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NUMERICAL INVESTIGATION OF SUSPENDED LOAD DEPOSITION CONSIDERING THE EFFECTS OF CHANNELS

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The paper presents a two dimensional coupled one dimensional numerical model to simulate inundation and sediment deposition over the paddy field considering the effect of channel network. The results show that the roads in the research area have significant influence to flood propagation and sedimentation; Main suspended load deposition happened near the inflow point and along the flow direction, the maximum deposition thickness on the ground surface is over 50 cm. And the sedimentation mode, that is the main deposition area and deposition thickness in the channels is similar to that on ground. The capacity of channel network and crop harvest may be seriously affected by the deposited sediment.

***Key words**: sediment deposition, channel network, inundation, numerical simulation*

1. Introduction

Flooding is the most devastating, widespread and frequent natural disaster and the climate change makes the loss of lives and property from it become increasingly serious. For example, the heavy rainfall in west Japan in 2018 caused 225 deaths and 13 people missing across 15 prefectures. However, the damage caused by sediment deposition associated with inundation cannot be ignored[1)]. In the case of embankment failure, lots of sediment would be transported by flood into living area, it would seriously influence people's daily life and cause economic loss. Some researchers have conducted relevant studies to investigate the sediment deposition under embankment failure assumption.[2),3),4)].

Farmland is very important because it has high economic value and is strongly related to people's living. On the other hand, it is also vulnerable to flood and sediment. Lots of studies have been conducted in order to accurately simulate the inundation and sedimentation. In this paper, the farmland is chosen as the research target. There are lots of irrigation or drainage channels distribute in paddy field which would play a very important role during flood disaster. Most of previous studies concentrate on the inundation and topography change over the ground surface[5), 6),7),8),9)], very limited research considers the effect of channel network.

The main objective of the research is to clarify the inundation and sedimentation effect over ground surface as well as in channel network. The model that has been applied to Kinu river flood disaster in September, 2015[10], is utilized to simulate an assumed flood in Mukaijima, Kyoto so that we can predict the influence of inundation and sedimentation and give appropriate countermeasures.

2. Numerical model

The two-dimensional model developed by Kawaike et al.[11] was employed to simulate the inundation and sediment deposition over the farmland, the governing equations of the model are as follow:

$$\frac{\partial h}{\partial t}+\frac{\partial (hu)}{\partial x}+\frac{\partial (hv)}{\partial y}=i-q_g \tag{1}$$

$$\frac{\partial (hu)}{\partial t}+\frac{\partial (hu^2)}{\partial x}+\frac{\partial (huv)}{\partial y}=-gh\frac{\partial H}{\partial x}-\frac{\tau_x}{\rho_m} \tag{2}$$

$$\frac{\partial (hv)}{\partial t}+\frac{\partial (huv)}{\partial x}+\frac{\partial (hv^2)}{\partial y}=-gh\frac{\partial H}{\partial y}-\frac{\tau_y}{\rho_m} \tag{3}$$

$$\frac{\partial (hC)}{\partial t}+\frac{\partial (hCu)}{\partial x}+\frac{\partial (hCv)}{\partial y}=-q_g C+iC_* \tag{4}$$

$$\frac{\partial z_b}{\partial t}+i=0 \tag{5}$$

Where h is the water depth; u is the water velocity of X direction; v is the water velocity of Y direction; C is the local sediment concentration; $C_*$is the sediment concentration on the bed; q_g is the interaction flow per unit area between ground surface and channel network; H is the water surface elevation; z_b is the elevation of the ground surface; τ_x and τ_y are the bed shear stress of different directions. ρ_m is the density of mixture of water and sediment; i refers to the erosion or deposition velocity[11], which is expressed as:
deposition velocity:

$$i=\delta\frac{C_\infty-C}{C_*}\sqrt{u^2+v^2} \tag{6}$$

erosion velocity:

$$i=\delta'\frac{C_\infty-C}{C_*-C_\infty}\sqrt{u^2+v^2} \tag{7}$$

in which C_∞ is the equilibrium concentration; δ and δ' are the coefficient of the deposition and erosion velocity, respectively. Here, they are set as 0.0001 and 0.0007 according to Kawaike et al. [11]

