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An Improved Three-Dimensional Modeling Method of Overburden Sagging Zone Based on GTP Model

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Abstract. So far, the methods of three-dimensional geological modeling are basically modeled from the original information such as borehole, but in the actual mining process, the overburden will produce deformation. In order to simulate the impact of resource development on terrain better, this paper presents a three-dimensional geological data model based on key stratum theory. This paper uses the original information such as borehole to construct the 3D geological model based on GTP, and determines the position of the sagging zone with the key stratum theory. Then we use the mathematical model of stratum movement in the sagging zone. Finally it renders the three-dimensional visualization of the sagging zone geologic model. The model simulates the change of the terrain after mining, and provides theoretical and material basis for the geological workers to make rational exploration and development decisions.

1. Introduction

In recent years, with the energy crisis intensified. The intensity of geological exploration increased. With the help of computer and graphic technology, it is possible to improve the visualization of geological prospecting and enhance geological analysis by constructing geological three-dimensional model.

Accurately simulating complex geological structures is one of the hot and difficult problems in the current three-dimensional geoscience research [1, 2, 3, 4, 5, and 6]. Over the past few decades, domestic and foreign scholars have proposed a large number of three-dimensional spatial data models. Wen Xuedong [7] and so on proposed the use of triangular prisms (TP) for geological modeling. Cheng Penggen, Liu Shaohua, Xi jianya [8] proposed a geometric modeling based on a triangular prism element (QTP) model. Taking into account the problem of borehole deflection, Wu Lixin [9] and others have been further improved and extended, proposed a generalized triangular prism (GTP) three-dimensional data model. Modelled methods mentioned above are basically modelled from the original information such as boreholes. However, in the actual mining process, the overburden will deform. Considering that the model modification method of overburden deformation parameters is less studied, this paper proposes a three-dimensional geological data model based on key stratum theory to meet the need of deformation parameters of overburden by revising and extending the generalized tri-prism (GTP).

2. A Framework of Sagging Zone 3D Modeling Method Based on Key Stratum Theory

After the coal mining, mined-out gob is formed, which destroys the natural stress state of the rock mass around the stope and the original stress equilibrium state in the overburden. This leads to the movement and deformation of the overburden, and finally to the surface, causing the surface movement and subsidence. The overburden from three belts, namely caving zone, fault zone and sagging zone. This paper is to study the three-dimensional simulation of the sagging zone (the whole moving zone).

According to interpolation of the existing borehole, it produces more coordinate points. Then invoking DirectX [10] API and using GTP model will integrate a number of coordinate points into a complex three-dimensional geological model.

According to the rock strata information, the position of the key stratum is determined, and the position of the sagging zone is confirmed. After the borehole information, rock strata information and mining information, the deformation parameters are calculated by the mathematical model of the sagging zone. On the basis of the original three-dimensional geological model, the sagging zone is moved and a three-dimensional model of the sagging zone is obtained.

