

Three-dimensional numerical simulation of storm surge disaster

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Abstract. The numerical simulation of storm surge flood routing is of great importance to the storm surge disaster management. Few studies devoted to the three-dimensional numerical stimulation of storm surge flood. At present, the three-dimensional $k-\varepsilon$ turbulence mathematical model coupled with the VOF method was adopted to achieve this target. A simulation on a storm surge flood in a certain coastal area was performed, and the hydrology information was analyzed, which can provide a scientific basis for the storm surge disaster management.

Introduction

Storm surge disaster brings great threaten to the society, economy and safety of people in the coastal areas yearly. Therefore, conducting the research of the numerical simulation of storm surge flood routing has been concerned by the storm surge disaster managers.

The numerical stimulation method has been adopted by many researchers to study the storm surge flood routing in the coastal areas at present.¹⁻⁵ However, the study of storm surge disaster mainly focuses on the two-dimensional numerical simulation which simplifies the actual three-dimensional flow and cannot reflect the vertical movement of the flow veritably.

The three-dimensional $k-\varepsilon$ turbulence mathematical model coupled with the volume of fluid (VOF) method was adopted in this paper to conduct the simulation of storm surge disaster. A simulation on a storm surge flood in a certain coastal area was performed, and the hydrology information, including the flood routing process, the flow rate and the water depth, was analyzed which can be useful to the consequence analysis, the flood control decision and the disaster response of the storm surge disaster.

Three-dimensional $k-\varepsilon$ turbulence mathematical model

The three-dimensional $k-\varepsilon$ turbulence mathematical model coupled with the VOF method, which can describe the free surface flow well and has been validated,⁶ was adopted to conduct the numerical simulation of storm surge flood routing. The governing equations of the model, including the continuity equation, the momentum equation, the turbulent kinetic energy equation and the turbulence dissipation rate equation, are shown as follows, respectively:

$$\frac{\partial r}{\partial t} + \frac{\partial(ru_i)}{\partial x_i} = 0. \quad (1)$$

$$\frac{\partial(ru_i)}{\partial t} + \frac{\partial}{\partial x_i}(ru_iu_j) = -\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j} \left[(m + m_i) \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \right]. \quad (2)$$

$$\frac{\partial}{\partial t}(rk) + \frac{\partial}{\partial x_j}(ru_jk) = \frac{\partial}{\partial x_i} \left[(m + \frac{m_i}{s_k}) \frac{\partial k}{\partial x_j} \right] + G - re. \quad (3)$$

$$\frac{\partial}{\partial t}(re) + \frac{\partial}{\partial x_j}(ru_j e) = \frac{\partial}{\partial x_i} \left[\left(m + \frac{m_t}{s_e} \right) \frac{\partial e}{\partial x_i} \right] + \frac{C_{1e} e}{k} G - C_{2e} r \frac{e^2}{k}. \quad (4)$$

Where ρ is density of fluid, kg/m^3 ; x_i is Cartesian coordinate, m; u_i is absolute fluid velocity component, m/s; μ_j is absolute fluid velocity component, $\text{N}\cdot\text{s/m}^2$; P is piezometric pressure, Pa; μ is molecular dynamic viscosity, $\text{N}\cdot\text{s/m}^2$; μ_t is turbulent viscosity, $\text{N}\cdot\text{s/m}^2$; k is turbulence kinetic energy, m^2/s^2 ; ε is dissipate of turbulence kinetic energy, m^2/s^2 ; G is turbulent energy ratio; σ_k , σ_ε , C_{1e} , C_{2e} are constants.

Case study and results

A storm surge flood of 50 year frequency in a certain coastal area was chosen as the object of study. The study area can be determined based on factors of terrain, water-retaining structures, rivers and so on, which is shown in Figure 1.



Fig. 1. The sketch map of the study area.

Dynamic distribution of the volume of fluid in the study area, which can describe the whole flood routing process, is shown in Figure 2. At the end of the flood routing, affected by the terrain, several dead water regions can be found.

