Based on the Profile of Complex Three Dimensional Stratum Modeling

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***Abstract*—With the development of computer technology and geological modeling study of the gradual maturity, 3D for the engineering geological modeling and information visualization analysis system of opportunities and challenges brought about. Have carried on the detailed introduction to the three dimensional geological modeling tool and the method. Summarized the three dimensional geological modeling basic step. Surface topography information deduce the initial construction of the geological model project . Carry out the calculation of occurrence. How to use the discrete value of the occurrence of information, production level surface equation method , And study of the surface intersection, Initial generation of 3D geological model .This paper discusses the adoption of the new access to the geological information on how to modify the initial model editor .Application algorithm for the generation of surface fitting interpolation. Display system for the section of geological strata, faultage and three-dimensional geological model of the effect drawings of block geological. At the same time, it provides a reliable scientific authority for the decision-making of the underground construction projects.**

***Index Terms*—2D modeling, 3D modeling , block track Delaunay Triangulation**

I. INTRODUCTION

Three-dimensional engineering geological modeling refers to the proper establishment of the geological features of the data structure mathematical model and use computer graphics technology to mathematical description of the geological 3D photorealistic images to be expressed in the form. Not only can the use of 3D modeling technology and intuitive description of the complex underground geological conditions, the image to express the morphological characteristics of geological structure, as well as structural elements of spatial relations, and the combination of engineering geological information, can make analysis more intuitive and accurate, so as to fast, dynamic three-dimensional reproduction of engineering geology and geological information to develop a comprehensive analysis and effective way.

According to the concept of limited geological prospecting data,Comprehensive geological expert knowledge and understanding of the geological features, we can use of the border zone between faults and the topology of the geological structure,then, applied mathematics fitting, stitching algorithm and cell block.

This modeling system is the source of geological information database based on multi-service support platform for the effective use of topographical, geological boundaries, faults, geological occurrence and small-surface histogram and other information on the establishment of surface geological model, the application borehole data, surface occurrence data extrapolating the initial geological vertical section. Since then, the application system provided by the longitudinal profile editor, editing by geological experts to amend the initial longitudinal section in the longitudinal profile with the correct, based on the generated cross-sections along the baseline.

II. THREE-DIMENSIONAL GEOLOGICAL MODELING

Three-dimensional geological modeling research focuses on design of multi-coupling Geological data and knowledge integration of geological experts.According to reliable information provided a Kinds of geological data ,it accurately reflect the distribution of spatial structure and internal relations department of modeling methods.Based on the concept of the project of geological data, Geological expert knowledge, computer processing, fitting and Computational Mathematics , Method is divided into four steps: first, geological features and 2D / 3D geological interpretation section; Second, information between the establishment of Profile Control Automatic Search and Surface geological unit block; third, Using surface fitting and triangulation network technology Integrated operation section block; Fourth, Using cell block set computing complex three dimensional Transfer model for reconstruction.

A. The definition of 3D geological modeling

We have the concept of two-dimensional block structure model can be extended to three-dimensional

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description of three-dimensional block structure model. Is not difficult to believe that three-dimensional block structure model that can actually be considered the same stratigraphic section in the adjacent block connections. Shall also belong to the same strata in the adjacent section of the envelope body. Each layer of blocks is a separate geological blocks, each a separate block with its own geological geological properties and the outer surface. The use of surface space for three-dimensional geological model describes the block can be three-dimensional geological block is defined as: $g = H_u \bigcup H_d \bigcup S_b$. Of which: H_u Block for the upper layer interface; Block for the lower layer interface; S_b To block surrounded by the lower layer interface for the closed boundary surface. Three-dimensional geological block gives the definition of the airspace defined three-dimensional geological model and the geological nature of the bulk of the set operations:

(1) Complicated geological structure model body formation can be three-dimensional reconstruction of geological blocks of space *n* independent body, and set descriptions, denoted by $G = \bigcup_{i=1}^{n} g_i$. This means: any complex three-dimensional geological model can be applied to simple structure, a collection of geological unit body composition.