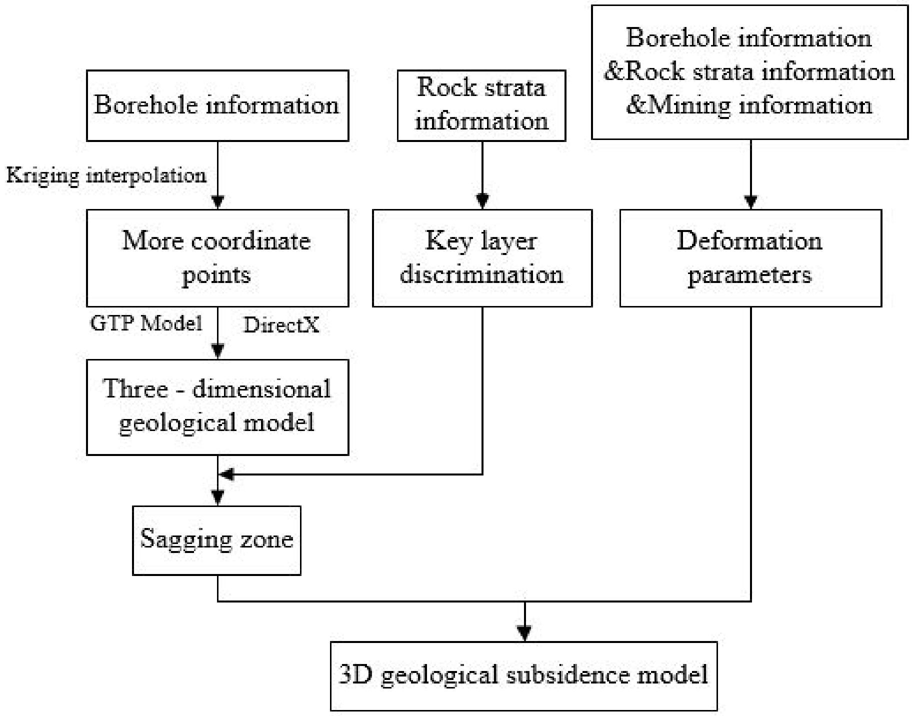

Fig. 1 Process of 3D geological modeling

3. Three-Dimensional Simulation of Sagging Zone of Overburden Based on GTP Model

3.1 GTP Structures

The generalized triangular prism (GTP) spatial data model is a real 3D spatial data model, which is based on the geological borehole (especially the deep borehole with borehole deflection). As shown in Figure 2, it consists of upper and lower two non-parallel triangles and three side quadrilaterals. The modeling unit has nodes, Tin edges, sides, Tin faces, side triangles and GTP. The structure of the GTP model is shown in Fig. 3. The structure of the GTP-based geological model uses the nodes to represent the strati graphic interface point of the borehole. The edge of the Tin, the side and the diagonal is the elements of the connecting node. The Tin triangle is closed by the Tin edge, and the side face is surrounded by a side, a diagonal and a Tin edge. Two Tin triangles and three side faces are closed to form a GTP body[11]. The complex three-dimensional geological model is formed by the combination of several GTP bodies.

