Large deformation analysis of soil slope with anti-slide piles base on a three dimensional and parallelized soil-structure-coupled SPH model

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ABSTRACT

Large deformation failures of soil slope are triggered by many factors (earthquake, liquefaction, rainfall and so on) and usually place a great threat to peoples' lives and property. It is essential to simulate the large deformation of geomaterials and to validate the performance of prevention measures, such as anti-slide piles, drainage, and reinforcement. Due to the absence of the soil-structure coupled analysis and the parallel optimization in previous SPH researches, this study proposed a three dimensional and soil-structure-coupled SPH model, based on the sub-loading cam-clay theory and elastic equation. The skin friction of piles is also added to the SPH code to realize the pile-soil interaction. After that, this SPH model has been optimized through the OpenMP parallel framework. Then, the proposed SPH model simulated the sliding process of soil slope failure without and with anti-slide piles. Results of the sliding displacement show that the analysis could represent the large deformation of soil and demonstrate the effect of anti-slide piles. Therefore, the proposed SPH model is a helpful tool for the soil-structure coupled analysis and the parallel implementation could provide a potential reference to other numerical methods in geotechnical engineering.

Keywords: soil-structure coupling, anti-slide pile, soil slope, SPH, parallel optimization

1 INTRODUCTION

Recently, many geological hazards involving the large deformation of soil occurred all over the world and placed great threats to peoples' lives and property. In order to reduce the impact of disasters, a lot of analysis methods have been developed and applied for the simulation of large deformation problems. Among these methods, the Smoothed Particle Hydrodynamics (SPH) method is widely used in the geotechnical engineering and there have been plenty of SPH researches on the run-out and flowing process of landslides. However, the SPH study on soil-structure interaction was still rarely found in literatures. Although Wang and Chan (2014) has proposed a frictional contact algorithm for the soil-structure interaction, their contact model is in the category of two dimension. Thus, this study proposed a three dimensional and soil-structure-coupled SPH model based on sub-loading cam-clay theory, elastic equation and frictional contact algorithm. Then, this model was verified by a 2D retaining wall and applied in the analysis of anti-sliding pile for a 3D soil slope.

2 CONCEPTS OF THE SPH MODEL

In the proposed SPH model, the soil phase was modelled as soft clay, the behavior of which is described by the sub-loading cam-clay model. For the structure, elastic theory was adopted to calculate the incremental stress during the simulation. Controlling equations in this study consisted of continuity equation and momentum equation. The OpenMP has been selected to conduct the parallel implementation.

3 SOIL-STRUCTURE INTERACTION

The two-dimensional contact algorithm referred to the study of Wang and Chan (2014). But in the three dimensional simulation, the particle line turns into plane consisting of structure particles, as in Fig. 1.

Therefore, in the 3D problem, three nearest structure particles will be found out for a computing soil particle...
at first and the surface between them can be calculated. After that, the perpendicular point of soil particle will be determined according to the theory of analytic geometry. By the linear interpolation of structure particles, we can obtain the mass and the velocity vector of perpendicular point. At last, with the velocity difference of soil particle and its perpendicular particle, the contact force of structure on the soil can be calculated by

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\begin{align*}
F^i_n &= \frac{m_i \Delta V^i_n}{\Delta t} \\
F^i_\tau &= \frac{m_i \Delta V^i_\tau}{\Delta t},
\end{align*}
\]

where, \(n\) indicates the normal direction and \(\tau\) indicates the tangential direction. The contact forces on three nearest structure particles can be determined by the linear interpolation of structure particles.

4 VERIFICATION OF SOIL-STRUCTURE INTERACTION

The sliding zone and its earth pressure distribution of a soil slope with retaining wall have be simulated by the proposed SPH model. Sand was used with following parameters: density was 1460 kg/m\(^3\), friction angle was 17° and friction coefficient between soil and structure was 0.268. Fig. 2 is initial dimension and simulated sliding line with an incline angle of 53°, which is very close to the theoretical result 53.5°.

Fig. 2. Initial dimension and the simulated sliding zone.

Besides, Fig. 3 is the distribution of active earth pressure, compared with the result of Rankine pressure theory. Although it is different from the theoretical result, the distribution is still close to others’ simulation (Cai 2007). Therefore, the proposed SPH model can be applied in the soil-structure interaction problem.

5 SPH SIMULATION ON THE ANTI-SLIDING PILE IN 3D SOIL SLOPE

In this part, a 3D soil slope with 40559 particles was analyzed by the proposed SPH model with two cases: one had no anti-sliding pile and another had two anti-sliding pile. Fig. 4 and Fig. 5 are SPH simulated flowing processes of slope without pile and slope with piles, respectively. It can be found that anti-sliding piles in the soil slope can reduce the run-out of soil slide.

Fig. 4. Flowing process of slope without anti-sliding piles.

Fig. 5. Flowing process of slope with anti-sliding piles.

The computing time of slope without pile is 477 min using 32 threads (two Intel Xeon E5-2620 V4), while it is 860 min using 16 threads. For the slope with piles, the results are 595 min using 32 threads and 1071 min using 16 threads. It indicates the high efficiency of OpenMP optimization.

6 CONCLUSIONS

This study proposed a three dimensional and soil-structure-coupled SPH model. Simulations on the retaining wall and the anti-sliding pile of soil slope proved that the proposed SPH model can effectively analyze the contact force between soil and structure for both 2D and 3D problems. Computing times under different thread number indicated the high efficiency of the parallel optimization in this study.

REFERENCES