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RESEARCH PAPER

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Design and development of a self-activating flood control drainage gate (Baharang): Climate resilient solution

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ABSTRACT

The study introduces a self-activating flood control drainage gate (Baharang) designed to improve flood management in low-lying and flood-prone areas. The objective of the device is to protect flood-prone areas from rising water levels. Traditional drains are often inadequate during a flooding scenario, particularly in preventing backflow from swelling rivers. The mechanism of the device utilizes a mechanically engineered torsion spring and a vessel counterweight system to provide automated closing of the gate during rising floodwater and reopening once the water level subsides. A quick-release level is provided for manual operation and maintenance. The gate is power-independent, cost-effective, and easily retrofittable to current culvert designs. The solution that is low-maintenance, self-dependent, eco-friendly, and people-oriented attributes of a sustainable community also secured the strengthening of local disaster resilience that goes in line with the medium-term goals of climate adaptation and infrastructure modernization. Moreover, it advances several United Nations Sustainable Development Goals (SDGs), particularly SDG 13 (Climate Action) and SDG 9 (Industry, Innovation and Infrastructure). This innovation proves how eco-engineering can provide practical, community-oriented solutions to environmental problems, fostering sustainability and climate resilience.

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INTRODUCTION

The Philippines experienced an average of 3.5 destructive typhoons per year (1990 to 2003) with damages costing up to P 96.566 B mostly incurred from flood-damaged properties, infrastructures and crops (CTI Engineering International Co., Ltd., 2004). For the Cagayan River, flooding has been a perennial problem. This longest river in the Philippines has a total length of 520 km within a drainage area of 27,493.49 km^2. It covers 2,459 barangays in 122 municipalities/cities in 12 provinces within three regions namely Region 3, CAR, and Region 2 conditions (Department of Environment and Natural Resources [DENR], 2017). It has been projected that the water surface level in the Cagayan River will rise up by 1-3 m versus the baseline conditions (DENR, 2017). Of the estimated 388,494 hectares (14% of the river basin) susceptible to flooding, about 60% of this has high to very high susceptibility. Areas near the river systems have high to very high susceptibility to flooding mostly parts of Isabela and Cagayan. Recently, typhoon Ulysses (2020) brought essentially parts of Cagayan underwater, registering a 13.30 m flood height recorded at Buntun bridge at the lower Cagayan River surpassing the previous record at 12.70 m in 2010. This new record costs about 10B (CNN Report, 2020) both in infrastructure and in agriculture, affecting 3.67k people, displaced 2.77k people, 73 deaths, and damaged 67k houses (CNN Philippines, 2020; United Nations Office for the Coordination of Humanitarian Affairs [UN-OCHA], 2020).

Several studies and government initiatives have attempted to address flooding through structural measures, hydrological modeling, and disaster risk management programs. For example, the Asian Development Bank Integrated Flood Resilience and Adaptation Project (InFRA1), which emphasizes large-scale structural interventions and capacity building for the Department of Public Works and Highways (Asian Development Bank [ADB], 2023). Hydrological modeling studies have applied GIS-based hydrologic-hydraulic simulations to produce geospatial flood hazard maps using LiDAR technology to support local government units in disaster preparedness (Paringit *et al.*, 2015). The system-based analysis of flood risk has also featured the essential of integrated approaches that combine infrastructure, governance, and community resilience (Mercado, 2020).

Moreover, studies show that the main culprit is climate change. The occurrence of El Niño and La Niña phenomena has not spared even the advanced societies. Goal 13 of the UN Sustainable Development Goals (SDGs) specifically urges all member states to combat climate change and its impacts. Along with SDG 9, resilient infrastructure must be built to promote inclusive and sustainable industrialization and foster innovation. This project was conceptualized to come up with resilient flood control infrastructures using a science-based approach and modern tools tested and proven abroad.

Despite these efforts, the literature continually reveals recurring challenges such as the inadequacy of drainage systems to control backflow and the shortened service life of flood control infrastructures due to technical and implementation issues. Moreover, the absence of localized, adaptive technologies that can be deployed or adopted at the community level, and most of the current approaches remain heavily focused on large-scale structural projects and broad hydrological assessments, which, while valuable, often fail to address the specific problem of inland flooding caused by backflow in the drainage systems.