(2) In any complicated geological structure, the various geological block independent existence and disjoint, ie $\bigcap_{i=1}^{n} g_i = \phi$.

(3) Complicated geological stratigraphic structure model can be arbitrarily broken down into different numbers of sub-set of the geological block model, namely: $V = G - \bigcup_{i=1}^{l} g_i$

The three-dimensional geological modeling software development status and the significance of topics. Have carried on the detailed introduction to the three dimensional geological modeling tool and the method. Summarized the three dimensional geological modeling basic step. Secondly, this article discussed how based on the geological boundaries、geological occurrence, such as surface topography information deduce the initial construction of the geological model project . Carry out the calculation of occurrence. How to use the discrete value of the occurrence of information, production level surface equation method , And study of the surface intersection, Initial generation of 3D geological model .

This paper discusses the adoption of the new access to the geological information on how to modify the initial model editor .Application algorithm for the generation of surface fitting interpolation.At last, display system for the section of geological strata faultage and three-dimensional geological model of the effect drawings of block geological.

B. The Implement structure of 3D geological modeling

Three-dimensional geological block constituted by a number of facets, each facet has its own border curve and control points, where the boundary curve is a patch with other facets of the intersection line determines the surface film scope, while the control point determines the appearance of patches of the geometry. Three-dimensional surface of these films do not have the appearance of the rules are often complex, often use triangulation to represent the space of these complex surface film, will be a continuous three-dimensional discrete surface patches into a series of triangular mesh can be effectively expressed the three-dimensional geometric surface patches appearance. It is shown in Figure 1:

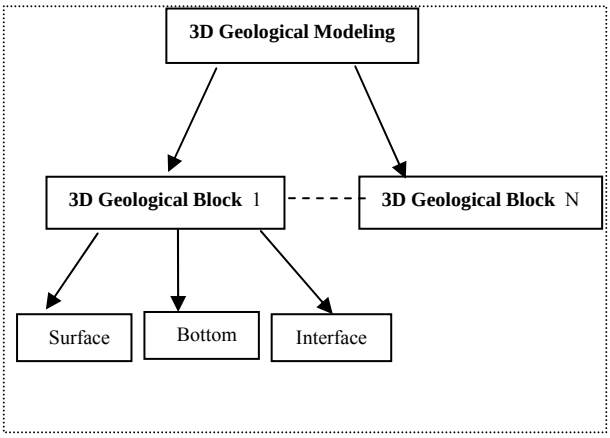

Figure1. Three-dimensional geological block diagram topology

C. The generation of 3D geological modeling

Geological unit provided a good theoretical basis and research premise, therefore, three-dimensional reconstruction method is an important research project. Typically, the basis of engineering geological studies data, which are from the drilling, exploration and topography data tunnel. Obviously, Complex geological structure is different from the actual construction of the geological unit.

The definition of the geological unit , the fault plane constitutes an integral element in the geological units. Geological unit to establish the initial conditions and

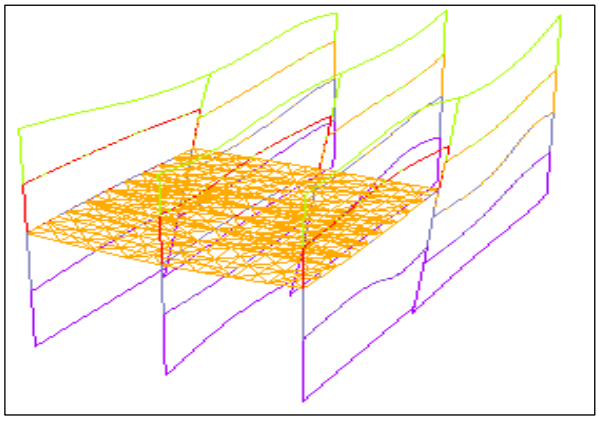

Figure2 . Geological unit

hree-dimensional manner heuristic Quality model framework to build, it has the following advantages: First, the fault plane smooth, avoiding the geological profile layer, fault interpretation Inconsistency; second,this method helps geologists understanding the spatial domain changes in the characteristics of the geological structure; third,No single geological structure of the model can explain the geologic section, auto-complete Into the geological model and improve the efficiency of a simple model of the reconstruction.

