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CIVIL INFRASTRUCTURE

Modelling Buildings During Flood Inundation Using TELEMAC-2D

Global climate change significantly increases flood risk. Inundation around buildings in both urban and rural areas can pose significant risk to life and property. Accurate and precise modelling is the key to a better understanding and quantification of flood risk. This study applies three different methods for modelling buildings within TELEMAC-2D from a dyke breach scenario: a) buildings excluded from the mesh; b) buildings modelled as elevated bathymetry; and c) buildings modelled as vegetation friction. The maximum flood hazard rating for each method is then calculated from the hydrodynamics generated by the model and compared. The results show that using vegetation friction to represent the buildings in the model is the most effective and accurate approach in evaluating the flood risk.

Keywords:
Flooding, buildings, modelling, TELEMAC, River Severn.

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INTRODUCTION

Climate change and increasing urbanisation have left communities globally more exposed to flooding. Flooding affected 54.86 million people worldwide in 2022, directly causing 7,398 deaths [1]. The estimated cost of flooding in 2019 was approximately 52 billion US dollars [2].

Buildings, particularly housing and commercial premises, are one of the primary assets at risk from flooding. When floodwater surrounds a structure there is a significant risk to life, and there can be considerable financial losses. The way that water flows around structures influences local inundation depths, flow velocities, as well as pollutant and debris transport. These in turn all influence the risks to life and property. To better understand the increasing risk, flooding needs to be accurately modelled. It is important to evaluate various modelling methods in comparison to one another and where possible verify them with empirical evidence.

Research has focused on models with uniform buildings in a simplified urban district [3], porosity modelling of bulk areas [4] and modelling buildings with Manning's roughness coefficient, reflection boundaries and raised beds [5]. The contrasts between bare earth models against raised buildings have been examined but not using a resistance method or exclusion for buildings [6]. Comparisons between similar methods as those proposed in this study have been made previously, but they did not use the same resistance formulation [7].

Bewdley is a village on the River Severn in Worcestershire, England, and is known for its frequent flooding [8]. The village has erectable temporary flood defences operated by the UK Environment Agency (EA), as well as some permanent embankment defences. This paper introduces three different approaches for modelling buildings in TELEMAC-2D, examining a group of buildings near the River Severn in Bewdley. Flood Hazard Ratings are generated for the different methods and comparison made between them.

MATERIALS AND METHODS

TELEMAC-2D is a modelling framework that simulates free surface flows in a two-dimensional space by solving the Saint-Venant depth averaged shallow water equations with the finite-element or finite volume methods, using an unstructured, irregular triangular mesh.

In this study, the finite element method is used and the building zone at Bewdley adjacent to the River Seven as highlighted in Fig. 1 is selected for model application.

Fig. 1. Satellite image (Google Maps) of the River Severn and part of Bewdley, with building outlines used in this study highlighted in red.

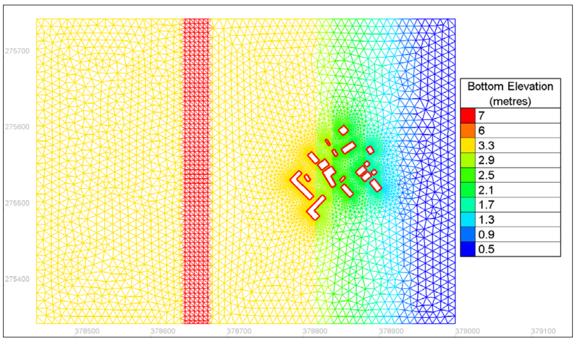

Fig. 2. Computational mesh for the domain with bottom elevation.

The computational domain is idealised from the study site shown in Fig. 1. The bathymetry is assumed to incline from the edge of the dyke, moving across the buildings zone to the rightmost edge of the modelled area. The drop over the incline is 5m, a gradient of 1:64. This allows the model to drain once the dyke is breached and the inundation has peaked.

Three methods are examined here for modelling buildings:

1) **BH Method**: Buildings are excluded in the computational mesh, meaning that no hydrodynamic computations are carried out within the boundaries, as shown in Fig. 2.

2) **BR Method**: Raising of the bed level at building locations is used. The mesh is raised to uniform levels of 5.8m and 3.2m, depending on whether the building is 1 or 2 stories high.

