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Study on a Computing Technique Suitable for True 3D Modeling of Complex Geologic Bodies

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Abstract: True 3D solid modeling of complex geologic bodies still face many difficulties. In this paper, a new technique of true 3D solid modeling is addressed, which incorporates the application of 2D&3D interactive aided section technology to revise scatter point aggregates , the means of two-body 3D data structure (improved B-rep 3D solid data structure) to organize data and the usage of vector shear technology for modeling. Based on such techniques, a true 3D solid model of a large hydropower engineering project in southern China was built to serve as intuitive platform for engineering survey, design, and construction. In the light of its wide application to many projects, it can be considered as a reasonable and effective method for 3D modeling of complex geologic bodies.

Keywords: Complex geological bodies, 3D modeling, Two-body 3D data structure, Vector shear, China.

INTRODUCTION

Because of the complexity and nonvisibility of underground geologic structure, one common characteristic of geological data acquired is the incompleteness of structural information, relation information, evolution information, and parameter information (Wu Chonglong, 2011), which partly implies that geology cannot be considered as a quantitative science. With the progress made in information technology, 2d analysis and abstract generalizations to intuitive observation and analysis in 3D space has been developed. With regard to the modeling of geologic bodies, earlier workers have conducted extensive research work on many of these aspects (Jonathan Raper, 1989; Li Deren, 1997; Gong Jianya, 1997; Xu Yuanbin, 1997; Li Qingquan, 1998; Santos, 2000; Wu Chonglong, 2001; Wu Lixin, 2003; Pan Mao, 2003; Wu Xincai, 2004).

Generally, in spite of 2d sections (i.e. presented as a line in plan and as section in space), a large number of inferences need to be made so that the obtained geological data can be represented in accordance with the geological set up though the data is insufficient. There are numerous such sections in 3D space and most of them have no supporting data, so interpretation of new data is necessary for processing so as to obtain the spatial distribution information of the various geological units of the underground geologic body. However, results obtained by interpolation are not always consistent with the geological framework, and in some cases, great differences may arise.

In addition, both 3D data structure and 3D modeling methods are important factors influencing the 3D geological modeling. At present, the widely used methods include wireframe model (Mun Wai Lee, 2003; Bastante, 2005), solid model (Michael Reed, 1999; Gershon Elber, 2005), CSG (Constructive Solid Geometry: Jacques-Louis Lions, 1999; Suzanne F. Buchele, 2004), B-Rep (Boundary Representation: Fleisig, 2005; Cervera, 2005), sweep representations (Shih,, 2005; Dibakar Sen, 2008). However, these methods are not applicable to the complex geologic bodies and that the 3D models constructed are not as ideal as one can expect.

OBTAIN AND ANALYSE DATA OF COMPLEX GEOLOGIC BODY

The data of complex geologic bodies are generally obtained from the ground survey, geological mapping, misering, exploratory tunnels, trenching, geophysical exploration, geological test and geological sampling, etc.

The data can be divided into two categories:

1 Spatial data of location and boundaries to describe spatial location of each unit of the geologic body. This includes describing the research area in 3D space, terrain surface, interface of stratigraphic unit of the geologic body, geological structure, interface of surface water, surface ground water level, varying degrees of weathering, and spatial distribution (as shown in Fig.1);

2 Attribute data of background and characteristics: i.e. data of each geologic unit representing geological background, geological age, lithology, parameters of physico-mechanical properties, degree of integrity, stability, etc.

Analysis of a complex geologic body includes geological background analysis, landform analysis, drilling analysis, profile analysis, plane analysis, stratigraphic lithology analysis, features of each geologic units analysis, spatial location and distribution analysis, etc.

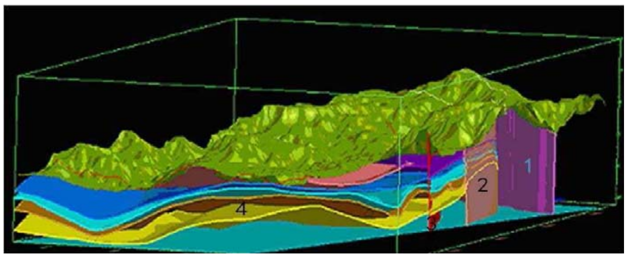

Fig.1. Structure schematic of complex underground geologic bod. 1 - Boundaries of two intrusive rocks. 2 - Boundary of intrusive and sedimentary rocks. 3 - Fault plane. 4 - Interface of stratigraphic unit.