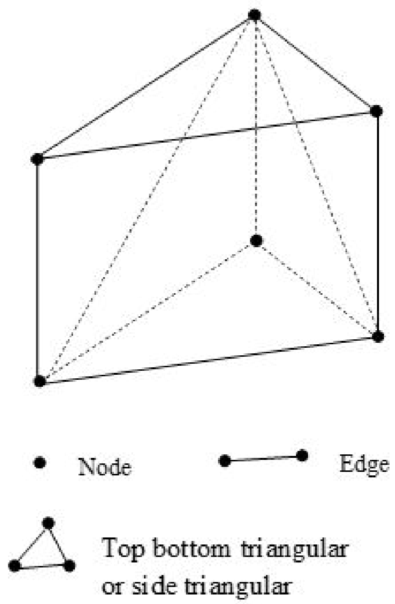

Fig. 2 GTP unit components

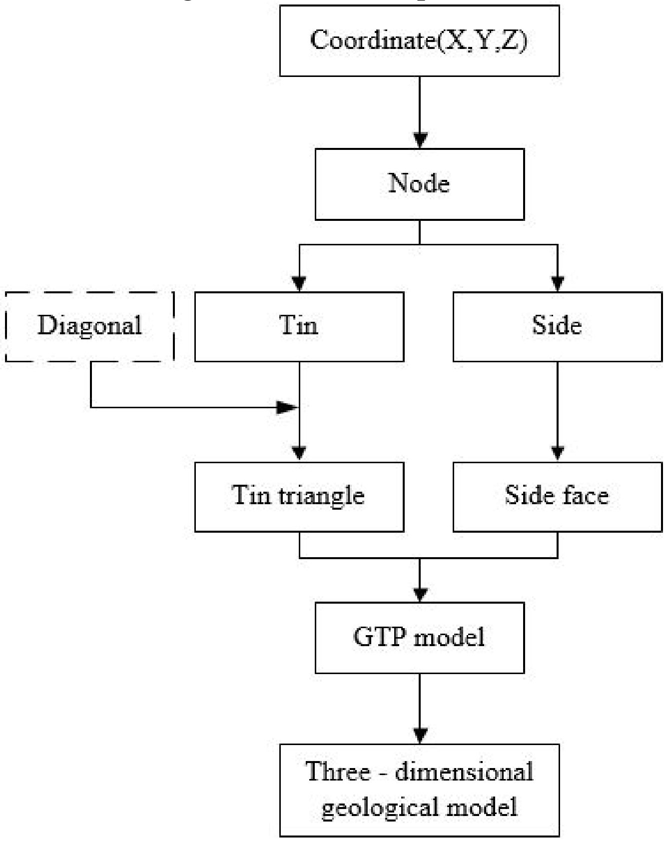

Fig. 3 Geological model structure based on GTP

3.2 Data Structure of GTP Model

The GTP data structure consists mainly of nodes, Tin edges, Tin triangles, side, side face and GTP elements. Each data structure has an ID number tagged instance. The data structure of the GTP model consists of four layers. The first layer is the node. It stores the coordinate of point. The second layer consists of Tin and side. The NodeID array of Tin edges stores the starting point and end point of the edge. The side structure is the same as the Tin side. The third layer consists of the Tin triangle and the side face. The Node array of the Tin triangle stores the three vertices of the triangle, and Edge array stores three vertices of the edge. The side of the TinEdge array stores up and down Tin side, and SEdge array stores two side edges. The fourth layer is GTP body element, the GTP LayID storages

GTP element's layer number. The tinTriangle array stores up and down two triangles, and the Sidequad array stores three side faces. Specific data structures design is in Table 1.

Table 1. GTP data Structures

Data structure	Program
Node	struct Node{long id; double x, y, z; // point coordinates};
Tin edge	struct TinEdge {long id; long NodeID[2]; //starting and end point};
Tin triangle	struct TinTriangle {long id; long Node[3]; //three vertexeslong Edge[3]; //three edges};
Side edge	struct Sedge {long id; long NodeID[2]; //starting and end point};
Side quad	struct SideQuad {long id; long TinEdge[2]; long SEdge[2]; //two side edges};
GTP	struct GTP{long idint LayerID; TinTriangle tinTriangle[2]; SideQuad sideQuad[3]; }

3.3 Key Strata Identification Methods

According to the literature [12], a layer or layers of rock strata, which control the movement of overlying strata or local strata up to the surface, are known as key strata in the overburden in the stope, which are called the main key stratum and the Sub key stratum respectively. When key stratum sinks and deforms, the subsidence of all or local overburden is synchronized with it.

According to the research of Xu Jialin [13] and other people, the key stratum identification first needs to determine the hard rock position. Mainly by determining whether the deflection of the m+1th layer is less than the deflection of the mth layer, the Formula 1 is the criterion for determining the stiffness of the key stratum. In the concrete discrimination, we start from the first layer above the coal seam to the upper layer, and calculate all the hard rock strata satisfying the condition.

$$E_{m+1} h_{m+1}{}^{2} \sum_{i=1}^{m} h_i V_i > V_{m+1} \sum_{i=1}^{m} E_i h_i{}^{3} \tag{1}$$

Where E_i, h_i and V_i are respectively the elastic modulus, thickness and bulk weight of the ith stratum;

These hard formations may become key strata, but the strength of the key stratum must be met. Then calculate the breaking distance of each hard formation, and ith layer of hard rock breaking distance (l_i) can be calculated by the following formula:

$$l_i = h_i \sqrt{\frac{2e_i}{q^i}} \tag{2}$$

Where e_i and q_i are respectively for ith layer of hard formation of tensile strength and load.

q_i can be determined by the following formula:

$$q_i = \frac{E_{i,0} h_{i,0}{}^{3} \sum_{j=0}^{m_i} h_{i,j} V_{i,j}}{\sum_{j=0}^{m_i} E_{i,j} h_{i,j}{}^{3}} \tag{3}$$

Where $E_{i,j}$, $h_{i,j}$ and $V_{i,j}$ are respectively elastic modulus, stratified thickness and bulk weight of the jth strata in the soft formation group controlled by ith hard formation.