The research gap in this study indicates the need for innovative, low-cost, and resilient flood control solutions that are power-independent, retrofittable, and community-oriented. Few studies have shown mechanically engineered, self-activating devices that directly mitigate backflow and also align with eco-engineering principles and sustainability goals.

This present study responds to this research gap, which aimed to design and develop a self-activating flood control drainage gate that employs a torsion spring and vessel counterweight system to automatically regulate water flow. Unlike traditional infrastructures, the Baharang is cost-effective, low-maintenance, and eco-friendly, which makes the device highly adaptable for local government units and communities. Its design contributes to medium-term climate adaptation and infrastructure modernization goals and aligns with several United Nations Sustainable Development Goals (SDGs). Thus, by filling this gap, the study demonstrates how eco-engineering can provide practical, science-based, and community-centered solutions to mitigate flood risks and strengthen resilience in vulnerable areas.

MATERIALS AND METHODS

Study design

This study employed an engineering design-and-development approach to develop and evaluate a self-activating flood control drainage gate (Baharang) for preventing floodwater backflow in drainage systems. The research followed a systematic process consisting of problem identification, conceptual design, prototype fabrication, and functional evaluation, consistent with established engineering product development methodologies (Cross, 2008; Ulrich and Eppinger, 2016).

Design and prototype fabrication

An inventory of existing flood-control initiatives and drainage management practices in the Cagayan Valley was conducted and complemented by a review of passive flood barriers and backflow prevention systems (Caltrans, 2015; ScienceDirect Topics, 2019; Hydro Gate, 2024). The review identified the need for a power-independent, low-maintenance device capable of preventing reverse flow while remaining compatible with existing culvert structures (Caltrans, 2015; FloodBreak, 2025).

Based on these requirements, a functional prototype was fabricated using rigid steel to ensure structural strength and rubber seals to provide watertight closure. The gate incorporated calibrated torsion springs within the hinge assembly and a vessel-type counterweight connected through a steel chain mechanism. The torsion spring maintained the gate in an open position during normal drainage, whereas the increasing weight of the floodwater-filled vessel automatically closed the gate during backflow. A quick-release lever was also integrated to facilitate inspection and maintenance. Torsion springs were selected because of their reliable rotational performance under repeated loading conditions (The Spring Store, 2024; Acxess Spring, 2024).

Functional evaluation

The prototype was evaluated under controlled operating conditions to assess its ability to (i) remain open during normal drainage, (ii) close automatically during reverse flow, (iii) respond consistently to changes in water level, (iv) provide effective sealing through the rubber gasket, and (v) reopen after floodwater subsided. Functional performance was qualitatively assessed through repeated operational cycles by observing gate movement, response of the torsion spring and counterweight mechanism, sealing efficiency, and overall operational stability, as illustrated in Fig. 1–4. Similar qualitative evaluations are commonly applied during prototype validation of passive flood-control systems (Caltrans, 2015; Garrison Flood Control, 2024).

Engineering considerations

The Baharang operates entirely through passive mechanical principles, relying on hydrostatic pressure, gravitational force generated by the water-filled vessel, and the restoring torque of the torsion spring without requiring electrical power or hydraulic actuators. Such passive systems are recognized for their reliability during flood events because they remain functional even during power outages (ScienceDirect Topics, 2019; Presray Corporation, 2024; Orange Flood Control, 2025). The use of steel structural members and rubber sealing components further enhances durability, sealing performance, and compatibility with existing drainage infrastructure (JR Smith Manufacturing Co., 2024; T-T Pumps, 2024).

RESULTS AND DISCUSSION

Prototype components and functionality

The fabricated self-activating flood-control drainage gate consisted of six primary components: a rigid steel gate with a rubber sealing gasket, torsion spring hinge assembly, floodwater vessel, steel chain-link mechanism, protective outer shell, and quick-release lever (Fig. 1–4). Each component performs a complementary mechanical function that enables the system to operate automatically without external power.

Under normal drainage conditions, the torsion spring maintained the gate in an open position, allowing uninterrupted one-way flow through the drainage system. As the downstream water level increased and reverse flow occurred, floodwater gradually filled the counterweight vessel. The increasing weight of the vessel generated sufficient mechanical force through the chain-link mechanism to rotate the gate into a closed position. Once seated against the drainage opening, the rubber gasket compressed to form a watertight seal, thereby preventing floodwater from flowing back into the protected area. As water levels receded, the reduction in vessel weight allowed the torsion spring to restore the gate to its original open position, permitting normal drainage to resume.