Therefore, obtaining the data of complex geologic bodies is a process of gradually determining a variety of boundaries and properties of each unit within boundaries, and the analysis includes analyzing the spatial location, boundaries and the properties of each unit within boundaries. Such characteristics are greatly similar to the method of B-rep in solid modeling, that is, the data organization and modeling method of B-rep meet the needs of data acquisition and analysis of complex geologic bodies, however, the data structure of B-rep is complicated and a large amount of time would be expected to deal with complex geologic bodies.

SELECTION AND IMPROVEMENT OF 3D DATA STRUCTURE

Given a series of restricted factors, i.e. complexity, invisibility, incomplete data acquisition, high cost of data acquisition, 3D data structure is considered as bottleneck of 3D geological modeling.

The wireframe modeling method describes the geometric shape of the object using the measure of vertices and edges. Surface modeling describes each surface of objects employing topological relations of surface and edge. As for solid modeling, it can not only give the geometry information but also define the topological information of point, line, surface and body, so, it is currently a commonly used method.

As a solid modeling method, B-rep can represent the object information such as geometric information, topological information and attribute information in three areas by describing the various objects and their internal borders, hence, it can describe spatial information of the complex geologic body (geometry information and the topological relations) and feature information of each specific geological unit (attribute information), thus it can satisfy the expression and analysis of complex geological bodies.

The advantage of B-rep is that the point, line, surface and other geometric elements of a solid are exposed and can be drawn out much more quickly, which will serve as an easy access to a variety of operations on the solid body. However, the drawback is that the complex data structure would take a lot of storage space and lead to a long time on processing the complex geologic body, e.g. the shear process between the large-scale complex geologic bodies.

Keeping in view the above issues, the traditional B-rep method was improved here by proposing "two-body three-dimensional data structure", of which the definition refers to as: "the two contact surfaces between two adjacent body units were merged into a side surface, each section was allowed to be adjacent with two solid elements at a maximum to constitute coplanar structure of the two-bodies and the sharing section has the properties of two solid bodies".

The proposed data structure is illustrated in Fig.2, which was simplified into a 2d section diagram for representation and convenience. The figure shows six body units ,which are referred to as V1, V2, V3, V4, V5 and V6 and five surfaces and dividing lines between each two body units.(i.e. A, BCD, E, F, G (G for the lenticular body boundary). Surface A is interface of V1 and V2 and contains the properties of V1 and V2, interface E and F wedge out on the surface BCD, interface BCD is involved in a total of four body units, i.e. V2, V3, V4, V5. In order to obey the rule of "each surface allowed to be adjacent with two solid units at maximum", the two intersection points of interface E , F with surface BCD were taken to divide surface BCD into three independent interface, B, C, and D. Thus, the interface B is involved in two body units of V2 and V3, the

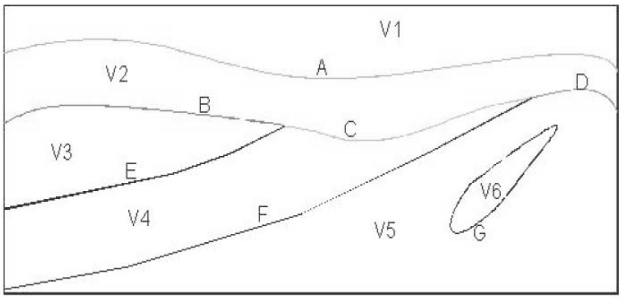

Fig.2. Schematic diagram of two-body 3D data structure.

properties which can be assigned to the sharing interface B. Likewise, the properties of V2 and V4 were assigned to interface C, the properties of V2 and V5 to interface D, the properties of V5 and V6 to interface G.

On inspection of the body unit, except of the study area boundary, the V1 includes only the surface A, V2 is constructed by the surrounding interface A, B, C, D, V3 is made by surrounding interface B, E, V4 is made by the surrounding interface C, E, F, V5 is made by the surrounding interface D, F, G, and lenticular body G is made of the closed interface G. If there are different properties of geologic bodies in lenticular body V6, we can divide V6 further into more different interfaces, until all of the body units meet the requirement of "two-body data structure".

