Engineering Geology 212 (2016) 1–9

Contents lists available at ScienceDirect

Engineering Geology

journal homepage: www.elsevier.com/locate/enggeo

Application of the material point method to simulate the post-failure runout processes of the Wangjiayan landslide

Xinpo Li [a,b,*], Yong Wu [a,b], Siming He [a,b,c], Lijun Su [a,b,c]

[a] Key laboratory of Mountain Hazards and Earth Surface Processes, CAS, Chengdu 610041, China
[b] Institute of Mountain Hazards and Environment, CAS, Chengdu 610041, China
[c] CAS Center for Excellence in Tibetan Plateau Earth Sciences, China

ARTICLE INFO

Article history:
Received 25 March 2016
Received in revised form 29 July 2016
Accepted 30 July 2016
Available online 2 August 2016

Keywords:
Material point method
Run-out analysis
Landslide deposition
Kinematics
Effects of buildings

ABSTRACT

The first part of the paper presents a brief description of the material point method (MPM) including the governing equations, solution scheme and a benchmark problem of soil collapse simulated using the method. In the second and third part of the paper, the post-failure runout process of the Wangjiayan landslide is simulated and analyzed. The landslide's final topography and information from post-failure in-situ survey and laboratory tests are used to constrain the accuracy of computational results. The kinematic behaviors of the failure mass are investigated in terms of displacement, velocity, effective plastic strain fields and topography changes during the movement. Comparisons are made between conditions with and without buildings on the deposition area. Numerical computations demonstrate that the presence of buildings on the sliding path strongly governs the flow regime, run-out distance, velocity, strain field and final deposition topography of the landslide. So it is very essential to incorporate the effects of buildings in the modelling and analyses. Numerical results considering buildings show that the slide lasts about 30 s with the most rapid phase occurring between 6 and 12 s, and that the maximum simulated velocity among the sliding particles in the landslide is 43.5 m/s, indicates that the moving of the landslide mass was very fast. The run-out distance simulated with MPM matches the measured post-earthquake topography well, whereas the shape of the simulated deposition zone is a little differs. The buildings influence the sliding by shortening the overall run-out distance, decelerating the movement of the bottom layer, and increasing the internal deformation and mixing among deposition layers.

© 2016 Elsevier B.V. All rights reserved.

1. Introduction

On 12 May 2008, the Mw7.9 (USGS, 2008) Wenchuan earthquake occurred as a result of rupture on the series of predominantly north–northeast striking thrust faults that lie in the Longmenshan region at the eastern margin of the Tibetan Plateau, adjacent to the Sichuan Basin. Numerous large scale landslides were triggered in the steep topographic escarpment in Longmenshan mountains area (Wang et al., 2009; Yin et al., 2009). In the post-failure runout process, large scale landslides can transfer to an extremely rapid, massive, flow-like motion of fragmented rock. The runout process of this type of landslide exhibits great mobility and can cause extensive damage to human lives and engineering structures in its path.

Physical experiments and numerical simulation are two ways in studying of the runout process of large scale landslides. Generally, the size of a lab-scale model is too much smaller than the real landslide and the centrifuge model test is too expensive both on money and time. These limits of physical experiment can be perfectly avoided by numerical methods. Among the landslide post-failure studies, most of the numerical methods used in literatures can be classified into two categories: the discrete model and the continuum model. Tang et al. (2009) studied the post-failure kinematic behavior of the Tsaoling landslide triggered by the Chi-Chi earthquake using the distinct element method (DEM), and the same method was also used in the post failure analysis of Hsiaolin landslide by Lo et al. (2011), Donghekou landslide by Yuan et al. (2014) and Zhou et al. (2013). The discontinuous deformation analysis (DDA) method was used by Wu and Chen (2011) and Zhang et al. (2015) to study the Tsaoling landslide and Donghekou landslide. In the past few decades, continuum models such as the smoothed particle hydrodynamics (SPH), the material point method (MPM), and the computational fluid dynamics (CFD) methods based on shallow water equations have gained significant progress. The Savage–Hutter model has been used more frequently to simulate the motion process of landslide or rock avalanches because of it can reveal the character of landslide well (Savage and Hutter, 1989; Iverson and Denlinger, 2001; Hungr, 1995). Recently, post-failure analysis of slopes or landslides was conducted using SPH by Bui et al. (2011), Huang et al. (2012) and Dai et al. (2014). Based on shallow water equations and depth-

