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DYNAMIC MODELING OF LANDSLIDE THROUGH GEOLOGICAL MODELING AND FINITE ELEMENT SUBDIVISION

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ABSTRACT

Landslide disaster is a kind of main geological disasters. Countries in the world are all harmed by landslide disaster seriously. Achieving landslide's 3D dynamic simulation is helpful for the relevant regulatory authorities to guide the Prevention and Treatment of landslide disasters. For simulating landslide more intuitive and more realistic, and predicting the loss situation, we achieved landslide's 3D dynamic simulation based on landslide information extraction, modeling, finite element subdivision, and applying motion-displacement equation. At the same time, we take landslide disaster effect factors into consideration as the parameters variable of motion-displacement equation. The effect factors include lithology, soil moisture, vegetation coverage, acceleration of gravity and terrain and so on. At last, the simulation result would be taken as a guide to provide reference in landslide disaster relief. As a result, we can realize the dynamic simulation of landslide process, calculate area influenced by landslide, by calculate landslide's motion trajectory. On basis of it we can reduce loss amount of our economy caused by the landslide also.

Keywords: *Landslide, Finite Element Mesh, Motion-Displacement Equation, Geological Modeling*

1. INTRODUCTION

Landslide means that part of the rock and soil shears and declines overall oriented the free surface along the slope internal weakness, under the combined effects of a series of natural and man-made factors. Landslides are geological disasters of largest scale, largest number and most serious in mountains deformation break. As for as the frequency of occurrence and breadth, it's scale is more lager than earthquake disaster and volcanic activity. It is one of the main types of geological disasters. Landslide hazard causes more than ten billion dollars economic losses to human society each year. According to statistics, more than 300 cities or counties of China's 20 provinces , Hong Kong and Taiwan are all threatened by landslides, causing huge economic losses and casualties each year, the annual economic losses not less than 10 billion RMB. The cost of project of China's mountain railway is about l0 million RMB each year, which is spend on renovating landslides, collapses, debris flow and other environmental geological disasters. According to the Data result sorting from the Three Gorges Reservoir Area pivot landslide, Quaternary geological map, survey report and literature, there is a total of more than 2500 landslide and collapse accumulation body in landslide and collapse accumulation body, including ancient landslide, stability potential and unstable landslide [1].

Previously, the research of landslides geology disaster, mainly based on mathematical physics, combines with Traditional statics, modern rock mechanics, modern mathematical mechanics and nonlinear science theory. Researching with the aid of two-dimensional planar graph, simple 3D modeling and 2D topographic analysis can't provide Image, intuitionistic description for Landslide progress, Landslide inversion analysis and control engineering. It is not conducive to in-depth analysis and control strategies of landslide disaster.

In recent years, along with the development of computer hardware and software, computer graphics, graphics and image processing technology, remote sensing technology, 3D modeling and dynamic simulation technology obtained a rapidly development. Technology of extracting thematic information from remote sensing image had applied to the study of the landslide. It made the landslide information extraction and dynamic simulation of the process become possible. According to the geological

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knowledge and expert experience, Liu Zhifeng et al. used the combined modeling method and stratigraphic correlation technology to construct 3D geological body. In the foundation of summing up the correlative achievements of the regional geological environment, landslides characteristic and stability evaluation of landslide, dynamic simulation of landslide under variety of external force had been achieved, regarding different types of slope and landslide stability evaluation model as the prototype. Taking landslide body of Squeeze fang ping in Three Gorges Reservoir Area as an example, using TRIANGULATE function and TRIGRID function of the visualization software IDL and Delaunay triangulation , Tian Jinhua had established Squeeze fang ping' landslide body regular grid terrain model and shallow, deep sliding surface 3D visualization model and realized 3D simulation and reproduction of landslides. Combined with geological profile, Tan Debao et al. realized the true three dimensional simulation of landslide area by modeling methods based on the three prismatic voxel. According to the original data of landslide survey, Huang Liang realized 3D visualization simulation of landslide, which accomplished by reference to the existing research achivements of landslide motion process and choosing landslide motion model proposed by Sassa. K. But in the past, research for landslide process simulation mainly focus on landslide geological modeling, as to landslide motion trajectory calculation involves less. Therefore this paper puts forward movement-displacement equation for landslide trajectory calculation, and realizes dynamic 3D simulation of landslide process.

