Numerical simulation of earthquake-induced landslide run-out

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ABSTRACT

Landslides trigged by earthquake have leaded to tremendous deaths, injuries and property loss. Therefore, it is an urgent need to make out the flow characteristics, which is fundamental for hazard assessment and risk evaluation. However, the traditional mesh method, which is based on a framework of solid mechanics, has difficulty in simulating the run-out process of landslides considering its deficiency in modelling large deformations. In this paper, the moving particle simulation (MPS) is introduced to simulate landslide run-out. To bypass the pressure fluctuation of the original MPS, this method is modified in three aspects including the kernel function, source term of the Poisson equation and the free surface discrimination. The effectiveness of the pressure stability of the modified MPS is verified and validated by two classical benchmark problems: the dam break problem and the static problem. To preferably describe the dynamic feature of landslide, the Bingham constitutive model with the Mohr-Coulomb yield criterion is introduced into the modified MPS and an equivalent Newtonian viscosity is adapted to bridge the gap between Bingham flow model and Newtonian flow model. Finally, the proposed method is applied to analyze the landslide run-out of the Tangjiashan landslide which is induced by the Ms 8.0 Wenchuan earthquake. The simulated results are compared with the field data to evaluate the effectiveness and the accuracy of the proposed numerical scheme. All calculated results show good agreement with the field data, which indicates that the proposed method is capable to capture the fluidization characteristic of landslide and to reproduce the whole flow process of earthquake-induced landslide. This will ultimately help people assess the hazard to reduce or even avoid this disaster in earthquake-prone zones.

Keywords: landslide, moving particle simulation, Wenchuan earthquake, pressure fluctuation

1 INTRODUCTION

Tangjiashan landslide, located on the right bank of Tongkou River, about 6 km from upstream of the Beichuan County, whose volume was about $2.04 \times 10^7$ m$^3$ (Xu et al. 2009). It presented typical rheological characteristics including high speed, long run-out and flow-like behaviour (Huang et al. 2012), which lead to great challenge to analyse its flow process.

Numerical method is becoming more and more popular in geohazards analysis. With the development of computer, many sophisticated numerical methods appear. Among them, mesh based methods governed by solid mechanism such as FEM, FDM, FVM and so on have got some promising results. However, these traditional mesh methods focus on the analysis of factor of safety and instability condition. The flow process of landslide, such as Tangjiashan landslide, is rarely reported in previous articles using mesh method. Mesh method has difficulty in modelling rheological phenomenon with considerable deformation due to the excessive distortion of mesh when the advection term is calculated.

In this paper, a particle method, moving particle simulation (MPS), is adopted to simulate the flow behaviour of Tangjiashan landslide. MPS is first proposed by Koshizuka and Oka (1996) to model the fragmentation of incompressible fluid. MPS is based on computational fluid dynamic and is a fully incompressible method. The pressure is calculated implicitly. MPS has been successfully applied in various fields.

Considering the pressure fluctuation in original MPS, Huang and Zhu (2015) revised the code including kernel function, Poisson equation and free surface judgement to proposed modified MPS. The improvement was verified by using two classical problems: dam break problem and static pressure problem. To describe the behaviour of geomaterials, Huang and Zhu (2014) introduced Bingham model combined with Mohr-Coulomb critical equation into the modified MPS code. The proposed numerical scheme has been successfully applied to the simulation of various types of geohazards.
of flow slide of municipal solid waste. In this work, the modified MPS is adopted to simulate the flow process of Tangjiashan landslide.

Fig. 1. Pre- and post-earthquake topography of Tangjiashan landslide. (based on Hu et al. 2009)

2 MODIFIED MPS METHOD

2.1 Governing equation

The continuity equation,

$$\frac{DP}{Dt} = 0$$  \hspace{1cm} (1)

The Navier-Stokes equation,

$$\frac{D\mathbf{u}}{Dt} = -\frac{1}{\rho} \nabla P + \mathbf{F}$$  \hspace{1cm} (2)

in which $\nabla$ is the gradient model, $\mathbf{F}$ is the external force such as viscous force and gravity.