Engineering geological 3D visualization of significance not only in improving the efficiency of geological mapping, More importantly, it built up in a timely manner to reflect the rapid geological information integration of the three-dimensional geological model, to the geological staff, the designers of the Turkish-geological problems in the correct judgment, analysis visualization of integrated information . Summarized the three dimensional geological modeling basic step. Secondly, this article discussed how based on the geological boundaries geological occurrence, such as surface topography information deduce the initial construction of the geological model project . In short, engineering geological information visualization will be the development of the geological engineering an important direction and has great theoretical and practical value.

III. THE THREE-DIMENSIONAL GEOLOGICAL MODELING PROFILE

A. The principle of the profile geological modeling

Three-dimensional geological block model is defined as a complex three-dimensional geological modeling to provide the basis of modeling method. As a result, the complex three-dimensional geological modeling into two adjacent geological strata of the two-dimensional cross-section block with the same body connection, for one stratigraphic section and the other a cross-section there is no such attribute for formation of the stratigraphic pinch-out processing block join algorithm research, namely through the strata block join algorithm processing block after the election of the three-dimensional structure of the geological unit body is enclosed envelope volume is a polyhedron composed of four. Figure in the C1, C2, C3 and C4, respectively, two-dimensional block stratigraphic structure, in which C2 for the pinch-out formation.

The actual engineering geology, geological section is to explain Quality experts to complete the geological structure and geological features of the important map Pieces. Generated in the system for interactive and geological geological section. Formation properties with multi-segment line profile composed of layers, each layer line Segment endpoint is the intersection topology, topological intersection is the line and ground layers Form, formation, fault, or the intersection of section boundaries. Thus, Take advantage of profile formation, fault and topology of the boundary line profile intersection Search space to establish an automatic multi-geological unit of information storage body Storage data

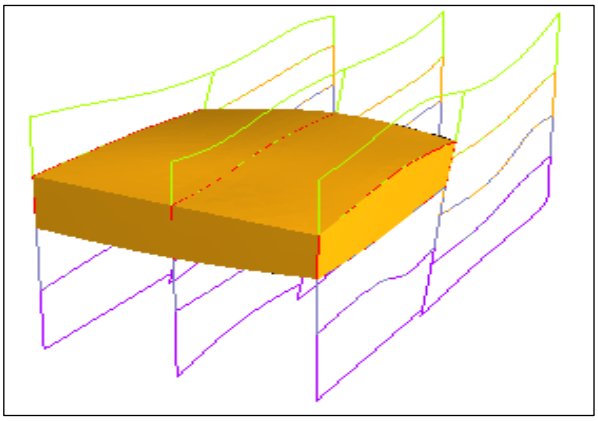

Figure3. 3D geological modeling

structure used to store profiles terrain, stratigraphy, faults, layers Segment intersection control point information and topology information.

Because of changes in geological conditions, the complexity and diversity, the same connection will be very complicated stratum. But can be summarized as follows to connect several stratigraphic correlation:

(1) 1 to 1 relationship
(2) 0 to 1 or 1 to 0
(3) 1 or more pairs of a multi-relationship
(4) many to many relationship

Ray methods play a vital role in seismic exploration. Among all ray methods, Gaussian beam method is a fast method of seismic wave field modeling. The seismic wave field obtained by this method has wave properties in both kinematics and high-frequency dynamic. By merging wave equation with the ray theory, the method obtains ray tracks by the kinematical ray tracing, and obtains distributions of high-frequency by the dynamic ray tracing. As a result, it has the dynamic and geometric characters while costing little calculation time, and shows good precision.

B. The traditional method of 3D modeling

A simple three-dimensional geological building block approach is the use of two-dimensional geological block contour reconstruction three-dimensional shape. Achieve the two-dimensional geological block adjacent contour lines between the three-dimensional model reconstruction is to use a range of interconnected triangular piece will be two adjacent contour lines to connect in space. show in Figure 2

However, how to ensure connecting the three-dimensional surface model is reasonable, and has a good nature need to be carefully studied. Connecting adjacent two-dimensional geological block the various control points of the contour line formed by a number of basic triangular face, should constitute the interconnected three-dimensional surface, but not between the internal intersection of triangulated surfaces.