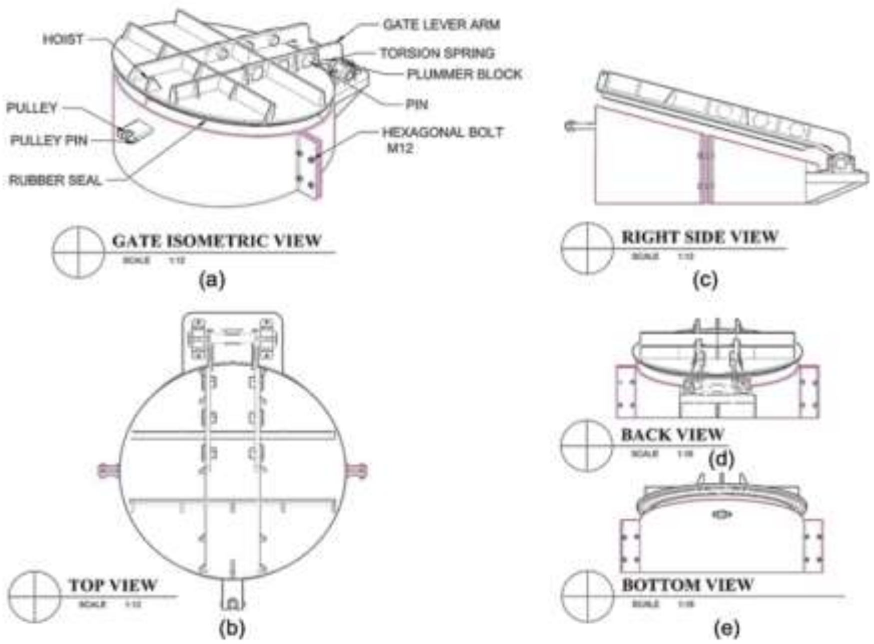

Fig. 1. Self-activating drainage gate (a) Isometric view, (b) Top view, (c) Right side elevation, (d) Back view, (e) Bottom view

The sequence of operation demonstrates a practical application of passive mechanical principles, in which hydrostatic loading and gravity are converted into controlled gate movement without electrical, hydraulic, or pneumatic actuators. Similar operating mechanisms have been reported for flap gates and passive flood barriers that rely on differential water pressure to regulate one-way flow (Hydro Gate, 2024; ScienceDirect Topics, 2019). However, unlike conventional flap gates that depend primarily on hydraulic pressure, the Baharang incorporates a vessel-type counterweight that progressively increases the closing force as floodwater rises. This additional mechanical advantage improves gate stability and sealing performance under increasing flood depths.

The engineering configuration shown in Fig. 1–4 also demonstrates that the prototype was designed with practical installation in mind. The compact hinge assembly, modular base plate, and independent vessel system enable installation in existing circular or rectangular culverts with minimal structural modification. Such retrofit capability is particularly important for local government units where complete drainage reconstruction is often economically impractical.

