

Stormwater Flow Regulation Using a Passive Vortex Control Device

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Abstract –

Urban stormwater flooding is increasingly caused by uncontrolled peak discharge and downstream sewer surcharge during high-intensity rainfall events. In many cases, flooding occurs when the Hydraulic Grade Line (HGL) rises above ground level rather than when pipes are completely filled. This study presents a passive vortex-based flow control device designed to regulate stormwater discharge at critical drainage nodes. The device operates using rotational flow dynamics and does not require moving parts or external power. A scaled experimental model was developed to analyze its hydraulic behavior under controlled inflow conditions. Observations from the experimental setup indicate improved regulation of stormwater flow, stabilization of downstream loading, and better utilization of upstream pipe capacity as temporary detention storage. The proposed vortex flow control device provides a simple, sustainable, and cost-effective approach for enhancing urban stormwater management and reducing flood risks in drainage systems.

Key Words:

Stormwater Management, Vortex Flow Device, Urban Drainage, Hydraulic Grade Line, Flow Regulation, Sewer Surcharge.

1. INTRODUCTION

Urbanization alters natural hydrological processes by increasing impervious surfaces such as concrete and asphalt. These surfaces reduce infiltration and significantly increase surface runoff during rainfall. Existing drainage infrastructure was designed for lower population densities and historical rainfall intensities, making it vulnerable to modern high-intensity storm events. Flooding is often misunderstood as a condition where pipes are completely filled. In reality, flooding occurs when the Hydraulic Grade Line (HGL) rises above ground level due to downstream backpressure, even if parts of the upstream network still have available capacity.

In many cases, the primary issue is uncontrolled peak discharge entering downstream sections too rapidly.

When flow is not regulated, downstream pipes become overloaded, causing a rapid rise in pressure and water level. Controlling discharge at critical points can help stabilize the system and utilize upstream pipe volume as temporary storage. This approach improves drainage performance without requiring major reconstruction of existing infrastructure.

2. LITERATURE REVIEW

Flow regulation in stormwater systems has traditionally been achieved using simple hydraulic restriction devices. The most common method is the orifice plate, which limits discharge through a fixed opening. The discharge through an orifice is governed by:

$$Q = C_d A \sqrt{2gH}$$

Although effective, small orifice openings are prone to clogging due to debris, sediment, and solid waste present in urban drainage systems. This reduces reliability during heavy rainfall events.

Active mechanical control systems, such as motorized gates and sensor-based regulators, have also been implemented in some urban networks. These systems allow adjustable discharge control but require continuous power supply, regular maintenance, and higher installation costs. During extreme storm events, power failures may affect their performance.

Vortex-based flow control devices were developed as a passive alternative. These systems use rotational flow dynamics to regulate discharge without reducing the physical outlet size. By creating a stable air core within the chamber, vortex devices limit effective discharge under high head conditions while maintaining a larger physical opening, reducing the risk of blockage.

3. PROBLEM STATEMENT

- Intense rainfall causes rapid stormwater runoff.
- Downstream pipes become overloaded, creating backpressure.
- HGL rises above ground level, leading to flooding.
- Upstream pipe capacity remains underutilized.
- A passive system is needed to regulate peak discharge and reduce surcharge.

4. DESIGN AND METHODOLOGY

The proposed device is installed at the outlet invert level of a manhole.

The vortex chamber consists of:

- Tangential inlet to initiate rotational flow.
- Circular chamber to sustain vortex motion.
- Central outlet throat larger than a conventional orifice to reduce blockage risk.

At low head conditions, water passes with minimal restriction. As head increases, rotational velocity increases, forming a stable vortex and central air core. The air core reduces effective discharge area, limiting peak outflow automatically.

Froude similarity principles were applied to ensure realistic hydraulic behavior in the scaled experimental model.