The complex geologic body contains a large number of interconnected elements, landform units, tectonic elements, stratum units and geography units (e.g. river system). The shapes of these body units are generally irregular, that is, their interfaces are complex and irregular. The traditional B-rep needs to express each irregular interface of each unit, which means that the more body unit present, the more interfaces needed to be describes repeatedly. From this point of view, the data organization of B-rep can be more than complex and accordingly the description and analysis of complex geologic body becomes much more difficult. In the "two-body 3D data structure", there is only one sharing surface between two interconnected body units and the nodes are also shared in the sharing surface. Thus, the difficulties from traditional B-rep method such as complexity of data structure, possible gaps between two body units, huge storage space and long time for processing of complex geologic body, can be effectively relieved, making it more

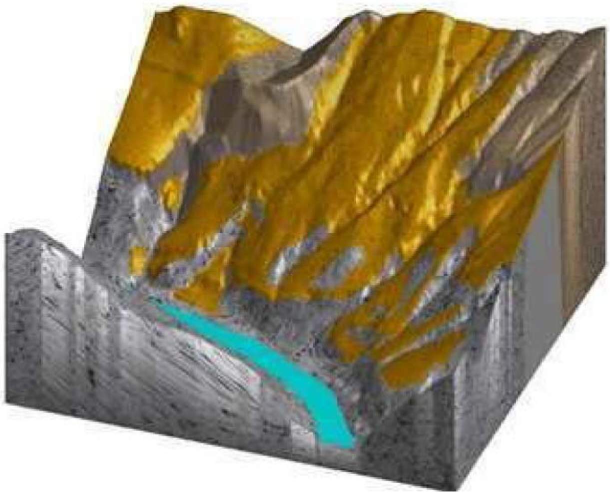

Fig.3. 3D model of hydropower engineering in southern China.

adaptive to the needs of complex 3D geologic body modeling. Fig.3 shows a typical 3D model based on the two-body structure principle.

Figure 4 is a partially enlarged figure and much vector shearing of underground construction model and geological model, which is based on the process result of two-body 3D data structure. In the enlarged map, various geological conditions encountered by the buildings in the underground such as stratum lithology, geological structure and country rock integrity are clearly shown, which provide an intuitive background for the analysis and decision of the engineering survey, design and construction. Since the B-rep has been improved, the expression and analysis of these complex issues are much facilitated.

CORRECTION OF SCATTER POINT AGGREGATE OF COMPLEX GEOLOGIC BODY INTERFACES

As can be seen from the preceding discussion, to build up 3D modeling of complex geologic bodies based on two-body 3D data structure needs to ascertain the interface of geologic bodies and each unit of the geologic body, the determination of the interface which depends on a variety of means to obtain exploration data (such as surface mapping data, misering data, exploratory tunnel data, geophysical data, etc). These exploration data determine a series of scatter

Fig.4. Partial enlargement figure of shear results and large scale shear of geologic model and underground building model.

point aggregates which are on the boundaries of each surface (such as the scatter point aggregate at the same stratum surface which exposed by a group of the drilling). Through the scatter point aggregate we can interpolate to create the various interfaces.

The most commonly used surface interpolation methods include TIN (Triangulated Irregular Network), rectangular grid, trend surface fitting, NURBS (Non-Uniform Rational B-Spline) curved surface interpolation, etc. all of which follow some rules of mathematics or geometry. These interpolation results often do not fully comply with the rule of geology, especially in the case that geological data is not sufficient, resulting in the noncoincidence of curved surfaces with the actual geological conditions.

To overcome this defect we use interactive aided sections of 2d and 3D, firstly, based on the existing exploration data and taking advantage of general surface interpolation methods, such as NURBS surface interpolation, the interface of each unit of the complex geologic body was established (the initial surface model). Next, referring to the general geological rules and underground geological conditions revealed by areas where exploration data is sufficient, a series of man-made aided sections were added to increase the density(interpolation) of the existing data or revise part of the conventional interpolation data in the areas where exploration data is relatively less or geological conditions change greatly. Finally, based on the revised scatter point aggregate, we rebuilt the interface of each unit of the complex geologic body (corrected surface model).