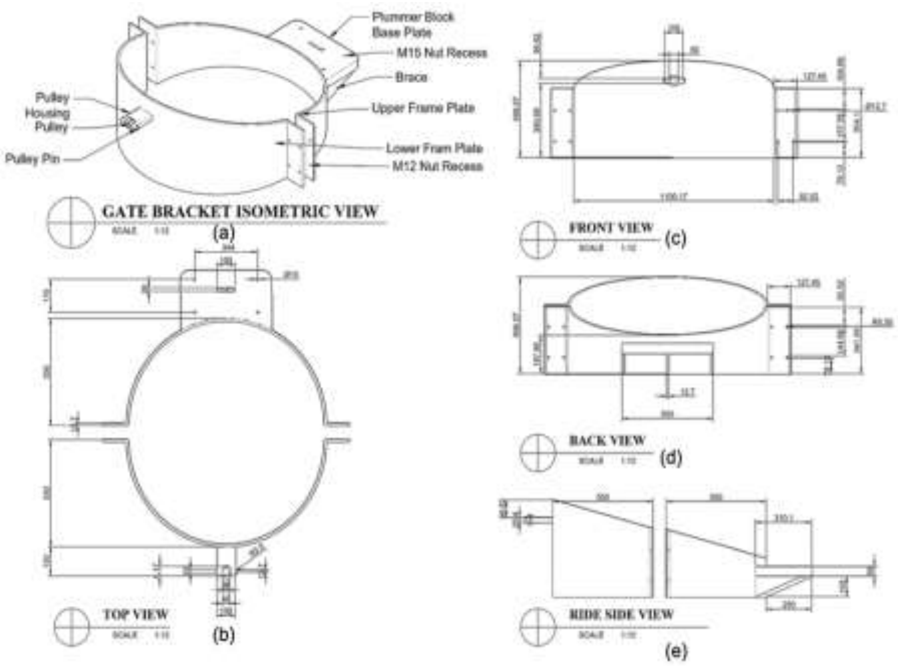

Fig. 2. Design of the self-activating drainage gate (a) Gate bracket isometric view, (b) Top view, (c) Front view, (d) Back view, (e) Right elevation

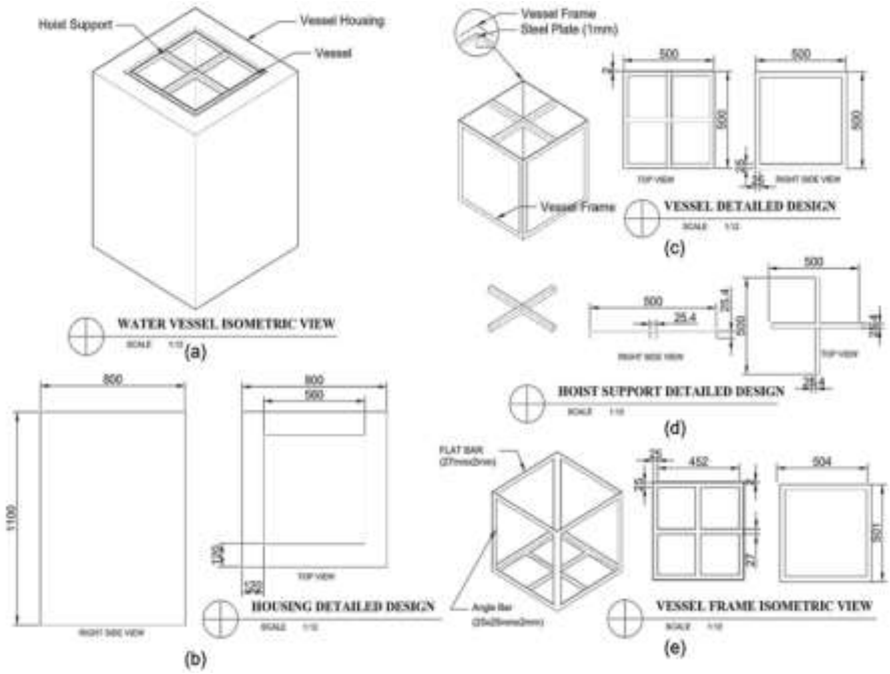

Fig. 3. Design of the self-activating drainage gate (a) Water vessel isometric view, (b) Housing, (c) Vessel, (d) Hoist support, (e) Vessel Frame

Operational principle

Functional evaluation demonstrated that the Baharang operated as a completely passive flood-control device. During repeated operating cycles, the gate responded automatically to changes in water level without requiring manual intervention or an external energy source. The gradual increase in hydrostatic loading produced a corresponding increase in the weight of the floodwater vessel, resulting in progressive closure of the drainage gate. This mechanical response reduced the likelihood of sudden impact loading while maintaining continuous sealing as water levels increased.

The operating principle is consistent with the behaviour of commercial flap gates and automatic backflow prevention systems that close in response to reverse hydraulic pressure (Whipps Inc., 2025; Hydro Gate, 2024). Nevertheless, the incorporation of a calibrated torsion spring and counterweight vessel distinguishes the developed system from many conventional flap gates by providing controlled reopening once hydraulic conditions return to normal. Consequently, the design balances reliable flood protection with efficient post-flood drainage, reducing the need for manual operation after flood events.