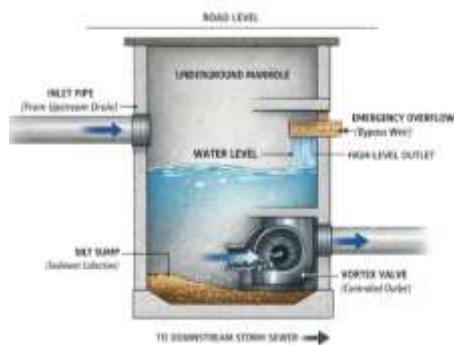


Fig.1- Section



Fig.2- Vortex Valve

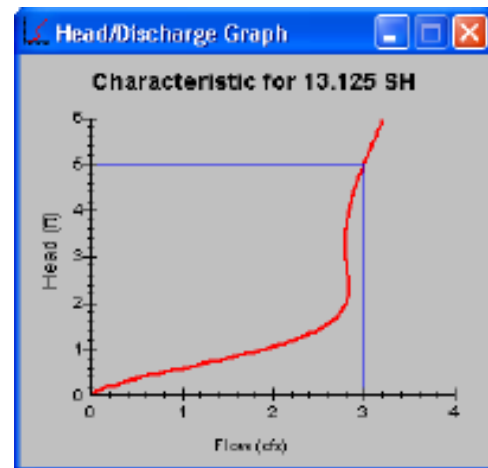


Fig.2 & 3-
Head/Discharge Curve (Credits-HydroCAD)

Pond 1P Special & User-Defined Outlet

Description: Reg-U-Flo SH 5.0-in Routing: Primary

Invert Elevation: (feet) 0.00

Discharge Multiplier: 1.00

☐ Extrapolate ☐ Set Head Loss

Load From File...

Line	Elev (feet)	Q (cfs)
1	0.00	0.000
2	0.06	0.012
3	0.12	0.036
4	0.18	0.065
5	0.24	0.097
6	0.30	0.129
7	0.36	0.159
8	0.42	0.186
9	0.48	0.208

OK Cancel Help

5. HYDRAULIC BEHAVIOUR

The hydraulic behavior of the vortex device changes according to the water head inside the manhole. At low inflow conditions, water enters the chamber tangentially but does not create strong rotation. No stable air core forms, and the water exits almost freely. In this stage, the device allows normal drainage with minimal restriction.

As the upstream water level increases during heavy rainfall, the rotational velocity inside the chamber increases. Centrifugal force pushes water toward the outer wall, creating a low-pressure zone at the center. When a critical head is reached, a stable air core develops near the outlet. This air core reduces the effective flow area and forces water to follow a spiral path, increasing internal energy losses.

Due to this mechanism, discharge does not increase rapidly even when head continues to rise. The upstream water level increases gradually, allowing temporary storage within the drainage network and reducing the risk of sudden surcharge. When inflow decreases, the vortex weakens, the air core collapses, and the device returns to near-free discharge conditions. This self-regulating behavior enables automatic flow control without moving parts or external power.

This preliminary experiment helped in understanding the basic working principle of the vortex flow control device and its potential application in stormwater flow regulation.

Parameter	Orifice Plate	Active Gate	Vortex Device
Power Required	No	Yes	No
Moving Parts	No	Yes	No
Clogging Risk	High	Medium	Low
Maintenance	Medium	High	Low
Cost	Low	Very High	Moderate

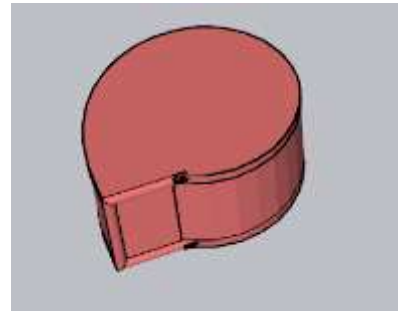


Fig.4- Modelling Vortex Valve



Fig.5- 3D Print Vortex Valve

6. EXPERIMENTAL WORK-

An experimental study was carried out to observe the flow behavior of a vortex-based flow control device under simple laboratory conditions. The vortex valve was first designed using computer-aided design (CAD) software to create a circular chamber capable of generating rotational flow. The design included a tangential inlet and a central outlet to facilitate vortex formation inside the chamber.