2. MODELING OF LANDSLIDE

In order to get possible landslide area in advance and accurately simulate dynamic landslide process, I conduct a research on the simulation of landslide, under the basis of previous studies. The concrete steps are as follows:

(1) Extract Landslide Information. I adopt object-oriented approach [2] to extract landslide areas from high-resolution remote sensing images. And combined with landslide district surveying data, layer structure information and other background information, we can extract landslide sliding surface.

(2) Building the landslide body model. Using the borehole data of the landslide area, sliding surface data, the landslide zone boundary data, terrain data builds a three-dimensional model of the landslide by triangulation method. And in order to partition landslide model into a limited infinitesimal, we execute finite element mesh to the constructed landslide model. In this article we use tetrahedralization method as the finite element mesh method.

(3) Calculating the landslide trajectory. At last we use the infinitesimal of the landslide model by the finite element mesh, applying sports - displacement equation, using the parameterized lithology, soil moisture, vegetation coverage, the acceleration due to gravity, terrain and other factors of the landslide area as the parameter of the sports - displacement equation, to calculating the landslide trajectory.

2.1 How To Get Landslide Information

Before we conduct various analyses to the landslide, a vital step is to extract landslide Information, defining the landslide area and the sliding surface. As to the landslide information extraction, we adopt object-oriented landslide information extraction method based on high-resolution image. This method integrates spectrum, special, morphological characteristics and expert knowledge is also integrated into it. So we can extract landslide information well. The critical steps are as follow:

(1) Building image objects. By the mean shift multiscale splitting of the high-resolution images of the research district [3], we can create image objects contain landslide features.

(2) Building extraction rules. We can build the extracting feature of the typical object according to the feature of the object and image [4].

(3) Extracting landslide information. We can extract other typical objects of the image according to previous rules. So we can achieve the goal of extracting landslide area.

(4) Determining landslide area. We can conduct accuracy assessment of the landslide information, by the combination of high-resolution images and the result of field measurement. And we can reassure the landslide area.

(5) Determining the sliding surface. We can calculate the landslide surface according to the range of the landslide and the statistics of the underground, terrain, ground and other background information.

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Figure 1: The Result Of Landslide Area Extract

2.2 Building 3d Models of Landslide

After Extraction of landslide area and the slip surface, first based on the drilling data, the landslide boundary data, Surface topographic data, using Delaunay method of triangulation [5], construct the whole geological body model; and then Finite element meshing on the over part of the sliding surface of landslide , the sliding surface of landslide above is divided into finite element. Finite element mesh method are many, here, we use the classic TetGen triangulation [6].

2.2.1. Building the geological model of landslide

Delaunay subdivision is the standard of one triangulation, it has a variety of algorithms, including random incremental method, scan line method, partition. This paper mainly introduces the Lawson algorithm steps of incremental method:

1) To construct a super triangle, contains all the scattered points, into a triangle list.

2) Put scattered points of point set inserted in a triangle list, find out the triangle (called the point affected triangle)of which the circumscribed circle contains the insertion point in the triangle list , delete the public side affected triangle, connect the insertion point with all vertexes affected triangle, thus completing insert a point in the Delaunay triangle list .

3) According to the optimization criterion to optimize the local newly formed triangle. Put the formed triangle in the Delaunay triangle list.

4) Circle the above second step loop execution, until all scattered points been inserted.

Geological body of landslide model is constructed based on borehole hierarchical information, and make Delaunay triangulation for the surface topography of triangulation data. By drilling hierarchical information can be calculated the every stratum location, depth, thickness. Each layer topology refers to the surface drilling points between the topology can connected, and then completed the whole geological body of landslide modeling. Figure 2 is accomplished landslide geological model.

