Discrete Element Method for Granular Material Analysis

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Abstract

A discrete element method is a mathematical approach in which statistical measures of general characteristics or behavior of a phenomenon are deducted from individual motions and interactions of an entity of elements. The research uses this methodology to demonstrate analyses of earth pressure against the retaining walls, including the quasi-static pressure of the earth and the lateral pressure of passive soil. Quasi-static analysis using the Discrete Element Method on Yade Software is an analysis of active and passive earth pressure distribution behind a retaining wall. Soil mass in a big container is treated as comprising blocks that are associated with elastoplastic. Yade Methodology, i.e., discrete element method, uses unbalanced ratio, damping ratio and inertial number as independent variables of simulated particles that are subject to time-step and P-wave velocity. Unbalanced ratio, damping ratio, and inertial dynamics equations are used based on the Classical Newtonian second law of motion. The forces and movements of each particle are traced and kept at every time step. Contact forces rely on the particle geometry overlap and material compositions. The interaction force of each particle is included in the normal, tangential and moment components. Therefore, the Discrete Element Method is the best method for analyses of soil structures, and the advantages of using this method are discussed.

Introduction

Granular materials are normally found in natural materials as well as in different industrial aspects. Granular materials are conglomerations or collections of discrete or macroscopic particles associated with loss of energy as a result of particle interaction (Šmilauer and Chareyre, 2010). Thus, when granular materials interac,t there is a loss of energy. For instance, these materials can be found or are found in the extraction of mineral raw and transport, powder mixing, concrete, cereal storage, etc. Also, the granular materials are found in cohesive-frictional materials. Therefore, granular materials portray particular phenomena, which need more studies to develop a better understanding of them. The elements can be deformed as macroscopic particles or solid bodies or soils, and they possess the ability to flow like liquids and compress like gases. Due to granular phenomena characteristics, the numerical simulation method is seen as the best method that could help understand the materials and as well predict their behavior. Simulation has become a force to reckon with when it comes to the

optimization of industrial processes (Šmilauer and Chareyre, 2010). Therefore, the technological advancement in computing power is making researchers use and implement numerical methods in experimental studies. Thus, the simulation method helps researchers to use the deductive method in analyzing the behavior of granular materials. Hence, the simulation method helps researchers to deduct a material characteristic from studying individual grain rather than studying as an entity.

Since the granular materials can be deformed as solid soils, they are highly discontinuous. Therefore, we should expect to use an intermittent simulation method to have a better understanding of these materials. Up to date, the Discrete Element Method (Method) is the best approach to studying the behavior of the granular material. The discrete element analysis modeling is simple: the elements in the simulation are grains; they interact through pairwise contacts and are subject to external forces, i.e., gravitational force or interaction with surrounding objects (Šmilauer and Chareyre, 2010).

Discrete Element Analysis

A discrete element method is a mathematical approach in which statistical measures of general characteristics or behavior of a phenomenon are deducted from individual motions and interactions of an entity of elements. Therefore, it uses the deductive method, i.e., from specific to general. The discrete element analysis is mostly used where theoretical knowledge has no established mathematical equations. There are different systems that exist that possess a certain phenomenon. For instance, there are gas systems, liquid systems, solid systems etc., but there are those systems that are made of processes of the gas, liquid and solid systems like granular materials. Since these exist and we don't have enough knowledge and a better understanding of them; thus, we develop a better research method to study them. Therefore, the best method to study these granular materials is the introduction of an efficient and effective simulation method to help conduct experimental studies. There are different simulation methods that are used in engineering sciences today. They include Discontinues Deformation Analysis (DDA), Finite Element Method (FEM) and the Discrete Element Method (DEM) (Šmilauer and Chareyre, 2010).

The best method to conduct our experimental studies is the Discrete Element Method. This method is best suited because its simulations are numerical and arithmetic in nature. The DEM method can identify hard and soft particles. The numerical approach helps in establishing the contact force of the granular materials. This method is the best for analyzing powder mixture, extraction of raw minerals and other related industries.

Due to granular phenomena characteristics, the numerical simulation method is seen as the best method that could help understand the materials and as well predict their behavior. Simulation has become a force to reckon with when it comes to the optimization of industrial processes (Šmilauer and Chareyre, 2010). Therefore, the technological advancement in computing power is making researchers use and implement numerical methods in experimental studies. Thus, the simulation method helps researchers to use the deductive method in analyzing the behavior of granular

materials.

Consequently, this discrete element method incorporates a damping ratio in its numerical approach. The damping ratio measures the oscillatory behavior of the system when it's disturbed away from its equilibrium level. For instance, when spring is pulled, it bounces until it finds its equilibrium again. Also, the methods ensure that the inertial number remains under 0.01%. Moreover, it ensures that the unbalanced force ratio remains within its desired range. The process of settling the particle under gravity must be repeated several times to ensure that the unbalanced force ratio remains within its desired range. Furthermore, the method uses a time-step tool. The Time Step simulation tool enables you to particularly outline the operating conditions and acquire a power flow solution for a limited amount of time. The time step provides the tools needed to evaluate the operation of the simulation systems by taking a specified amount of time.

