# 2D numerical simulation of urban dam break and its effect to building using lax scheme with numerical filter

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**Abstract.** Dam-break is one of the disasters that can occurred due to earthquake. The earthquake vibration may damage the dam construction and therefore causing a dam-break flow. The flow can cause severe destruction to the downstream urban area. Dam-break modeling offers a way to analyze its effect of buildings. In this study, a 2D model for analyzing dam break flow is developed based on the Saint Venant equations and solved using Lax Scheme. The initial condition of the modelling is a rectangular channel with obstacles at both sides of the channel and two similar columns in the middle of the channel. These obstacles are considered as buildings in an urban area. Numerical filter is used to increase the stability of the simulation. The developed model is able to perform well in simulating a case of urban dam-break based on a previous experiment. In addition, the applied numerical filter is able to handle shock, therefore maintaining the stability of the model while reducing the simulation time without the needs to use a higher order numerical scheme.

## 1 Introduction

Earthquake is one of the most devastating natural calamities which causes sudden shaking of the earth surface. It causes damages to buildings and other structures, moreover affects the surrounding environment and our lifestyle significantly [1]. The strong vibration of an earthquake can cause construction structures to collapse. One of the example construction is a dam. Dam is a structure formed by landfill, rock dumps, concrete, and/or stone pairs, that is built not only to hold and store water, but also be built to hold and contain mine waste (tailings), or contains mud therefore it is forming a reservoir. Dams or reservoirs are artificial containers formed as a result of the construction of dam [2]. Dam failure can be caused by several factors, such as geotechnical failure, construction strength, excessive pore water pressures, quality of material used for construction, errors in construction planning, natural disaster including earthquake, etc. [3].

With regards to earthquake, the embankment and critical appurtenant structures of a dam should be evaluated for seismic stability. The analysis should consider the seismic zone of the site. Dam-sites over active faults should be avoided if possible. For dams located near or over faults in earthquake areas, special geological and seismological studies should be performed in the design stage. Defensive design features for the embankment and structures should be used, and in the case of strong seismicity, it is desirable to locate the spillway and outlet works on rock rather than in the embankment or foundation overburden. The common performance criteria are: (i) dams should be capable of surviving the controlling Maximum Credible Earthquake (MCE) without a catastrophic failure that would result in loss of life or significant damage to property; (ii) dams should be capable of resisting the controlling Operating Based Earthquake (OBE) within the elastic range, remain operational, and not require extensive repairs.

In the operation of the post-construction dam, errors or failures can occur, one of which is damage to the body of the dam, commonly called Dam-Break. Dam-Break is a catastrophic type of failure, characterized by the sudden, rapid and uncontrolled release of impounded water, or the likelihood of such an uncontrolled release [4]. Dam-Break failure will destruct area next to the dam by the dangerous flow to the downstream and the effect caused by the dam break is exposed in [5]. Hence, Dam-Break analysis is important in obtaining the performance of dams.

Shallow Water Equation (SWE), usually also known as Saint Venant Equation, is the common method to simulate tsunami wave run-up, and often used with Manning approach for modelling the bottom friction [6]. Previous study [7] reveals that SWE is also commonly used to describe Dam-Break problem mathematically. Many studies have been carried out by researchers in

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analyzing this Dam-Break event. A 1D dam break modelling using several numerical methods had been studied [8,9]. Numerical simulation of dam break is one of the effective methods in analyzing the case [10]. Hydraulic computing uses numerical methods in solving an equation to review the relationship between flow and changes in water depth. The numerical methods commonly used are the finite difference method, finite element method, characteristic method, and finite volume method.

To further understand the effect of Dam-Break, this study simulates a case of Dam-Break flow based on laboratory experiment of previous study [11]. In this research, the case is simulated using a finite difference Lax Scheme with additional numerical filter. The results is then compared to those obtained using finite volume model in the previous study [11].

