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Numerical Modeling of Flood Disaster in Kyoto's Cultural Heritage Considering Architectural Form Characteristics

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1. Introduction

The number of disasters occurring globally has been steadily increasing (UNISDR, 2009). Traditional research on natural disasters has focused on hazards mechanisms and their impacts on societal infrastructure, human lives and properties. However, the consideration of cultural heritage has often been overlooked. Meanwhile, cultural heritage managers and decision-makers tend to concentrate on heritage preservation, restoration, fire prevention, and aging mitigation, but not the impact of natural disaster on heritage. Current limited research predominantly centers on large-scale risk assessments, neglecting in-depth studies on the specific characteristics of individual hazards. There remains a notable gap in interdisciplinary research on cultural heritage disaster prevention.

This study is grounded in the interdisciplinary field of cultural heritage and flood disaster research, aiming to address the inadequacies in the current research of cultural heritage for flood disasters. The research seeks to elucidate the anticipated external forces and scales of flood faced by cultural heritage. Recognizing the significant differences between historical and contemporary buildings, the study strives to reasonably incorporate architectural features influencing flood distribution into the numerical model. In this paper, cultural heritage primarily refers to immovable cultural assets, such as structures, gardens, monuments, and so on.

2. Materials and Methods

Kyoto City has a rich historical heritage and abundant resources, making the study of cultural heritage disaster prevention particularly significant in this area. This research focuses on the Katsura Rikyū, internationally renowned for its Japanese garden design and representation of Japanese aesthetics, holding substantial historical value. Situated adjacent to the Katsuragawa, the Katsura Rikyū has faced multiple instances of flooding over its centuries-long existence, with the flood in 1721 leaving imprints on the interior walls of the Shōkin-tei pavilion within the garden (桂宮日記). Additionally, the Katsuragawa has experienced numerous floods, and although there are no official records of heritage damage, it is speculated that the Katsura Rikyū may be susceptible to flooding (Kawasaki, 2013).

The author has collected data from the Geospatial Information Authority of Japan (GSI) maps and relevant literature, comparing and refining the overall map to accurately depict the architectural layout and detailed dimensions of the Katsura Rikyū for subsequent numerical simulations.

This study employs 2D inundation model (Kawaike, 2002) to investigate flood scenarios. This model provides comprehensive representations of the temporal evolution of floods in urban areas. The distinguishing features of historical buildings, in contrast to modern structures, include overhanging eaves, high floor structure, and surrounding walls. These three architectural features directly influence the distribution of floodwaters (Fig.1). In this research, these characteristics are integrated into the numerical model to accurately simulate their impact on flood distribution.

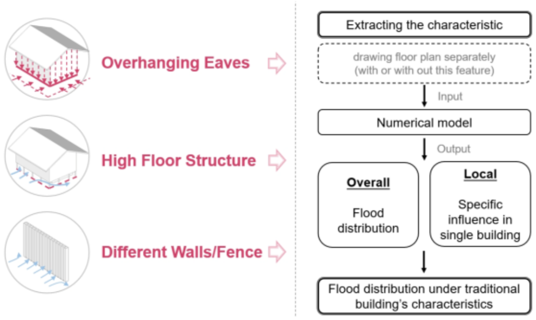
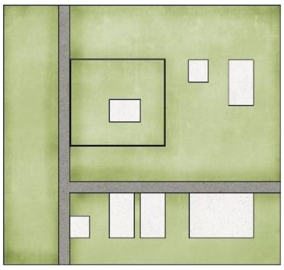
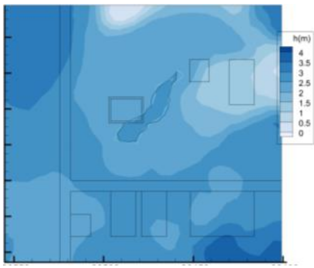


Fig. 1 Research Diagram of Three Characteristics

3. Results and Discussions

The study begins with a comprehensive diagram to validate the research methodology for three features. It is assumed that the area under investigation includes roads, buildings, and walls (Fig. 2).





Left Fig. 2 Assumed Study Subject

Right Fig. 3 Comparison of Water Depth

Concerning eaves, calculations were did using roof outline and exterior wall outline. Graph is represented by light and dark blue lines separately (Fig.3). The results indicate that areas with deeper water depths are more extensive when using roof outline.

Regarding high floor structure, the method of increasing DEM values was used. Calculations were conducted for both non-elevated buildings and buildings elevated by 1 meter (Fig.4). The results indicate that the simulation with elevated buildings demonstrates a noticeable effect, effectively capturing the characteristic.

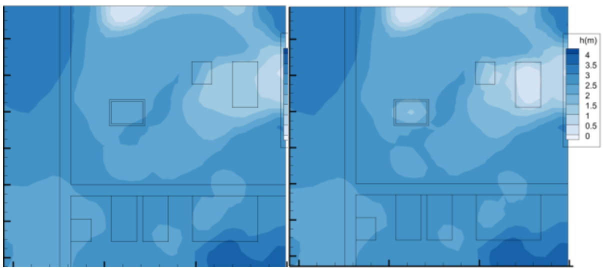


Fig.4 Left Original DEM Right Higher DEM (1m)

Regarding walls, the representation involved gaps between solid walls. Calculations were carried out with different gap ratios, and the DEM was elevated by 3 meters. The results indicate that regardless of frequency, if there are gaps in the walls, the final state of flood distribution is generally the same. However, in the early stages of flooding (Fig. 5), the flood spreading area and speed vary. Examining the flooding situation at 600 seconds, it can be observed that the lower the gap ratios, the lower the average water depth within the walls during the initial stages of flooding.

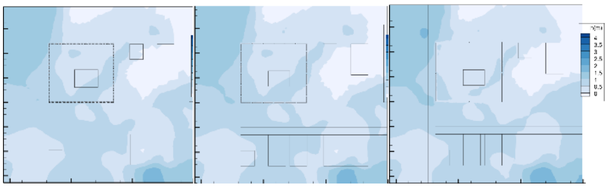


Fig.5 Flood at 600s with ratio of 2:1, 8:1, 26:1

Quantifying these three features for the simulation of the Katsura Rikyū, assuming a closed boundary and specifying breach points, yields two-dimensional numerical simulation results at the architectural level (Fig.6). These results contain inundation depth, extent, flow velocity, direction at different time intervals.

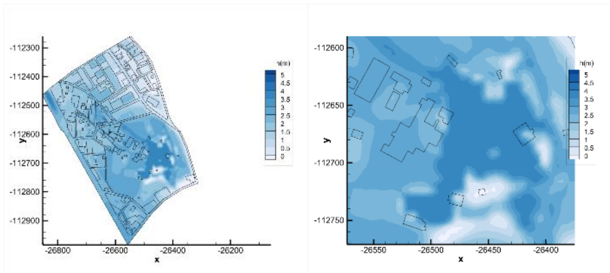


Fig. 8: Flood distribution of Katsura Rikyū

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