3) **BV Method**: Buildings are represented by the vegetation friction in TELEMAC-2D with a specific built-in module. It simulates the buildings as ultra-high friction zones with near zero velocity fields. Vegetation friction can be modelled as a linear superposition with the bed roughness [9], in this case Manning's roughness coefficient.

$$\lambda = \lambda\text{^}' + \lambda\text{^}'' \tag{1}$$

where, λ is total roughness, λ' is bed roughness and λ'' is vegetation resistance per unit area. With the method proposed by [10], it simulates vegetation as a drag coefficient, by considering the vegetation diameter, treated as a cylinder, and vegetation density as:

$$\lambda'' = \begin{cases} 4C_D \cdot \dfrac{Dh}{\Delta^2} & for\ h \le h_p \\ 4 \cdot \left(\dfrac{1}{\sqrt{C_D \dfrac{Dh_p}{\Delta^2}}} + \dfrac{1}{\sqrt{2}\kappa} ln \dfrac{h}{h_p} \right)^{-2} & for\ h > h_p \end{cases} \tag{2}$$

where C_D is the drag coefficient, D is the plant diameter, h is the flow depth, Δ is the element spacing, κ is von Kármán constant and h_p is the vegetation height. It also has two layer flow for submerged and non-submerged vegetation.

A dyke breach scenario simulates the rapid inundation of buildings as may occur during a fluvial flood. The water level behind the dyke rises in accordance with the symmetrical storm design used in ReFH2 [11]. Near the peak water level, the dyke breach begins over a given width and period via the TELEMAC-2D user function by lowering the dyke by 2 m over 15 minutes. This causes water to rapidly flow through the dyke to the building zone and the surrounding area.

The EA provides guidance on assessing the risk to life from flood waters [12]. It combines the effects of water depth and velocity as Flood Hazard Risk (FHR) as:

$$FHR = D(V + 0.5) + DF \tag{3}$$

where D is water depth (m), V is velocity (m/s), and DF is a debris coefficient varying from 0-1 depending on local conditions. The output can then be graded with a numerically stepped risk classifier, shown in Table 1.

FHR	Level	Description
<0.75	L	Flood zone with shallow flowing water or deep standing water.
0.75 – 1.25	M	Moderate Danger for some (i.e. children). *Danger: Flood zone with deep or fast flowing water.*
1.25 - 2.50	H	Significant Danger for most people. *Danger: flood zone with deep fast flowing water.*
>2.50	E	Extreme Danger for everyone. *Extreme danger: flood zone with deep fast flowing water.*

Table 1. Classifications of Flood Hazard Risk

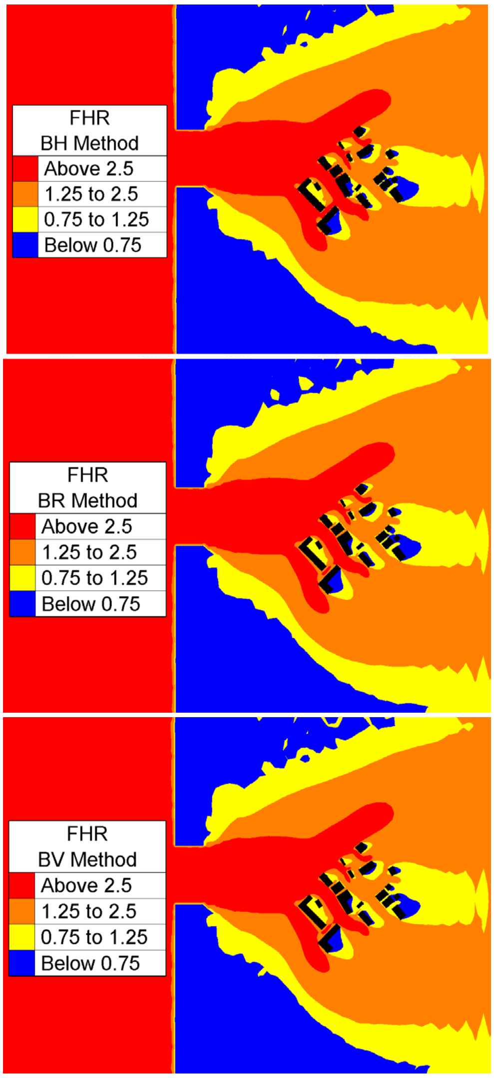

Fig. 3. Maximum FHR with: (a) BH method (top), (b) BR method (middle), and (c) BV method (bottom).

RESULTS

FHR Maps
FHR maps were produced from the model results, which are shown below. Figure 3. shows the maximum FHR from the three methods proposed for simulating buildings. In general, the FHRs for the 3 methods are similar, with the shape and size of the extreme danger zones (>2.5) being nearly identical for all methods, and the other danger zones having the similar distributions. There are small discrepancies in the spaces between the buildings and in-between the low and medium risk zones further out from the buildings.

