FEMによるトンレサップ湖および周辺域の氾濫湛水シミュレーション
FEM Simulation for Inundation in and around Tonle Sap Lake and its Vicinities

○ファム　タイン　ハイ*　清水克之*　増　本　隆　夫*
○ Pham Thanh Hai, Shimizu Katsuyuki and Masumoto Takao

1. Introduction

During the rising part of the annual monsoon, the Mekong River forces part of its flow upstream in the Tonle-Sap River towards the Lake. At the same time, other part of the river flow reaching the confluence at Phnom Penh is diverted through the Bassac River and the remaining part of the flow runs further south in the Mekong. With continuing rise of the water level in the Mekong, the river starts to spill floodwater into the surrounding flood plains. By end of the monsoon, the water level in the Mekong starts to fall. At a certain level, the water level at Phnom Penh is lower than the level in the Tonle-Sap Lake. At this time the flow in the Tonle-Sap River is reversed and flow from the lake towards the delta will occur.

In order to examine unique characteristics mentioned above, therefore, a simulation model is developed to reproduce typical flows of the years 2000 and 2003 (as representatives of recent largest flood and drought years) in the river and flood plain systems by applying Finite Element Method with depth averaged 2D shallow water equations. The simulation covers the Mekong River from Kratie in Cambodia to TanChau in Vietnam, the Bassac River down to ChauDoc in Vietnam, the Tonle-Sap River and Tonle-Sap Lake.

2. Governing Equations

Continuity equation:

$$\frac{\partial H}{\partial t}+\frac{\partial (Hu)}{\partial x}+\frac{\partial (Hv)}{\partial y}=0 \qquad (1)$$

Horizontal Momentum equations:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}-\varepsilon\frac{\partial^2 u}{\partial x^2}-\varepsilon\frac{\partial^2 u}{\partial y^2}+g\frac{\partial (H+z)}{\partial x}+\frac{gu\left(u^2+v^2\right)^{1/2}}{HC^2}-\frac{K|W|W_x}{H}-fv=0 \qquad (2)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}-\varepsilon\frac{\partial^2 v}{\partial x^2}-\varepsilon\frac{\partial^2 v}{\partial y^2}+g\frac{\partial (H+z)}{\partial y}+\frac{gv\left(u^2+v^2\right)^{1/2}}{HC^2}-\frac{K|W|W_y}{H}+fu=0 \qquad (3)$$

where: H is water depth; t is the time; u and v are the depth averaged velocities in the x and y coordinate directions respectively; ε is eddy viscosity coefficient; g is gravitational acceleration; z is bed elevation; K is wind stress coefficient; W is wind velocity; C is the Chezy coefficient; f is Coriolis parameter.

3. Convert data from DEM & Finite element mesh generation

The Digital Elevation Model (DEM) data with 100m grid covers the Mekong flood-plain from Kratie to the center of the Mekong Delta in Vietnam. This DEM data is generated based on source of data of SOGREAH contours map and Philippine survey, that is, 1m interval contour-lines of elevation data-set. From DEM map, an ERDAS Imagine software is used to convert raster image data to ASCII data file, which

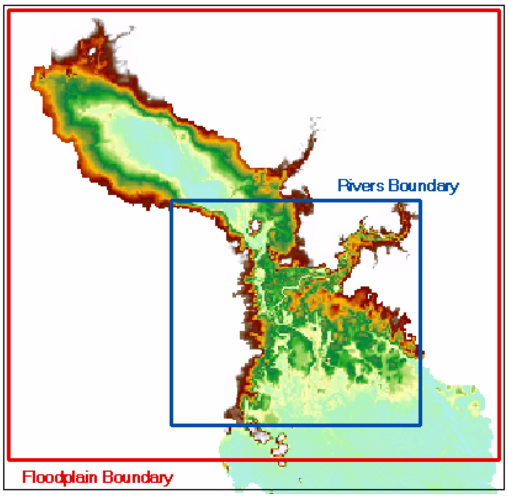

Fig.1 Selected area to data conversion.

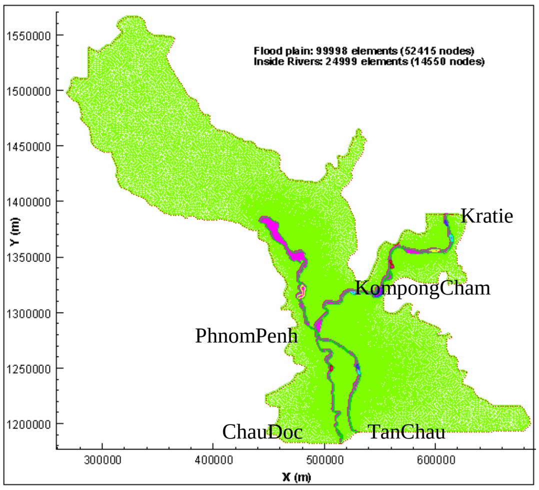

Fig.2 Generated meshes and elements in the study area.

---

*農業工学研究所 - National Institute for Rural Engineering

Keywords: FEM, Inundation, Tonle Sap Lake and its Vicinities, Moving boundary

contains the coordinates (x, y, z) of each pixel in tabular format. The limit of study area, which was selected to convert data, is from the upper part of the DEM map downwards to TanChau and ChauDoc water level gauges (Fig. 1). This converted data is used in mesh generation and bed elevations interpolation processes.