If the kth stratum hard formation is the key stratum, the breaking distance should be smaller than the breaking distance of all the hard formations in the upper part, Therefore, the strength discrimination condition of the key stratum is

$$l_k < l_{k+1} \tag{4}$$

If the breaking distance of the kth layer is greater than the breaking distance of the k + 1th layer above, the load on the k + 1th layer hard formation is added to the kth layer hard formation, and recalculate the breaking distance of the kth layer hard rock. If the breaking distance of the calculated kth layer hard rock is still less than the breaking distance of k+1th layer, then take $l_k = l_{k+1}$. It is indicated that the fracture of the kth layer hard rock is controlled by the k+1th layer of the hard rock.

The key stratum discrimination of the three layers strata in Fig. 4 can clearly show the whole process of discriminating the key stratum, and finally get the position of the main key stratum.

3.4 Estimation Methods for Deformation Parameters of Overburden Sagging Zone

For the curved subsidence zone strata, the mathematical model is analyzed according to the media properties. The model is regarded as a continuous medium, and the self-weight stress of rock mass in subsidence zone can be calculated by the principle of continuum mechanics. The study of the sagging zone by Xia Xiaogang [14], the single strata movement model in the sagging zone under the action of the lower strata back force can be expressed as:

$$w(x,y)=(-1)^{2-\alpha}\frac{p_0 p_i^2 q_i^2}{\alpha(\alpha-1)(3p_i^2+3q_i^2+p_i q_i+Kp_i^2 q_i^2)}\left(\frac{x^2}{2p_i}+\frac{y^2}{2q_i}-1\right)^{\alpha} \quad (5)$$

$w(x,y)$ is as a function of the deflection of the key stratum;

p_i, q_i are the basic parameters for the ellipsoid parabola (the same number);

α is characterize the morphological parameters of the subsidence trajectory in the vertical direction $(0<\alpha\leq 2)$;

K is reaction coefficient of i-1th layer formation to the ith rock formation;

p_0 is the load on the ith layer strata, that is, the weight of the ith layer strata and the overlying strata;

The formula for further pushing the form parameter of the performance:

$$\alpha=\frac{1+\sqrt{1+\frac{4p_0 p_i^2 q_i^2}{mq\cos\theta\,(3p_i^2+3q_i^2+p_i q_i+Kp_i^2 q_i^2)}}}{2} \quad (6)$$

m is thickness of coal seam;

q is sinking coefficient;

θ is Coal seam inclination;

