

Houses as reservoirs in urban flood modelling

Faut-il modéliser les bâtiments comme réservoirs lors de simulations d'inondation?

Pritsis, S.^{1*}; Naves, J.²; Del Puerto, X.²; Deltsidis, N.³; Cea, L.²; Bermúdez, M.⁴; Papakonstantis, I.⁵; Puertas, J.²; Sylaios, G.³; Anta, J.²; Tscheikner-Gratl, F.¹; Bellos, V.³

¹ Norwegian University of Science and Technology (NTNU), Department of Civil and Environmental Engineering, Høgskoleringen 1, 7034 Trondheim, Norway

² University of A Coruña, Rúa da Maestranza 9, 15001 A Coruña, Spain

³ Democritus University of Thrace, Campus, 69100 Komotini, Greece

⁴ University of Granada, Av. del Hospicio, 1, 18071 Granada, Spain

⁵ National Technical University of Athens, Iroon Polytechniou 9, 15772 Athens, Greece

RÉSUMÉ

Le pourcentage de bâtiments inondés durant une inondation dépend de la vulnérabilité du système à différentes échelles (de l'échelle de la ville à celle du bâtiment). Les bâtiments inondés se comportent comme des réservoirs retenant une partie des eaux, provoquant un effet de stockage. Jusqu'à présent l'impact de ce phénomène n'a été étudié ni numériquement ni expérimentalement. Cette étude consiste, lors d'essai de simulation d'inondation en laboratoire sur une aire urbaine, à l'analyse des hauteurs d'eau et des hydrographes de sortie pour différents scénarios d'inondation. Le modèle à échelle réduite consiste en une plateforme bétonnée de 26.1 m² sur laquelle 25 modules ont été disposés. Les modules représentent des bâtiments avec sous-sol et sont munis de portes amovibles. Le modèle est surmonté d'un simulateur de pluie. Différentes configurations urbaines ont été testées sous deux intensités de pluie différentes. Les résultats préliminaires suggèrent qu'en zone urbaine dense, les effets de stockage des bâtiments peuvent avoir un impact important sur l'ampleur de l'inondation. Nous suggérons donc la prise en compte de ces effets lors de modélisation d'inondation urbaines. Les objectifs additionnels de l'étude sont i) de proposer un cadre conceptuel permettant de prendre en compte ces effets dans les modèles numériques et ii) de collecter des données permettant de caler les paramètres liés à cet effet.

ABSTRACT

The percentage of the houses flooded during an urban flood event depends on the vulnerability of the system within all scales (from the entire city to each building). The flooded houses are acting as a reservoir storing flood volume, the so-called storage effect. So far, this phenomenon has not been approached, neither numerically nor experimentally. To address this gap, this study presents measurements of water depths (inside and outside of buildings) as well as the outflow hydrograph for five pluvial flood scenarios simulated under laboratory conditions. The setup consists of an artificial rainfall simulator which provides controlled precipitation for a 26.1 m² concrete platform with 25 blocks (representing buildings with basements), with detachable doors. Varying configurations of the setup regarding storage availability were tested using two different rainfall intensities. Preliminary results suggest that the storage effect of the houses has a significant impact on the overall flood characteristics in densely urbanized areas, suggesting that further consideration should be given to including the storage effect in urban flood modeling. One of the goals of this study is to provide insights about incorporating this effect in numerical models and datasets for calibrating them.

KEYWORDS

experimental hydraulics, pluvial flood, storage effect, urban environment, vulnerability

1 INTRODUCTION

Increasing urbanization of the planet led the research community to focus more on urban flood dynamics in the last decades (e.g., Jha et al., 2012). In general, two ways exist for simulating flood events: numerical and physical modelling (Bellos, 2012). In our era, the advances in computing technology and the development of various software combined with the significant cost of the physical modelling (in terms of both time and money), led the scientific community to prefer numerical modelling, either using models based on the one-dimensional (1D) or on the two-dimensional (2D) form of the Shallow Water Equations (SWE). However, there are still lot of phenomena, especially in complex set-ups such as urban environments, which cannot be fully captured or explained with the current practice in numerical modelling, especially when taking into account the variety of existing and unaccounted for model uncertainties (Bellos et al., 2020). Also, the computational burden of more advanced numerical models such as those based on the full form of Navier-Stokes (known also as Computational Fluid Dynamics models), makes their application non feasible for real-world flood problems for the current scales. This is the main reason for the ongoing research interest in physical modelling to fill the knowledge gaps and allow the improvement (and calibration) of the available numerical models.