Introduced in front of three-dimensional reconstruction based on contours of geological block model method, this method has the advantage of simple and can effectively build three-dimensional geological block model, but requires the user to draw a large number of two-dimensional geological section, as algorithm is carried

out only two-dimensional geological profile of the direct connection, instead of interpolation and smooth, so only when the density profile when the larger model can be connected out of the fine work. However, in practical work hard to give high-density two-dimensional geological section, so this method in actual use is very limited. The current reconstruction algorithm based on contour lines and more used in medical image reconstruction, because the two-dimensional slices for the reconstruction of tissue density is very high, space between adjacent sections, only about 1mm or so. However, in geological exploration to provide such a high-density two-dimensional geological section is very difficult, in the work area in a three-dimensional, two-dimensional profiles can be used for modeling is often less, directly connected and disconnected three-dimensional contour surface is very rough, in order to construct Fine three-dimensional geological model, you must use some method of interpolation or fitting, however, the entire algorithm in the previous three-dimensional geological surface triangulation by a closed form, the present three-dimensional shape for the space not an accurate and efficient interpolation algorithm to the entire closed triangle interpolation and segmentation. If you want to smooth the model for fine structure must be a complete closed triangle divided into several surface patches of different surface patches using some interpolation method to interpolate, and then use interpolation functions and sub-triangular structure encryption accurate smooth model.

$$
\begin{aligned}
&P(u) = au^3 + bu^2 + cu + d \\
&a = -2(P_1 - P_0)/\Delta^3 + (P_1^{'} + P_0^{'})/\Delta^2 \\
&b = 3(P_1 - P_0)/\Delta^2 + (P_1^{'} + 2P_0^{'})/\Delta \\
&c = P_0^{'} \\
&d = P_0
\end{aligned}
\tag{3-1}
$$

$$
\Delta_i P_i^{'} + 2(\Delta_{i-1} + \Delta_i)P_{i+1}^{'} + \Delta_{i-1}P_{i+2}^{'} = 3(\Delta_i \frac{P_i - P_{i-1}}{\Delta_{i-1}} + \Delta_{i-1} \frac{P_{i+1} - P_i}{\Delta_i})
$$

two-dimensional geological profile with the curve method in three dimensions you can use the surface to represent the geological model, three-dimensional geological aspects of surface model, from the level model, can see the first three-dimensional geological model of the entire surface to be ground, ground surface, bounding surface model of the fault surface and split into multiple three-dimensional geological block, each a three-dimensional geological block some of the patches the surface composition of each surface to be more geological body share. Second, in the space of each surface level of the basic present form, does not back off in the space phenomenon, it is because the formation of sedimentary strata remained through the layered structure caused by the surface in space because there is no return to the basic discount and, therefore, can use the existing Some two-dimensional surface interpolation method uses the known profile of the curve control points for surface interpolation, so that a smooth curved surface can be constructed to achieve the purpose of refining the model.

Surface interpolation function can be used to construct three-dimensional space in a continuous smooth surface, but this is controlled by the surface interpolation function scope is infinite, however, three-dimensional level model of each surface are some control over their own range, the boundary line of each surface and the surface by the model cross-border wire. Intersection between the surface here is very critical, it is by the intersection of two surfaces of the decision, which determines the direct line of approach is to surface intersection, surface interpolation function, however, is often more complex, costly direct Intersection. A more convenient way is to use topological relations, starting with the profile to find the intersection curve, then the intersection of multiple profiles connected in the space of a basic spatial intersection, the use of function interpolation intersection curve interpolation, structure smooth space intersection, and then smooth the encrypted space as the intersection of two surface interpolation control points used by the interpolation control points, so that the two surfaces constructed through interpolation function to generate pre-pay online for the control of space point, Some two-dimensional surface interpolation method uses the known profile of the curve control points for surface and after the intersection encrypted and therefore a high density of control points to guarantee the accuracy of the two surfaces.