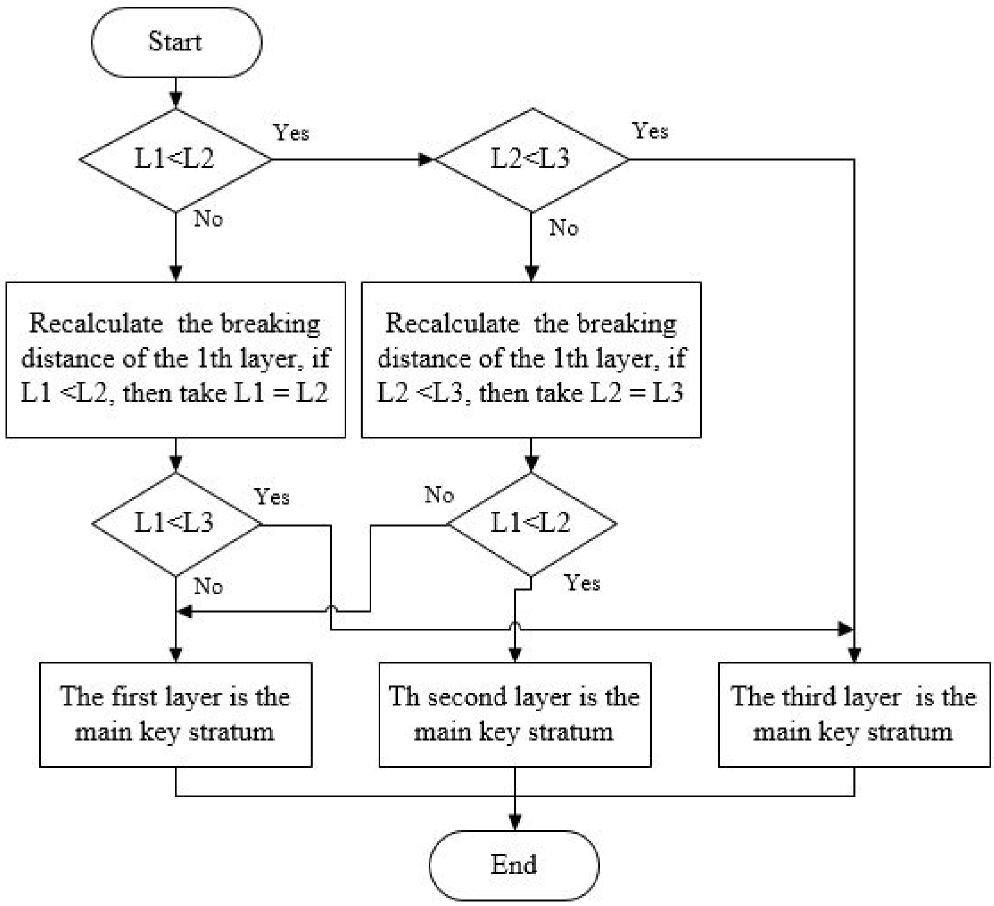

Fig. 4 Flowchart of Distinguishing key strata

3.5 GTP-Based Correction Models of the Construction Process

Due to the limited number of boreholes, it is not possible to meet the geometrical modeling of coal mine geologic body. So it is necessary to carry out Kriging interpolation on the basis of existing borehole data [15], as shown in Figures 5.1 and 5.2. The user then maps the X and Y coordinates of the borehole data to the origin as symmetrical as possible. Initial modeling based on the GTP model mentioned in 3.1 and 3.2, selecting the point in the upper left corner as the starting point, and add the triangular surface associated with that point to the tin triangle set or side set. After that, traversing the nodes that are drilled and interpolated and do the same operation whose process as shown in Figure 5.3 and figure 5.4. The GTP set of this layer is formed after each layer is traversed. The initial modeling results are shown in Figure 5.5. In the actual mining process, the overburden will be deformed. Therefore, for each rock strata under the main key stratum apply a curved sinking mobile model. First of all, we extract the bulk weight, thickness, load and so on. Then the key stratum is computed according to the discriminant method mentioned in 3.3, and the strata range of the sagging zone is obtained. Boreholes data and the mining information are imported into the mathematical model of the sagging zone mentioned in 3.4, and the amount of sinking is calculated. On the basis of the preliminary modeling of GTP, the model is modified. The final GTP correction model for the deformation parameters of overburden is obtained by sinking the coordinates of each sagging zone, as shown in Fig. 5.6.