In paddy field, channel network plays an important role in drainage and irrigation, and it will also significantly affect the inundation and sedimentation result during flood disaster. Therefore, in this research, one-dimensional numerical model was utilized to simulate the channels, the governing equations of the model are as follow:

$$\frac{\partial h}{\partial t}+\frac{\partial (hu)}{\partial x}=i+\frac{q_c}{B} \tag{8}$$

$$\frac{\partial (hu)}{\partial t}+\frac{\partial (hu^2)}{\partial x}=-gh\frac{\partial H}{\partial x}-\frac{\tau}{\rho_m} \tag{9}$$

$$\frac{\partial (hC)}{\partial t}+\frac{\partial (hCu)}{\partial x}=\frac{-q_c C}{B}+iC_* \tag{10}$$

$$\frac{\partial z_b}{\partial t}+i=0 \tag{11}$$

Where q_c is the interaction discharge per unit length between channel and ground surface; B is the width of the channel.

3. Application to research area

(1) Topography process

The paddy field in Mukaijima, Kyoto near the Uji River was chosen as the target area in this paper. **Fig. 1** refers to the satellite image of target area. The figure shows that the area is covered by paddy field, but there are several roads and two highways cross the area and divided the area into three parts (area A, B and C as shown in figure 1). Through field investigation, we found that there are several passes under the highway deck, it would significantly influence the flood propagation. Therefore, we manually modify the 5m solution DEM data to make the topography consistent with actual scene. **Fig. 2** shows the DEM data after modification. The information of channel network is acquired from Geospatial Information Authority of Japan. In this study, the channel is simplified as link and node,

and each channel is divided into several reach with length no longer than 20 m. As the solution of the DEM data is 5m, which is not sufficient to reflect the elevation of channel bottom, in the model, we use the coordinate of each node and embed the channels into ground surface mesh, then the elevation of the mesh that each channel reach central point located in is used to reduce the channel depth to determine the channel bed elevation. **Fig. 3** shows the distribution of channel network.

