

The soil runout analysis of slope using material point method

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Introduction

The prediction of landslide has always been an important topic in the field of geotechnical engineering. Traditional numerical methods such as the FEM (Baecher and Ingra, 1981) was usually used to simulate the complex slope behavior in the pre-failure and failure stages under an assumption of small deformations, which is unsuitable for simulating the post-failure stage since mesh distortion will be encountered when the large soil deformation occurs during the slope failure. Nevertheless, the slope post-failure behavior analysis is quite crucial to the assessments of influence zone and runout distance. Material point method (MPM), however, can make up for the deficiency of the traditional methods in calculating large deformations (Sulsky et al., 1994).

The MPM method

The MPM is a method combining Lagrangian phase and Eulerian phase, where the material is represented as Lagrangian particles and the equations of motion are solved on a Eulerian grid (Zhang et al., 2016). An MPM computational cycle consists of four steps as illustrated in Fig. 1, (i) particle maps to grid, (ii) grid momentum update, (iii) grid maps to particle, (iv) grid is reset.

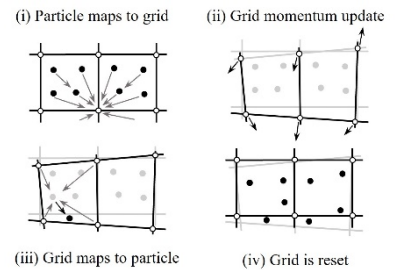


Fig. 1 An MPM computational cycle

Numerical analysis

This section investigates the implementation of the MPM in slope failure analysis. A slope as shown in Fig. 2 is selected as the research model, and the failure process under gravity is simulated. The material parameters are listed in the Table 1. To investigate the effects of strength parameters on the runout characteristics, only the change of strength parameters have been applied in the simulation, where cohesion  $c = 1, 5$  and  $10$  kPa and internal friction angle  $\phi = 15, 20$  and  $25^\circ$ . In this study, 7.5 seconds have been simulated, because the movement have almost stopped at this time.

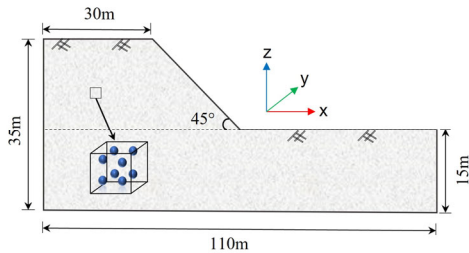


Fig. 2 A slope model

Table 1 Material parameters

Parameters	Value
Young's modulus, $E$ (MPa)	70
Poisson's ratio, $\nu$	0.3
Density, $\rho$ ( $g/cm^3$ )	2.1
Cohesion, $c$ (kPa)	1, 5 and 10
Internal friction angle, $\phi$ ( $^\circ$ )	15, 20 and 25

Firstly, the parameters with  $c = 5$  kPa and  $\phi = 20^\circ$  is analyzed to demonstrate the MPM in the large deformation of slope. Fig. 3 shows the movement process of slope failure. In the simulation, large deformation occurs in the slope at  $t = 1.0$  s. When  $t = 7.1$  s, the movement of the slope almost stops, where the maximum runout distance is 16.68 m. Then, Fig. 4 is illustrated at  $t = 7.5$  s to reveal the effects of strength parameters on the characteristics of running mass. We can find that the strength parameters,  $c$  and  $\phi$ , both have a great influence on the runout characteristics of the slope after failure. From Fig. 4, it is shown when the internal friction angle is constant, the maximum runout distance, volume, and maximum kinetic energy decrease with the increase of cohesion ( $c = 1, 5$  and  $10$  kPa). Similarly, when the cohesion is constant, the maximum runout distance, volume, and maximum kinetic energy decrease with the increase of the internal friction angle ( $\phi = 15, 20,$  and  $25^\circ$ ). It is worth noting that the maximum kinetic energy, in Fig. 4(c), decrease slightly when  $\phi = 25^\circ$  and  $c$  change from 5 kPa to 10 kPa. To clarify the cause of this consequence, the change of energy is analyzed. It can be seen from Fig. 5(a) that the smaller the strength parameter, the greater the internal energy. Obviously, this is caused by the deformation. In addition, according to the change of kinetic energy, the running characteristics of the mass

can be analyzed. As shown by Fig. 5(b), at  $t = 0 - 0.2$  s, mass begins to move and the kinetic energy gradually increases to a peak, which causes, such as  $t = 0.2 - 0.3$  s, the mass deformation to restrain the movement by adjusting its state (internal energy is increasing). Like  $t = 0.3 - 7.5$  s, when the movement capacity exceeds the restraint capacity, the slope begins to move over a long distance until balance. On the contrary, when the movement capacity less than the restraint capacity, the slope may only occur large deformation but does not move. Therefore, the maximum runout distance and maximum kinetic energy are small for the simulation with  $c = 10$  kPa and  $\phi = 25^\circ$ .