2.2 calculation function

The interaction between particles is controlled by kernel function. The original kernel function has a singularity at $r=0$, which will lead to pressure oscillation. The kernel function, which is proposed by Jung et al. (2008), is used in the modified MPS. This kernel function can overcome the shortcoming of the original one. The original Poisson equation can reduce particle density error accumulation, but it causes serious pressure fluctuation. In modified MPS, we adopted a modified source term including one main part and two error compensating parts (Kondo and Koshizuka 2011). The Bingham model is employed to describe the rheological behaviour of Tangjiashan landslide (Huang et al. 2012). The equivalent viscosity (Moriguchi et al. 2005) is introduced and the yield value is replaced by the Mohr-Coulomb equation. The approximated equation of Bingham model (Papanastasiou 1987) is adopted in this work. More detail information about the modified MPS can be found in our previous work (Huang and Zhu 2014).
2.3 Calculation process
The calculation process is divided into two steps (Koshizuka and Oka 1996). First, temporary velocity is determined explicitly considering the external force without the pressure term. The temporary position of particles is computed according to temporary velocity. Second, the pressure is got implicitly by solving Poisson equation. The temporary position of particles is revised considering pressure term.

2.4 Boundary condition
The boundary consists of P-wall particles and dummy particles. The pressure of P-wall particle is calculated to repeal the fluid particle, while the dummy particles are only used to compute particle number density.

The free surface is determined by the condition of particle number density due to lack of particle out of the free surface.

3 SIMULATION OF TANGJIASHAN LANDSLIDE
The Tangjiashan landslide is represented by 1065 particles including 565 fluid particles and 500 boundary particles. The simulation model and the post-earthquake configuration are shown in Fig. 1. And the parameters used in this simulation are listed in table 1 (Huang et al. 2012). The simulated flow process is presented in Fig. 2. At 5s, the soil mass reaches the bottom of the valley and then rush to the opposite of the bank around 10s. The soil mass is nearly silent with a few particle moving in the slop at 15s. The whole soil particles fall into the valley at about 20s. The calculated configuration is compared with the field data in Fig. 3. From the comparison, we noted that the simulation topography agrees well with the field data, which indicated that the modified MPS is capable to capture the dynamic characteristics of flow-like landslide.

Fig. 2. Flow process of Tangjiashan landslide at different time.

Fig. 3. Comparison between simulated configuration and field data of Tangjiashan landslide.

The simulation can present more dynamic information including velocity and impact force besides the configuration of landslide. According to the simulation, the hazard assessment of the landslide can be realized, which will help the official make decision and prevent similar disasters happen.

Further calibration and validation is needed for the simulation of the flow-like landslide. Moreover, the real landslide is three dimensions. Therefore, it is significant to conduct 3D modelling using modified MPS. However, the authors firmly believe that the present simulation is sufficient to provide preliminary
understanding of the flow-like landslide and can provide suggestion for the choosing suitable location of reconstruction in the future.

Table 1. The parameters used in the simulation of Tangjiashan landslide (Huang et al. 2012).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density ( \rho ) (kg/m(^3))</td>
<td>2000</td>
</tr>
<tr>
<td>Cohension ( c ) (kPa)</td>
<td>30</td>
</tr>
<tr>
<td>Angle of internal friction ( \phi ) (°)</td>
<td>30</td>
</tr>
<tr>
<td>Acceleration of gravity ( g ) (m/s(^2))</td>
<td>9.8</td>
</tr>
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</table>

4 CONCLUSIONS

Wenchuan earthquake has caused enormous destruction and numbers of casualties. Moreover, Wenchuan earthquake has resulted in thousands of landslides. Among them, Tangjiashan landslide is the largest one. In this paper, we used a particle method, MPS, to simulate the rheological characteristics of Tangjiashan landslide. The original MPS is revised to improve the pressure stability and the Bingham model combined with the Mohr-Coulomb equation is introduced to the modified MPS. The proposed numerical scheme is applied to simulate the flow process of Tangjiashan landslide. From the comparison, it is founded that the modified MPS method can capture the rheological behaviour of landslide, which will finally provide preliminary suggestions for hazard assessments and risk prevention.

REFERENCES