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Development of a 3d Computer Simulation Model Using C++ Methods

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Abstract. The article presents modelling of spherical elements based on the developed computer model. We recorded the main combinations of spherical particles during filling, which are formed in the hopper. It was found that the most likely combination that occurs when modelling spherical elements consists of three balls. It should be noted that in the cross-section of such a combination passing through the center of the balls, an equilateral triangle is formed. And in the cross-section of the structure, which consists of four spherical balls, a rhombus is formed, if you connect the centers of these spherical elements. It is worth noting that from this formed combination of spherical elements, it can be seen that the rhombus forms two smaller equilateral triangles that fix the process of pushing the spherical balls apart. In turn, the process of pushing spherical elements apart made it possible to fix the contact between spherical elements, as well as to state the stable position of each (individual) particle.

This paper also presents the main fragments of encoding the source text of a 3D computer model for modelling spherical elements, which made it possible to optimize the model parameters. It was found that from the obtained data on the distribution of coordination numbers for different volume fillings of spherical elements, it follows that the largest filling was 72 %, which corresponds to the state when 112 lobules have an average coordination number of 3.92.

1 Introduction

The modern period of modern development is characterized by a significant influence of computer technologies and information technologies that penetrate into all spheres of human activity[1, 2]. This rate of development of computerization ensures the dissemination of information flows in society [3, 4], as well as allows the use of the latest technologies [5, 6], use a statistical approach for a compact presentation of coded data [7, 8, 9]. In turn, the use of the latest technologies in the field of information technologies allows us to move from a specific observation of research and establishing the irrefutability of existence to a qualitative prediction of various properties of spherical elements [10, 11], materials [12, 13], processes [14, 15], optimization of parameters [16, 17, 18], etc [19, 20]. In particular, modern methods of computer modelling allow solving problems of complex systems for various purposes, that is: information, technical, social, economic, environmental, etc – both at the stage of their design and in the process of their operation [21, 22, 23].

Creating a computer model is a troublesome and creative process that requires the researcher not only deep theoretical knowledge in the field of various mathematical and technical components, but also a creative approach to their implementation [24, 25]. Therefore, today the issue of optimizing and establishing a statement of facts of a 3D computer model for modelling spherical elements is acute [26]. And also, the ability to generate specific heuristics that correspond to the deep essence

of this research will make it possible to reduce the number of time-consuming and cumbersome field experiments [27, 28].

2 Main Part

In [29, 30], the authors developed geometric models for single - and multi-layer structures. The main focus was on modelling various element shapes, and the authors also considered the influence of individual factors on the particle cross-section. With such a broad study, the real parameters of computer modelling are poorly taken into account, which do not allow predicting the results obtained with a reliable error. The team of authors [31] investigated the environment of software modelling for solving problems of spherical elements, as well as studied in detail the main properties of structurally inhomogeneous materials, in particular: particle shape, particle size, microstructure of the sample surface, etching process, advantages of the iterative process, etc.at the same time, it would be good to pay more attention to the fragments of the software source code. In [32], modelling of laser and electron beam technologies for obtaining spherical balls is formulated. The main mathematical elements of Monte Carlo methods are highlighted, but the results of computer modelling of our own development are poorly presented. Scientific works [33, 34] show the results of the behaviour of parts under the influence of external power load. With such a wide range of studies, it is not very clear which combination is most likely to occur when modelling spherical elements. In studies [35], the main attention is paid to the flowability of elements by ball indentation, but the process of pushing spherical elements apart, which would allow recording the interaction between particles, is not fully justified. In scientific experiments [36, 37], a digital approach to modelling spherical elements is used. It should be noted that the proposed materials can be applied to both polydisperse and non-spherical particle systems. This indicates that the proposed method using the digital approach is general and entails a traditional problem statement. Experimental results [38] mainly show the packing behaviour of metal (spherical) particles, and the processes of compaction and indentation of balls are presented. It should be noted that the authors needed to further expand the modelling process in order to establish a functional relationship between the particles, as well as fix the average coordination number. In [39], studies are presented, namely: compaction of elements under hydrostatic loads and at high temperatures using the finite element method. This study is mainly based on theoretical aspects, which does not allow predicting the results obtained at a qualitative level, since there is no correlation between the theoretical and practical components. In [40], the identification of analytical dependences of operational characteristics of workpiece clamping mechanisms during reversible movement of the input link is mainly highlighted. At the same time, the authors of this paper very narrowly highlighted the developed simplified dynamic models for describing various stages of the computer modelling process. Scientific groups [41] reviewed the methods of the mathematical approach to spherical elements based on physical principles. At the same time, the position of packing spherical elements is not justified and the parameters of the computer model are not optimized. The authors' teams [42] developed a two-dimensional DEM hysteresis model for polygonal particles of arbitrary shape. It should be noted that the force model is applicable to both convex and concave polygonal particles. Also, the correlation of theoretical and practical experiments is described, but the deviation error is 7%, which makes it impossible to predict the properties of particles at a qualitative level. In [43], a new stiffness scaling methodology is proposed for modelling discrete elements of cohesive fine powders. It should be noted that the established scaling law for contact adhesion, the force estimation scheme for calculating contacts, and the van der Waals interaction are used only for spherical small balls. At the same time, the shape of the particles must be perfectly processed, which does not always correspond to real capabilities. The work teams [44] combine the CFD-DEM model to model dry round balls. Checking and analyzing the sensitivity of the main particle parameters is described in detail, but the model parameters, as well as fragments of the computer model encoding, are completely absent. In [45], the effect of particle propagation is modelled. An empirical equation describing the distortion deformation of the propagation parameters of spherical elements is proposed in the form of approximation dependencies. The results of numerical