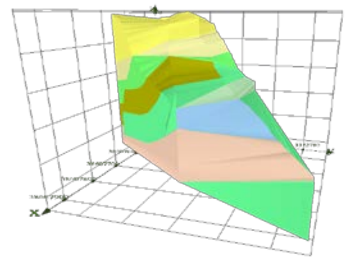

Figure 2: Geological Body Of Landslide Model

2.2.2. Finite element subdivision of landslide geological model

TetGen tetrahedron subdivision is essentially a Delaunay triangulation algorithm 3D extension, its main algorithms is basically identical with Delaunay triangulation [7]. The TetGen program is mainly used for construction irregular tetrahedral network in 3D field [8]. Its goal is through using the finite element method and finite volume method to generate appropriate tetrahedral mesh. In addition, as a tetrahedral mesh generator, it can also serve as a split form applied to many fields of science and engineering.

Finite element meshing on the geological body model purposes to divide the geological body into finite element, prepare data for calculation movement trajectory of landslide. The landslide body is adopt different subdivision when uses TetGen Delaunay triangulation: separately subdivide the sliding part on top of landslide slip surface, and mark it layered, but the under part not. This is done for meticulous dissection of the landslide body on sliding part in different levels, and only 3D construction for landslide which under the sliding surface, does not perform detailed subdivision. Doing so could reduce the data volume of triangulation; improve the operation speed and optimization the effect of model.

2.3 Calculate Landslide Motion Track

When we calculate landside trajectory, we take landslide infinitesimal element after finite Element split as the basic research units to research landslide trajectory finite element split. For each infinitesimal element's space movement situation, we divided it into x, y, z three directions to research. According to the force of every infinitesimal at every moment, adopt the motion-displacement equation to calculate the acceleration. And then given out a time interval, calculate infinitesimal element's position of the next moment. At this point, the

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vegetation coverage, lithology, soil moisture, slope and aspect etc. influencing factors changed accordingly, gain the force at next time. And so on and cycle to the final moment. Every moment's landslide state equivalent to the combination state of all infinitesimal elements. When slid to the bottom, control Z coordinates, end the calculation, and the trajectory of the landslide equivalent to the combination of landside body's state at all time[9].

2.3.1. Base algorithm equation

Landslide is considered as a non-continuous media and the infinitesimal plotting separate motion, Each micro-element are arranged to each other and void characteristics in accordance with the characteristics of the landslide itself has a fixed position in space at each moment in a state of equilibrium. Constraints when the boundary force more than block external force causes the acceleration of the corresponding displacement occurred after a certain period of time, and the landslide micro element space varies according to the time. After the displacement of the micro-cell generation to the next time contact, it determine the new external force and acceleration obtained by the equation of motion and the displacement of the next time point, thereby obtaining the entire moving process. In the course of the campaign, we are into the actual problem:

(1)The whole movement constituted by the movement of each micro state;

(2)Adjacent micro contact force generated as a full contact

We use the most simple joint forces decided acceleration model. We calculate Joint forces of every infinitesimal element triangulated from landslide body first, and then obtained the centroid acceleration and determined the speed and the next moment displacement of infinitesimal element according to the Newton's second law.

$$\frac{du}{dt}=\frac{F}{m} \quad (1)$$

$$\frac{du}{dt}=\frac{u^{t+\Delta t}-u^{t}}{\Delta t} \quad (2)$$

Finish:

$$u^{t+\Delta t}=\frac{u^{t-\Delta t}\cdot F(t)}{m\cdot\Delta t} \quad (3)$$

$$u^{t+\Delta t}=u^{t}\cdot\Delta t+u^{t} \quad (4)$$

Here, u stands for element speed, t stands for time, F stands for joint forces element bear, m stands for element quality, $u^{t+\Delta t}$ stands for element speed at $t+\Delta t$, $u^{t-\Delta t}$ stands for element speed at $t-\Delta t$, u^{t} stands for element speed at t , Δt stands for time interval.

