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Drifting motion of vehicles in tsunami inundation flow

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Abstract

In order to investigate the stability limit and movement of motor vehicles in tsunami flooding, and the drift and collision behavior to the tsunami evacuation tower, both physical and numerical model experiments have been carried out. For the numerical study, Ladd's Lattice Boltzmann Method (LBM) model for particle suspension, which has been extended with free surface and SGS turbulence model, is further modified to satisfy the simulations of motor vehicles with irregular shape. The interactions between fluid and vehicle body, and vehicle and vehicle are numerically simulated by the exchange of momentum, due to the application of link-bounce-back scheme for the movable solid particles in the fluid. The present numerical model is verified through the physical experiments using up to 80 car models.

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Keywords: Lattice Boltzmann Method; drift behavior; vehicles; tsunami evacuation tower

1. Introduction

During tsunami inundation, secondary damages are caused by collision of moving and drifting large debris such as motor vehicle, boat and container. The collision of large drift in the inundation flow is hazardous for people and buildings, but there is little knowledge about the stability limits and control methods of even typical object, motor vehicle. It is thus necessary to investigate the stability limit and movement of motor vehicles in tsunami flooding and the collision behavior to buildings, especially to the facility used to protect the safety of life, i.e., tsunami

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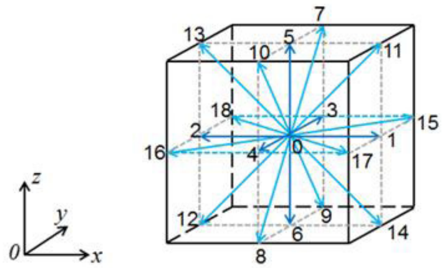

Fig. 1. Schematic diagram of D3Q19 LBM model.

evacuation tower. For this purpose, a numerical model based on 3D Lattice Boltzmann Method is developed for simulating the behavior of drifting vehicles due to tsunami inundation flow. To validate the 3D LBM model simulations, physical model experiments using a 1:60 scale model of 1 up to 80 vehicles are carried out to investigate the stability limit due to dam-break flows and the drift and colliding behavior against bridge type of tsunami tower (with a large distance between pillars).

2. Numerical model based on LBM

2.1. Lattice Boltzmann equation

D3Q19 lattice model shown in Fig. 1 is applied, as it is necessary to determine the macroscopic variables of momentum flux as well as density, velocity from the particle Distribution Function (DF). The velocity vectors $\mathbf{e}_i$ (i=0, 1, ..., 18) of each single lattice are given as 0 (i=0), e (i=1, 2, 3, 4, 5, 6), $\sqrt{2}e$ (i=7, 8, …, 18), where $e = \Delta x / \Delta t$ (Δx and Δt are lattice interval in space and time, respectively).

The basic LBM algorithm consists of two steps; the streaming step and the collision step. Before streaming, the fraction of virtual particles moving with a certain velocity of an independent lattice is represented by the DF $f_i(\mathbf{x}, t)$. During the streaming step, all DFs are advected to the adjacent fluid lattice with the corresponding velocity direction. During the collision step, the virtual particles are redistributed with a percentage of Δ_i to a local equilibrium state. All the DFs after collision step can be obtained by the Lattice Boltzmann Equation,

$$f_i(\mathbf{x} + \mathbf{e}_i \Delta t, t + \Delta t) = f_i(\mathbf{x}, t) + \Delta_i(\mathbf{x}, t) \tag{1}$$

The virtual particle's DF, $f_i(\mathbf{x}, t)$ shows the number of particles with a velocity vector of i direction in the lattice of $\mathbf{x}$ position at t time. With the particle distribution function, the density, velocity, momentum flux and local equilibrium DF of the fluid field can be expressed respectively with weighted coefficient of a^{e_i} in the following form:

$$\rho = \sum_i f_i, \quad \rho\mathbf{u} = \mathbf{j} = \sum_i f_i \mathbf{e}_i, \quad \mathbf{\Pi} = \sum_i f_i \mathbf{e}_i \mathbf{e}_i \tag{2}$$

$$f_i^{eq} = a^{e_i}\left[\rho + \frac{\mathbf{j}\cdot\mathbf{e}_i}{c_s^2} + \frac{\rho\mathbf{uu} : \left(\mathbf{e}_i\mathbf{e}_i - c_s^2\mathbf{1}\right)}{2c_s^4}\right]$$
$$a^0 = \frac{1}{3}, \quad a^1 = \frac{1}{18}, \quad a^{\sqrt{2}} = \frac{1}{36} \tag{3}$$

The particle distribution function for the next step, namely the post-collision DF, $f_i^* = f_i + \Delta_i$, can be calculated as