* Corresponding author.
E-mail address: lixinpo@imde.ac.cn (X. Li).

http://dx.doi.org/10.1016/j.enggeo.2016.07.014
0013-7952/© 2016 Elsevier B.V. All rights reserved.

averaged integration as the Savage–Hutter model, landslide dynamic models were developed to simulate problems such as pore pressure and frictional heating evolution (He et al., 2015) and landslide mobility over erodible beds (Ouyang et al., 2015; Liu and He, 2015).

Originating from the particle-in-cell method in computational fluid dynamics, the Material Point Method (MPM) was firstly developed to simulate problems such as impact/contact, penetration and perforation with history dependent internal state variables (Sulsky et al., 1994, 1995) and later applied to granular flows (Bardenhagen et al., 2000; Cummins and Brackbill, 2002; Bhandari et al., 2016). It recently found entrance into a broader field of geotechnical engineering including slope failure analysis (Andersen and Andersen, 2010; Sołowski and Sloan, 2015), soil-structure interaction (Coetzee et al., 2005; Ma et al., 2014; Mast et al., 2015) and saturated/unsaturated soil deformation (Bandara and Soga, 2015; Yerro et al., 2015; Bandara et al., 2016). The basic idea of the material point method is to discretize a continuum into a collection of particles, or material points, each of which carries all state data for the small region of material that it represents. A separate computational grid/mesh which carries no permanent information is employed for solving the governing equations. This mesh is chosen arbitrarily for computational convenience and can change in each time step, but more often, the same fixed regular grid is used in all time steps. The standard implementation of the MPM is done by mapping the particles' state variables forward to the computational mesh and backward after the time-advanced nodal velocities are obtained. Since this grid carries no permanent material information, the grid could be reconstructed each time step after deformation for convenience in the computation. And therefore, the distortion and entanglement of mesh that often occur in large deformation simulation using FEM are avoided in MPM. Another attracting feature of the MPM is that no special treatment of the contact conditions is required. The material point velocity is determined using the computational mesh which automatically ensures no inter-penetration between the contacting bodies. Therefore MPM is well suited to model problems such as landslide movement in which large deformations occur.

As one of the most catastrophic landslide disasters triggered by the 2008 Wenchuan earthquake, the Wangjiayan landslide killed 1600 people and destroyed hundreds of houses. The landslide were previously studied by Yin et al. (2015) using the finite discrete element code, FLAC3D. Their dynamic analysis provided time history of acceleration and factor of safety of the landslide. However the mesh-based method is generally limited to analysis of relatively small displacements due to mesh distortion; therefore, their works mainly focus on stability analysis. Huang et al. (2012) and Dai et al. (2014) conducted run-out analyses of flow-like landslides triggered by the 2008 Wenchuan earthquake using SPH method and the Wangjiayan landslide was used as one of their illustrative examples. Though the motions of the landslides and some movement characteristics of the avalanching mass had been represented, no information of internal velocity, stress/strain profiles were presented. Furthermore, the effects of buildings on the runout of the landslide were ignored. In this study, the MPM is applied to simulate the landslide as a material point assembly. MPM combines the advantages of Eulerian (fixed finite-element grid) and Lagrangian (moving material points) approaches of the media. These features make MPM very useful to solve problems involving large deformations and stress/strain analysis. The aim of the paper is to analyze the post-failure runout processes of the Wangjiayan landslide considering the effects of buildings and to further validate the accuracy and feasibility of the material point method for post-failure simulation of large-scale landslides, and show the potential of the procedure for future applications in landslide simulation. The final topography and the information from post-failure in-situ survey and laboratory tests are used to constrain the accuracy of computational results. The MPM software used in this study are modified from the open source version from the Computational Dynamics Laboratory, School of Aerospace, Tsinghua University.