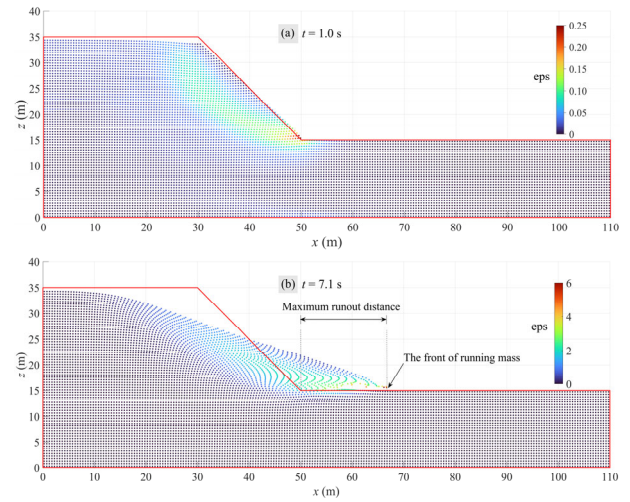


Fig. 3 The movement process of slope failure

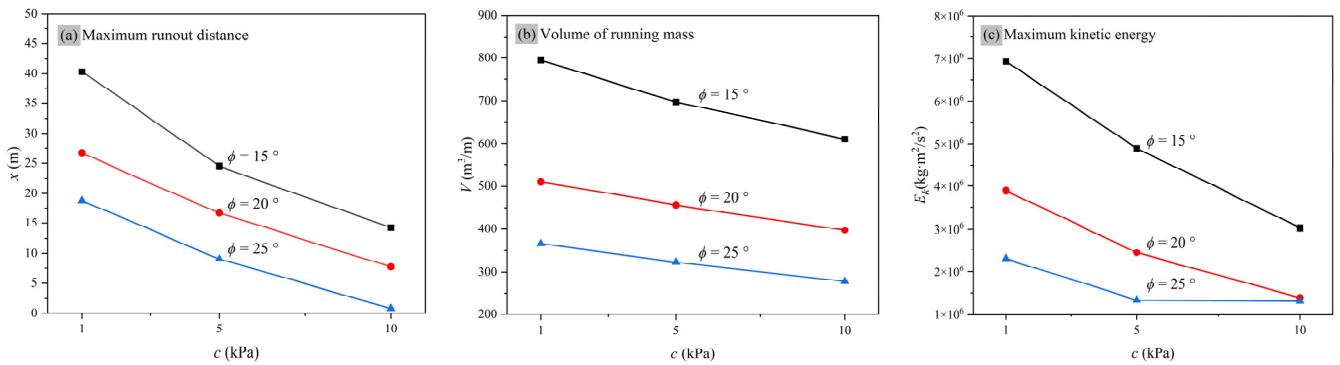


Fig. 4 The effects of strength parameters

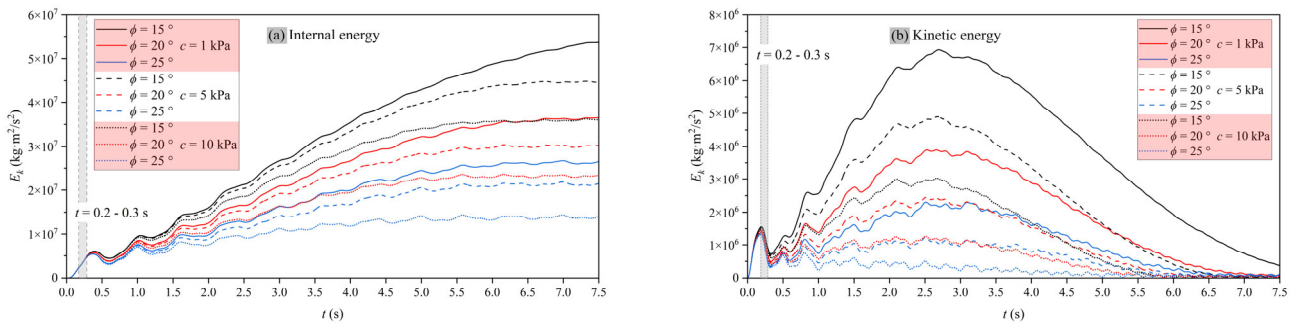


Fig. 5 The change of energy with time

**Conclusion**

a) Compared with FEM, MPM is an effective method to simulate the runout process of slope failure. b) By using MPM, it is found that the strength parameters of the material have a crucial influence not only on the stability of the slope, but also on the runout characteristics of the slope after failure. c) The change of energy can reflect the runout characteristics of slope after failure.

**Reference**

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 Sulsky, D., Chen, Z., and Schreyer, H.L. 1994. A particle method for history-dependent materials. Computer Methods in Applied Mechanics and Engineering, 118(1-2): 179-196.  
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