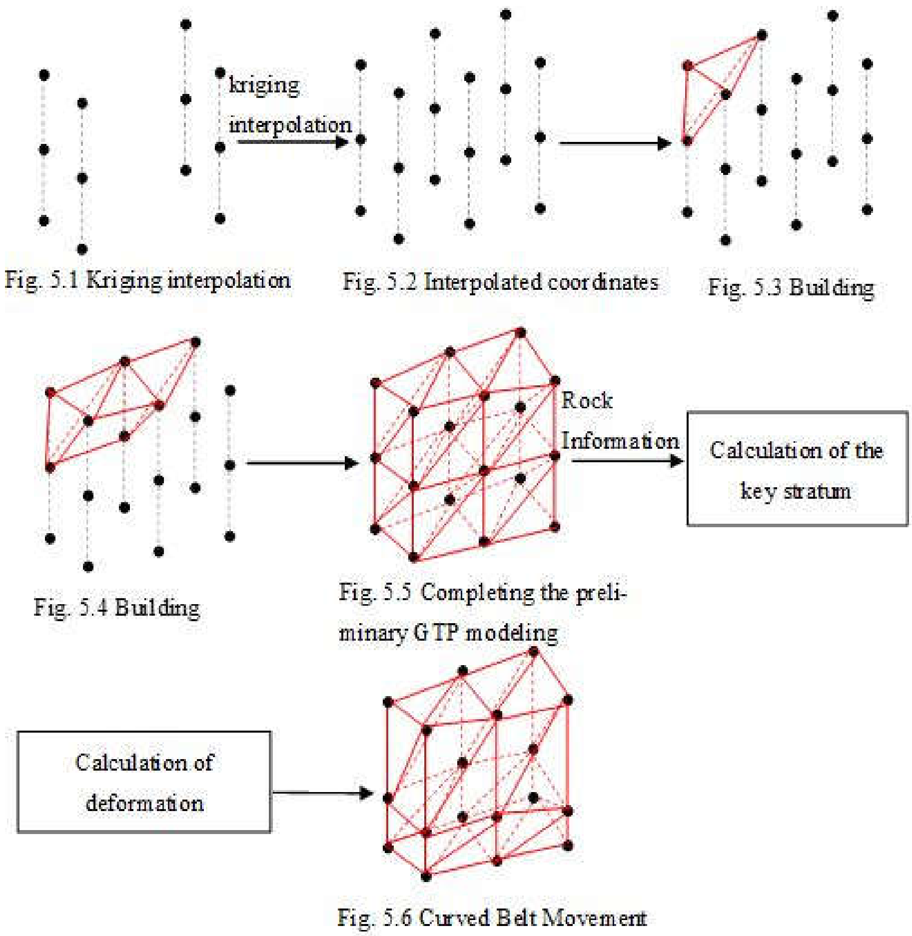

Fig. 5 Construction process of geological model

4. Experiment

Taking the model of Hongliulin field as an example in Shenbei Mining Area, Shaanxi Province, Hongliulin coal mine is located in the northwest of Yulin Shenm County, Shaanxi, north of the Loess Plateau, which is open terrain. The topography is generally characterized by high northwest, southeast low, middle higher, low north and south. In this paper, 304 drilling holes were drilled in the mine field, and a more representative 19 boreholes were used to study the application of GTP three-dimensional geologic model. The field layer of Hongliulin well consists of Aeolian sand layer, weathering layer, fine sand layer, slit layer and coal seam. Through the DirectX graphical API, the three-dimensional GTP geological model, as shown in Fig. 7.5, is rendered. And according to the 3.3, key stratum discriminant method and the data in Table 2 to determine the location of the key stratum. The basic parameters (p_i, q_i) of the ellipsoid paraboloid are 50000, 50000. The sinking coefficient (q) is 0.5, the dip angle of the coal seam is 1°. Calculate the values from the key stratum to the coal seam according to formulas 1, 2 and the corresponding parameters. On the basis of the previous three-dimensional geological model, the geological subsidence model is constructed, as shown in Fig. 7.6. The model can clearly show the three-dimensional image before and after bend band sinking

Table 2. Parameters of each rock stratum

Sequence of layer	Engineering geological unit	Elastic Modulus (10^4MPa)	Bulk weight (g/cm^3)	Thickness (m)
5	Aeolian sand layer	0	1.60	11.18
4	Weathering layer	0	2.22	28.74
3	Fine sand layer	1.70	2.31	33.76
2	Slit layer	1.51	2.37	83.24
1	Coal seam	0.22	1.29	10.77