Using the previous method can be constructed out of smooth three-dimensional layered model, three-dimensional geological block model with the surface layer has a close relationship, three-dimensional geological block model by the multiple layered mosaic of surface patches.three-dimensional geological block definition, in which the lower layer block model of the interface formation is the level surface; Some two-dimensional surface interpolation method uses the known profile of the curve control points for surface the upper interface of the upper strata may consist of multiple patches splicing form;boundary surface formation blocks and the model fault plane is usually constitute a boundary surface and boundary surface layer of the block can be further broken down into four sub-patches all around.

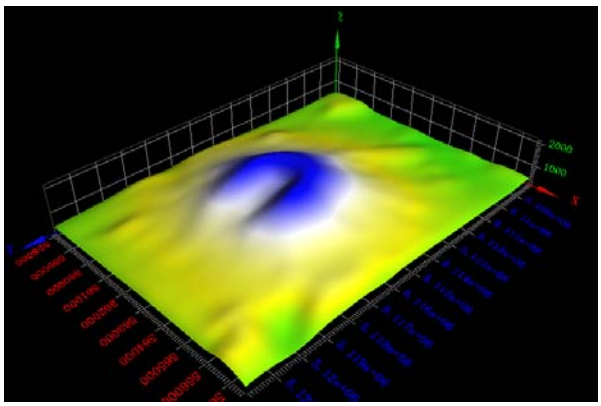

Figure4. The traditional method of 3D modeling

IV. TRIANGULATION AND LIMITED ENCRYPTION ALGORITHM

A. *Llimit the triangulation*

Triangulation is to describe the basic elements of three-dimensional body surface is an important tool for three-dimensional geological modeling. The use of triangulation techniques can be drawn in a number of user profiles on the irregular distribution of stratigraphic control point to connect the triangular structure into a continuous surface to approximate the three-dimensional geological body surface. For a given n points $p_1, p_2, \ldots, p_n$, triangulation refers to disjoint line segment *connecting* p_i *and* p_j, $1 \le i, j \le$ n, i $\neq j$, and so that each net is a triangular area. Triangle Network is a plan, it has n vertices, it contains at most 3 n -6 edges. If you can give them the edge of a table, then get a solution of the problem. However, in practical applications often required for the triangulation made a number of constraints, this chapter in the Delaunay triangulation on the basis of further information on how to optimize three-dimensional subdivision.

$$\begin{cases} z_i(x,y) = a_0 + a_1 x + a_2 y \\ \quad + \sum_{\substack{j=1 \\ j \neq i}}^{n-1} F_j r_{ij}^2 \ln(r_{ij}^2 + \varepsilon) + c_i F_i \\ \sum F_i = \sum F_i x_i = \sum F_i y_i = 0 \end{cases} \tag{4-1}$$

B. *Triangulation encryption algorithm*

In a three-dimensional work area, the use of limited Triangulation Triangulation model can be established in the performance of the basic geometry of geological surface features, but if the user is given control points more sparse, or non-uniform density of data points, then constructed a triangular network a rough, partial rapid change. In order to construct a more smooth and delicate three-dimensional geological model, we must take a complete closed triangular mesh into several surface patches, in order to meet the requirements of precision surface patches, the need for further breakdown of surface patches.

According to computer graphics coordina related to the concept of translation and rotation transformation, computing the first r blocks (j = 1,2,3, ... L) data on the total transformation matrix:

$$T_{m_j} = T_c \cdot R_x \cdot R_y . \tag{4-2}$$

With the general transformation matrix, we can discrete points.

$$\left[x_r^{'}, y_r^{'}, z_r^{'}, 1\right] = T_{m_j} . \left[x_r, y_r, z_r, 1\right]^T \tag{4-3}$$

Spatial discrete data points after this transformation, and projected onto the corresponding plane, you can directly through the two-dimensional triangulation procedures to deal with. This block generates the triangular mesh over a simple combination is that we need a basic triangular grid. This basic right triangle mesh is subject to elimination of duplicate vertices, grid optimization, trajectory line generation process, three-dimensional discrete data can be three-dimensional subdivision.