Below we will give out the process of how to calculate the accelerated speed gx 、 gy in x direction and y direction based on grade $GradeX$, $GradeY$ in x direction and y direction:

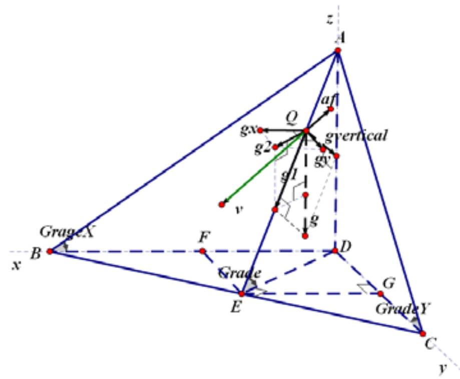

Figure 3: Solving Schematic Diagram Of Slope And Aspect

Set $AD=1$

$$CD=\frac{AD}{|\tan GradeY|} \quad (5)$$

$$BD=\frac{AD}{|\tan GradeX|} \quad (6)$$

$$BC=\sqrt{BD^2+CD^2} \quad (7)$$

$$DE=\frac{BD\cdot CD}{BC} \quad (8)$$

$$Grade=\left|\arctan\frac{AD}{DE}\right| \quad (9)$$

$$BE=\sqrt{BD^2-DE^2} \quad (10)$$

$$CE=BC-BE \quad (11)$$

$$vz=-vx\cdot\sin GradeX-vy\cdot\sin GradeY \quad (12)$$

Finally available:

$$gx=\frac{DE\cdot EC\cdot g\cdot\sin Grade}{CD\cdot\sqrt{AD^2+DE^2}} \quad (13)$$

$$gy=\frac{DE\cdot BE\cdot g\cdot\sin Grade}{BD\cdot\sqrt{AD^2+DE^2}} \quad (14)$$

$$afx=-\frac{vx\cdot g\cdot\cos Grade\cdot f}{\sqrt{vx^2+vy^2+vz^2}} \quad (15)$$

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$$afy = -y\frac{vx \cdot g \cdot \cos Grade \cdot f}{\sqrt{vx^2 + vy^2 + vz^2}} \quad (16)$$

Motion-displacement equation describes how to figure out the speed, acceleration and displacement at the next moment according to the speed and acceleration of landslide infinitesimal element previous moment. The following is a detailed description of motion-displacement equation of landslide infinitesimal element in x , y , z direction.

x direction:

$$V_{xnew} = V_{xold} + (gx + afx) \cdot \Delta t \quad (17)$$

$$S_x = \frac{(V_{xnew} + V_{xold}) \cdot \Delta t}{2} \quad (18)$$

y direction:

$$V_{ynew} = V_{yold} + (gy + afy) \cdot \Delta t \quad (19)$$

$$S_y = \frac{(V_{ynew} + V_{yold}) \cdot \Delta t}{2} \quad (20)$$

Δt Stands for the time interval, V stands for speed, S stands for the amount of displacement. gx 、 gy stands for acceleration decomposition from acceleration g along the x , y direction. afx And afy are related to lithology, soil moisture and vegetation coverage. It is a parameter described the frictional properties of the rock and varied in different landslide. This parameter ranges from 0 to 1. The greater the parameter's value indicates the more intense its ability to impede the movement of the infinitesimal element (less prone to landslides), the smaller the parameter's value indicates its ability to impede the movement of the infinitesimal element is weaker (more prone to landslides).