The designed model was fabricated using 3D printing technology, allowing the complex geometry of the vortex chamber to be produced accurately. After printing, the model was cleaned and prepared for preliminary testing.

For the experimental testing, a simple setup was arranged using a water bucket as the source of inflow. Water was allowed to enter the vortex valve through the inlet pipe. As the water entered tangentially into the chamber, a circular motion developed inside the valve, resulting in the formation of a vortex before discharge through the outlet.

The experiment mainly focused on observing the vortex formation and flow behavior within the device. Multiple trials were conducted to observe the stability of the vortex and the discharge pattern at the outlet. Photographs of the designed model and the 3D printed valve were taken for documentation and analysis.

7. PRACTICAL IMPLEMENTATION

For effective performance, the vortex device must be installed at the outlet invert level of the manhole to ensure proper head development. Wall-mounted installation aligned with the outgoing pipe invert allows stable vortex formation under surcharge conditions.

The outlet throat should be sized based on design storm intensity and allowable discharge rate. Since the device maintains a larger physical opening compared to an orifice plate, clogging risk due to debris and sediment is reduced.

The system is suitable for retrofit installation in existing drainage networks without major structural modification. Maintenance access through standard manhole openings remains unaffected.

8. ADVANTAGES AND LIMITATIONS

Advantages-

- No moving parts.
- No external energy requirement.
- Lower clogging risk compared to small orifices.
- Suitable for retrofit installation.
- Reduced maintenance requirements.

Limitations-

- Requires sufficient head for stable vortex formation.
- Proper hydraulic sizing is necessary.
- Not a substitute for severely undersized drainage networks.

9. APPLICATIONS

The proposed vortex flow control system can be applied in:

- Urban stormwater drainage networks prone to surcharge
- Flood-prone intersections and low-lying areas
- Housing societies and commercial complexes
- Industrial drainage systems
- Smart city stormwater infrastructure upgrades
- Campus and institutional drainage management

The device is particularly useful in systems where downstream pipe capacity is limited but upstream storage potential exists.

10. FUTURE SCOPE

Future work may include Computational Fluid Dynamics (CFD) analysis to study detailed vortex formation, pressure distribution, and discharge behavior under varying head conditions. CFD modelling can help optimize chamber geometry and improve hydraulic efficiency before full-scale implementation.

In addition, low-cost IoT-based water level sensors can be integrated for real-time monitoring of the Hydraulic Grade Line (HGL) inside manholes. Such monitoring would support early flood warning, performance evaluation, and data-driven stormwater management while maintaining the passive nature of the device.

11. Conclusion

Urban stormwater flooding is primarily driven by downstream surcharge and uncontrolled peak discharge rather than complete pipe filling. The passive vortex flow control device regulates discharge by

converting excess hydraulic head into rotational energy, limiting peak outflow automatically. By utilizing upstream pipe volume as temporary detention storage, the system reduces HGL rise and lowers flood risk. Experimental validation demonstrates significant peak flow reduction and improved hydraulic stability. The proposed approach offers a sustainable, low-maintenance, and cost-effective solution for enhancing urban stormwater drainage systems.

12. References

- [1] Hydro International, "Hydro-Brake® Vortex Flow Control," Hydro International, U.K., Technical Brochure.
- [2] B. J. Adams and F. Papa, *Urban Stormwater Management Planning with Analytical Probabilistic Models*, John Wiley & Sons, 2000.
- [3] American Society of Civil Engineers (ASCE), *Design and Construction of Urban Stormwater Management Systems*, ASCE Manuals and Reports on Engineering Practice No. 77, 1992.
- [4] V. T. Chow, *Open-Channel Hydraulics*, McGraw-Hill, 1959.
- [5] Central Public Health and Environmental Engineering Organisation (CPHEEO), *Manual on Sewerage and Sewage Treatment Systems*, Ministry of Housing and Urban Affairs, Government of India.
- [6] H. Chanson, "Hydraulics of vortex flow and air-core formation," *Journal of Hydraulic Engineering*, ASCE.