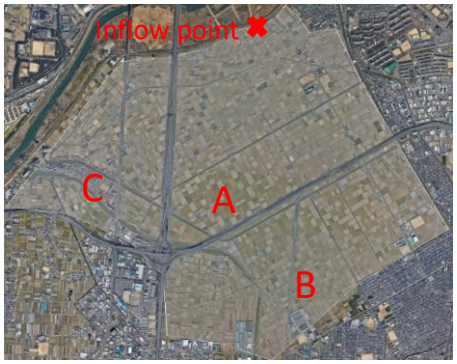


Fig. 1 The satellite image of research area

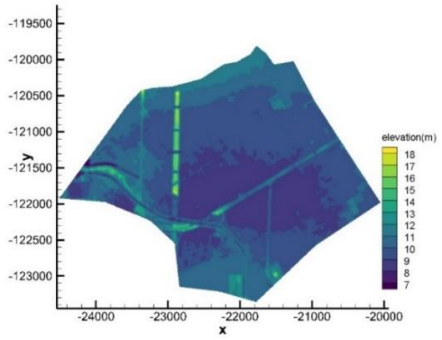


Fig. 2 The DEM data of research area

Fig.3 The distribution of channel network

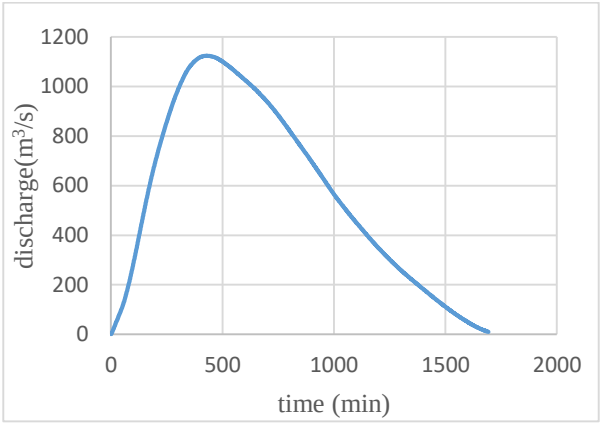


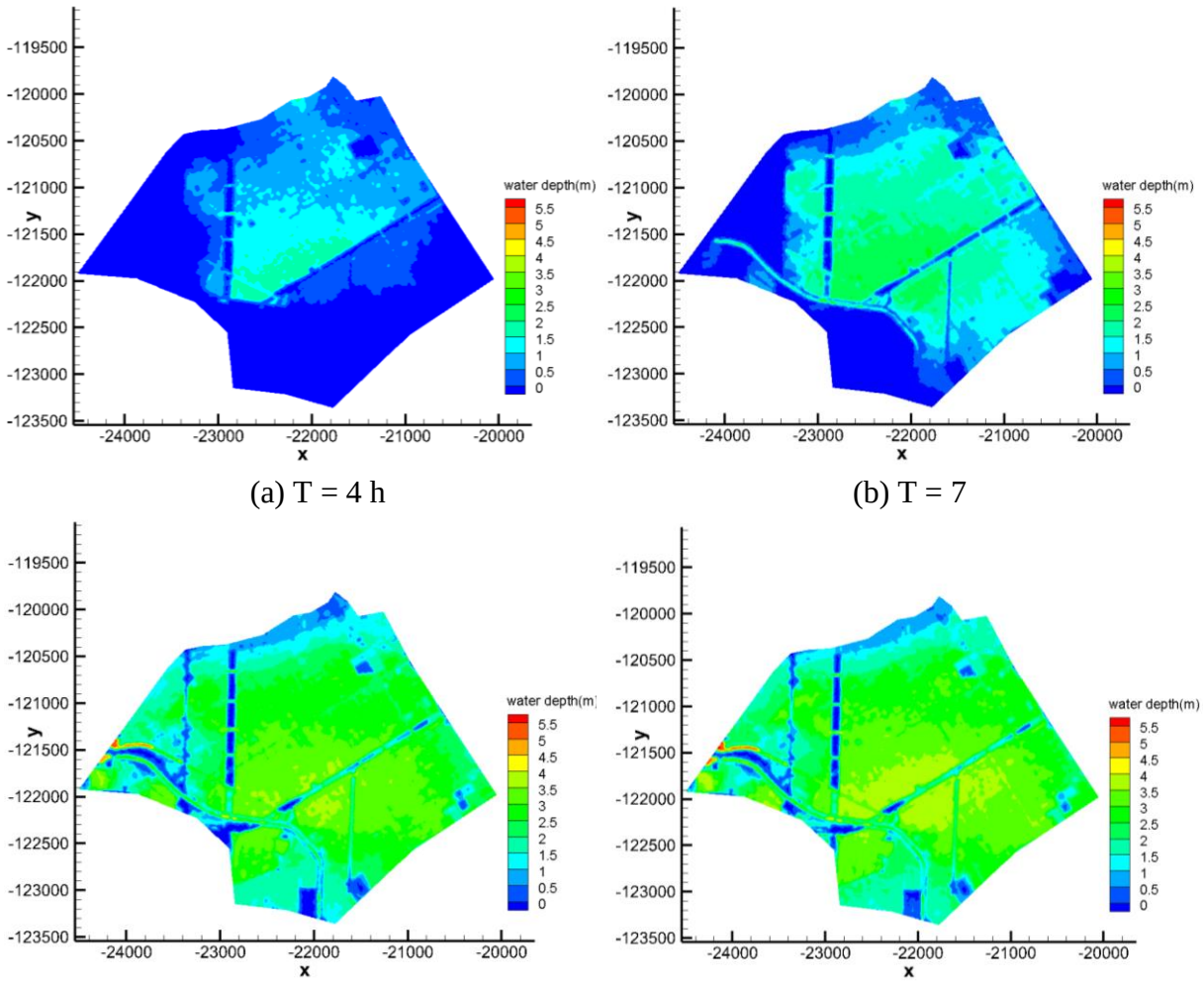
Fig. 4 The inflow discharge process

(2) Computational condition

The research area is divided into 62658 unstructured meshes with scale of 20 m. The roughness of the paddy field is set as 0.08 based on Kawaike's research[10]. As the main purpose of this study is to investigate the inundation and sedimentation over paddy field, the inflow process is given as the boundary condition to 5 meshes, the condition of other boundary meshes is set as wall. Also, we assumed that the water level of Uji river is very high, so the channels cannot drain water out. An embankment failure model was utilized to obtain the inflow discharge. **Fig. 4** shows the discharge process. The sediment volumetric concentration of is 0.05 and the diameter of sediment is 0.1mm. The duration of the simulation is 24 hours and the time step is 0.05 second.