The simulations are never in equilibrium status; thus, to make the equilibrium more balance, the level of unbalanced force must be as minimal as possible. Consequently, the level of inertial number must be at less than 0.01%. Therefore, keeping these factors float and at their smallest level in their equation, will help in achieving static simulation. Therefore, the method establishes whether the simulations are at an equilibrium level.

Constructing a Frame for the Discrete Element Method

The aim is to select a framework solution that can handle different simulation models. Therefore, the only model that can analyze the object-oriented abstractions is the analysis of the Discrete Element Method (DEM). Other models, i.e., Geometrical Model and Finite Element Method, cannot be used to analyze the granular materials. The DEM method was first developed by Cundall with the aim of analyzing rocks. Therefore, the DEM method is a numerical approach that can illustrate the mechanical behavior or characteristics of an entity of discrete elements. The suitable interactions between the elements are noted to account for the mechanical compositions of the medium. Therefore, the macro-mechanical feedback of the granular material, i.e., deformability and strength, is regenerated by establishing the micro-properties of the substance in contact interaction forces,i.e., normal, tangential and local friction. The method is is suitable since it gives new insight into collective modeling because the physical processes which dictate the collective behavior can be understood from a single grain. Discrete Elements constitute different geometries, but they keep a low arithmetic calculation cost. The spherical containers are used, and it will be the same in our case. The purpose of using the YADE Discrete Element Method is to ensure a stable and constant environment for the implementation of computational algorithms.

Scientific Simulations

Taking into consideration that simulation involves bodies in which their interactions occur. The interactions are identified and processed to a particular level of computational algorithms and physical rules. The algorithms result in a moment, a force, etc., which generates a response that influences the state of the body. Therefore, bodies and interactions assist in computational algorithms, which are scientific simulations.

Generation of a Discrete Element Method Sample

There are different generation methods that can be used to solve the sphere in the three dimensions. The methods include the following. First, dynamic compaction, this method is used to raise the density of the soil higher when a particular subsurface disadvantages other methods' functionality. Therefore, this method helps in increasing the density of the soil. Second, radius growth helps in solving geometrical equations for the sphere arrangement. The obtained arrangement has to possess the required porosity, and the sphere container should be as small as possible. The sample is produced by assuming that spheres' positions randomly can overlap one another; thus, the sample is in a bigger volume than the target volume. After this is done the compression is done without friction and cohesion taking place, this done until the required stress of the walls is achieved. You can opt to use kinematic radius growth or dynamic compaction for the activity. The compression is done by using triaxial compression.

DEM Formulation

Let small container (S) and bigger container (B) be in contact. Therefore, the radius of the spherical element of the small container is Rs, and that of b is rB. In general set of axes, their jurisdiction is interpreted by two vectors ~xS and ~xB. The interaction force can be represented by the element of S and the element of B; thus, these elements can be decomposed into a shear vector.

The figure shows the interaction between two discrete elements: a smaller container (sphere b) and a bigger container (sphere a).

The interaction moment is performed to ensure that representation of the missing particles in the spherical Discrete Element Method, the contact moment is determined by using the rolling stiffness Kr:

Thus, °At=c and °Bt=c are the first orientations of the containers, taking into consideration the time contact was created.

Whereas °At and °Bt are immediate orientations of spheres

Symbol° represents a quaternion

The ~V (•) function changes from a qa quaternion form to a vector form:

Interpretation

The °q is a quaternion with these functions a, bi, cj and dk. Therefore, incase rotation angle α = 0 axes will become anything since the angle evolvement all zeros are assigned to x, z, and y function.

YADE is designed in such a way that new simulation models are reused. Thus, the new simulations are easily defined.

Unbalanced Force Ratio

Unbalance force: the entity of particles under experimental studies settle in the bottom of the spherical containers due to gravity they bounce back. The process of settling the particle under gravity must be repeated several times to ensure that the unbalanced force ratio remains within its desired range. The position for unbalancing force ratio is required to be less than 0.01.

Newton's second law states the acceleration of the object is directly proportional to the size net force, in the same direction as the net and inversely proportional to the mass of the object. Therefore, until the unbalanced force ratio is below 0.01, then their experimental results become invalid.

Damping Ratio

For the simulation to reach an equilibrium level, there is a need for a damping ratio. Thus, the damping ratio helps the DEM to maintain simulation at an equilibrium level. The damping ratio measures the oscillatory behavior of the system when it's disturbed away from its equilibrium level. For instance, when spring is pulled, it bounces until it finds its equilibrium again. Thus, bouncing is an oscillatory behavior, and it is measured using a dimensionless measurement called damping ratio. Therefore, when conducting the experiment, we shall insert gravitational force until the particle settles in the bottom. Since our desired damping ratio is 0.02, the system parameter will be underdamped. Therefore, we will conduct the simulations by factoring in unbalanced force and velocity to maintain particles at their equilibrium level.