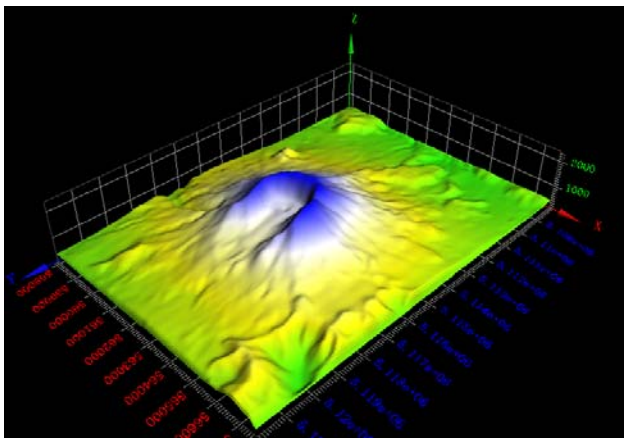

Figure 5. The Triangulation encryption algorithm of 3D modeling

Formed by the deposition of strata, and therefore has a layered Structure characteristics. After several subsequent tectonic movements occurred in all strata Kinds of deformation, the formation of various types of faults are segmented.The structure has become complex and diverse underground strata. Two-dimensional modeling of geological section Description should provide an effective means of complex geological phenomena. Common Two-dimensional modeling approach is the use of curve profiles to describe the surface.Chord section can be improved spline Uneven distribution of sample points on the shape of the curve, elimination curve Kinks.

C. *Surface adaptive optimization rule*

Adaptive subdivision surfaces is divided into sub-standard and sub-rules of two parts: a number of sub-criteria are used to control the subdivision process; subdivision rules used to recursively subdivided triangle. Subdivision standards are typically used to represent the maximum curvature surface. Directly solve the maximum surface curvature calculation of a large amount of practical application is a multi-curvature estimate.

$$\begin{pmatrix} 0 & R_{12} & R_{13} & \cdots & R_{1n} & 1 & x_1 & y_1 \\ R_{21} & 0 & R_{23} & \cdots & R_{2n} & 1 & x_2 & y_2 \\ \vdots & \vdots & \vdots & & \vdots & \vdots & \vdots & \vdots \\ R_{n1} & R_{n2} & R_{n3} & \cdots & 0 & 1 & x_n & y_n \\ 1 & 1 & 1 & \cdots & 1 & 0 & 0 & 0 \\ x_1 & x_2 & x_3 & \cdots & x_n & 0 & 0 & 0 \\ y_1 & y_2 & y_3 & \cdots & y_n & 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \\ \vdots \\ a_n \\ w_0 \\ w_1 \\ w_2 \end{pmatrix} = \begin{pmatrix} z_1 \\ z_2 \\ \vdots \\ z_n \\ 0 \\ 0 \\ 0 \end{pmatrix} \tag{4-4}$$

其中 $R_{ij} = r_{ij}^2 \ln(r_{ij}^2 + \Delta)$

Curvature Estimation of a variety of methods, such as the surface point to its planar approximation. shown in Figure 4. The maximum distance piece, or the height of the surface area divided by the surface to represent the other. the triangle vertices in the corresponding points in the outer surface method vectors N1, N2, N3, each vector

of foreign law must be satisfied (1-Ni.Nj) <ε, i ≠ j and i, j ∈ (1,2,3). ε is tolerance, used to adjust the grid density. For the high-curvature regions are always segments continue, such as the Regional shrink to one point, then stop segments. In order to make triangular pieces as much as possible close to the surface to generate a better grid, ε generally taken to be 1.0 × 10-2-1.0 × 10-4.