2. Description of the MPM

2.1. Governing equations

In a material domain Ω, the basic equations of continuum mechanics are the mass conservation

$$\frac{d\rho}{dt} + \rho \nabla \cdot \boldsymbol{v} = 0 \tag{1}$$

and the momentum conservation

$$\rho \frac{d\boldsymbol{v}}{dt} = \nabla \cdot \boldsymbol{\sigma} + \rho \boldsymbol{b} \tag{2}$$

where ρ is the current density, $\boldsymbol{v} = \boldsymbol{v}(\boldsymbol{x}, t)$ is the material velocity, $\boldsymbol{\sigma}$ is the Cauchy stress tensor, and $\mathbf{b}$ is the specific body force. Taking an arbitrary test function $\mathbf{w}$ and integrated over the domain Ω with boundary $\partial\Omega$, the standard finite element weak form of Eq. (2) can be obtained as

$$\int_\Omega \boldsymbol{w}\rho \frac{\mathrm{d}\boldsymbol{v}}{\mathrm{d}t} \mathrm{d}\Omega = -\int_\Omega \nabla(\boldsymbol{w})\boldsymbol{\sigma} \mathrm{d}\Omega + \int_\Omega \boldsymbol{w}\rho\boldsymbol{b}\mathrm{d}\Omega + \int_{\partial\Omega} \boldsymbol{w}\boldsymbol{\tau}\mathrm{d}S \tag{3}$$

where $\boldsymbol{\tau}$ is the vector of surface traction. This weak form will be solved by the MPM solution schemes described in the following section.

2.2. Solution scheme of MPM

As shown in Fig. 1, the material domain Ω is discretized by a finite set of material points (which will be also called particles in the paper), and a background computational grid that covers the computational domain of interest is also set up. Let x_{ip}, m_p and v_{ip} denote the coordinate, lumped mass and velocity at particle p. Thus, these material points provide a Lagrangian description of the continuum body. Since each material point contains a fixed amount of mass for all time, mass conservation as defined by Eq. (1) is satisfied implicitly in MPM. In contrast with most other particle methods in which the momentum equations are solved on the particles, the momentum equations are solved on the predefined background grid in the MPM. In the first phase of the solution scheme of MPM, the mass and momentum information from the material points is mapped to the background grid nodes using equations of the form

$$m_I = \sum_p N_{Ip} m_p \tag{4}$$

$$p_{iI} = \sum_p m_p v_{ip} N_{Ip} \tag{5}$$

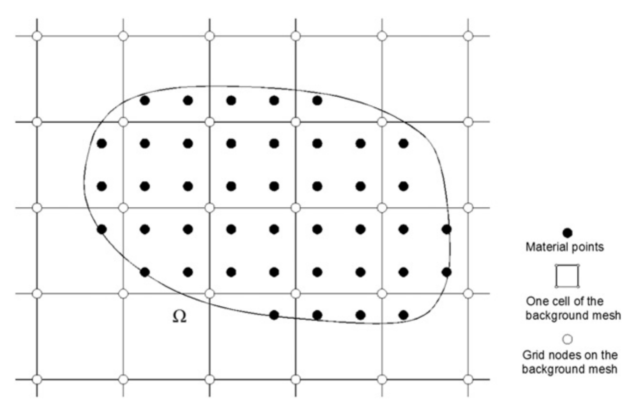

Fig. 1. Material discretization in MPM.

Download English Version:

https://daneshyari.com/en/article/4743065

Download Persian Version:

https://daneshyari.com/article/4743065

Daneshyari.com