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Simulation Of Deformation Of Loose Continuous Media On The Basis Of Particles Method

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Abstract- In this paper, on the basis of the particle method method of soil deformation is implemented, which is an aggregate of mineral grains, which are interconnected by a system of forces in the areas of contact between the mineral particles. It is assumed that the contact strength between the mineral particles is much smaller than the strength of the mineral particles themselves. To describe the behavior of soilLennard-Jones two-parameter potential of interconnection was chosen. In integrating the system of equations of motion the so-called algorithm Verlet is used. Some model problem for deforming the layer of soil in the gravity field was fixed. Before deformation of the soil layer the so-called process of "stacking" of mineral particles of the soilin the field of increased force of gravityhas been implemented. In the process of soil deformation algorithm for solving the problem contained the possibility of breaks on contacts between the mineral particles of the soil. The problem was solved in the two-dimensional formulation. In solving the problem algorithm parallelization based on heterogeneous computing clusters using graphics cards (GPU) was used. The calculations were performed on a heterogeneous computing cluster, each of the seven units of which three GPU AMD Radeon HD 7970 were installed.

Keywords: contact, friction, finite element method, particle method.

1. INTRODUCTION

The modern development of computer technology, including the parallel computing systems, provides ample opportunities for modeling continuum media at the micro level. In recent time, such modeling is based on the particle method [1-6]. Particle method lies in the fact that the continuum is represented as a set of interacting material particles. The particles can act as atoms and molecules of matter and mineral particles of soil materials. At the moment, the interatomic interaction potentials for the majority of materials are known, which cannot be said about the potential for describing the behavior of deformable continuous media, especially the shifting ones.

One of the important advantages of the particle method is that if it is applied, much less information about the properties of the material is required. Complex mechanical processes can be modeled to some extent by using simple Lennard-Jones potential. For a description of each of these effects a separate theory is required, while during the simulation of method of particles these effects are the result of integrating the equations of motion.

2. RESEARCH METHODOLOGY

Consider the collection of material particles from N that interact with each other in a potential field. Particle motion is described by the following equation of motion

$$m\ddot{r}_k = \sum_{n=1}^{N} \Phi\left(r_{kn}\right) r_{kn} + \sum_{n=1}^{N} \Psi\left(r_{kn}, v_{kn}\right) r_{kn} + \varphi\left(r_{kn}\right) + \psi\left(r_{kn}, v_{kn}\right)$$

Where r_k and v_k - vectors of position and velocity of k particle,

$$r_{kn} \overset{def}{=} r_k - r_n, v_{kn} \overset{def}{=} v_k - v_n,$$

m - Particle mass, $\Phi\left(r\right)$ and $\Psi\left(r,v\right)$ describe conservative and non-conservative component of interaction between the particles, $\varphi\left(r\right)$ and $\psi\left(r,v\right)$ describe conservative and non-conservative external

force field. Conservative component of interaction $\Phi(r)$ can be found by the formula:

$$\Phi(r) \overset{def}{=} \frac{1}{r} f(r),\ f(r) \overset{def}{=} -\dot{\Pi}(r),$$

Where $f(r)$ - scalar potential power $\Pi(r)$ - the interaction potential. Non-conservative of component $\Psi(r,v)$ allows to describe energy dissipation.

The main problem of the particle method is the integration of a very large number of equations of motion, and a lot of time spent on the definition of force that acts on a given particle. This is due to the necessity of the summation of a large number of terms in determining the nonlinear interaction forces with neighboring particles, which reduces the effectiveness of the methods that require multiple calculations of the right side of the equation. To accelerate the calculation the potential of interaction is usually cut at a predetermined distance from the target particle, i.e. it is believed that the interaction between the particles is very small and is not considered in the calculations.

Most often, when integrating the equations of motion algorithm of Verlet is used [7]. The position of the particle is defined by two of its previous position:

$$r(t+\Delta t) = 2r(t) - r(t-\Delta t) + \omega(t)\Delta t^2,$$

where Δt - step of integration $\omega(t)$ - the acceleration of the particles obtained. This scheme is applicable if there are no non-conservative forces.