## 2 Research methodology

### 2.1 Governing equations

Surface flow can be described using a 2D Saint Venant equation. This equation consists of continuity and momentum equation. The governing equations are obtained as follows:

$$\frac{\partial h}{\partial t}+\frac{\partial (hu)}{\partial x}+\frac{\partial (hv)}{\partial y}=0 \qquad (1)$$

$$\frac{\partial (hu)}{\partial t}+\frac{\partial (hu^2)}{\partial x}+\frac{\partial (huv)}{\partial y}+gh\frac{\partial h}{\partial x}-gh(S_{0x}-S_{\mathrm{fx}})=0 \qquad (2)$$

$$\frac{\partial (hv)}{\partial t}+\frac{\partial (hv^2)}{\partial y}+\frac{\partial (huv)}{\partial x}+gh\frac{\partial h}{\partial y}-gh\left(S_{0y}-S_{\mathrm{fy}}\right)=0 \qquad (3)$$

### 2.2 Numerical scheme

In this study, a 2D Saint Venant Equation is approached using finite difference method. Lax Scheme is one of explicit finite difference method. In Forward-Time-Centered-Space (FTCS) Scheme, the base point for approximating partial differential equation (PDE) is grid point (i,t). This method approximates the time derivative by the first-order forward difference and the space derivative by the central difference.

FTCS approximation is unconditionally unstable. Therefore, Lax (1954) proposed a modification to the FTCS Scheme to obtain better stability in approximating PDE [12]. The discretization of Saint Venant equations approximated by Lax Scheme are as follow:

$$hlax_{i,j}^{t}=\frac{1}{4}\left(h_{i+1,j}^{t}+h_{i-1,j}^{t}+h_{i,j+1}^{t}+h_{i,j-1}^{t}\right) \qquad (4)$$

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$$ulax_{i,j}^{t}=\frac{1}{4}\left(u_{i+1,j}^{t}+u_{i-1,j}^{t}+u_{i,j+1}^{t}+u_{i,j-1}^{t}\right) \qquad (5)$$

$$vlax_{i,j}^{t}=\frac{1}{4}\left(v_{i+1,j}^{t}+v_{i-1,j}^{t}+v_{i,j+1}^{t}+v_{i,j-1}^{t}\right) \qquad (6)$$

$$h_{i,j}^{t+1}=hlax_{i,j}^{t}-\frac{\Delta t}{2\Delta x}\left(u_{i+1,j}^{t}h_{i+1,j}^{t}-u_{i-1,j}^{t}h_{i-1,j}^{t}\right)-\frac{\Delta t}{2\Delta y}\left(v_{i,j+1}^{t}h_{i,j+1}^{t}-v_{i,j-1}^{t}h_{i,j-1}^{t}\right) \qquad (7)$$

$$u_{i,j}^{t+1}=ulax_{i,j}^{t}-\frac{\Delta t}{2\Delta x}u_{i,j}^{t}\left(u_{i+1,j}^{t}-u_{i-1,j}^{t}\right)-\frac{\Delta t}{2\Delta y}v_{i,j}^{t}\left(u_{i+1,j}^{t}-u_{i-1,j}^{t}\right)-g\frac{\Delta t}{2\Delta x}\left(h_{i+1,j}^{t}-h_{i-1,j}^{t}\right)+g(So_x-Sf_x) \qquad (8)$$

$$v_{i,j}^{t+1}=vlax_{i,j}^{t}-\frac{\Delta t}{2\Delta y}v_{i,j}^{t}\left(v_{i,j+1}^{t}-v_{i,j-1}^{t}\right)-\frac{\Delta t}{2\Delta x}u_{i,j}^{t}\left(v_{i+1,j}^{t}-v_{i-1,j}^{t}\right)-g\frac{\Delta t}{2\Delta y}\left(h_{i,j+1}^{t}-h_{i,j-1}^{t}\right)+g\left(So_y-Sf_y\right) \qquad (9)$$

### 2.3 Numerical filter

Numerical filter is applied to reduce oscillations, thus the model has better stability [13]. For each iteration at each node, the water depth and velocities are updated by the following equation:

$$F_{i,j}=C*F_{i,j}+\frac{\left(F_{i-1,j}+F_{i+1,j}+F_{i,j-1}+F_{i,j+1}\right)}{4}*(1-C) \qquad (7)$$

Where F is the parameter to be filtered and C value is taken to be 0.99.

## 3 Result and discussion

This study analyzes a dam break case with obstacles at the both sides of channel and at the downstream. The obstacles are considered as buildings in urban area. This case has been analyzed by Peng [11] using finite volume method.

