C210

Flood Behavior under the Influence of Porous Hedges: Experimental and Numerical Analysis for Heritage Flood Resilience

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1. Introduction

Due to their unique historical and ecological value, Cultural heritage sites are particularly vulnerable to flood risks (Kalogeropoulos et al., 2023; Orr et al., 2021; Sánchez et al., 2020). Enhancing the flood resilience of these areas has become an urgent research priority. Porous hedge, as an eco-friendly and heritage-compatible solution, have shown significant potential in mitigating flood impacts and improving heritage sites protection.

The Katsura Imperial Villa in Japan, famous for its traditional bamboo hedge design (Fig. 1), provides a notable example. Along its side facing the Katsura River, a 250-meter-long porous wall made of living bamboo serves as a natural barrier against flood (Kawasaki, 2013). Similar ecological barriers, though not always composed of living bamboo, are common built in Japanese traditional buildings, such as shrines and temples, where porous walls are favored over solid ones. This widespread use underscores the importance of studying porous hedges as a representative case for flood mitigation.

Fig.1 The living bamboo hedge (桂垣)

This study aims to investigate the hydrodynamic mechanisms of flood interaction with porous hedge through experimental and numerical analyses. It also seeks to develop a reliable simulation methodology and evaluate the potential of porous hedges in enhancing flood resilience for cultural heritage sites, using the Katsura Imperial Villa as a case study.

2. Materials and Methods

This study employed flume experiments to evaluate how porous walls influence flood behavior based on hydrodynamic principles. The experiments were conducted at the Ujigawa Open Laboratory under steady flow conditions, measuring water levels across five different hedge porosity levels (from 0.1 to 0.5). The primary focus was on how porosity affects flood energy dissipation and flow velocity reduction (Fig. 2).

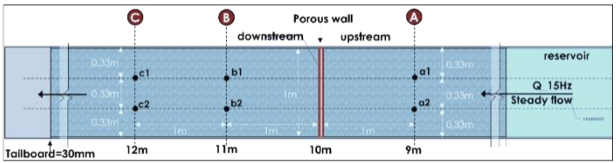


Fig.2 Schematic diagram of the flume experiment setup

Numerical simulations incorporated porosity and additional drag terms to modify the 2D shallow water equations, adding on the 2D inundation model by Kawaike (2002) to develop a hydrodynamic model suitable for porous hedges. Additional experimental data from walls with porosities of 0.12 and 0.15 were used to validate and calibrate the model, ensuring greater precision, especially in the highly sensitive porosity range of 0.1 to 0.2. The calibrated numerical model was then applied to analyze the protective effectiveness of porous hedge in the heritage context of the Katsura Imperial Villa.

3. Results and Discussions

The experimental results demonstrated that the existence of porous hedges significantly reduced flow velocity and weakened hydrodynamic impacts, exhibiting excellent flood-buffering capacity. Porous walls with porosity levels in the range of 0.1–0.2 provided stronger resistance effects, while the performance dropped sharply beyond 0.3.

Two methods were used to improve the numerical simulation: modifying the flux directly or more adding a drag source term. The comparison showed that the second method better matched the experimental results, accurately capturing the hydrodynamic effects of porous hedges. This numerical method could further revealing the spatiotemporal evolution of flood behavior under different porosity conditions (Fig. 3).

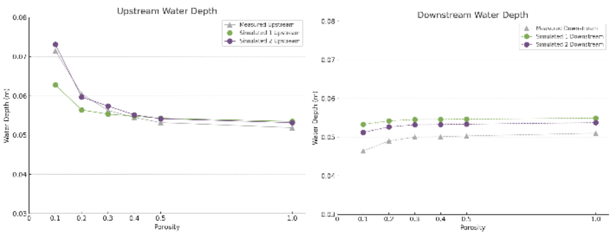
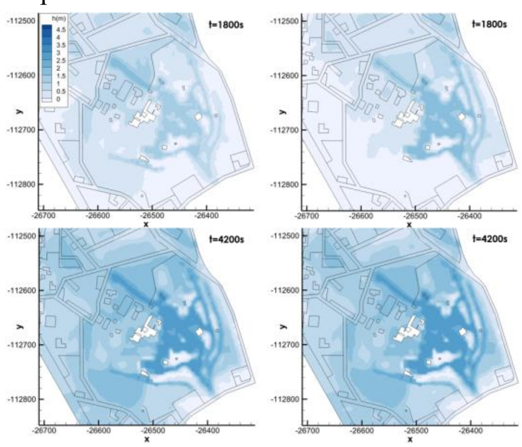


Fig.3 Comparison of experimental and simulation results

The simulation of the Katsura Imperial Villa scenario (Fig. 4) showed that porous hedges effectively reduced flood depth and flow velocity, demonstrating their role as a natural flood barrier. Additionally, the hedges enhanced the overall resilience of the site by mitigating water intrusion and minimizing hydrodynamic impacts. Notably, this was achieved without compromising the structural stability or aesthetic harmony of the heritage landscape.



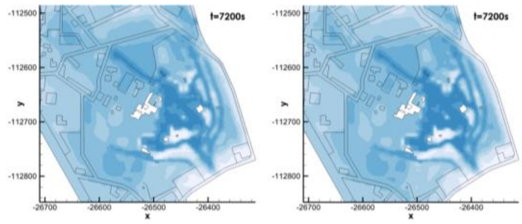


Figure 4. Simulation result of the Katsura Imperial Villa, comparing with (left) and without (right) porous hedge over time

4. Conclusion

4.1 Porous hedges significantly reduce flow velocity and hydrodynamic impacts, making them an effective ecological measure to enhance flood resilience in cultural heritage areas.

4.2 The numerical model, modified by incorporating porosity and additional drag terms into the 2D shallow water equations, showed strong agreement with experimental results, confirming its applicability and accuracy.

4.3 The Katsura Imperial Villa case study demonstrated that properly arranged porous hedges not only mitigate flood impacts but also preserve the integrity of heritage landscapes and structures, highlighting their practical value for broader application.

References:

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