We consider the pair potential $\Pi(r)$, the interaction force $f(r)$ corresponding to it is defined as

$$f(r) \overset{def}{=} -\dot{\Pi}(r),$$

σ, a, b - The distance at whichthe potential becomes null as well as its first and second derivatives:

$$\Pi(\sigma) \equiv 0, \dot{\Pi}(a) \equiv -f(a), \ddot{\Pi}(\sigma) \equiv -\dot{f}(b).$$

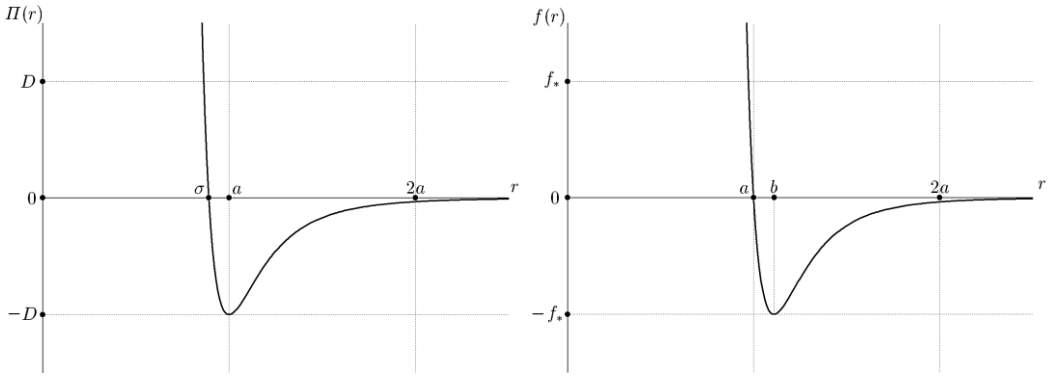

Fig. 1. Potential and interaction force

The main property of the potential is: when approaching each other $(r < a)$ particles repel each other, while withdrawing they are attracted $(r > a)$, if the particles withdrew to considerable distance $(r < 2a)$, the interaction forces tend to zero. Distance a is the equilibrium distance, distance b is the critical distance at which the gap between the particles happens. This assumption is valid only for the crystal, which takes into account only the interaction of nearest neighbors. In the position of equilibriumrigidity of relationship between the particles is equal to

$$C \overset{def}{=} \ddot{\Pi}(a) \equiv -\dot{f}(a),$$

linearized interaction force

$$f_L = C(a-r).$$

The potential and power of Lennard-Jones potential is usually taken in the form

$$\Pi(r) \equiv D\left[(a/r)^{12} - 2(a/r)^6\right],\ f(r) \equiv \frac{12D}{a}\left[(a/r)^{13} - (a/r)^7\right],$$

Where D - the binding energy a - the bond length (the distance at which vanishes interaction force).

The most promising technology for the solution of these problems are a heterogeneous

computing clusters using graphics cards (GPU). One GPUdevice is equivalent for solving problems of seismic waves to about 50 CPUs Xeon [8]. However, this technology has some limitations on the amount of available memory as internal memory GPU of the devices is much less than traditional memory cluster nodes. To implement calculations on graphics accelerators a library with open source VexCL is used [9]. This library simplifies the development of applications using OpenCL technology and allows to use intuitive notation for writing basic operations of linear algebra [10, 11]. The calculations were performed on a heterogeneous computing cluster. On each of the seven cluster nodes three GPU AMD Radeon HD 7970 are installed.

3. THE RESULTS OF THE CALCULATIONS, THEIR ANALYSIS AND CONCLUSIONS

To illustrate the possibilities of the proposed algorithm the model problem of deformation of layer of soilhas been solved (such as sandstone), which was under its own weight [12, 13]. In the process of soil deformation algorithm for solving the problem was laid on the possibility of breaks on contactsbetweenmineral particles of soil. The problem was solved in the two-dimensional formulation. Initially, a layer of soil was placed on a perfectly rigid obstacle, the central part of which at some point of time $t = 20$ (it should be noted that the time is a dummy variable and does not correspond to the real, and the decision itself is a quality one) instantly disappeared. A layer of soil under its own weight caved in, causing its partial destruction. Figures 2-3 show the configuration that takes the compactor mass in the process of bending and partial destruction, depending on the time for different values of parameters D and a , used in the Lennard-Jones potential. Analysis of the deformation of layer of soil leads to the conclusion that the destruction in it proceeds according to "brittle destruction" type and continuous media of such a type in the first approximation can be modeled using the Lennard-Jones potential.

Fig. 2

Fig. 3

4. CONCLUSION

Particle methodwas implemented in the work which allows to investigate the interaction of a system of material points that are in a potential field. To describe the motion of the material points systemthe system of motion equationswas used. Its integration was carried out using the method of Verlet. On the basis of Lennard-Jones potential model problem of deformation and partial destruction of the soil mass, located in the gravity fieldhas been solved.

CONFLICT OF INTEREST

The author confirms that the data do not contain any conflict of interest.

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