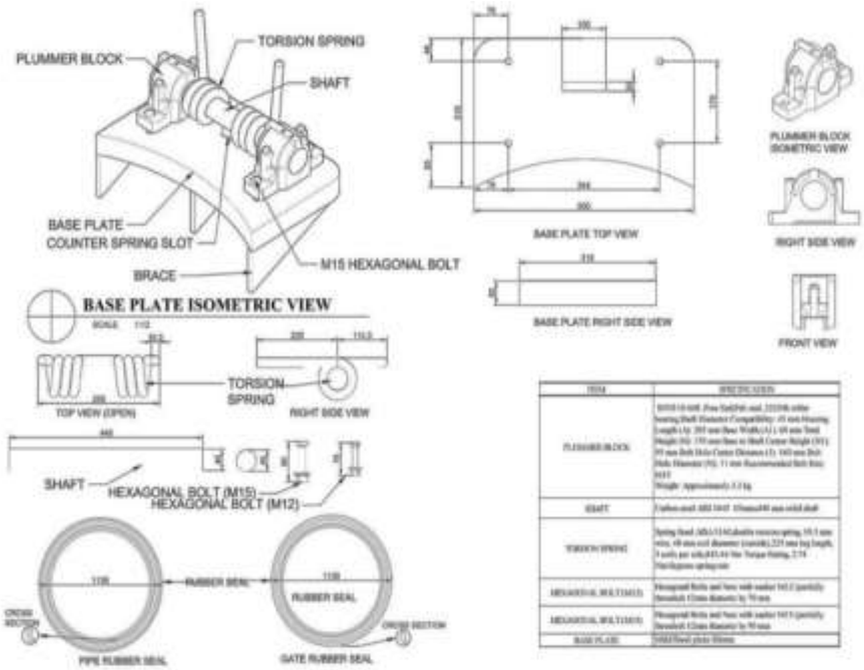

Fig. 4. Base plate isometric view

Passive operation and reliability

One of the major advantages of the Baharang is its completely passive mode of operation. Since the system does not depend on electricity, pumps, sensors, or programmable controllers, its performance remains unaffected during power outages that frequently accompany severe flooding. Passive flood-control technologies have consistently demonstrated high operational reliability because their activation depends solely on natural hydraulic forces rather than external power systems (Presray Corporation, 2024; Orange Flood Control, 2025).

The mechanical simplicity of the developed prototype also minimizes maintenance requirements and reduces the number of potential failure points commonly associated with powered flood-control systems. This characteristic is particularly beneficial for rural communities and local government units with limited technical and financial resources. The ability of the prototype to operate autonomously therefore enhances its suitability as a climate-resilient flood mitigation technology.

Material performance and durability

Material selection contributed substantially to the expected long-term performance of the prototype. The rigid steel structural components provided the mechanical strength required to withstand repeated hydraulic loading, while the rubber sealing gasket maintained effective contact with the gate seat during closure. Together, these components are expected to improve resistance to leakage and mechanical deformation under flood conditions.

The use of corrosion-resistant steel and replaceable sealing materials is consistent with engineering recommendations for flood-control infrastructure exposed to continuous wetting and environmental loading (JR Smith Manufacturing Co., 2024; T-T Pumps, 2024). Likewise, the torsion spring mechanism was selected because of its ability to deliver stable rotational force during repeated operating cycles while requiring relatively little maintenance (The Spring Store, 2024; Acxess Spring, 2024).

Overall, the combination of durable structural materials, passive mechanical operation, and modular construction supports the practical application of the Baharang as a cost-effective and sustainable flood-control solution. Its ability to prevent backflow automatically while maintaining normal drainage under ordinary conditions demonstrates its potential for improving the resilience of drainage infrastructure in flood-prone communities.

CONCLUSION

This study successfully designed and developed the Baharang, a self-activating flood-control drainage gate that provides a passive, power-independent solution for preventing floodwater backflow in drainage systems. The prototype demonstrated reliable automatic opening during normal drainage, closure under reverse-flow conditions, and reopening as floodwaters receded through the combined action of a torsion spring and vessel-type counterweight. Its modular design, durable construction, and compatibility with existing culvert systems make it a practical and cost-effective option for flood-prone communities. Further field evaluation under varying hydraulic conditions is recommended to validate its long-term performance and support wider implementation.

RECOMMENDATIONS

Future studies should evaluate the Baharang under actual field conditions and varying hydraulic scenarios to validate its long-term performance, durability, and maintenance requirements. Quantitative hydraulic testing, including measurements of backflow prevention efficiency, gate response time, and sealing performance under different flow conditions, is also recommended. In addition, assessing the prototype in different culvert sizes and drainage configurations would help determine its adaptability and support its application in flood management programs by local government units and other implementing agencies.

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