Inertial Number

The initial number ensures that the level of stress, density, and rate of the wall are within the desired range. The inertial number determines the types of static in simulations. Therefore, to keep the simulations Quasi-static, the inertial number must be less than 0.0001.

Quasi-static

The simulations are never in equilibrium status; thus, to make the equilibrium more balance, the level of unbalanced force must be as minimal as possible. Consequently, the level of inertial number must be at less than 0.01%. Therefore, keeping these factors float and at their smallest level in their equation, will help in achieving static simulations. The inertial number and unbalanced force ratio facilitate achieving the quasi-static.

Time-Step

The Time Step simulation tool enables you to particularly outline the operating conditions and acquire a power flow solution for a limited amount of time. The time step provides the tools needed to evaluate the operation of the simulation systems by taking a specified amount of time. Discrete Element Method has limited time in its simulations; thus, the time the simulations will take a specific amount of type. YADE duration of the simulation is limited; thus, time plays an important factor in simulations (Matsuzawa and Hazarika, 1996). The time step must be very small to understand how long one force does take to move from one place to another.

P-wave Velocity

The P Wave is an accumulation wave produced by the deforming front as it moves the atria. The right wave atrium depolarizes a moment before the left atrium; thus, the speed the right atrium takes to travel to the light atrium is considered to be p-wave velocity. P-wave velocity: it is a direction compression wave; the p-wave velocity helps you in determining the time-step. The P-wave velocity is the speed that one force takes from moving from one place to another. Therefore, determining the time step, we calculate the distance the force has covered and note the p-wave velocity (Matsuzawa and Hazarika, 1996). Thus, we have distance and speed we can determine the time step.

Advantages and Disadvantages of the Discrete

Element Method

One of the advantages of the discrete element method is that it can be used in simulating a wide variety of granular materials and help in understanding better rock mechanics conditions. The researchers have, on their own, developed software that is capable of simulating (Šmilauer and Chareyre, 2010). These simulation software are now adopted in experimental studies in a wide range of engineering applications. Therefore, the discrete element method helps in studies of granular flow and extraction of raw mineral and adhesive powders.

Also, the DEM method gives detailed research of the interactions of micro-dynamics of granular materials rather than physical experiments. Thus, the method gives comprehensive and details experimental studies that help the researchers to understand granular materials.

Disadvantages of the DEM

The number of particles and duration of the simulation is limited by the computing power. Thus, the method cannot simulate a lot of particles since the software requires a certain amount of particles with limited time to conduct the experimental study.

Discrete Element Method is numerical demanding, due to this factor the method has not been widely adopted in engineering sciences and related computational industries. However, the method has wide large computing core, which is tedious. Also, the method is not as energy efficient as CPUs.

Conclusion

In conclusion, granular materials are normally found in natural materials as well as in different industrial aspects. These materials can be understood better by experimenting with them using the Discrete Elements Method since granular materials are conglomerations or collections of discrete or macroscopic particles associated with loss of energy as a result of particle interaction. Thus, when granular materials interact, there is a loss of energy. For instance, these materials can be found or are found in the extraction of mineral raw and transport, powder mixing, concrete, cereal storage, etc. Also, the granular materials are found in cohesive-frictional materials. Therefore, granular materials portray particular phenomena, which need more studies to develop a better understanding of them. The materials can be deformed as macroscopic particles or solid bodies or soils, and they possess the ability to flow like liquids and compress like gases. Due to granular phenomena characteristics, the numerical simulation method is seen as the best method that could help understand the materials and as well predict their behavior. Simulation has become a force to reckon with when it comes to the optimization of industrial processes. Therefore, the technological advancement in computing power is making researchers use and implement numerical methods in experimental studies. Thus, the simulation method helps researchers use the deductive method in analyzing the behavior of the

granular material (Kenmochi And Yagi, 1978). A discrete element method is a mathematical approach in which statistical measures of general characteristics or behavior of the phenomenon are deducted from individual motions and interactions of an entity of elements. Therefore, it uses the deductive method, i.e., from specific to general. The discrete element analysis is mostly used where theoretical knowledge has no established mathematical equations. The Discrete Element Method is the most effective simulation method that can help us understand the phenomenon of particles better. Unlike the other simulations, the Discrete Element Method (DEM) uses a mathematical approach to evaluate and analyze particles under study. The position for the unbalancing force ratio is required to be less than 0.01 to make sure the simulation is at a static level. Similarly, the inertial number is supposed to be below 0.01% to ensure simulation is in order. Therefore, keeping these factors float and at their smallest level in their equation, will help in achieving static simulations. The inertial number and unbalanced force ratio facilitate achieving the quasi-static.

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