modelling clearly show that the effect of particle propagation occurs due to uncontrolled parameters of the hopper, on the basis of which it is not possible to obtain high-quality packaging of spherical elements. In scientific works [46], complex modelling by the discrete element method for calculating the energy of spherical particles is presented. During the study, the authors were given only the shape of the particles, the size of the particles, and the initial velocity. This indicates very narrow research results. In [47], the rheological scaling of spherical metal elements dispersed in thermoplastics and its correlation with the possibility of extruding filaments for 3D printing are presented. It should be noted that such a viscosity of the suspension of homogeneous particles was extremely high, which does not meet the basic requirements of GOST. Therefore, from the above analysis of literature sources, we can conclude that a number of questions in the field of computer modelling remained open. And today, the issue of optimizing the parameters of a 3D computer model for modelling spherical elements is acute, as this will make it possible to reduce the large number of time-consuming field experiments[48, 49]. And also, to predict the main properties of forming the structure of materials at a significantly new and qualitative level.

The aim of the study is to optimize the best parameters of the developed 3D computer model, as well as present the main coding fragments of the computer model for modelling spherical particles.

Materials. In order to simulate the filling of spherical elements, it is necessary to build a hopper (container) of the corresponding parameters at the initial stage. That is: the width of the container is 1500 mm, the height of the container is 1500 mm, the shape of the particles is spherical, the diameter of the spherical ball is 20 mm, the experiment time is 20 minutes, the number of experiments is 5. It is also worth noting that this 3D computer model provides for the use of horizontal and vertical vibrations for better compaction of spherical elements. And also, investigate the average coordination number of filling inFig. 1 shows the window interface of the developed computer model for modelling spherical elements.

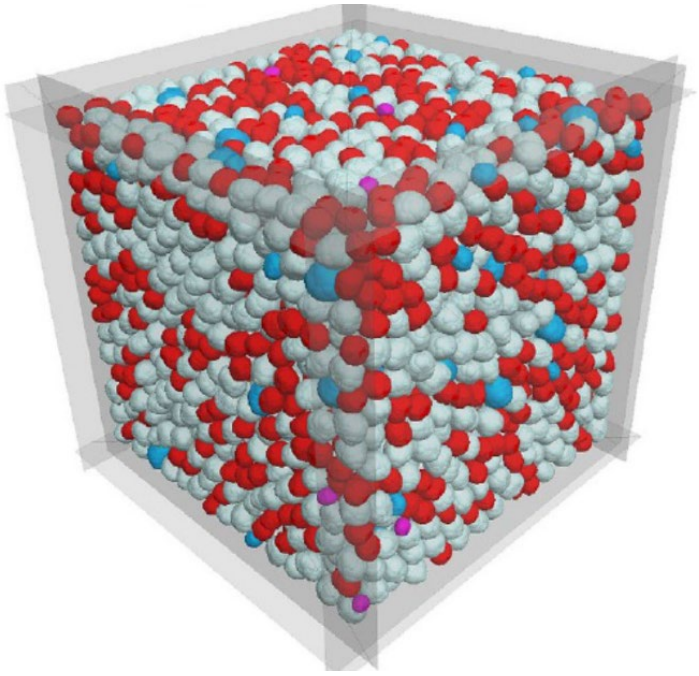

Fig. 1. Interface of the developed computer model for modelling spherical elements with an average coordination number of 1.05%

It should be noted that the developed computer model for modelling spherical elements reduces the time spent on conducting field experiments, as well as predicts the results of the study with a small deviation of up to 1-3 %.