One of these gaps during an urban flood event, is the behaviour of the system of the buildings damaged by the flood which are acting as a big reservoir, or a system of small distributed reservoirs, storing water volume. This can be caused either due to the vulnerability of each building against the dynamics of flood (water enters through the several openings; such as doors, windows), or in some cases on purpose, when a house is designed to receive a flood water volume at the basement, which is behaving as a retention basin on a small scale and could even be controllable. The latter concept is also known as wet floodproofing (FEMA, 2014), in contrast with dry floodproofing where houses are not damaged inside although the city is hit by the flood. The phenomenon in which houses are storing flood volume is known as storage effect at the relevant literature. One of the research questions posed by several researchers (Syme, 2008; Bellos and Tsakiris, 2015) is on the impact of this effect for the flood characteristics, such as water depths and flow velocities. In this work we investigate this effect for a pluvial flash flood generated by a rainfall simulator in an idealized city under laboratory conditions. The pluvial type of flash flood (observed more often in the Mediterranean area than continental climate zones) posed an additional challenge for the study, since the majority of experimental hydrology is oriented towards the fluvial type and so new terrain has been entered.

2 METHODOLOGY

2.1 Experimental setup

A model of an idealized city was built for testing using an artificial rainfall simulator in the Hydraulic Laboratory of the Centre of Technological Innovation in Construction and Civil Engineering (CITEEC) at the University of A Coruña (Naves et al., 2020). The simulator provides three possible rain intensities, 30, 50 and 80 mm/h. The total surface of the platform representing the urban catchment is $5.8 \text{ m} \times 4.5 \text{ m}$ ($=26.1 \text{ m}^2$). To define the outlet of the catchment, a major and a minor slope were given to the platform, of 0.5% and 0.1% respectively. A grid of 25 (5×5) blocks, representing buildings, were built near the outlet of the catchment. The area of each block is $30 \times 30 \text{ cm}$, with a height of 20 cm above ground level and 7 cm below, representing a basement. Small detachable parts, representing doors, were installed on two sides of each block (one facing the major slope, one facing the minor one). A 5 cm high wall was built at the perimeter of the platform with a 50 cm opening to create a clearly defined outflow point. PVC was used for the blocks and the removable doors, concrete for the ground surface and wood for the perimeter wall.

Figure 1 shows the planned and built laboratory setup.

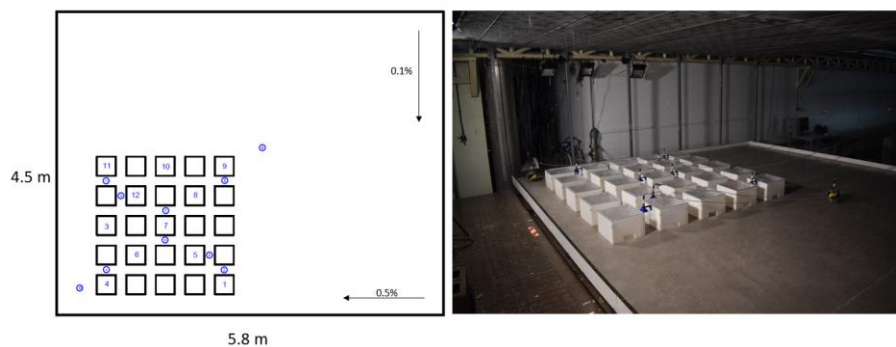


Figure 1 Experimental setup. Top view, CAD plans showing the blocks and sensor placement (left). Photograph of the final setup from personal archive (right)