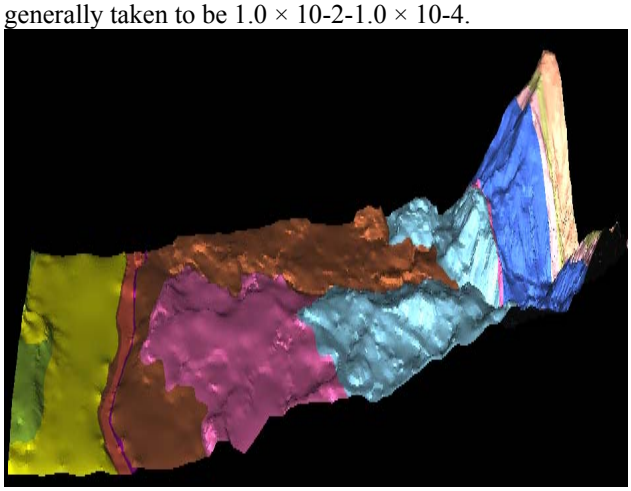

Figure6. Surface adaptive optimization rule

Generate the initial triangular mesh surface, the surface in order to meet the precision requirements, the need for their networks to generate the curvature of each triangle test. Right triangle does not meet the tolerance requirements of a breakdown, while the relationship between changes related to the adjacent triangle until all triangles satisfy the tolerance requirements.

Three dimensional forward modeling by ray method needs three dimensional stream modeling and ray tracing. However the three dimensional geological modeling, especially the complex model structure usually is quite difficult. This article proposes a model expression method of three-dimensional geological model based on three-dimensional geological block, and introduces a algorithm which uses two-dimensional geological cross section to construct the three dimensional geological model. The algorithm has effectively solved the complex geological modeling problem. Based on the firsthand information about two-dimensional geological cross section edited by users, the method automatically structures initial model on three-dimension geological blocks, then smoothes the results, to output a polished, exquisite, and the reasonable triangle grid model. The separate triangle grid may describe the complex geologic structure. But, because of containing massive triangles, it causes the beam tracing efficiency quite to be low. Therefore this article introduces a method by using space surrounding box carries on fast ray tracing on the triangular net model. Using this method, it is possible to quickly complete the beam tracing on the complex model, even up to ten thousand strip beams, while costing little calculation time. The method is helpful for three dimensional forward modeling and has the very strong practical value.

IV. System Testing

By the study of three-dimensional geological modeling and Gaussian beam method, this paper designs an architecture of the distributed three-dimensional geological modeling and Gaussian beam seismic wave field modeling software, based on three layers software framework and net database. We have developed the complete autonomic intellectual property software with Qt and OpenGL, the results of a lot of examples testing indicate that this software is stability and effective, and has a bright perspective in practical application.

Three-dimensional geological modeling function modules to achieve the main idea is: in the geological profile model based on the application described in chapter IV of geological modeling principles, the interconnection between adjacent cross-section of the strata building block method of modeling three-dimensional geological model . Three-dimensional geological model of the formation contains a three-dimensional structure, and fault structure of the geological structure information.

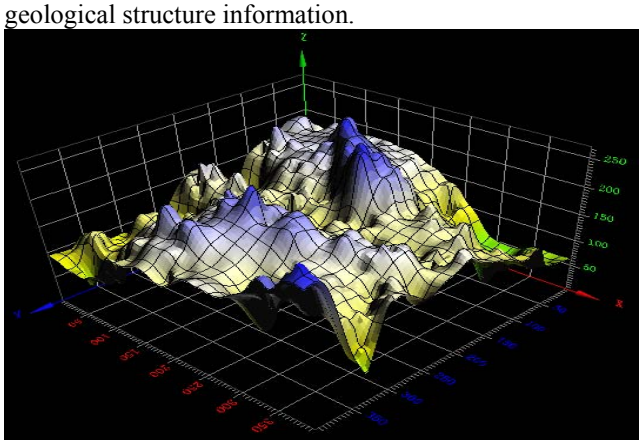

Figure7. Testing A of 3D modeling

For initial mesh scale, it can rectangular domain horizontal longitudinal ratio and will short side grid number set 1 or a base n, long side grid number Make length ratio and short side grid Number product . Thus established by two-dimensional profiles fine geological model of the basic idea is: First, the surface interpolation using surface interpolation methods, formation and fault surfaces; and then find out the three-dimensional geological block and surface topology of each space to construct three-dimensional geological block. The following is the profile based on surface interpolation method for three-dimensional geological modeling of the general introduction.