Comparison of FHR Maps
A direct comparison of the results took the differences between the maximum FHR outputs, highlighting any significant changes in risk profiles between methods.

The scale used for comparisons shows minimal changes between ±0.1 as white space.

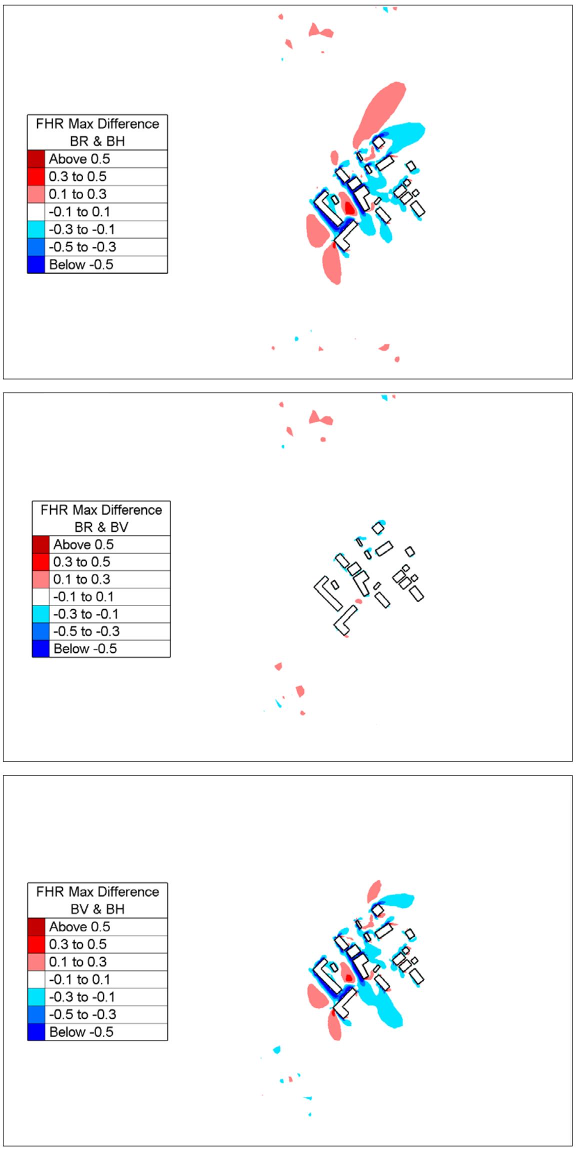

Fig. 4. The difference of the maximum FHR values between: (a) BR and BH (top), (b) BR and BV (middle), and (c) BV and BH (bottom).

DISCUSSION

The three methods examined in this study have broadly the same output when considering the general shape, size, and FHR classification of structures within the flow.

The BR and BV methods are in good agreement in their FHR results. There are a few zones of change (Fig. 4. Part b) near to the buildings, but these are small, and nearly all within the range of 0.1 to 0.3 or -0.3 to -0.1 range.

There are some discrepancies between the BR and BV methods and the output of the BH method. The BH method predicts significantly higher (Dark blue, -0.5 or below) FHR values near the front of buildings. This is accompanied by a zone of lower risk (Red, 0.3 to 0.5) between buildings in the centre of the study area. The area of the change is smaller for the BV method (Fig. 4. Part c) than for the BR method (Fig. 4. Part a). These discrepancies require further analysis, especially to determine which of the methods, if any, is the most physically realistic.

Excluding the buildings from the mesh prevents any water from entering. However, buildings are not impenetrable structures, but are often porous to some degree. The exclusion method (BH) makes any porosity or overtopping impossible and therefore may be the less representative of the three methods.

The vegetation friction method can capture building infiltration and storage and is simple to apply to any model. These advantages along with its broad agreement with the raised bedforms method make it potentially useful and applicable in modelling floodwaters.

CONCLUSIONS

This paper outlines three methods to model buildings on a flood plain during a dyke break scenario in TELEMAC-2D.

The methods have general agreement in terms of maximum FHR but there are discrepancies between the BH method and the BV and BR methods.

The use of vegetation friction is to the authors knowledge a novel method. It has acceptable model outputs and so could be a valid option to choose to model buildings during a flood event.

Future work is needed concentrating on the discrepancies between methods, as well as validation cases. Models need to account for additional floodplain obstructions, and a mesh density sensitivity analysis should be completed.

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Conflicts of interest
The authors declare no conflict of interest.

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