The domain of this simulation is rectangular channel of 1.6 m (length) x 0.6 m (width) x 0.6 (height). The dam is located at x = 0.4 m with initial water depth 0.15 m and at downstream the water depth is 0.01 m. Two buildings (0.1 m x 0.1 m x 0.3 m) are placed at x is 1.2 m in the middle of channel with the space 0.1 m. There are also six small buildings placed on the both sides walls (at x = 0.4 m, 0.8 m, and 1.2 m). The initial condition is shown in Fig. 1. In this simulation, buildings are assumed as walls so that the velocities in x and y directions (u and v) are equal to 0. The model is simulated in grid spacing (dx and dy) 0.01. The total time simulation is 2 s, with time step (dt) is 0.001 s

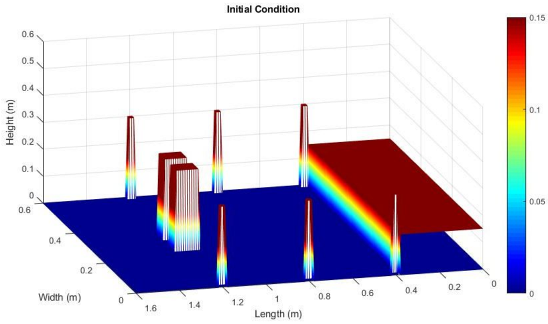
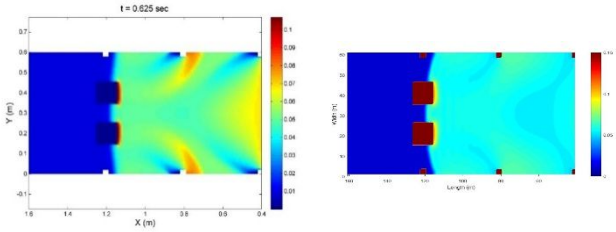
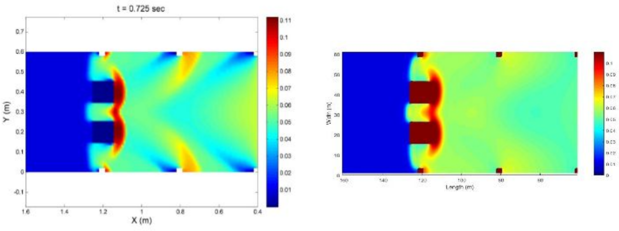


**Fig. 1.** Initial condition of simulation.

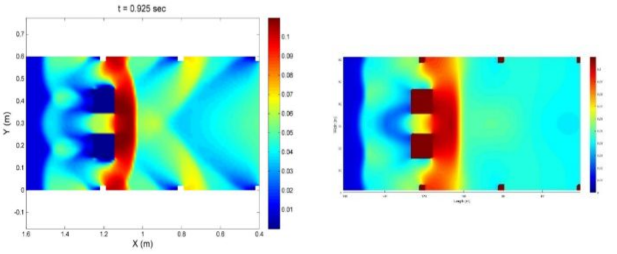
After finishing the model and conducting the analysis, the results will be compared with the ones from previous study [11]. To evaluate the developed model, the simulation result from the two studies (current and previous ones) will be analyzed visually. Therefore, this study uses similar time step as in the previous study. Then the results from this study and the previous one are matched side by side for all simulation results. Fig. 2 shows a comparison of simulation result from previous study [11].



(a). t=0.625 s



(b). t=0.725 s

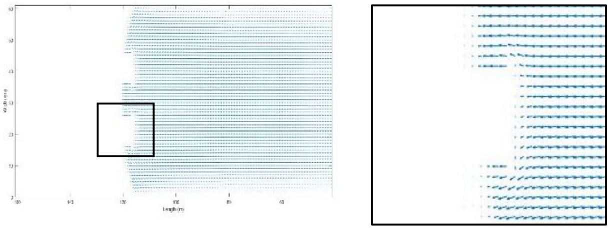


(c). t=0.925 s

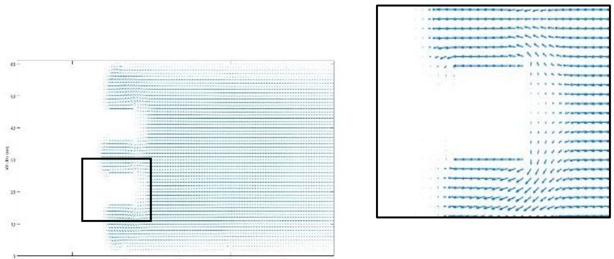
**Fig. 2.** Simulation results from previous study [11] (left) and this study (right)

In general, the results from the developed model show a good comparison to those from previous study [11]. At t = 0.625 s, the dam-break induced flow has propagated to the middle of the buildings (Fig. 2a). Reflection of the wave can be seen as the water hits the buildings. This is also shown in the previous study. The wave propagates further throughout the buildings at t=0.725 s (Fig. 2b). In this time step, other phenomenon such as diffraction and contraction due to the buildings are observed. The wave moves further downstream as shown in Fig. 2b and 2c.