Three dimensional forward modeling by ray method needs three dimensional stream modeling and ray tracing. Based on the firsthand information about two-dimensional geological cross section edited by users, the method automatically structures initial model on three-dimension geological blocks, then smoothes the results, to output a polished, exquisite, and the reasonable triangle grid model. The separate triangle grid may describe the complex geologic structure. However the three dimensional geological modeling, especially the

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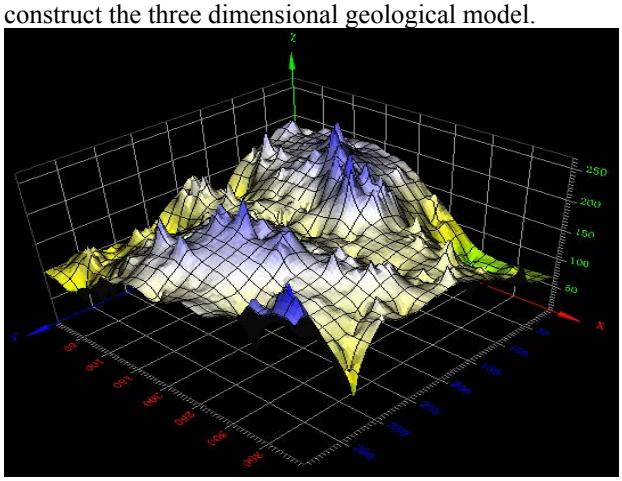

Figure8. Testing B of 3D modeling

As is shown above, the whole performance of the system improve in more obvious results, reducing the appearance of the triangle tip-off.

B Test Conclusion

Through a series of comparison tests, adaptive Interpolation method for large-scale data is an effective solution to containing a large number of discrete data points of the surface surface interpolation.

Geological research is very important basic research. However, engineering geological modeling analysis system software with a certain scale of software research, at china have not yet ripe related software products. With the development of computer technology and geological modeling study of the gradual maturity, 3D for the engineering geological modeling and information visualization analysis system of opportunities and challenges brought about. Engineering geological 3D visualization of significance not only in improving the efficiency of geological mapping, More importantly, it built up in a timely manner to reflect the rapid geological information integration of the three-dimensional geological model, to the geological staff, the designers of the Turkish-geological problems in the correct judgment, analysis visualization of integrated information . In short, engineering geological information visualization will be the development of the geological engineering an important direction and has great theoretical and practical value.

V. CONCLUSION

We can draw the following conclusions through testing:

In this paper, construction engineering, water conservancy construction and geological Disasters, Spatial Structure of engineering geology, information visualization research Study proposed a complex three-dimensional geological model of structure formation square Reconstruction Method of its features are: the concept of geological unit body, maximum Simplify the complex geological modeling approach.geological experts Computer interactive process of knowledge and technology to ensure the building of the complex Better reflect the geological model geological features.Application Formation, the boundary fault and the model topology of the body of information and effective Solution to the geological unit blocks automatically search and create.Since the introduction of the concept of geologic unit cell model of visual resistance increased Performance and operability. The proposed combination of any geological unit cell modeling, simulation Tracking browser type, model and any cutting roaming visualization cave exploration technology. Important feature of this method is realized in only a few reliable The case of raw data, by geological experts, computer processing Close integration of theory and modeling of complex geological structure of the construction of the fine Model, an effective solution to the reality of operational and geological modeling Be practical. Inadequate aspects of the method for generating geological Too much profile need geological experts to participate, making the model a long time; mode Finesse-type formation and geological sections directly related to accuracy. The former terminal with multi-operating system application software is also distributed Will eliminate, any method which is difficult to avoid.

Using Based on the three-dimensional geological modeling profile has the following advantages: Application algorithm for the generation of surface fitting interpolation. Display system for the section of geological strata 、 faultage and three-dimensional geological model of the effect drawings of block geological. At the same time, it provides a reliable scientific authority for the decision-making of the underground construction projects etc.

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