In the study, a Mesh-Generator software is used to generate unstructured triangular meshes, which are used in 2D-FEM simulation. To create flood-plain and river boundaries, we extracted outer points from converted data of flood-plain and river domains. These flood-plain and river boundaries are used as external and internal boundaries in mesh generation processes. Node distributions of the boundaries are modified at meandering parts of rivers so as to make a smoother mesh result. Considering the topography of the study area, scale of the study and mesh smoothing conditions, mesh size of flood-plains area is selected from 2,500m to 5,000m, and inside rivers domain is from 200m to 450m. Final results of mesh generation are showed in Figs.2 and 3, with 52,415 nodes and 99,998 elements in flood-plain area, and with 14,550 nodes and 24,999 elements inside rivers area.

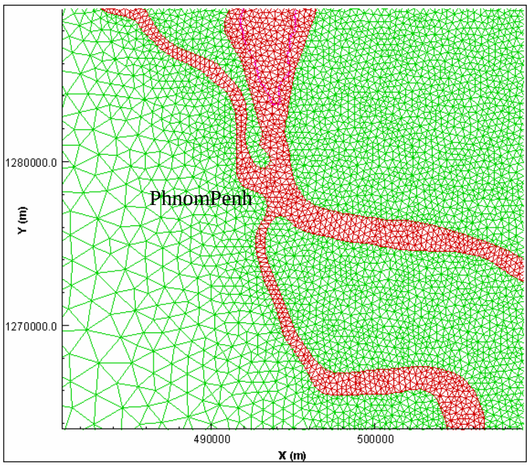

Fig.3 Generated mesh results at sites near Phnom Penh.

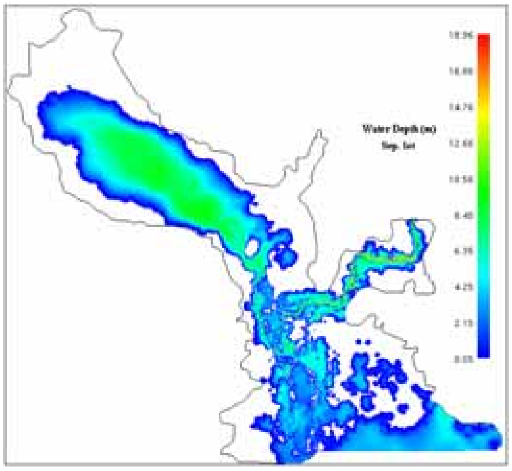

Fig.4 Simulated results of inundation on Sep. 1st, 2000.

4. Solution of Finite Element Method & Treatments of Boundary and Initial Conditions

The weighted-residual of the standard Galerkin FEM is applied to the 2D shallow water equations (1), (2), and (3) for spatial discretization, and the selective lumping two-step explicit FEM is employed for numerical integration in time, as proposed by Kawahara *et al.* (1986).

At land boundaries, the flow cannot flow through the boundaries, slip condition imposed along these boundaries and normal velocities of nodes belonging to land boundaries are imposed to zero. Measured water levels as a function of time at Kratie water gauge is specified for the inflow of upstream conditions, and at TanChau and ChauDoc water gauges as for outflow of downstream conditions. Initial values for all the flow variables u, v and H are necessary for starting simulation. The model is run with an assigned zero velocities $(u=0, v=0)$, and a linear slope water surface elevation which is based on observed water level data.

As for the moving boundaries, the method proposed by Leclerc *et al.* (1990) is adopted. Elements near the water edge may be dry or wet or partially wet. To treat this problems, a certain threshold depth dh=0.05m is used to discriminate these types of nodes: if total water depth $H<dh$, then node is considered as dry, and if $H \geq dh$, then node is considered as wet. An element is considered entirely dry if $H<dh$ at all three nodes, then such an element is not considered in the computation for the time step; a simulation imposes $u=v=0$ on each node. If $H<dh$ for some nodes, element is partially wet, then only the mass balance equation is used, momentum exchange is neglected (impose $u=v=0$ for the dry node). If water depth $H \geq dh$ at all three nodes, then an element is assumed to be wet, the normal finite element formulation is employed.

5. Results and Conclusions

One of the simulation results is described in Fig. 4 for the calculation of the 2000, a recent largest flood. Results showed that in case of large scale basin, which has complicated bed topography, the simulation needs a more flexible treatment for moving boundary problems. In the next steps, the simulation needs to consider following problems: refinement of inflows (including observed and calculated discharges) of tributaries as boundary conditions; flow difference between inside river and flood-plain areas, flow over from river to flood-plain domains and vice versa; flows at hydraulic works as bridges and weirs. Furthermore, in long-term simulation, it is necessary to consider the influences of rainfall, evaporation, infiltration on the simulation.

Reference:

1) Kawahara M *et al.* (1986). *Finite element method for moving boundary problems in river flow*. IJNMF, (6):365-386.
2) Leclerc M *et al.* (1990). *A finite element model of estuarian and river flows*. Advances in Water Resources, (4):158-168.