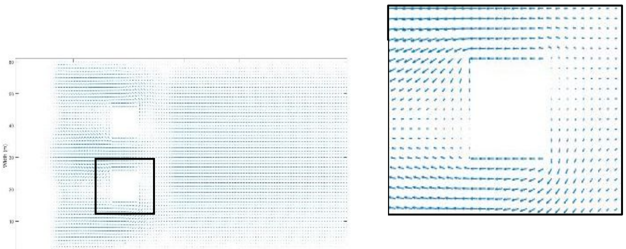
The results show that the developed model is able to simulate wave propagation process of a dam-break induced flow effects to buildings, as in the case of previous study [11]. It should be noted that the proposed numerical scheme used in this study is much simpler.
Flow direction around the building is given in more details in Fig. 3. The reflection and diffraction effect can be seen clearly. The wave stops as it arrives at the location of the building. The 2D model is able to simulate the flow circling the building as the wave propagates further downstream. The flow between the buildings is faster than the flow on the other side. This is due to the contraction effect from the buildings position.



(a) Flow around building at t=0.625 s



ing at t=0.725 s



ing at t=0.925 s

**Fig. 3.** Flow around building

The long section profile of the flow at the building location is given in Fig. 4.

It can be seen clearly that the flow depth in front of the building, facing directly to the wave, is approximately twice of the upstream flow depth. On the other hand, the downstream of the building water depth is much lower. It is noted that due to diffraction, the downstream water depth is not immediately maximum at the building.

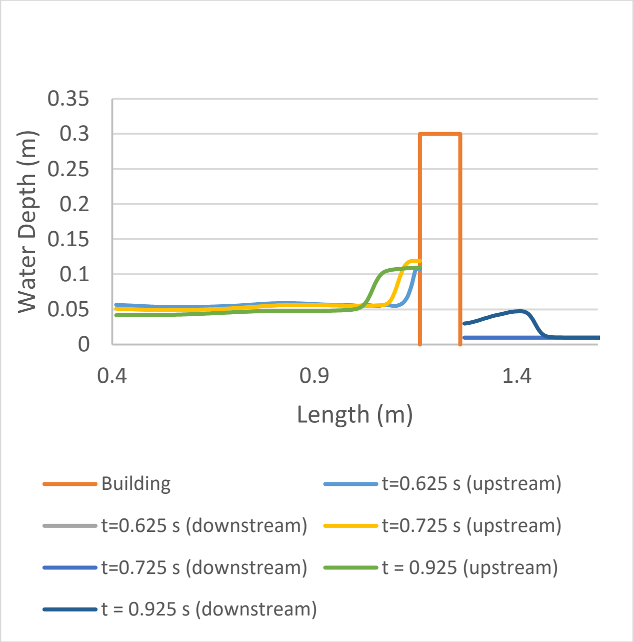


**Fig. 4.** Water depth around the building

## 4 Conclusion

Dam-Break is one of the disasters that can occurred due to earthquake. Dam-Break is a catastrophic type of failure, and will destruct area next to the dam by the dangerous flow to the downstream.

In this study, a 2D numerical model for simulating Dam-Break flow in urban area has been developed. The model is based on Shallow Water Equation, solved using Lax Scheme. The scheme is easy to use and flexible to modify. A numerical filter is added to ensure the model stability.

The model is then used to simulate a case of urban dam break. The developed model shows good comparison to the previous study. The model in this study is able to reproduce known phenomena such as reflection, diffraction, as well as contraction. It is found that wave reflection at the front of the building cause the flow depth to increase approximately twice.

The developed model is very useful for disaster mitigation of dam-break event. In addition, dam break flow characteristic is similar to tsunami induced flow. Therefore, the developed model has a high range of applicability including a tsunami induced flood. The model can be further verified by simulating a real case of dam-break or tsunami induced flood event.

This study is supported by P3MI LPPM ITB and ITB Research INOVASI KK: 91c/I1.C01/PL/2019.

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