Spherical particles at the initial fall into the Hopper are in contact with one point with its surface and can create various combinations. The most likely combination consists of three balls, which is

shown in Fig. 2. In the cross-section passing through the center of the balls, an equilateral triangle is formed that connects their centers to each other. It should be noted that the sides of an equilateral triangle ABC are equal to the diameter (radius) of the balls, and the angles are equal to 62°. The blank part of the space between the balls that makes up the shape in cross-section is created by three arcs of a circle, the lengths of which are equal to 60°. The center of this figure is located at Point B of the intersection of the medians of equilateral triangle ABC. In Figure 2 and 3 the main combinations of spherical particles at initial filling are presented.

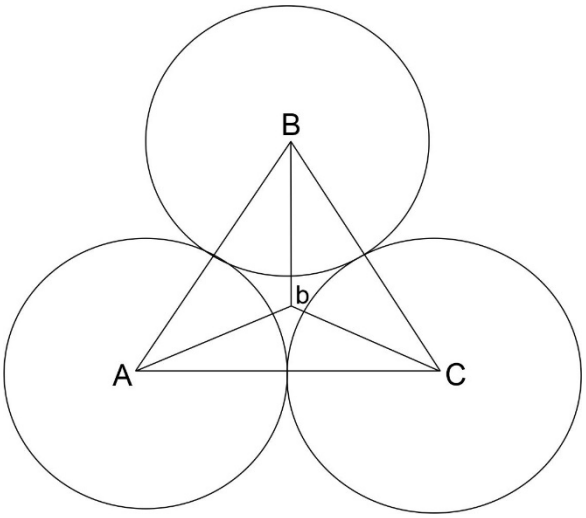

Fig. 2. A combination of three spherical balls

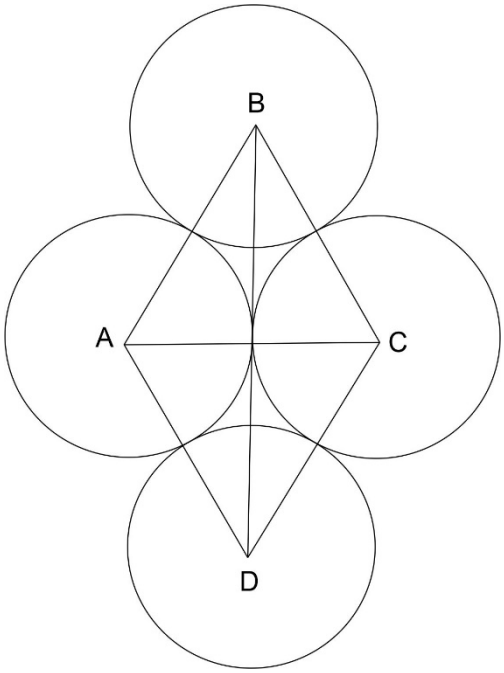

Fig. 3. A combination of four spherical balls

In the cross-section of a structure consisting of four spherical balls (Fig. 3) a rhombus is formed if the centers of these spherical elements are connected. In this case, the rhombus ABCD has sides of length d. Its smaller AC diagonal also has a length of d. Sharp angles are 60°, and obtuse angles are 120°. It is worth noting that from this combination of elements (Fig. 3) it can be seen that the rhombus forms two smaller equilateral triangles, which fix the process of pushing the spherical balls apart. The process of pushing the spherical elements of the first layer (filling line) apart will end when two adjacent balls of the second layer find their stable position in the hopper. In this case, two adjacent balls of the upper i.e. the second layer will touch each other relative to each other, where you can fix the contact between spherical elements. The same principle will be used to create both the third layer and the fourth layer (a string of filling balls) in the hopper. In Fig. 4 shows the filling of spherical elements, which consists of four units and forms a square.

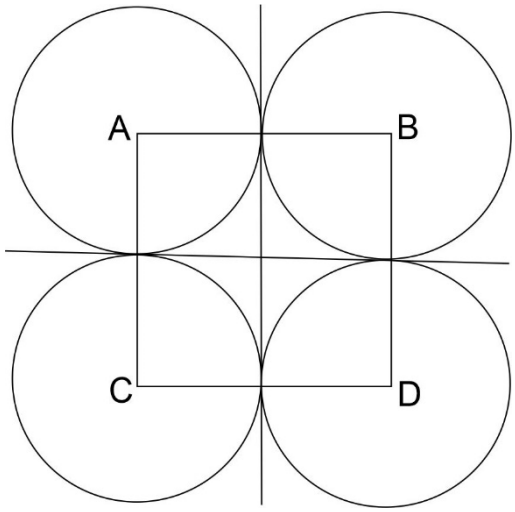

Fig. 4. Combination of filling spherical elements with a square

The main fragment of such a structural combination (filling spherical elements with a square) will be described by two conditional layers – one hemisphere of the second layer and four parts of 1/8 of the volume of the ball of the lower row (layer). Such combinations of spherical balls are part of a parallelepiped with a base area of in$d_k^2$and a height equal tod_k / 2.