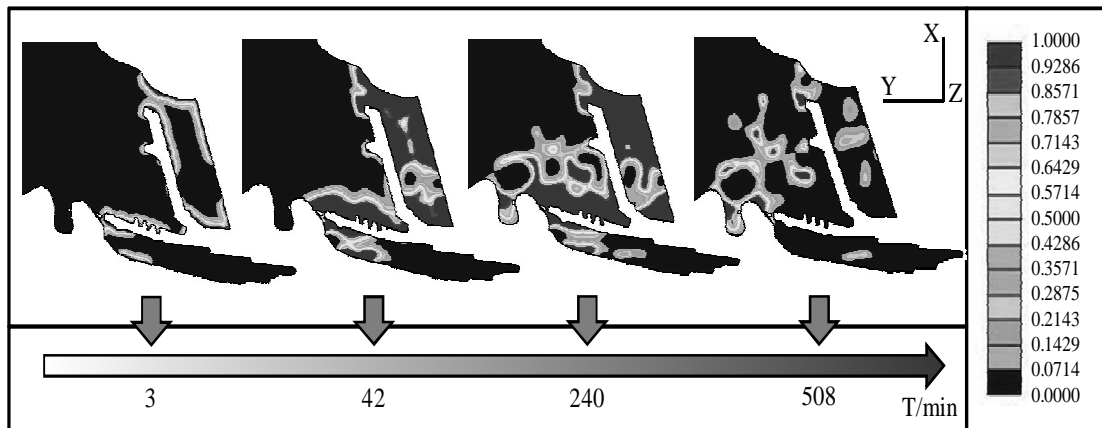


Fig. 2. Dynamic distribution of the volume of fluid (VOF) in the study area (dimensionless).

The velocity distribution at 240min is shown in Figure 3. Because of the resistance of upland and seawall, the phenomena, such as the swirling flow and the backflow, appeared in these areas.

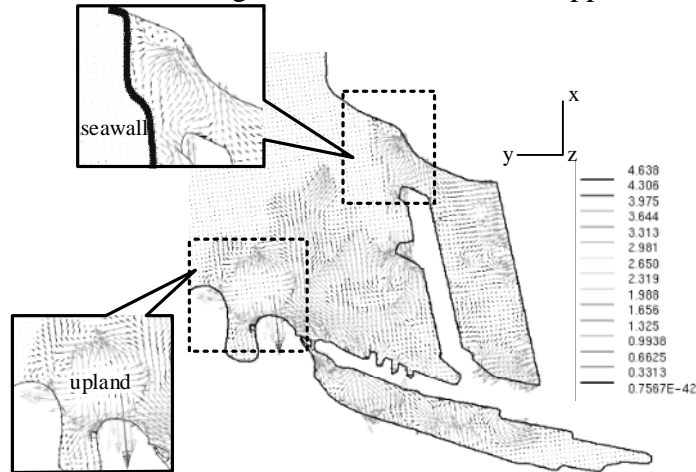


Fig. 3. The velocity analysis at 240min.

Four typical sites were selected here to analyze the water depths, shown in Figure 4(a). Affected by the locations and terrain, the water depth curves present different trends, shown in Figure 4(b). And the typical site 3 and typical site 4 existed the stagnant water, which was in accordance with the VOF analysis.

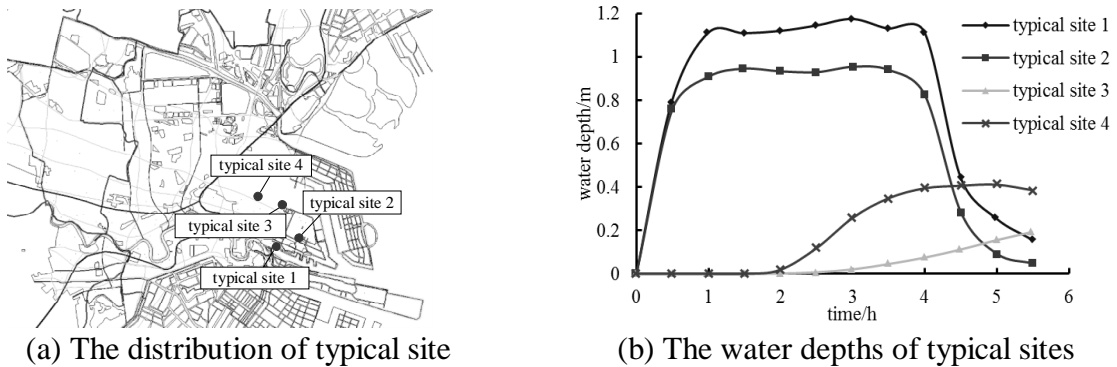


Fig. 4. The water depths analysis of typical sites.

Conclusion

According to the research status that the analysis of storm surge disaster mainly focuses on the two-dimensional numerical simulation, the three-dimensional k- ϵ turbulence mathematical model coupled with the VOF method was adopted in this paper. A storm surge flood in a certain coastal area was simulated, and the hydrology which includes the flood routing process, the flow rate and the water depth, information was analyzed.

The results show that the three-dimensional numerical simulation can describe the whole flood routing process well, and find the phenomena, such as stagnant water, the swirling flow and the backflow, which can provide a scientific basis for the storm surge disaster management.

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