According to the study of Yang Yonghong, Liu Shuzhen, et al. [10], soil moisture and vegetation coverage have a great impact on the stability of the landslide. It's largely determined the trajectory of landslide. So based on this study, multiple considering the landslide zone lithology, soil moisture, vegetation coverage, etc., we could figure out the sliding friction angle of landslide in the landslide area[11], and converted it into friction factor f, obtained afx , afy by geometric relationships. The sliding friction angle of landslide has different methods of calculation in different regions. Detail calculates process as follows:

(1)For completely bare land area, the sliding friction angle of landslide is calculated as follows:

The first layer:

$$\lg\alpha = 1.55 - 0.016\omega \quad (21)$$

The second layer:

$$\lg\alpha = 1.59 - 0.014\omega \quad (22)$$

The third layer:

$$\lg\alpha = 1.61 - 0.013\omega \quad (23)$$

(2)For completely covered woodland area, the sliding friction angle of landslide is calculated as follows:

The first layer:

$$\lg\alpha = 1.59 - 0.014\omega \quad (24)$$

The second layer:

$$\lg\alpha = 1.60 - 0.013\omega \quad (25)$$

The third layer:

$$\lg\alpha = 1.62 - 0.010\omega \quad (26)$$

(3)For neither entirely bare land nor completely covered woodland landslide areas, we can set a vegetation cover variable a (unit%, range 0-100), derived the sliding friction angle of landslide by linear interpolation calculation. Its formula could make follows improvements:

The first layer:

$$\lg\alpha = 1.55 \cdot (100 - a)\% + 1.59 \cdot a\% - 0.016 \cdot (100 - a)\% \cdot \omega - 0.014 \cdot a\% \cdot \omega \quad (27)$$

The second layer:

$$\lg\alpha = 1.59 \cdot (100 - a)\% + 1.60 \cdot a\% - 0.014 \cdot (100 - a)\% \cdot \omega - 0.013 \cdot a\% \cdot \omega \quad 28)$$

The third layer:

$$\lg\alpha = 1.61 \cdot (100 - a)\% + 1.62 \cdot a\% - 0.013 \cdot (100 - a)\% \cdot \omega - 0.010 \cdot a\% \cdot \omega \quad (29)$$

After calculated the internal friction angle α , convert α for friction factor f, and its formula is:

$$f = \tan\alpha \quad (30)$$

According to f , figure out af , and its direction opposite direction of V .

$$af = f \cdot gvertical \quad (31)$$

And then figure out afx , afy by decompose af to x , y directions according to the geometric relationship. $\lg\alpha$ Stands for the logarithmic value of internal friction angle α , ω stands for the water content, $gvertical$ stands for acceleration decompose from g decompose to the vertical direction.

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z Direction: z values reference to the DEM value of landslide body surface DEM image at (x, y). The DEM value figures out by bilinear convolution algorithms interpolation.

2.3.2. Calculate tracks of landslide model

The original input data of Trajectory calculation are DEM elevation data of the landslide area, landslide body data after finite element subdivision, and coverage of vegetation in the region and soil moisture content. The output data are Mesh files, which specialized for describe landslide bodies' state at various moments in landslide sliding process.

Trajectory calculation adopted a simple infinitesimal element analysis method, the aggregate external force determined acceleration, and acceleration determined velocity-time formula at the next moment, and obtain the displacement in x, y direction finally. According to the new x, y coordinate obtained the initial moment model's DEM value in this coordinate, and then used the interpolation method to calculate the z coordinates. Firstly, give out the mesh files at initial moment, generated the mesh file of next moment by calculate each infinitesimal element, and then given show. So continuously take previous moment's mesh file as initial input, and generate the next moment's mesh file. Do like this until the landslide slipping stops.

First before calculate the landslide slipping trajectory, we should calculate each raster pixel's grade $GradeX$, $GradeY$ in x, y direction separately based on DEM data of the landslide area. Subsequently, according to the calculated $GradeX$, $GradeY$, calculated each raster pixel's acceleration gx, gy in x, y direction of the landslide area separately. Finally, calculate different strata's friction factor f based on the vegetation coverage and soil moisture input.