Tests. Code snippet of the computer model, namely: building a bunker:

```
    #include "DrawBunkerDialog.h"

    DrawBunkerDialog::DrawBunkerDialog(QWidget *parent)
    : QDialog(parent)
    {
    ui.setupUi(this);
    paintArea = newPaintAreaB(ui.areaContainer);
    paintArea->setGeometry(10, 23, 380, 380);
    //polygon.clear();
    //connect(paintArea, SIGNAL(painted(std::vector)), this,SLOT(writeMassCenter(std::vector)) );
    //connect(paintArea, SIGNAL(cleared( )), this, SLOT(clearMassCenter( )) );
    //connect(ui.loadButton, SIGNAL(clicked()), this, SLOT(showBunkerDialog()));
    }

    DrawBunkerDialog::~DrawBunkerDialog()
    {

    }
/*
    voidDrawBunkerDialog::writeMassCenter(std::vectorlist)
    {
    polygon = list;
    unsignedintind = polygon.size() - 1;
    QStringtemp;
    ui.massX->setText(temp.setNum(polygon[ind].x()) );
    ui.massY->setText(temp.setNum(polygon[ind].y()) );
    }

    voidDrawBunkerDialog::clearMassCenter( )
```

```
    {
ui.massX->setText("");
    ui.massY->setText("");
    polygon.clear();
    }

    b2Vec2* DrawBunkerDialog::convertPoints(std::vectorlist)
    {
    intsize = list.size();
    b2Vec2* arr = newb2Vec2[size-1];
    for (inti = 0; i<size-1; ++i) {
    floatx = (float(list[i].x()) – float(list[size-1].x()) ) / 10.0;
    floaty = (float(list[size-1].y()) – float(list[i].y()) ) / 10.0;
    arr[i].Set(x, y);
    }
    returnarr;
    }
    */
```

Code snippet of the computer model, namely: simulation of spherical balls:

```
    #include "CirclePhysicBody.h"
    #include "Render.h"

    CirclePhysicBody::CirclePhysicBody(b2World *world,
                                                    ShapeType shapeType,
                                                    BodyType bodyType,
                                                    const b2Vec2& massCenter,
                                                    float32 radius,
                                                    const b2Color& color,
                                                    const std::string& sextureFile)
    : PhysicBody(world, shapeType, bodyType, massCenter, color, sextureFile)
    , m_radius(radius)
    , m_shape(new b2CircleShape)
    {
    setBodyType();
    m_bodyDef.position.Set(massCenter.x, massCenter.y);
    // Call the body factory which allocates memory for the ground body
    // from a pool and creates the ground box shape (also from a pool).
    // The body is also added to the world.
    m_body = m_world->CreateBody(&m_bodyDef);
    // The radius
    m_shape->m_radius = m_radius;

    // Add the ground fixture to the ground body.
    m_body->CreateFixture(m_shape, 1.0f);

    m_area = 3.141592653589793f * radius * radius;

    m_BCradius = m_radius;
    }
    CirclePhysicBody::~CirclePhysicBody()
```

```
{
if (m_shape)
delete m_shape;
}

void CirclePhysicBody::render()
{
Renderer renderer;
renderer.DrawSolidCircle(m_body->GetWorldCenter(),
m_radius, b2Vec2(0, 0), m_color);
}
```

3 Conclusion

Thus, as a result of the conducted research, we obtained different degrees of filling of the volume container under the action of compressive force. From the obtained data on the distribution of coordination numbers for different volume fillings of spherical elements, it follows that the largest filling was 72 %, which corresponds to the state when 112 particles have an average coordination number of 1,05. It was achieved by shaking the particles in the hopper with the help of vibration vibrations. Checking the adequacy of the proposed model by comparing computer and field experiments showed their good consistency.

The implementation of a 3D computer model allows you to solve simulation problems in the following areas:

1) forecasting the main properties of forming the structure of materials, in particular spherical elements;

2) statement of facts of contacts between particles, components and structure of spherical elements;

3) reduce the number of time-consuming and cumbersome field experiments.

The prospect of further research is the development of a 3D computer model for modelling non-isometric shapes of particles, as well as the study of their main properties during filling simulation.

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