4. Results and discussion

Fig. 5 shows the inundated process. The result shows that highways in the research area have significant influence to flood propagation. The inundated area is clearly divided into three parts by roads and embankment. As area A is directly faces the inflow point and surrounded by embankment, this area is firstly inundated and water level increased very fast. Besides, the elevation of this area is relatively lower, the water depth in this area is very high, the maximum depth is over 3.5 m. With the water level rises and exceed the elevation of the pass under the highways, the flood flow into B and C area.



(a) T = 4 h (b) T = 7

(c) T = 16 h (d) T = 24 h

Fig.5 The inundation results at different time

Fig. 6 refers to the final results of sediment deposition. (the 'de' in the figure refers to deposition thickness.) The figure shows that the deposition mainly happened near the inflow point and along the flow direction. In some place, the thickness of deposition is over 50 cm. It could be anticipated that the crop would be seriously affected, and the harvest may be also influenced in the next season if the deposition is not cleaned up. The figure shows that there is a clear deposition boundary between area A and B, it indicates that the "road embankment" has significant influence not only to inundation, but also to sedimentation.

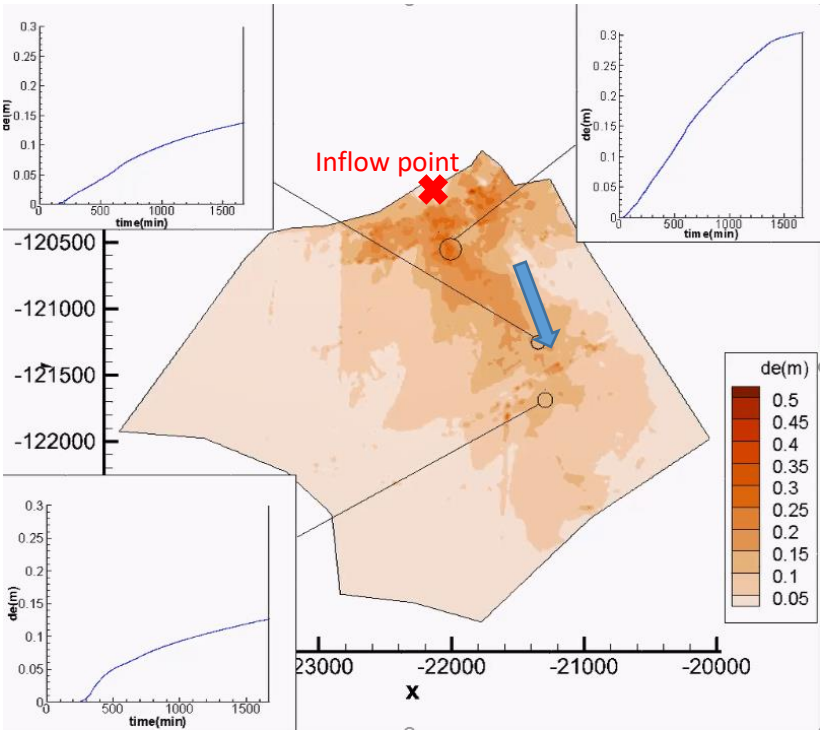


Fig. 6 The final deposition result on ground surface

Fig. 7 shows the final deposition results in the channel network. Similar to the inundation results, in area A, the deposition thickness in channels near the inflow point and along the flow direction is relatively higher, numerical data shows that the thickest deposition is higher than 50 cm; The results show that the drainage or irrigation capacity of channel network would be significantly decreased by the sedimentation during the flood, it also increased the difficulty in post-disaster recovery.

Fig. 7 The final deposition results in channels

5. Conclusion

A 2D coupled 1D numerical model was employed to simulate the inundation and sedimentation over the paddy field considering the effect of channel network. As the model has been applied and verified by the measured water level data, hence we didn't verify it in this research. The numerical results show that the highways in the research area play a role like embankment, which influence the flood propagation process and sediment deposition results. Sedimentation mainly happened near the inflow point and along the flow direction, in some area, the deposition thickness is over 50 cm, it would significantly influence the harvest of crops. The deposition along the channel network presents the similar mode with that on ground surface, in some channels near the inflow point, the thickest deposition is over 50 cm; The results would be helpful to predict the sedimentation and conduct more accurate disaster loss assessment.

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