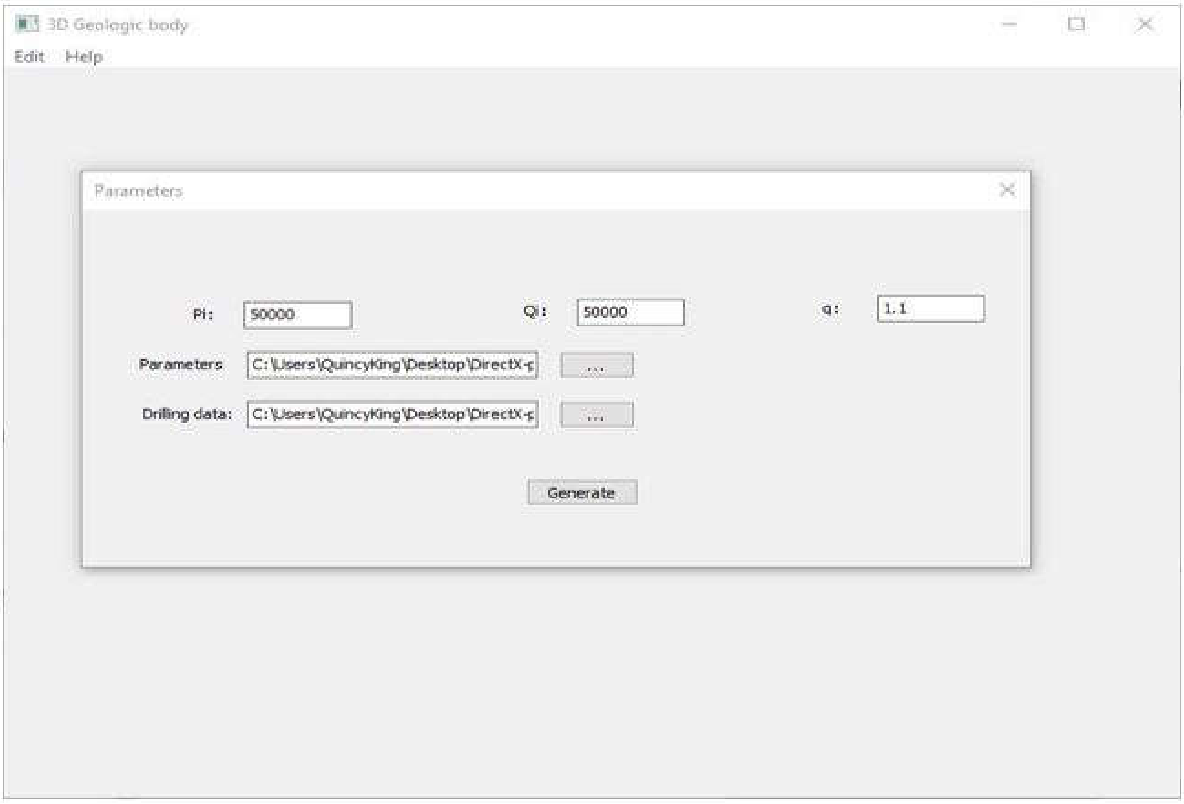

Fig. 6 Input parameters

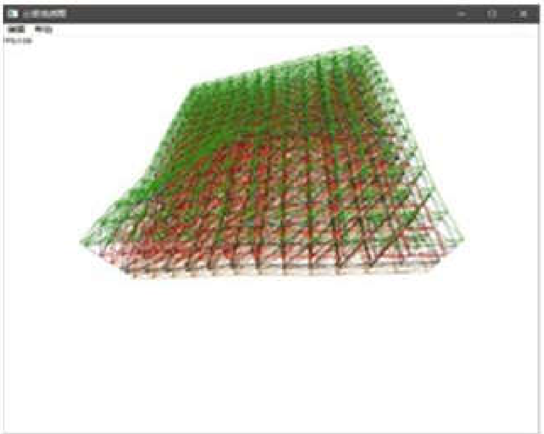

Figure 7.1 3D GTP model of geological body

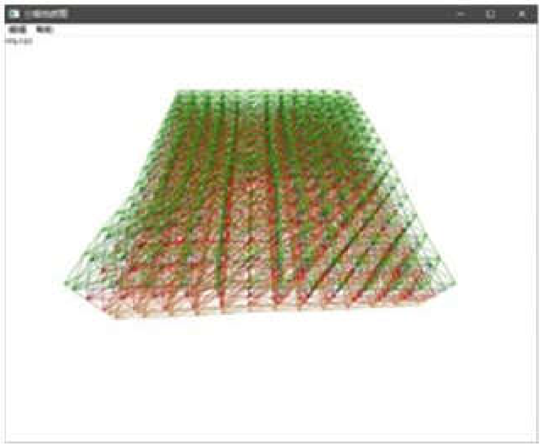

Figure 7.2 3D GTP model of geological subsidence

Fig. 7 Hongliulin field model

5. Conclusion

(1) After the processing information and geologic information are transformed into the overburden deformation parameters, the three-dimensional data model based on the key stratum theory is more reasonable by revising the GTP model.

(2) Using the modified GTP model, a three-dimensional modeling method based on the key stratum theory is proposed, which is feasible.

(3) The author applies the three-dimensional modeling method based on the key stratum to the drilling of Hongliulin field in Shenbei mining area of Shaanxi province. It simulates the subsidence of the sagging zone of the overburden in the mining area, which is of great significance to estimate mining results.

Acknowledgments

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