Figure 5 shows the schematic layout of the aided section, where the condition of inference can be inferred to have changed. However, the existing data is not sufficient and in this figure, the thin line represents the existing exploration line while the thick line is the added line of aided section.

Figure 6 is an aided section made by shearing one of the aided section lines with the initial surface model. Taking A, B, C, D points as an example, based on the geological rules, we firstly insert the point C and point D that are located in the same boundary surface with point A and point B, and then combine the A, B, C, D point into a smooth curve that complies with the geological rules to complete the operation of aided sections in the 2d environment.

For the space surface simulation, linear interpolation is rough, polynomial interpolation will produce the oscillation phenomenon, and the number of polynomial interpolation, the higher the calculation quantity will increase quickly. We can also use double cubic spline interpolation. The equation is :

$$z = a_1 x^3 y^3 + a_2 x^2 y^3 + a_3 x y^3 + a_4 y^3 + a_5 x^3 y^2 + a_6 x^2 y^2 + a_7 x y^2 + a_8 y^2 + a_9 x^3 y + a_{10} x^2 y + a_{11} x y + a_{12} y + a_{13} x^3 + a_{14} x^2 + a_{15} x + a_{16}$$

Among them, the a1, a2, ... , a16 is undetermined parameters.

Based on general geological rule, first insert C, D two points artificially, then according to the above method or other mathematical method, make A, B, C and D become a smooth curve.

Figure 7 is an enlarged map that shows the revised data of the aided section in the 3D environment. Figure 8 is an interface which is rebuilt based on revised and densified scatter point aggregate.

Based on the geological rules, aided section technical

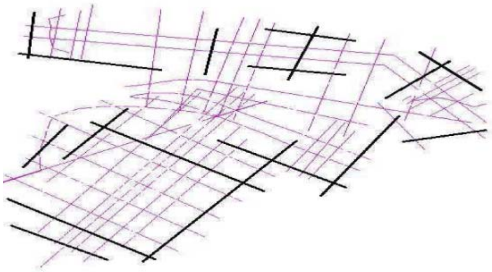

Fig.5. Layout of aided section

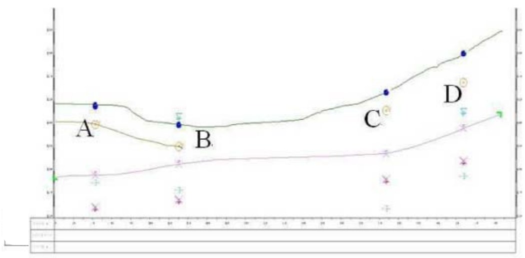

Fig.6. Interpolation based on general geological rules

Fig.7. Aided section back to 3D environment portion

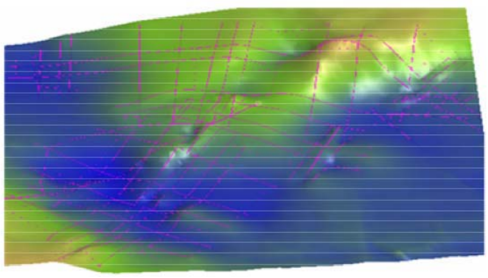

Fig.8. Interface through increased density scatter point aggregate

conducted a systematic correction of data points of general interpolation methods, making the interface more consistent with rules of geology, and the 3D model of the complex geologic body built more reasonable.

SUMMARY AND DISCUSSION

Adopting technical methods suitable for complex geological 3D visualization expression and analysis can present a complex geologic body in a digital and transparent manner, and can serve as an intuitive display and analysis platform for the survey, design and construction of complex geological areas, it can be used for a wide range of applications.

The two-body 3D data structures proposed improve the way of data organization of B-rep, simplify the complexity of data organization, greatly reduces the data volume and improve the efficiency of the shear. The usage of aided section technology, and to a certain extent, overcomes the defect that conventional surface interpolation is not entirely consistent with the geological rules. The vector shear modeling method based on two-body data structure makes the 3D modeling of complex geologic bodies more intuitive and easily controllable. Therefore , it is a suitable technical method for 3D modeling of complex geologic bodies.

This technical method has been applied to the field of hydropower engineering and geologic hazards, and is currently thought of as an effective method to establish the geometry of complex underground geologic bodies.

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