After completed data preparation work, we can begin to calculate the movement of each infinitesimal element. We could calculated the coordinate values of the raster image according to the center point of the infinitesimal element's (x, y) coordinates first, and then according to the coordinate values to get the infinitesimal element's acceleration values gx, gy in x, y direction, and then figure out afx, afy according to the location layer, direction of original speed and different strata's friction factor f counted out before. Finally, according to the motion-displacement equation, obtained speed V_x and V_y at next moment, and deduced the amount of displacement S_x, S_y during Δt period followed, and then you can calculate infinitesimal elements' new (x, y) coordinates at next moment. After all, calculate the corresponding value of $(x, y)\, z$ by spatial interpolation algorithm and DEM data. So reciprocating calculated every moment's (x, y, z)coordinates, completed the simulation infinitesimal element's trajectory. The combination of all infinitesimal elements' trajectory is the trajectory of the landslide body.

2.3.3. Landslide motion process 3D simulation

After the landslide trajectory calculation, we can get the motion state of the landslide model mesh file each time. In MapGIS K9's 3D rendering view, we just set a static display for the mesh under sliding surface; for the part above the sliding surface, we get the trajectory calculation mesh file for a feature class, and then add these feature classes to the scene node. By the principle of the vertex shader, these feature classes can be colored. Respectively attached to the scene node model, we use frame listener in 3D engine, traverse all frame listener to be added before rendering and call the function FramStarted() rewritten before. Therefore, the scene of each rendering the scene node loaded model change to achieve the dynamic simulation. Figure 4 is landslide's original state, and figure 5 is the state of landslide when sliding stop.

Figure 4: Landslide's Original State

Figure 5: The State Of Landslide When Sliding Stop

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3. DISASTER DAMAGE ASSESSMENT

For disaster damage assessment, we mainly count and summary the losses including roads, houses, rivers, block and life. After the landslide dynamic simulation, we can get the coverage of landslide slipping, by which we can make sure the affected scope, and quantify the vector into zone file. Then, we will sort out the data of roads, houses, rivers, block in landslide district, such as attribute assignment, topology error, etc., and establish the landslide database. At last, we will have a overlay analysis of disaster area and roads, houses, rivers, block data which can tell us the number or value of rivers and roads that covered, the covered area of houses, the situation and loss of all kinds of block that covered, and the total loss of all block. Finally, we can calculate the number of the affected people according to the housing distribution.

Table I : Disaster Damage Assessment

Overall condition of loss	The specific values of loss
The rivers covered (line)	10
The roads covered (line)	10
Total losses value of road ($)	10000
The total number of houses covered (block)	4
Total area of houses covered (m^2)	480
Total losses value of house ($)	600000
Total area of plots covered (m^2)	346371
Total value of arable land loss ($)	0
Total value of public land loss ($)	0
Total value of residential land loss ($)	1000000
Total value of industrial land loss ($)	0
Total value of commercial land loss ($)	0
total value of disaster losses ($)	1956371
Affected persons(person)	20

4. CONCLUSION

In this paper, we studied the landslide dynamic simulation from a series of key links including landslide information extraction, landslide geological modeling, sliding motion trajectory calculation, the three dimensional visualization simulation and damage evaluation, etc., and all achieved good results. But the landslide is a very complicated process, with many complicated factors to concern, while we simplified a lot in the calculation of the landslide in the process of trajectory, just considering lithology, soil moisture, vegetation coverage, acceleration of gravity, terrain factors, not fully considering all possible affected factors of landslide sliding track. So the final result is only a rough approximation. In the future, the landslide process influence factors of consideration and calculation model improvement remains to be further strengthened. At the same time, the simulating effect of the landslide process dynamic is not complete. Henceforth the rainfall, the possibility of secondary disasters also should be taken into account. In addition, this paper is studying small scope and medium speed landslide, while landslides in real life are all sorts and varied. Different landslide sliding track calculation and simulation should use different methods. In order to study the landslide more efficiently, simulation study of different regions, different types of landslide sliding trajectory is very necessary.

In short, the process of landslide dynamic three-dimensional simulation research is still far to go, and there are many problems needed to be solved urgently. This need continuous exploration and practice of landslide disaster researchers.

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