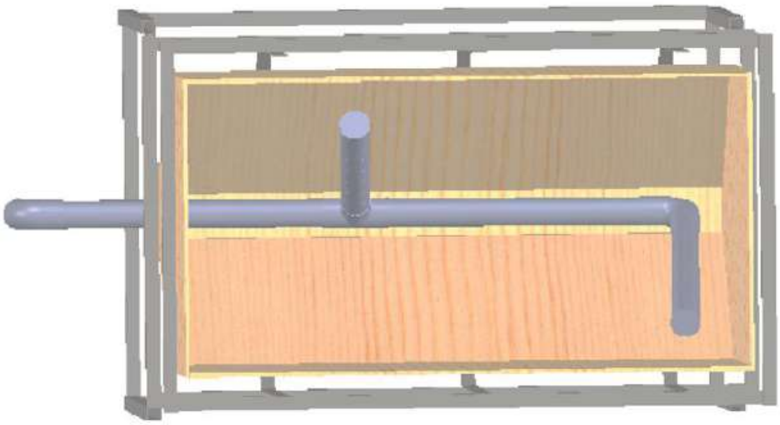

Figure 3. CAD Model of Perforated Pipe in Desilting Basin (Top View)

Figure 4. CAD Model of Perforated Pipe in Desilting Basin (Isometric View)

4. Testing Setup

Firstly, the desilting basin was filled with a mixture of water and sand. The sediments were manually stirred using a rod to ensure uniform distribution throughout the basin. The outlet valve was kept closed during this phase. Once the basin was filled, the lid was tightly secured to allow maximum suction during discharge. A total of 20 kilograms of sediment were added to the basin. After settling for a short duration, the outlet valve was opened to initiate flow through the perforated pipe. The water was then collected at the outlet using a fabric filter. The collected sediment was dried and weighed to determine the amount removed. On average, 13 kilograms of sediment were collected, indicating a removal efficiency of approximately 65%. This result in Figure 5 demonstrates the effectiveness of the perforated pipe design in enhancing sediment removal.

Figure 5. Collection of Sediments During Testing

5. Experimental Results and Discussion

The perforations on the pipe created low pressure inside the pipe that created suction for the sediments to flow with the water. Around 65% of the sediments was collected from the basin. The observed accumulation of 13 kilograms outside the basin indicates a significant removal of sediments, demonstrating the effectiveness of the system. Also, the design of perforations in the pipe significantly influenced the efficiency of the system.

The initial model testing setup involved setting a 60-second duration for the outflow of water containing sand particles sized at 500 microns. After 5 kilograms of sediment was added into the basin, it was observed that approximately 3 kilograms of sediment were discharged through the outflow. This preliminary experiment served as a baseline for understanding the sediment transport dynamics within the model.

In the final testing setup, the desilting basin was filled to its maximum capacity, and a total of 20 kilograms of sand was used as the input for the experiment. The outflow cap was promptly opened to facilitate the maximum discharge of sediments. Surprisingly, only around 13kg of sand accumulated in the outflow, indicating a discrepancy between the input and output sediments. The outlet flow rate was measured at 6.5 liters per second, providing a crucial parameter for assessing the system's efficiency in sediment removal. The results from both the initial and final model tests set the stage for a comprehensive discussion on the factors influencing sediment transport and the implications for the overall performance of the desilting system.

6. Conclusion

The demonstrative model was fabricated to serve as a visual aid to help better understand the working of the perforated pipes in the desilting basin. The pipes helped in reducing the amount of sediments that were accumulated in the basin.

The performance of the fabrication model showed a maximum efficiency of 65% at flow of 6.5 litre per second.

7. Recommendation

While the results were promising, considerations for regular maintenance and potential scalability should be acknowledged. Moreover, suggestions for future research to optimize the system further and explore its adaptability to varying conditions would contribute to the ongoing development of efficient drainage solutions. Similar approach of fabrication could be used to study the working mechanism of other perforated pipes. The sediments would be even easier to outflow if the function of automatic stirrer was added in the desilting basin. The real hydropower scenario would be clearly visible with concrete desilting basin built by well-trained individuals.

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