2.2 Measurement devices and data processing

The discharge at the outflow was measured using a volumetric method. The water was gathered in a (50 × 50 × 70 cm) tank and an ultrasonic depth sensor was mounted on top. To measure the water depth in the catchment, 8 ultrasonic sensors were placed between the buildings and 2 more were placed outside the house matrix (one upstream and one downstream) (Figure 1). The water depth inside of the houses was also measured using pressure sensors connected to a 10 mm tube connected to a hole at the bottom of 11 of the 25 houses. Finally, 5 digital cameras (Raspberry Pi Camera V2) were installed around the platform capturing video from different angles. A small number of scenarios were also simulated with the added component of seeding particles (fluorescent plastic particles illuminated with UV light) and 2 additional high-quality cameras installed.

Frames were extracted from the videos to perform LSPIV and these were rectified, scaled and filtered before using OpenPIV open-source code (Liberzon et al., 2016) to obtain surface velocities. All the cameras captured video at 20 frames per second. The sampling frequency of the ultrasonic and the pressure sensors was 10 Hz. A rolling median filter was applied to the timeseries recorded by the ultrasonic and pressure sensors. After discarding the outliers, the timeseries was upsampled to a 1 second resolution. Finally, a rolling average of 5 seconds was calculated.

3 RESULTS

A total of 22 scenarios were simulated. The preliminary results confirm the initial thesis, that the storage effect of buildings can be significant in urban pluvial floods. This is demonstrated in Figure 2, where scenarios with different numbers of open doors are compared by plotting the hydrographs at the outflow of the platform and water depths in the street nearest to the outflow.

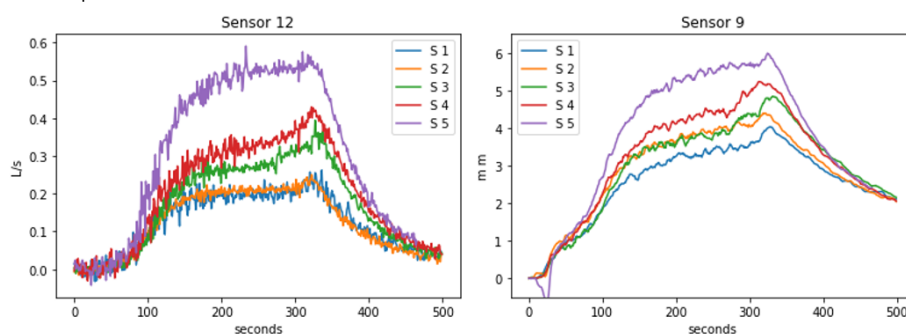


Figure 2 Measurement comparison of different scenarios. Hydrographs (left) and water depths (right)

The rain intensity was 80 mm/h for all presented scenarios. The only difference was in the configuration of the

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open doors. For S1, all doors are open, in S2, all doors facing at the direction of the major slope are open, in S3, all doors facing at the direction of the minor slope are open, in S4, the doors of nine of the houses are open and in S5, all doors are closed. In both graphs we can clearly see a correlation between the measured parameter (i.e., discharge and water depth) and the number of open doors. The significance of the direction of the doors is also seen in the differences between S2 and S3.

The open dataset can be a benchmark test for verifying numerical models (e.g., Iber (Bladé, E. et al. 2014)) and testing them in case studies of high complexity, such as the laboratory model of this proposal. Moreover, the findings indicate which phenomenon is more crucial for urban flooding (and hence researchers can focus on this) and probably they can contribute for posing new research questions and strategies for answering them. A proper flood defense scheme should couple structural measures, such as flood walls or retention basins, and non-structural measures, such as flood warning systems or several personal actions in which flood defense is performed in the scale of house, as previously described. The impact of a partial protection of a city against floods on the buildings which are finally flooded is probably significant and the findings on the latter topic might be useful to public services oriented to civil protection or to insurance companies.

All the experimental datasets obtained (including data and metadata) will be made openly available on Zenodo repository, as part of the broader Co-UDlabs community.

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